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Ontario Geological Survey
Open File Report 6192

Summary of Field Work and Other Activities 2006

2006

Ontario

ONTARIO GEOLOGICAL SURVEY

Open File Report 6192

Summary of Field Work and Other Activities 2006

Edited by

C.L. Baker, E.J. Debicki, R.I. Kelly, D.J. Rowell, J.K. Mason, J.A. Ayer, R.M. Easton and G.M. Stott

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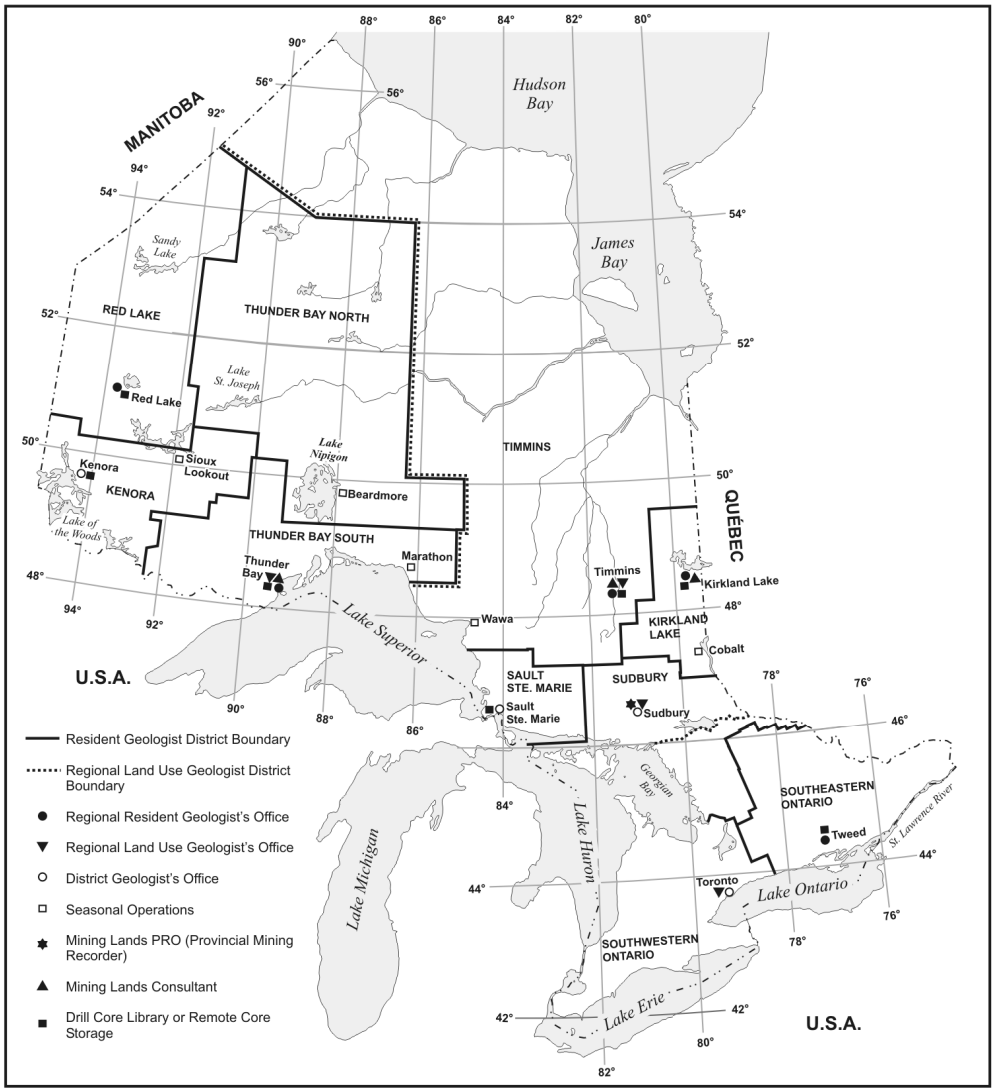

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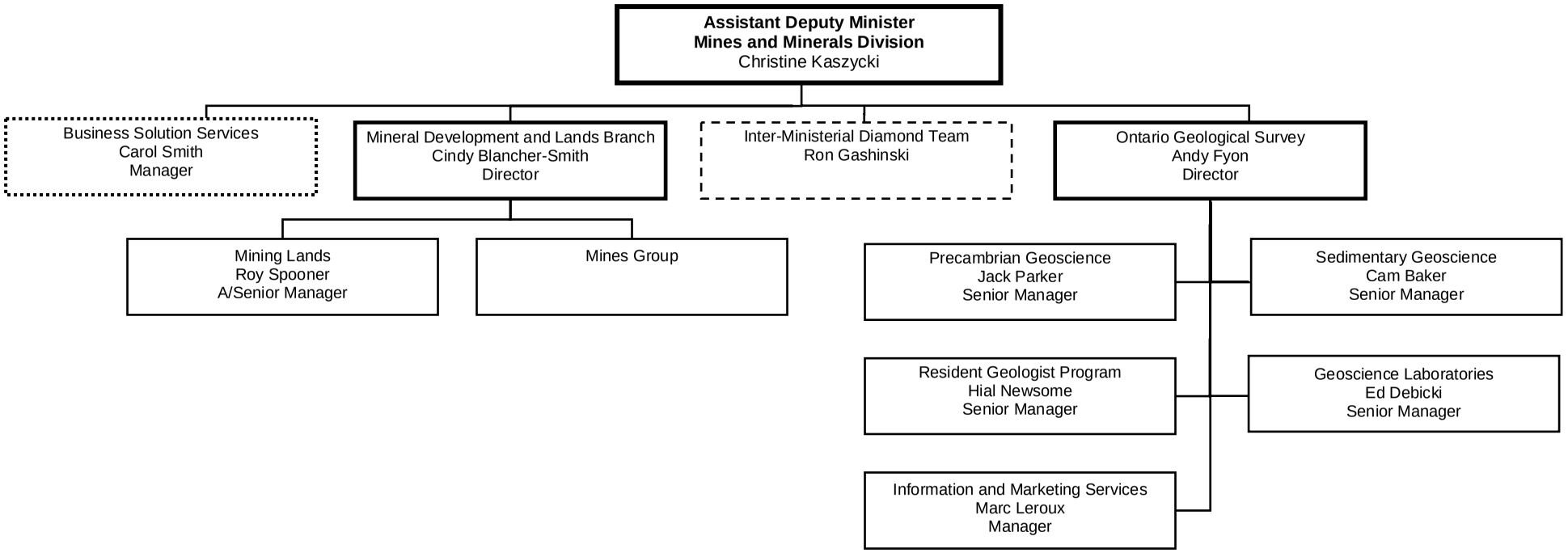

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J.A. Fyon[1]

[1]Director, Ontario Geological Survey

INTRODUCTION

The Ontario Geological Survey (OGS) Branch consists of 5 business units: Geoscience Laboratories, Information and Marketing Services Section, Precambrian Geoscience Section, Resident Geologist Program, and Sedimentary Geoscience Section (Figure 1.1, the OGS organizational chart).

The OGS is

- the expert provincial organization on regional to local, framework, geoscience data, information, and knowledge about Ontario;
- a principled and professional organization that operates with integrity;
- a supplier of credible and objective geoscience data and knowledge about Ontario in a time and form that meet the client needs for quality and accuracy within the limits of our capacity and resources.

MISSION AND CORE BUSINESS

The Mission of the OGS is to advance Ontario's public policy priorities by providing modern, objective, geoscience data, information and advice about Ontario in a form and time that meets or exceed user needs.

The OGS data, information and knowledge are fundamental to realizing the Crown's mineral resource stewardship responsibility, formulation of informed public policy, land-use planning, enhancing investment in mineral and non-renewable energy resource development, helping create economic development options for aboriginal and non-aboriginal communities, and contributing to safe, sustainable and efficient choices to be made about managing the Provincial mineral and non-renewable energy resources, ground water and the environment. OGS is the steward of the public geoscience data and provides public access to the geoscience information.

PRIORITIES

The Mines and Minerals Division, including the Ontario Geological Survey Branch, will be affected by several key Ministry and Branch priorities that we will be either directly or indirectly involved in, including a) modernizing the *Mining Act* and associated permitting and regulatory changes; b) diamond strategy; c) aboriginal constitutional obligations related to the duty to consult and the important precursor

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community-level engagement, information exchange, and relationship-building efforts; d) continued implementation of the Far North Geological Mapping Initiative; e) participation in community-led public geoscience initiatives, such as Discover Abitibi and Discover Atikokan; g) Targeted Geoscience Initiative III; h) Co-operative Geological Mapping Initiative; and, i) continuing to address recommendations made by the Provincial and internal audits. To meet these challenges, it will be necessary to adjust activities, in part by re-assignment of internal resources to focus on shorter-term priorities.

OGS Branch cohesiveness remains a priority. Branch staff and management continued to work to build on existing strengths to enhance branch-level project planning and integration of activities.

OGS strategic planning began in January 2006. Following working sessions with some Branch staff and Managers, and dialogue with a range of external experts, a draft OGS Branch strategic plan is under development.

Ontario faces some major planning and development challenges related to mineral resource access and development, groundwater resources, and security of energy supply. Consideration and incorporation of OGS geoscience data and knowledge into decision-making processes will help address these planning and development needs. To broaden the reach of OGS products and services, we continued to develop strategic relationships with several conservation authorities in southern Ontario, the Ministry of Natural Resources, Ministry of Energy, Ministry of Community and Social Services, aboriginal leaders and advisors, Confederation College, the mineral sector, the Geological Survey of Canada, and academe, such as Laurentian University.

In response to client need for accurate, accessible geoscience data in a form that can be easily searched and easily integrated into other software applications, the OGS Branch, working with Business Solutions Section, deployed Geology Ontario, a Web access to our geoscience data and products. Geology Ontario is a decision-assisting system, not just a data server. OGS continued to market Ontario's mineral potential to attract new mineral investment and enhance Ontario's competitiveness and technical services available through the Geoscience Laboratories and GEO Enterprises. A review of the marketing efforts is underway.

OGS has a pan-provincial mandate, but Ontario's Far North represents one of our last poorly mapped frontiers. The Far North Geological Mapping Initiative, announced in August 2005, continued to be implemented during the past year. In addition to technical geoscience projects, OGS jointly develops collaborative engagement, communication and relationship-building projects with remote aboriginal communities (*see* Fyon, this volume, Article 18; and Parker, this volume, Article 19).

CHANGES

The Director's Office has a new facsimile number: 705–670–5754.

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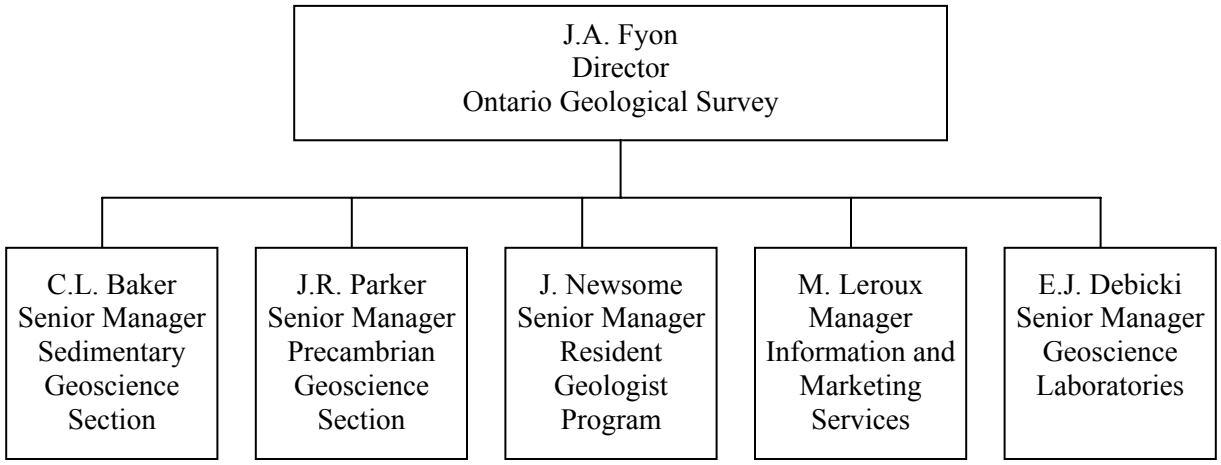
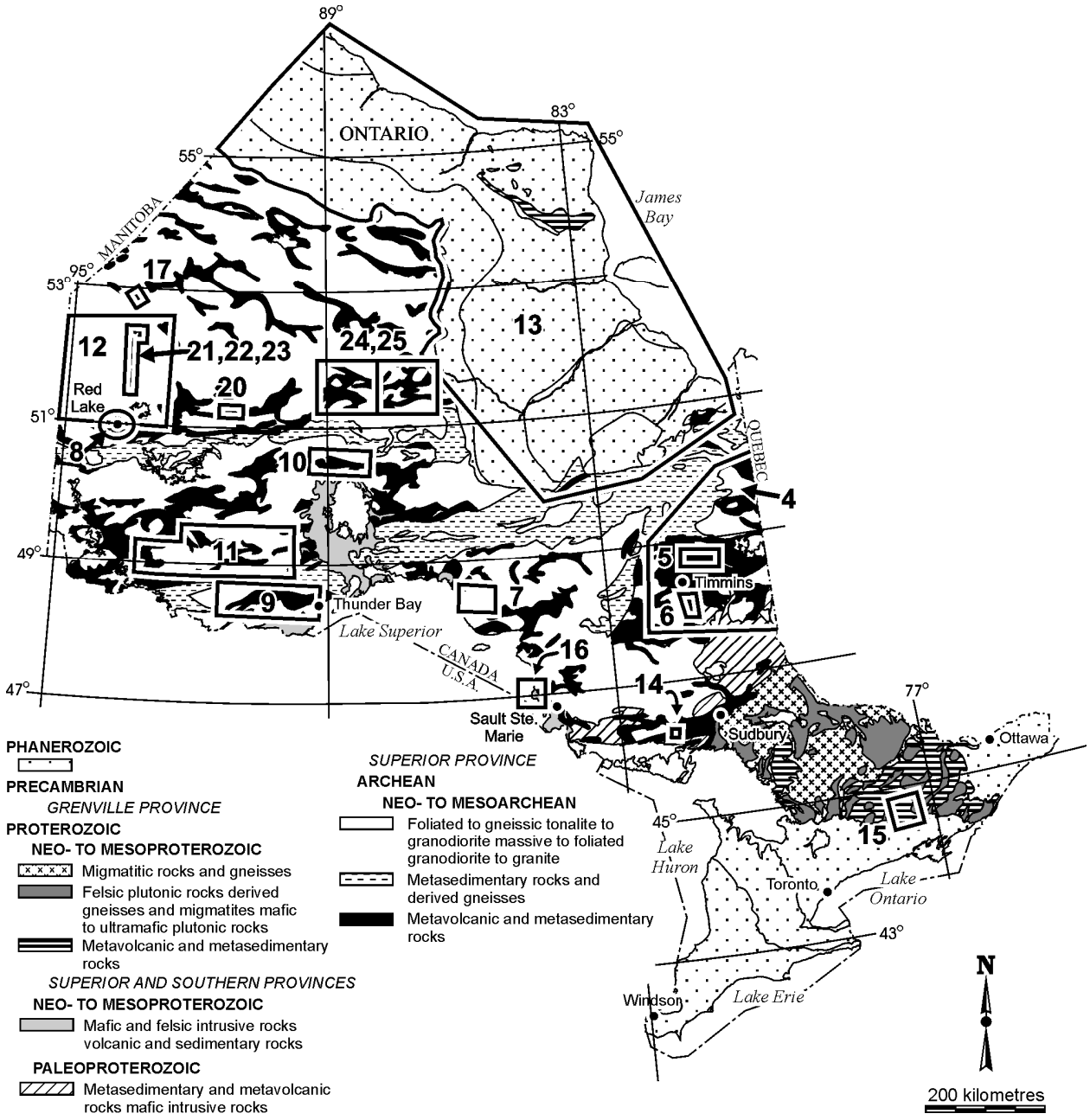


Figure 1.1. OGS organization chart.

Precambrian Geoscience Section



Location of Precambrian Geoscience Section projects for 2005–2006. Numbers correspond to articles numbers.

2. Precambrian Geoscience Section—Program Overview

J.R. Parker[1]

[1]Precambrian Geoscience Section, Ontario Geological Survey

GOAL AND RESPONSIBILITY OF THE PRECAMBRIAN GEOSCIENCE SECTION

The goal of the Precambrian Geoscience Section (PGS) is to improve the understanding of Precambrian geology and metallogeny of Ontario and to convey this knowledge to clients through multi-year, multidisciplinary geoscience studies that address critical geoscience problems in key geographic areas. These studies may be delivered as part of the PGS core bedrock mapping function or through collaborative partnerships.

PGS is responsible for

- mapping of Ontario's Precambrian bedrock and understanding of various mineral deposit settings; and
- regional gravity, magnetic and electromagnetic geophysical data and derivative products in support of the bedrock mapping program.

PROGRAM DIRECTION: STRATEGIC THRUSTS

Core Bedrock Mapping and Geophysics Program

The PGS Strategic Thrusts (Table 2.1) are derived from the Ministry business goals articulated in the Northern Prosperity Plan (NPP), which is derived from the Government's 5 major priorities:

- student success;
- healthier Ontarians;
- prosperity for people;
- strong communities; and
- stronger democracy.

The purpose of PGS Strategic Thrusts is to focus skilled staff and resources in key geological areas or geoscience themes, over a period of 3 to 5 years, to contribute to the goals of the NPP, which include expanding our geoscience expertise; supporting sustainable development and effective land-use planning; attracting new mineral investment; building new partnerships with Aboriginal communities, private sector and federal government; and collaborating with other ministries on horizontal initiatives.

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The PGS program is organized into 5 technical or administrative Strategic Thrusts:

1. Understand the geology and metallogeny of high mineral potential areas in the Superior, Southern and Grenville provinces.
2. Understand and inventory provincial-scale relationships, settings and descriptive data sets of commodities or mineral deposit types that are currently of interest to the mineral exploration industry (e.g., potential diamond-bearing rocks, gold mineralization, rare-element and/or petalite-bearing pegmatites, nickel-copper-platinum group element (PGE) mineralization and volcanogenic massive sulphide (VMS) mineralization) or may be of interest in the future.
3. Improve knowledge of, and access to, geophysical information by providing an effective and efficient information management system through the identification, recovery, (re-) formatting, organization and delivery of all available OGS and proprietary geophysical information; provide derivative geophysical products, concepts and ideas, based on those geophysical data, to support the bedrock mapping program.
4. Implement program support practices and instruments to address and refine the PGS core program, the human resource strategy, digital data standards, measurement of program results and impact and program management practices.
5. Develop and manage client and stakeholder relationships by providing a liaison role, representation, or support on behalf of the PGS on client committees, regional client association meetings, inter-Ministry committees and formal or informal working groups; and committees or working groups associated with professional or learned associations. Maintaining relationships and exchanging technical and administrative information with First Nation communities and organizations located in geographic areas where PGS specifically has a geoscience program interest between the present and 15 years into the future.

These strategic thrusts are addressed through a series of initiatives, built upon one or more projects. The purpose of the strategic thrusts is to focus PGS staff and resources in key geological areas to address the priorities and needs of the initiative. In addition, PGS participates in several collaborative projects to complement existing PGS staff skills and capacity and to expand the amount of geoscience data available that describe Ontario. Collaborative projects are an important means to extend scarce government resources and to capitalize on resources and expertise available in other government geological surveys, universities or industry.

Table 2.1. Strategic thrusts of the Precambrian Geoscience Section: 2006–2007.

Strategic Thrust	Thrust Objective	Initiatives To Achieve Thrust	Priority Action
1.Understand the geology and metallogeny of high mineral potential areas in the Superior, Southern and Grenville provinces	Improve understanding of the tectonic and metallogenic evolution and mineral potential of the Superior, Grenville, and Southern provinces by integration of systematic bedrock mapping, mineral deposit studies, geological and geophysical interpretation and compilation at scales of 1:5000, 1:20 000, 1:50 000, 1:100 000, 1:250 000 and 1:2 000 000.	Provincial Initiatives	Provincial Resource Allocation: Undertake bedrock mapping and compilation augmented with mineral deposit data and geophysical interpretation of: • *non-frontier* areas and mining camps at scales of 1:20 000 in Prosser and McArthur townships in the Abitibi greenstone belt. • *non-frontier* areas at 1:50 000-scale in the central Wabigoon Subprovince and the Caribou greenstone belt; 1:20 000-scale in the Shebandowan greenstone belt. • *non-frontier* 1:20 000-scale mapping in Baldwin Townships and diamond-drill core logging in Grimsthorpe Township. • *frontier* 1:20 000-scale mapping in the McInnes Lake greenstone belt; the Red Lake North area; the Frame Lake intrusion and the Fry Lake greenstone belt.
		Far North Initiative	Far North Initiative: In collaboration with several First Nation communities undertake the frontier, bedrock mapping and airborne geophysical data acquisition components of the Far North Geological Mapping Initiative by: • Conducting 1:20 000-scale bedrock mapping in the Fry Lake greenstone belt; • Conducting 1:20 000-scale bedrock mapping in the McInnes Lake greenstone belt; • Conducting 1:20 000-scale bedrock mapping of the Frame Lake intrusion; • Conducting 1:20 000-scale bedrock mapping of the greenstone slivers north of the Red Lake greenstone belt; • Airborne geophysical electromagnetic and magnetic surveys over the North Spirit Lake greenstone belt.
		Abitibi Initiative	a) *Abitibi Targeted Geoscience Initiative*: In collaboration with the Geological Survey of Canada, Géologie Québec, industry and academia participate in the Targeted Geoscience Initiative program through: • in-kind support by committing a portion of the PGS core bedrock mapping program to the Abitibi greenstone belt (Ayer, Berger, Houlé, Trowell, Josey); • deliver and participate in collaborative geoscience projects. b) *Discover Abitibi*: In collaboration with the Timmins Economic Development Corporation, academia and industry participate in and provide support to the planning stage of the Discover Abitibi program by: • providing Senior Geoscientist (Ayer) for participation on the Discover Abitibi Technical Committee.

Table 2.1. continued

Strategic Thrust	Thrust Objective	Initiatives To Achieve Thrust	Priority Action
1. (continued)		Proterozoic Initiative	a) Conduct bedrock mapping at 1:20 000-scale in Baldwin Township, southwest of the Sudbury Igneous Complex; b) Conduct logging of archived diamond-drill core to complete 1:20 000-scale bedrock mapping in the Grimsthorpe domain to study gold and diamond potential; c) Update the 1:50 000-scale compilation map of the River Valley area; d) Participate in ongoing regional compilation of the Midcontinent Rift system with the USGS; e) Complete a regional synthesis of the Lake Nipigon region as well as a 1:100 000-scale bedrock compilation map of the western Nipigon Embayment.
		Metallogeny and Geology of Northwest Ontario	Metallogeny and Geology of Northwest Ontario: a) *Geology of the central Wabigoon Subprovince:* Conduct bedrock mapping at 1:50 000-scale and complete synoptic report and final 1:250 000-scale bedrock compilation map. b) *Atikokan Mineral Development Initiative:* In collaboration with the Atikokan Economic Development Corporation, the Ontario Prospectors Association, academia and industry participate in and provide support to the planning stage of the Atikokan Mineral Development Initiative by: • providing Geoscientists (Stone, Rainsford) for participation on the Atikokan Mineral Development Technical Committee and at Geoscience Gap Analysis meetings.
		Initiatives with GSC	Collaborative Initiatives with Geological Survey of Canada (GSC): a) *Western Superior NATMAP and Lithoprobe initiatives:* In partnership with Geological Survey of Canada, work to complete and publish the maps and reports for the Western Superior NATMAP and Lithoprobe initiatives to resolve the distribution of old and young crust and its metallogenic significance (Stott, McIlraith). b) *Exposed Sachigo and Precambrian basement project:* In partnership with Geological Survey of Canada, to stimulate exploration and support regional-scale bedrock interpretation of northern Ontario, interpret the geology of the exposed Sachigo and the Precambrian substrate to the James Bay and Hudson Bay lowlands (Stott, Josey).

Table 2.1. continued

Strategic Thrust	Thrust Objective	Initiatives To Achieve Thrust	Priority Action
2. Understand and inventory provincial-scale relationships, settings and descriptive data sets of commodities or deposits types currently of interest to the mineral exploration industry.	Improve the understanding of, and mineral potential for, rocks that may contain economic concentrations of: - diamonds; - rare-metal and petalite-bearing pegmatites; - Ni-Cu-PGE; - Gold; - VMS-associated copper-zinc mineralization; and - metallic mineralization related to felsic magmatism	- Provincial-scale metallogenic inventory - Provincial-scale pegmatite mineralization	a) Document the distribution of, regional settings, and characteristics of: - Fractionated pegmatites and related fertile granites that may host rare-metals and petalite in Ontario (Breaks); - mineralized, intermediate to felsic plutonic systems (Beakhouse); - evolved (FI- to FIII-type) felsic metavolcanic rocks across the Superior Province (Hart); - by conducting on-going mapping and office-based compilations and inventories supplemented by field work (e.g., sampling and localized bedrock mapping at various scales). b) Maintain geochronology database for Ontario (Easton).
3. Improve knowledge of, and access to, geophysical information by providing an effective and efficient information management system through the identification, recovery, (re-) formatting, organization and delivery of all available OGS and proprietary geophysical information; and provide derivative geophysical products, concepts and ideas, based on those geophysical data, to support the bedrock mapping program.	Integrate regional geophysics into core business bedrock mapping projects. Improve client awareness of, and access to, all OGS and proprietary geophysical data sets.	Geophysics and Bedrock Mapping Integration Initiative Geophysics and Rock Properties Data Set Initiative	Provide on-going support of bedrock mapping and compilation projects. Develop new approaches, procedures and methodologies to integrate and establish geophysical component of bedrock mapping projects. Assess and apply new technologies for processing, interpreting and presenting geophysical data (i.e., geophysical inversion and 3D visualization software). Maintain the Geophysical Atlas containing a graphical index of all available airborne geophysical survey information describing Ontario. Maintain an on-line repository (master archive) of all available airborne geophysical survey information, which will be used to seed all publications of geophysical data and which will be maintained by the OGS geophysicist. Continue the implementation and development of a rock properties database as part of OGS bedrock mapping projects, i.e., recover rock density data; magnetic susceptibility data; specific gravity; establish data standards, storage format and plan. Acquire proprietary, multi-parameter, regional, airborne geophysical survey data. Provide support in the design and delivery of regional airborne surveys as part of the Far North Geological Mapping Initiative

Table 2.1. continued

Strategic Thrust	Thrust Objective	Initiatives To Achieve Thrust	Priority Action
4. Implement program support practices and instruments to address and refine the PGS core program, the human resource strategy, digital data standards and program management practices.	Implement human resource strategy by focussing on succession plans for critical positions and developing a PGS Learning Plan as required by Management Board Secretariat. Complete Management Board Secretariat (MBS) mandated Program Review of geoscience program. Continue to implement project management and impact assessment practices. Provide staff with the Information Technology (IT) tools and operational manuals required to deliver the 2006 summer field projects.	Strategic hiring and mentoring initiative to anticipate retirements of staff and loss of corporate and technical knowledge; Support and Program Management Practices Initiative - Project and Results Management Initiative - Methods Development and Data Standards Initiative	Address HR issues by: • Developing and implementing staff technical and other training plans; • Maintaining the OGS Health and Safety manual; • Hire and train "strategically" to anticipate retirement and loss of corporate and technical knowledge; • Participate in the OGS-Branch review of the functions and responsibilities of the Geoscientist classification. Continue to implement and maintain project management tools and practices, including: • Project planning processes; • Participating in the OGS Strategic Planning exercise; • Track results and impacts of PGS program; • Report on PGS performance measures. Assess solutions for point-of-observation collection and processing of field data and begin developing a new process for collecting and digitizing field observations to streamline the workflow process for producing hard-copy maps and digital data sets and creating a common archival format by: • Developing software and hardware solutions for field data collection and digitizing of geological observations; • Fully integrating new solutions with current GIS data workflow; • Working toward new data standards for PGS and facilitating production of hard-copy maps and digital data; • Developing a common legend for bedrock geology maps through the Common Legend Committee; • Purchasing software and hardware to be used for core program, pilot studies, methods development, and standards projects. Work with other business units in the OGS Branch and Ministry to implement the OGS Branch Information Management and Information Technology plan by contributing staff resources as required. Apply drafting and GIS functions in support of the PGS mapping program by providing targeted staff with: • ArcGIS® training for use in ongoing projects; • Operational field computers and peripheral equipment; • Up-to-date digital mapping manual; • Up-to-date mapping project manual.

Table 2.1. continued

Strategic Thrust	Thrust Objective	Initiatives To Achieve Thrust	Priority Action
5. Manage and maintain client, stakeholder, and First Nation relationships.	Contribute to awareness of external and internal clients and stakeholders and other ministries and governments, regarding the value of PGS geoscience program, have a direct means to communicate with the PGS geoscience program, and manage PGS-related issues at as early a stage as possible.	External Committees. Internal Government committees. Work with OGS Director's Office to maintain relationships and exchange technical information with First Nation communities and organizations located in geographic areas where PGS has a geoscience program interest between now and 15 years into the future.	<u>Client and stakeholder meetings:</u> Represent MMD, OGS, and PGS on/at: - APGO Council – Councillor for Northeastern Ontario; - Commissioner, North American Commission on Stratigraphic Nomenclature; - regional client associations; - PGS Program-level discussions with other governments.

GEOSCIENCE PROJECTS

During fiscal year 2006 to 2007, PGS supported 18 core projects, 7 add-on projects and 8 active collaborative projects (Rowell, this volume).

NEW PROJECTS

The following new technical projects will be operational and will require resources of the PGS during the 2006–2007 fiscal year:

- Abitibi Targeted Geoscience Initiative is a multi-year, multi-disciplinary collaborative initiative with the Geological Survey of Canada, Ontario Geological Survey, Géologie Québec, industry and academia to collect and compile up-to-date geoscience data in the Abitibi Subprovince to facilitate the discovery of base metal deposits. Bedrock mapping projects in the Abitibi are integrated into this initiative as in-kind support.
- Discover Abitibi (PGS staff are participating in this initiative, which is currently in the proposal/planning stage).
- Atikokan Mineral Development Initiative (PGS staff are participating in this initiative, which is currently in the proposal/planning stage).

ADD-ON PROGRAMS

PGS staff and management collaborated with other OGS staff to manage, deliver and participate in 1 significant add-on geoscience program:

- The Far North Geological Mapping Initiative (PGS is delivering the bedrock mapping and airborne geophysical data acquisition component of this initiative) (Parker, this volume, Article 19).

PROJECT PLANNING, MANAGEMENT, AND CONSULTATION PROCESS

PGS management and staff conducted planning and project management processes and practices to deliver 33 geoscience projects conducted by core staff and in collaboration with partners. Information required to describe projects, monitor and adjust progress, and assess their impact on the minerals industry is collected and analyzed to assess achievement of program goals.

To formulate and discuss project plans for summer of 2006 and to begin development of summer 2006 project plans, PGS staff were involved in several consultations with First Nation communities, the Geological Survey of Canada, Géologie Québec and regional client associations:

- February 2006: Southern Ontario Prospectors Association, Tweed
- February, May, June, September and November 2006: Geological Survey of Canada and Géologie Québec
- January to July 2006: Various planning meetings with North Spirit Lake First Nation, Slate Falls First Nation, Pikangikum First Nation and Kasabonika First Nation
- May 2006: Porcupine Prospectors and Developers Association, Timmins
- June 2006: Northern Prospectors Association, Kirkland Lake

PGS management also worked with the faculty of the Department of Earth Sciences at Laurentian University to revise the Laurentian University–Ontario Geological Survey Co-operative Graduate Mapping School Program. PGS management is also planning to establish a similar mapping school program at Lakehead University in Thunder Bay.

INTER-JURISDICTIONAL AND COMMITTEE REPRESENTATION

PGS staff represented the Ontario Geological Survey on several inter-jurisdictional committees, internal committees and associations during the 2006 to 2007 fiscal year, including

1. Commissioner, North American Commission on Stratigraphic Nomenclature
2. APGO Councillor for Northeastern Ontario
3. Discover Abitibi Technical Committee
4. MNDM Health & Safety Committee
5. Ontario Association of Remote Sensing
6. MSc committees at Laurentian University
7. Atikokan Mineral Development Initiative
8. Abitibi Targeted Geoscience Initiative
9. Institute on Lake Superior Geology

STAFFING CHANGES IN THE PRECAMBRIAN GEOSCIENCE SECTION

D.J. Rowell accepted the position of Manager, Bedrock Mapping & Geophysics for the PGS in January 2006.

N. Pettigrew accepted a position with the PGS as Precambrian Geoscientist in January 2006 to conduct bedrock mapping in the Far North of Ontario.

C.A. MacDonald accepted a position with the PGS as Precambrian Geoscientist in March 2006 to conduct bedrock mapping in northern Ontario.

S. Préfontaine, S. Buse and E. Dinel accepted contract positions as Precambrian Geoscientists in the spring of 2006 to conduct bedrock mapping as part of the Far North Geological Mapping Initiative.

Z.B. Madon, Geoscience Information Applicationist, accepted a temporary position as Compilation Geoscientist in January 2006, under the Far North Geological Mapping Initiative. S. Josey, as part of a training and development opportunity, was acting in the position of Geoscience Information Applicationist until September 2006.

J. Chartrand, as part of a training and development opportunity, was acting in the position of Geological Assistant from March to September 2006. P. Wright accepted a temporary assignment as Drafter for the PGS from March to September 2006.

R. VanClieaf accepted a temporary assignment as a Cartographic Technologist with the PGS from March to August 2006. R. VanClieaf accepted a temporary assignment as a Geological Assistant for the PGS in September 2006.

M.D. Young, a Precambrian Geoscientist, left the PGS in November 2005.

3. Precambrian Geoscience Section—Project Overview

D.J. Rowell[1]

[1]Precambrian Geoscience Section, Ontario Geological Survey

INTRODUCTION

The fundamental objectives of Precambrian Geoscience Section (PGS) projects are to

1. provide geoscience maps, reports, data, technical talks and posters, new concepts and ideas, and client consultation services; and
2. provide regional airborne magnetic and electromagnetic geophysical data, derivative products, and concepts based on those geophysical data to support the bedrock mapping program.

To meet these core objectives, the PGS produced 6 Preliminary Maps, 1 Geophysical Map, 5 Miscellaneous Release—Data (MRD) and 3 Open File Reports so far in calendar 2006. PGS staff members also presented approximately 30 technical talks and 35 posters at various geoscience forums so far this year.

The program direction and strategic thrusts of the PGS address the Ministry business goals as articulated in the Northern Prosperity Plan (NPP), which is derived from the government's 5 major priorities (Parker, this volume, Article 2). These strategic thrusts are achieved through a variety of initiatives that are built upon one or more projects. Therefore, project development, selection, planning and implementation are based on the strategic thrusts and initiatives in order to achieve alignment of the individual projects with Ministry priorities.

The PGS was extremely active during the 2006 field season. The section had 12 field parties and 37 summer students working in the field this year. New core or base-funded projects that were started this year went through a rigorous project planning and evaluation system as described by Parker (this volume, Article 2). This system allows for a good deal of input from staff members and allows for the evaluation of the project proposal based on its scientific and technical merit. Staff members who are available to start new core projects are assigned new projects based on their technical and scientific expertise and interest.

The most significant reason for the increase in field season activity this year was collaborative and add-on programs, such as the Targeted Geoscience Initiative III program—a collaborative effort between the Ontario Geological Survey (OGS), the Geological Survey of Canada (GSC) and Géologie Québec (Ayer et al., this volume) and the Far North Geological Mapping Initiative (FNGMI) (Parker, this volume, Article 19), which added significantly to the number of projects.

Table 3.1 is a list of active core projects within PGS for 2006–2007. Project objectives and current project status have been included in this table. PGS currently has 18 active core projects, 8 active collaborative projects (Table 3.2) and 7 active Far North Geological Mapping Initiative projects, for a total of 33 active projects. Sixteen of the total active projects are new projects for Fiscal 2006–2007 and are identified in the table by a "06" prefix (e.g., 06-001). In addition, PGS staff have completed 7 projects in the first 6 months of Fiscal 2006–2007 (Fiscal 2006–2007 runs from April 1, 2006 to March 31, 2007).

Summary of Field Work and Other Activities 2006,
Ontario Geological Survey, Open File Report 6192, p.3-1 to 3-6.

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PRECAMBRIAN GEOSCIENCE SECTION INITIATIVES

PGS initiatives are based on geographic or functional groupings and are made up of 1) team initiatives (i.e., Abitibi initiative) consisting of individual projects that are designed to meet an overall goal; 2) inter-jurisdictional team initiatives, such as the Targeted Geoscience Initiative, that consist of individual or joint OGS and GSC projects that are also designed to meet an overall goal or objective; and 3) individual, focussed projects. The major initiatives of the PGS are subdivided into 4 broad categories outlined below and in Tables 3.1 and 3.2.

1. Initiatives that involve collaborative agreements with the Geological Survey of Canada:
   - the Targeted Geoscience Initiative III focussed on the Abitibi, which also includes Géologie Québec;
   - the Hudson and James Bay lowlands initiative.
2. Initiatives involving provincial-scale metallogenic compilation and inventory studies:
   - documentation of pegmatite-hosted mineralization;
   - documentation of gold mineralization in the Superior Province.
3. Initiatives based on geographic areas:
   - Abitibi initiative;
   - metallogeny and geology of northwest Ontario;
   - Proterozoic initiative.
4. Initiatives involving geophysical projects:
   - geophysics and bedrock mapping integration initiative;
   - geophysics and rock properties data set initiative.

Core Projects

Denver Stone continued his work in the central Wabigoon Subprovince (Project No. 95-014). Denver will be revising some of his earlier 1:50 000 scale preliminary maps, based on the samples that were collected this year both for geochemical and geochronological analyses. Denver will be producing a 1:250 000 scale compilation map for this area in 2007 (Stone and Davis, this volume).

Tom Hart began a new project this year after successfully completing much of the work associated with the Lake Nipigon Geoscience Mapping Initiative. Tom started a multi-year study of the Shebandowan greenstone belt (Project No. 06-003). The Wye–Hamlin lakes area was mapped in the summer of 2006 (Hart and Trebilcock, this volume).

Carole Anne MacDonald started a one-year project in the Caribou Lake greenstone belt (Project No. 06-007). There was some previous geological mapping available for the greenstone belt, but the mapping was incomplete. Carole Anne mapped the "core" of the greenstone belt area (MacDonald, this volume).

Michael Easton continued his work on the geology and mineral potential in the Grimsthorpe area (Project No. 04-013) by logging a substantial amount of drill core (Easton, this volume, Article 15). Mike also mapped Baldwin Township at 1:20 000 scale (Project No. 06-005). This project continues the mapping that Mike had completed in the East Bull Lake area specifically in Porter and Vernon townships (Baldwin is located south of these townships). This is a one-year project (Easton, this volume, Article 14).

Table 3.1. Precambrian Geoscience Section core projects, 2006–2007.

Initiative	Project	Project Goal	Project Status
Abitibi Initiative	Cobalt–Temagami 1:100 000 scale compilation (Project No. 95-024)	Complete a 1:100 000 scale compilation map of the Cobalt–Temagami area of the Abitibi greenstone belt	1:100 000 scale map to be completed for publication in the fall of 2006.
	Bedrock mapping in the Shaw Dome area south of Timmins (Project No. 00-011)	Compile the township scale maps that were produced earlier as part of this project into a compilation map. Assemble the geoscience data into a Miscellaneous Release—Data and summarize in an Open File Report	MRD will be released in the fall of 2006. Compilation map will be released in April 2007 with the Open File Report ready for publication in the spring of 2007.
Proterozoic Initiative	River Valley bedrock compilation map (Project No. 01-009)	Individual maps in the River Valley area have been updated over the past few years. These maps will be assembled into a single compilation map (1:50 000 scale)	Map to be published in the fall of 2006.
	Geology and mineral potential of the Grimsthorpe area, Grenville Province (Project No. 04-013)	1:20 000-scale bedrock mapping of parts of Grimsthorpe, Tudor, Cashel and Limerick townships	Map and report to be published in the spring of 2007.
	Lake Nipigon compilation (Project No. 05-002)	Synthesize and compile a number of bedrock geology maps that were published as part of the Lake Nipigon Geoscience Mapping Initiative	1:100 000 scale compilation maps to be published in spring of 2007.
	Precambrian geology and mineral potential of Baldwin Township (Project No. 06-005)	Re-map Baldwin Township in order to assess its potential for Ni-Cu-PGE mineralization associated with East Bull Lake and Nipissing suite intrusions	A Preliminary Map and MRD will be completed and published in the spring of 2007.
	Lake Huron North Reconnaissance Project (Project No. 06-008)	A one-year reconnaissance level project to assess the mineral potential of the Huronian Supergroup rocks in an area north of Thessalon	This reconnaissance level work should allow for a preliminary assessment of the mineral potential in this area. Based on the results, a more detailed study may be undertaken. The project was suspended for fiscal 2006-2007.
Metallogeny and Geology of Northwest Ontario	Geology of the central Wabigoon Subprovince: bedrock compilation of the Ignace–Atikokan-Fort Frances area (Project No. 95-014)	Synthesize and compile a number of maps that were published at the 1:50 000 scale	1:250 000 scale compilation map to be completed and published in the spring of 2007.
	Precambrian geology of the Dinorwic–Butler lakes area, Wabigoon Subprovince (Project No. 99-001)	Map the Dinorwic–Butler lakes area at 1:20 000 and 1:50 000 scales	Maps and MRD to be completed and published in the fall of 2006 and early 2007.

Table 3.1. continued

Initiative	Project	Project Goal	Project Status
Metallogeny and Geology of Northwest Ontario, continued	Regional metamorphism of the Hemlo greenstone belt (Project No. 06-014)	1:50 000-scale map, report and database	Maps and report were published in August 2006.
	Geology and mineral potential of the Shebandowan greenstone belt (Project No. 06-003)	A multi-year project to analyze the mineral potential and tectonic settings of the Shebandowan greenstone belt. This will be accomplished by a combination of 1:20 000 and 1:50 000 scale mapping	The Wye–Hamlin lakes area was mapped during the summer of 2006. First year Preliminary Map and MRD will be available in the spring of 2007.
	Geology and mineral potential of the Caribou Lake greenstone belt (Project No. 06-007)	A one-year project to map unmapped areas of the Caribou Lake greenstone belt, and synthesize and compile mapped areas	Preliminary maps and MRD will be completed and published in the spring of 2007.
Provincial-scale Metallogenic Inventory Initiative	Distribution and documentation of rare-element pegmatites in the Superior Province of Northeastern Ontario (Project No. 02-003)	Summarize and document rare-element pegmatites in northeastern Ontario	Open File Report will be published in late 2006.
	Distribution and documentation of rare-element pegmatites in the Barbara–Gathering–Barbaro lakes area of north-central Ontario (Project No. 03-008)	Summarize and document rare-element pegmatites in north-central Ontario	Open File Report and MRD will be published in spring 2007.
	Distribution and documentation of rare-element pegmatites in the Fort Hope area (Project No. 04-039)	Summarize and document rare-element pegmatites in the Fort Hope area	MRD to be published in the spring of 2007.
	Update provincial 1:250 000 scale bedrock geology theme (Project No. 06-009)	Update the provincial bedrock geology	Revised MRD released in the fall of 2006.
	Geophysical support for bedrock mapping projects (Project No. 00-101)	Provide ongoing geophysical support, data and interpretation for bedrock mapping projects	Ongoing project
	Characteristics of mineralized intermediate to felsic plutonic systems (Project No. 00-012)	Gather and compile information on barren and mineralized felsic plutons across Ontario	An Open File Report will be released in the spring of 2007 for previous work on this project. Samples collected during the summer of 2006 will be analyzed and the results will be released in 2007.

Table 3.2. Precambrian Geoscience Section collaborative initiatives, 2006–2007.

Initiative	Project Collaborator(s)	Derived Project(s)	Project Status
Collaborative Projects with the GSC: Abitibi Targeted Geoscience Initiative III (TGI III)	Geological Survey of Canada (GSC), Géologie Québec, industry and academia	Bedrock mapping of the Kidd–Munro assemblage (Berger, Project No. 06-001)	The first year of this project will involve 1:20 000 scale mapping of Prosser Township; Preliminary Map will be published in the spring of 2007.
	Geological Survey of Canada, industry	Bedrock mapping in the Bartlett Dome area south of Timmins (Houlé, Project No. 06-002)	The first year of this project will involve 1:20 000 scale mapping of McArthur Township; Preliminary Map will be published in the spring of 2007.
	Geological Survey of Canada, Géologie Québec, industry and academia	Compilation of a 1:100 000 scale bedrock geology map for the Detour–Burntbush area (Ayer and Trowell, Project No. 95-024)	1:100 000 scale map to be completed for publication in spring 2007.
Collaborative Projects with the GSC: Lowlands Initiative	Geological Survey of Canada	Reprocessing and interpretation of the exposed Archean in the Sachigo Subprovince (Stott, Project No. 98-005)	Map to be published in early 2007.
	Geological Survey of Canada	Reprocessing and interpretation of the Precambrian basement in the James Bay Lowland (Stott, Project No. 98-006)	Map to be published in the winter of 2006.
	Geological Survey of Canada	Reprocessing and interpretation of the Precambrian basement in the Hudson Bay Lowland (Stott, Project No. 98-007)	Map to be published in early 2007.
Proterozoic Initiative	United States Geological Survey and the Minnesota Geological Survey	Midcontinent Rift Compilation (Easton, Project No. 03-002)	Project is ongoing.
Provincial-scale Metallogenic Inventory Initiatives	GoldCorp Limited	Characteristics of intermediate to felsic intrusive rocks in high gold endowment terranes of the Superior Province (Beakhouse, Project No. 05-009)	Miscellaneous Release—Data (MRD) to be published in the fall of 2006; an Open File Report will be published in 2007.

Norm Trowell will complete the 1:100 000 scale Cobalt–Temagami compilation map (Project No. 95-024). Fred Breaks and Gary Beakhouse continued their provincial-scale metallogenic inventory studies. Fred specifically for his rare-element pegmatite studies, and Gary working on a provincial-level mineralization study of intermediate to felsic plutonic systems (Beakhouse and Lin, this volume).

Finally, Tom Muir and Desmond Rainsford continue to provide geophysical support to core mapping projects (Project No. 00-101). In addition, both have been extremely active with the Far North Geological Mapping Initiative, providing geophysical data and interpretations. Tom and Desmond also provide geophysical support to other sections of the OGS (Rainsford and Muir, this volume). Finally, staff members will continue to complete previous projects already well underway.

Targeted Geoscience Initiative III Projects

The Targeted Geoscience Initiative III (TGI III) program is a 5-year federal geoscience program to sustain base metal reserves associated with established, base metal mining communities in Canada. The Geological Survey of Canada (GSC), Géologie Québec, the Ontario Geological Survey, industry and academia are conducting collaborative geoscience activities within the Abitibi greenstone belt (Ayer et al., this volume). The objectives include

- develop a multidisciplinary program to improve geological knowledge in the Abitibi to reduce the geological risk inherent in the exploration and discovery of base metals
- supply geoscience knowledge that will generate new anomalies and exploration targets, and stimulate significant new base metal exploration investment
- contribute to training and skills upgrading of highly qualified personnel in the base metal exploration sector

As part of this collaborative agreement with the federal and Quebec geological surveys, Ontario will complete mapping in the Kidd–Munro and Blake River assemblages. The mapping in the Kidd–Munro assemblage began in the summer of 2006 and will be completed by Ben Berger (Project No. 06-001; Berger, this volume). The Blake River assemblage mapping project will begin in the summer of 2007.

In addition to the 2 projects that are directly linked to the TGI III program, Michel Houlé began a project in the Bartlett Dome area, located just southeast of Timmins (Project No. 06-002). The first year of this multi-year project is based on the mapping of McArthur Township (Houlé, this volume). John Ayer and Norm Trowell started a 1:100 000 scale compilation map in the Detour–Burntbush area to complement the TGI III program.

Other Collaborative Projects

Greg Stott continued to work on 3 projects in the Far North. The GSC provided reprocessed geophysical data, which has allowed Greg to re-interpret the Precambrian basement rocks under the James Bay and Hudson Bay lowlands area (Project No. 98-006 and 98-007, respectively; Stott and Rainsford, this volume). Greg will also use this reprocessed geophysical data to re-interpret the exposed Archean in the Sachigo Subprovince (Project No. 98-005).

Finally, Michael Easton continued his collaborative work on the Midcontinent Rift project with the United States Geological Survey (USGS) and the Minnesota Geological Survey. Gary Beakhouse will complete a collaborative project with GoldCorp Limited later this fall (Beakhouse and Cassidy, this volume).

4. Project Unit 05-024. The Abitibi Subprovince: An Update on the Goals and Preliminary Results of the Precambrian Geoscience Section, Targeted Geoscience Initiative III and Deep Search Projects

J.A. Ayer[1], B. Dubé[2], W.D. Goodfellow[2], P.-S. Ross[2], W. Bleeker[2], B.E. Taylor[2], J.M. Peter[2], E.C. Grunsky[2], B. Hillary[2], P.C. Thurston[3], B.R. Berger[1], M.G. Houlé[1], G.P. Beakhouse[1], N.F. Trowell[1], D.B. Snyder[2], V.J. McNicoll[2], P. Keating[2], J.A. Percival[2], P. Mercier-Langevin[2], K. Lauzière[2], S.J. Paradis[2], J. Goutier[4], C. Dion[4], P. Pilote[4], M. Legault[4], T. Monecke[2], R. Dumont[2], P. Brouillette[2], P. Gosselin[2] and O. Van Breemen[2]

[1]Precambrian Geoscience Section, Ontario Geological Survey
[2]Geological Survey of Canada
[3]Mineral Exploration Research Centre, Laurentian University
[4] Géologie Québec, Ministère des Ressources Naturelles et de la Faune

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INTRODUCTION

This report summarizes the results of Abitibi greenstone belt (AGB) projects done in collaboration between the Precambrian Geoscience Section (PGS) of the Ontario Geological Survey (OGS), the Geological Survey of Canada (GSC) and Géologie Québec of the Ministère des Resources Naturelles et de la Faune as part of Targeted Geoscience Initiative III (TGI-3). The first part of the report provides an update on the PGS projects in the AGB in Ontario which represent in-kind contributions to TGI-3, the second part summarizes progress and results of the overall TGI program including the GSC and Géologie Québec projects that impact on Ontario. The design of the components of the program are based on the result of client consultations in 2005 and specific recommendation provided by the Porcupine Prospectors and Northern Prospectors Associations. All the projects have been designed to stimulate mineral exploration and development in the AGB.

PRECAMBRIAN GEOSCIENCE SECTION PROJECTS

Geological Compilation Project

(Participants: J.A. Ayer, N.F. Trowell, J. Chartrand)

To date, the multi-year Abitibi compilation project has published hard-copy and digital versions of the Timmins, Lake Abitibi, Kirkland Lake, Swayze and Matachewan areas at a scale of 1:100 000 and a 1:250 000 scale compilation map (in digital and hard-copy formats) covering all of the above areas (Ayer, Trowell and Josey 2004; Ayer, Berger et al. 2005, respectively). Work began on a 1:100 000 compilation of the Cobalt and Temagami area in 2005. A total of 8 new geochronological samples were analyzed from this area in 2005 and these data will be released with the compilation map in the latter part of 2006. This summer, work began on a 1:100 000 scale compilation map covering the Detour and Burntbush area. This work was done with the co-operation of a number of companies including Xstrata Copper and Eastmain Resources both of which provided access to unpublished data and core from a diamond-drilling program covering much of the area.

Summary of Field Work and Other Activities 2006,
Ontario Geological Survey, Open File Report 6192, p.4-1 to 4-19.

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A total of 8 geochronological samples were collected from this area and the results of these analyses will be released with the compilation map in 2007. These new products will provide the required framework for a future AGB-wide lithological compilation map to be done in conjunction with Géologie Québec. This upgraded geological framework, in conjunction with all theTGI-3 projects being undertaken by the 3 geological surveys, will enable establishment of a more formalized AGB stratigraphy, further refinement of the timing of mineralization events, and development of new metallogenic and geodynamic models for the evolution of the AGB. This will help explorationists to find new mineral deposits within the world's richest greenstone belt.

J.A. Ayer is the OGS co-ordinator for TGI-3 and the OGS representative on the Discover Abitibi Initiative (DAI) Technical Committee. Phase III of DAI, completed in early 2006 (*see* www.discoverabitibi.com), was a $12 million exploration-focussed, geoscience data acquisition and legacy data compilation project collaboratively funded with Provincial, Federal and private sector contributions (Ayer and Calhoun 2005). Recent initiation of Phase IV of DAI has resulted in the submission of 50 new proposals for evaluation by the Technical Committee. Development of a new business plan for presentation to government agencies and private sector stakeholders to solicit funding is the next step. This should lead to implementation of Phase V with a number of new geoscience projects expanding both the variety and areas of coverage of Phase III.

Kidd–Munro Project

(Participants: B.R. Berger, W. Bleeker)

This summer, B.R. Berger mapped Prosser Township at 1:20 000 scale (Berger, this volume). This work represents the first year of an OGS in-kind contribution to TGI-3 in the Kidd–Munro project and has been made possible through the co-operation of Xstrata Copper by providing unpublished data and access to their extensive collection of diamond-drill core. The Kidd–Munro project is a multi-year and multi-disciplinary effort intended to extend the stratigraphy of the assemblage beyond the Kidd Creek copper-zinc mine, erect structural sections across various parts of the assemblage, examine the geochemistry and chemostratigraphy, provide reconnaissance stable isotope mapping and examine the geochemistry of graphitic argillites and interflow metasedimentary units within the assemblage. In Ontario, OGS personnel are involved with each aspect of the project, but are most directly involved with geological mapping of areas not recently mapped or that are deemed critical to understanding the Kidd–Munro assemblage.

Prosser Township is located approximately 8 km northeast of the Kidd Creek Mine (Figure 4.1). The township has been the focus of extensive exploration over the last 40 years by Xstrata Copper (formerly Falconbridge Exploration Incorporated) and a number of zinc and copper occurrences have been discovered. The mapping in this area is largely dependant on access to the abundant diamond-drill core, and to geophysical surveys, as outcrop covers less than 1% of the township.

Bartlet Dome Project

(Participant: M.G. Houlé)

This past summer, M.G. Houlé mapped McArthur Township at 1:20 000 scale (Houlé, this volume). This work represents the first year of a multi-year project to map the Bartlett Dome area as an OGS in-kind contribution to TGI-3. The rational for its inclusion in TGI-3 is to enhance the potential of this area for the discovery of new base metal mineralization and, in particular, Ni-Cu-PGE mineralization associated with the komatiites within the 2710 to 2704 Ma Tisdale assemblage in the Shaw Dome to the

north and at the Texmont Mine to the south. A new geophysical survey is an important component of the Bartlett Dome project to enhance the exploration potential of this area. Under TGI-3 Abitibi, the GSC has provided funding and technical supervision for a new time-domain electromagnetic airborne survey (MEGATEM® II) that will cover not only most of the Bartlett Dome, but also the southern and western part of the Shaw Dome area (*see* Figure 4.1).

Last summer's mapping in McArthur Township has revealed a close spatial relationship between komatiites and sedimentary rocks (banded iron formation and sulphidic graphitic argillite), abundant olivine cumulates, and spinifex-textured sills hosted within komatiite flows (Houlé, this volume). These are considered to be features indicative of favourable geological environments for nickel sulphide mineralization associated with the komatiites. In addition, the contact areas between the tonalite stocks and the surrounding metavolcanic and sedimentary rocks south of McArthur Lake are prospective for gold mineralization and should be examined, as should the association between gold and the iron formations units.

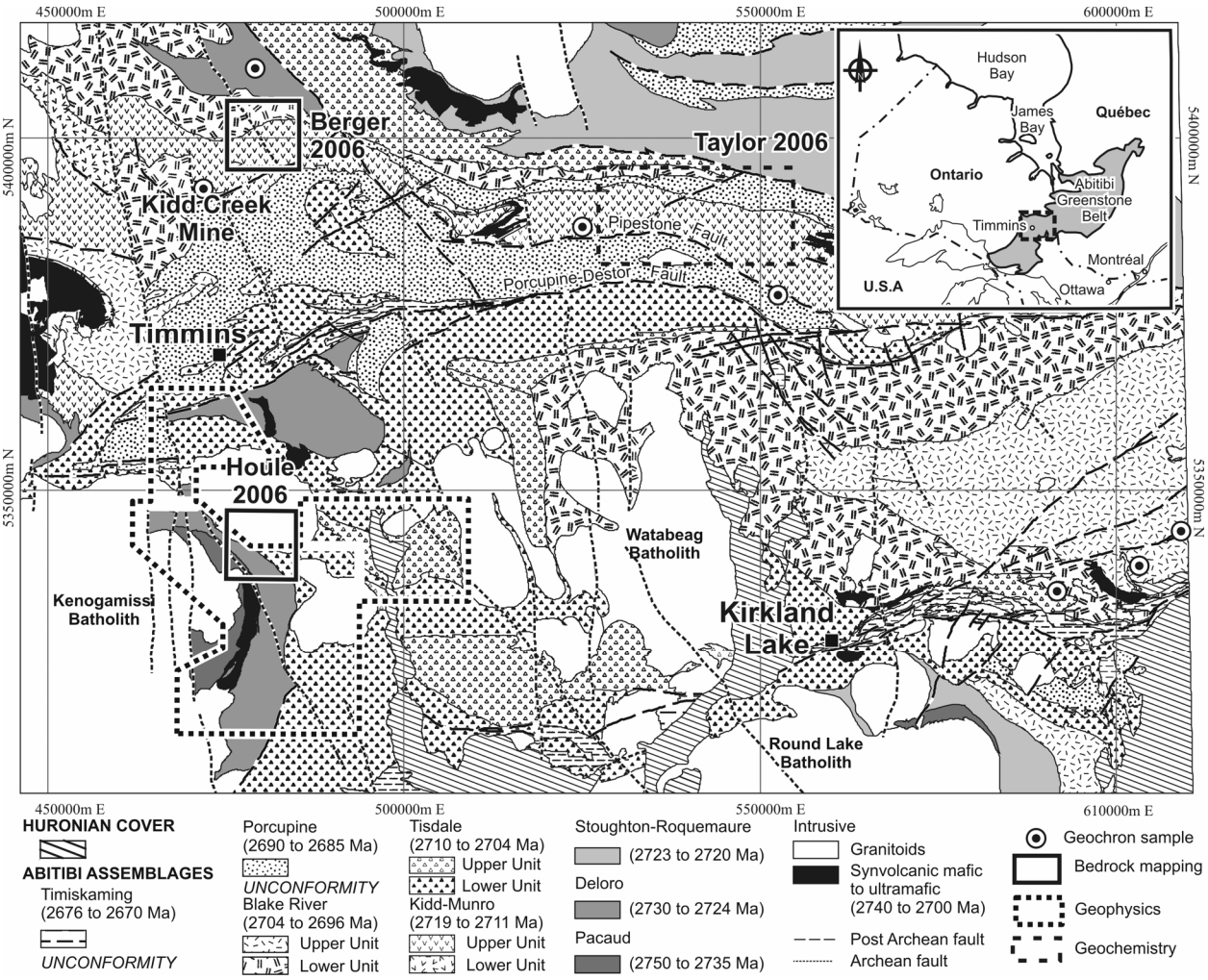

Figure 4.1. Lithostratigraphic assemblage map for the Timmins–Kirkland Lake region showing the location of field mapping, geophysical, isotopic, and geochronological sampling projects being undertaken in 2006 (*modified from* Ayer et al. 2005a).

Abitibi Granite Study

(Participant: G.P. Beakhouse)

A close temporal and spatial association between granitic intrusions and gold mineralization in the Superior Province suggests an as yet poorly understood genetic correlation. Over the past 2 years, G.P. Beakhouse has been examining granitic bodies in the Abitibi Subprovince to better understand this relationship (Beakhouse and Cassidy, this volume). Part of this project was initiated as a collaborative project agreement between the Ontario Geological Survey and Goldcorp (formerly Placer Dome Inc.) with the objective of providing a high-quality petrologic and geochemical database for Abitibi Subprovince intermediate to felsic intrusive rocks and interpreting the tectonic and metallogenic significance of these rocks. This database and derived interpretations will be compared with results from other Archean greenstone terranes (Red Lake, Western Wabigoon, Hemlo and portions of the Yilgarn craton of Western Australia) as part of a broader evaluation of the potential application of granite studies to predictive metallogeny.

TARGETED GEOSCIENCE INITIATIVE

Phase 3 of the GSC's Targeted Geoscience Initiative (TGI) program focusses on reversing the decline of base metal reserves in established mining communities. The principal objective of the TGI-3 program is to sustain the economic viability of existing mineral resource-based communities by stimulating private-sector resource exploration and deposit discovery. This will be achieved by improving and expanding the geoscience knowledge of established mining districts, collecting new data, undertaking new interpretation and developing improved geological and mineral deposit model(s). The TGI-3 Abitibi and Deep Search projects are a multi-disciplinary, fully integrated and jointly delivered provincial–federal geoscientific effort with participation by industry and universities that is focussed on vulnerable established mining communities of the Abitibi in Quebec and Ontario.

Specific objectives are

1. Generate new and improved geoscience data, to improve the skills of geoscientists, and to compile existing data into an updated context in order to help the mineral industry to use all available geological information to maximize the potential of finding new ore bodies.
2. Identify new anomalies, exploration targets and new exploration spending.
3. Develop and improve innovative methods of exploring for base metal deposits concealed at depth.
4. Contribute to filling the capacity gap in highly qualified personnel in the exploration sector and mining industry.
5. Identify geoscience information gaps critical to base metals exploration.

The project is largely based on new bedrock mapping, but will also integrate airborne and ground geophysics, geochemistry, isotopes, geochronology, three-dimensional (3D) modelling, and regional till surveys.

In the Ontario part of the Abitibi Subprovince, the focus of the joint OGS–GSC TGI-3 Abitibi project is on the Kidd–Munro, Tisdale and Blake River assemblages in the Timmins and Kirkland Lake region, but it also includes thematic studies, as well as an airborne MEGATEM® II survey.

The activities carried out during the 2006 field season included

- initiation of a study on geochemical process recognition within the Abitibi region (E.C. Grunsky and B. Hillary);
- field work to define the structural and stratigraphic framework of the Kidd–Munro assemblage and its implications for exploration (W. Bleeker, B.R. Berger, M.G. Houlé and J.A. Ayer);
- reconnaissance oxygen isotope mapping in the Kidd–Munro assemblage to better define paleomagmatic–hydrothermal systems in the Abitibi and their relationship to base metal deposits (B.E. Taylor and B.R. Berger);
- field mapping and sampling to study the volcanology, petrology, geochemistry of the Kidd–Munro assemblage rhyolite and its role in the formation of volcanogenic massive sulphide (VMS) deposits (A.D. Fowler, B. Moulton and B.R. Berger);
- undertaking of a mineralogical and chemical study of argillites in the Kidd–Munro assemblage to define vectors for detecting hidden base metal deposits (J.M. Peter, W.D. Goodfellow, D. Layton-Matthews and H. Chen);
- sampling of representative lithologies from drill core at the Upper Beaver copper-gold deposit to better understand the geology of the deposit (J.A. Ayer and P.C. Thurston);
- the initial stages of an integrated study of the Blake River Group (P.-S. Ross, J.A. Percival, P. Mercier-Langevin, V.J. McNicoll, J. Goutier, C. Dion, M. Legault and T. Monecke);
- limited field mapping and sampling to initiate a study on the geology of the mafic to intermediate dikes and/or intrusions within the Blake River Group (P.C. Thurston);
- the acquisition of new samples for U/Pb geochronology (V.J. McNicoll, O. Van Breemen, W. Bleeker, J.A. Ayer, B.R. Berger, P.-S. Ross, P. Mercier-Langevin, P. Pilote, C. Dion and M. Legault);
- geophysical compilation and a combined magnetic and electromagnetic survey MEGATEM® II to be flown during the fall 2007 over the Bartlett Dome near Timmins was awarded to Fugro Airborne Surveys Corp. (P. Keating and B. Dubé);
- merging multi-scale surficial geology maps for the trans-frontier Quebec–Ontario Abitibi area (S.J. Paradis, A. Smirnoff and É. Boisvert).

Geochemical Process Recognition

(Participants: E.C. Grunsky, B. Hillary and S. Adcock)

A component of the TGI-3 Abitibi Project is the compilation and evaluation of lithogeochemical data collected from a variety of sources. Geochemical process recognition within the Abitibi region of Quebec and Ontario involves the compilation, organization, levelling, analysis and interpretation of lithogeochemical data collected by provincial and federal government surveys combined with data from the mineral exploration industry and colleagues from universities. Data from various sources in Ontario (Ayer et al. 2005b; Ayer, Trowell and Josey 2004; Haus and Pauk 1993; Vaillancourt and Hall 2003; Galley et al. 2002) have been assembled into databases that can be used for subsequent evaluation by mineral exploration companies and detailed mapping by geological surveys. Data from other sources, including the mineral exploration industry, will be added during the initial phases of the project. The data will be evaluated using modern data analysis, statistical analysis and visualization that will help in identifying geochemical processes such as volcanic stratigraphy, regional and local-scale alteration and

signatures associated with base and precious metal mineralization, including massive sulphide deposits. The database is being compiled for the entire Abitibi greenstone belt region; however, emphasis will be placed on interpreting the lithogeochemistry in the Blake River and Kidd–Munro assemblages. These data will be released as a GSC Open File Report.

Key Assemblages for Base Metal Exploration

The Abitibi greenstone belt consists of a large number of Neoarchean volcano-sedimentary assemblages that are stratigraphically interlayered and structurally imbricated, multiply folded, and faulted. Mineral potential is unevenly distributed through time and space with some assemblages having significantly higher potential than others. All else being equal, mafic to intermediate to felsic volcanic successions (rhyolites and andesites and/or basalts, with or without komatiites), formed in extensional geodynamic environments, deeply penetrating synvolcanic faults, thin crust, and high heat flow, are most favourable for significant base (and precious) metals mineralization. Three assemblages, the Kidd–Munro (2719 to 2711 Ma), Tisdale (2710 to 2704 Ma) and Upper Blake River (~2701 to 2695 Ma), fit these general characteristics and historically have been highly productive supporting several major mining camps.

Kidd–Munro Assemblage

In Ontario, the Kidd–Munro assemblage is traditionally seen as the most prospective. It hosts the giant Kidd Creek VMS deposit (Bleeker 1999; Hannington, Bleeker and Kjarsgaard 1999) as well as a number of smaller deposits. Thus, it represents a key geological assemblage to investigate for both the TGI-3 Abitibi and Deep Search projects.

KIDD-MUNRO ASSEMBLAGE AND STRUCTURAL–STRATIGRAPHIC ARCHITECTURE

(Participants: W. Bleeker, B.R. Berger, M.G. Houlé, J.A. Ayer and O. Van Breemen)

Effective exploration for volcanogenic base metal deposits is dependent on detailed stratigraphic characterization, identification of key marker horizons, and recognition of extrusive centres and potential synvolcanic structures. Once identified, these need to be traced through numerous structural complications of tectonic origin (folds, faults) and through areas of poor exposure.

In Ontario, the TGI-3 Abitibi project is focussing on the Kidd–Munro assemblage, its internal stratigraphy, and its bounding structures. Extrapolation of relationships observed in the Kidd Creek Mine area (e.g., Bleeker 1999), regional stratigraphic considerations (e.g., Ayer, Amelin et al. 2002; Ayer et al. 2005a) and new insights from the Discover Abitibi seismic transects (Reed, Snyder and Salisbury 2005; Snyder et al., in press), draw attention to the contacts of the Kidd–Munro assemblage as major stratigraphic discontinuities in the Abitibi Subprovince, with the 2719 to 2711 Ma metavolcanic rocks structurally overlying and facing away from Porcupine Group (~2685 Ma) metagreywackes across the Pipestone fault (Photo 4.1). Although this contact is now subvertical, or dipping steeply to the north, it likely originated as an early, shallow dipping (out-of-sequence) thrust along which Kidd–Munro assemblage volcanic rocks were transported and emplaced on top of much younger Porcupine Group greywackes. In this process, Kidd-Munro assemblage rhyolites, komatiites and basalts—with their contained VMS deposits—were detached from a complex volcanic-plutonic substrate (as revealed by zircon inheritance; Bleeker, Parrish and Sager-Kinsman 1999; Ayer, Amelin et al. 2002; Ayer et al. 2005a) and transported as a thrust sheet, most likely in a southerly direction. The end phase of this early

contractional deformation, which must have closed a number of distinct volcano-sedimentary troughs, involved steepening of this thrust, and development of early, upright, tight to isoclinal regional folds that trend parallel to the outcrop belt of the Kidd–Munro assemblage rocks and duplicate and repeat its stratigraphy (e.g., folds in the Kidd Creek Mine area, *see* Bleeker 1999).

Confirmation of this early thrust contact will come from geochronological analyses of several samples on a continuous and well-exposed structural–stratigraphic section (in progress) through Munro Township, including one sample of north-younging Porcupine Group greywackes in the footwall of the thrust contact, followed by geochronology on north-younging volcanic rocks in the immediate hanging wall to the north, at the structural base of the Kidd–Munro assemblage. If confirmed, we propose to call this regional structure the "Pipestone Thrust", a fundamental structure likely at the scale of the Abitibi Subprovince. Structural–stratigraphic sections through areas of best outcrop and dense data will then evaluate the internal structure of the Kidd–Munro assemblage panel. An important question is what happens along the northern contact: Is there another thrust or a stratigraphic succession into younger rocks (again involving greywacke as suggested by previous mapping)?

Finally, both the Porcupine Group greywackes and Kidd–Munro assemblage (and the regional folds therein) are being progressively truncated to the east by the Porcupine–Destor deformation zone, with drag and other considerations suggesting large-scale sinistral net displacement (Bleeker 1995). A tentative estimate (Bleeker 1995; W. Bleeker, GSC, unpublished data, 2006 involves circa 100 km of net sinistral displacement on the Porcupine–Destor deformation zone.

Photo 4.1. Ontario Geological Survey geologist Ben Berger standing on thinly bedded Porcupine Group greywacke–mudstone turbidites just below the interpreted thrust contact with volcanic rocks of the Kidd–Munro assemblage. Statistical younging direction of the turbidites is to the north, thus placing them in the footwall of the older Kidd–Munro metavolcanic rocks.

Ultimately, the aim is to correctly restore the large faults in the Abitibi Subprovince, thus simplifying the stratigraphic understanding across the Ontario-Quebec border and the entire Abitibi Subprovince. This will significantly change the early paleogeography of the Abitibi Subprovince, and how we think about the assemblages and their primary environment. Furthermore, it will provide the structural and tectonic framework in which to view the main fault breaks and their significance for mineralization.

REVISION OF THE WESTERN PART OF THE MALARTIC GROUP: KIDD MUNRO ASSEMBLAGE CORRELATIVES IN QUEBEC

(Participants: P. Pilote, V.J. McNicoll)

As presently understood, the Kidd–Munro assemblage has not been correlated east of the Ontario border. The potential to discover Kidd Creek VMS-type ore deposits in equivalent rocks in Quebec makes the search for Kidd–Munro correlatives worthwhile. Several lithostratigraphic packages have been proposed as possible candidates, including 1) the Malartic Group (Pilote, Moorhead and Mueller 2000; Scott, Mueller and Pilote 2002); 2) parts of the Kinojévis Group (Goutier 1997); and 3) the Destor area (Goutier 1997). The western part of the Malartic Group was revised during summer 2006, and most of the 2 other sectors will be examined next year. Two rhyolites were sampled for U/Pb geochronology: one in the Malartic Group, the other in the Kinojévis Group. These data, in association with mapping and lithogeochemical studies, will help to establish and clarify large-scale stratigraphic correlations. The La Pause tonalitic intrusive complex, an assumed synvolcanic pluton, will also be subjected to geochronological analysis.

ARGILLITE AS MINERALOGICAL AND GEOCHEMICAL VECTORS TOWARD BASE METAL MINERALIZATION

(Participant: J.M. Peter)

A joint subproject of the Deep Search and Abitibi Projects of the TGI-3 program has been initiated to develop new methodologies for VMS targeting using circa 2.7 Ga sulphide-bearing, carbonaceous (graphitic), argillaceous sedimentary rock horizons that are a minor, but ubiquitous, feature of such deposits (e.g., Kidd Creek and Chance) within the Kidd–Munro assemblage.

The metals within these sedimentary rocks originate largely from hydrothermal and hydrogenous (i.e., seawater) sources and, to a lesser extent, from detrital input. The carbonaceous deposits (non-carbonate and graphitic carbon) are largely the product of microbial processes active within the volcano-sedimentary basins during hydrothermal activity. Because of their electromagnetic response, these horizons have been extensively mapped and drilled as potential exploration targets. Since these sediments formed in an anoxic ocean, they display important mineralogical and geochemical differences from most Phanerozoic exhalites and iron formations associated with VMS mineralization.

Reliable tools for recognizing barren versus mineralization-related horizons, and for vectoring towards mineralization, are presently lacking. The aim of this subproject is to develop new mineralogical, geochemical, and isotopic tools to discriminate potentially mineralized versus unmineralized horizons. Methods will include bulk geochemical analysis by conventional methods, X-ray diffraction, short wavelength-infrared (SWIR) spectroradiometry, and portable X-ray analysis to evaluate hand sample-scale bulk compositional variations, and laser ablation quadrupole and multi-collector-inductively coupled plasma mass spectrometry (ICP–MS) to evaluate small-scale compositional variations, as well as traditional and non-traditional stable (e.g., C and S, Fe, Zn, Cu) and radiogenic isotope variations. All data obtained will be incorporated into two-dimensional and, where justified, 3D geographical information systems (GIS) for analysis.

The purpose is to identify chemical and isotopic signatures of large-scale hydrothermal systems recorded in the sediments. The emphasis will be on regional-scale signatures, extending well beyond known mineral deposits. The proposed study has the potential to significantly increase the target size of mineralized areas by isolating chemical and isotopic signatures carried into the overlying water column at the time of ore formation and recorded in contemporaneous sediments.

The project will continue for several field seasons, and is planned to end in 2010. Sampling will be done in close collaboration with the OGS (Ben Berger, John Ayer), Xstrata Copper (formerly Falconbridge) personnel (Dean Rogers, Frank Santaguida), and the University of Ottawa (Mark Hannington). Two weeks of work encompassing detailed regional- and property-scale logging and sampling of shale (argillaceous) host rocks was done by Jan Peter (GSC), Daniel Layton-Matthews (Queen's University), and a postdoctoral fellow. Field analyses by FieldSpec Pro 3® SWIR spectroradiometer and Innov-X Systems Alpha 600® X-ray fluorescence (XRF) portable analyzer were also conducted. These samples will be analyzed by conventional methods at the GSC over the winter.

OXYGEN ISOTOPE MAPPING

(Participants: B.E. Taylor, B.R. Berger)

Whole-rock oxygen isotope mapping provides a unique method of identifying and mapping the distribution of paleo-hydrothermal systems in the Earth's crust. Depletion and enrichment of oxygen isotopes remains as a robust record of water–rock interaction under elevated temperatures despite any subsequent metamorphism. Volcanogenic massive sulphide deposits form in submarine hydrothermal systems typically associated with subvolcanic intrusive centres. Isotopic mapping can be used to delineate high-temperature up-flow paths leading to deposits, as well as lower temperature, post-mineralization isotopic enrichment of overlying hanging-wall rocks.

Reconnaissance whole-rock oxygen isotope investigations in the Kidd–Munro assemblage have been initiated under the TGI-3 program. The first phase of this endeavour began in July 2006 with the sampling of rock powders derived from the archives of previous OGS mapping. Approximately 200 samples from the townships of Carr, Clergue, Taylor, Wilkie and Walker were collected (*see* Figure 4.1). Oxygen isotope analysis of these samples will be carried out at the Light Stable Isotope Lab, GSC–Ottawa, and the results combined with those of previously published studies of the Kidd Creek Mine and vicinity by Huston and Taylor (1999) and Taylor and Huston (1999) (Figure 4.2). Future sampling and analysis will extend these studies eastward, throughout the Kidd–Munro assemblage. Together, these isotopic studies will indicate areas of potential economic interest which will be pursued in greater detail. Isotopic maps and interpretive reports will be produced for publication.

Tisdale Assemblage: Bartlet Dome Project

(Participants: M.G. Houlé, P. Keating, R. Dumont)

The Tisdale assemblage (2710 to 2704 Ma) is the most prospective AGB assemblage for komatiite associated Ni-Cu-PGE associated deposits. The assemblage hosts the past-producing Langmuir #1 & #2, Redstone and Texmont mines south of Timmins and a large number of other prospects and occurrences. Smaller deposits (i.e., 1 to 2 million tonnes) of this type have recently become much more economically viable with recent increases in nickel and copper prices and the conversion of one of the circuits at the Xstrata Copper metallurgical site in Timmins in order to process the nickel-copper ore from the Montcalm deposit. Thus, it represents an important geological assemblage to investigate for TGI-3. This project will involve a mapping component by M.G. Houlé (see above) and a MEGATEM® II survey (see below).

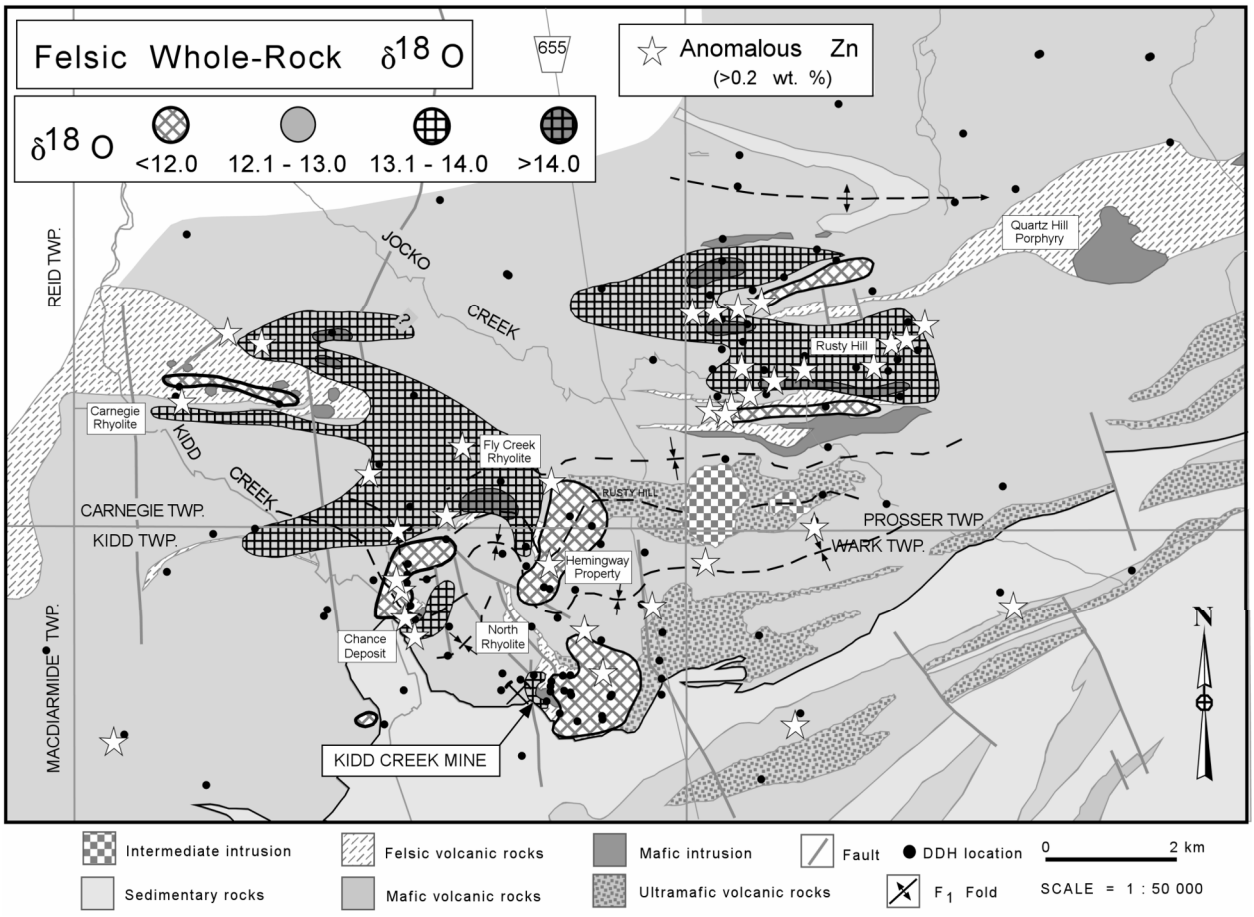

Figure 4.2. Distribution of folded oxygen isotope zones in the Kidd Creek Mine region (*from* Taylor and Huston 1999).

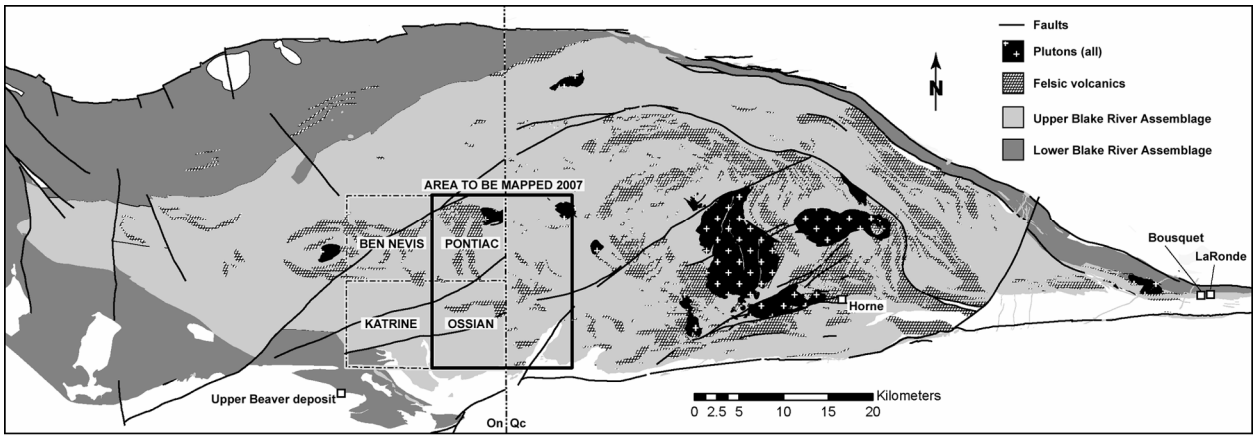

Figure 4.3. Simplified geologic map of the central part of the Blake River assemblage in Ontario and Quebec, showing the location of mineral deposits mentioned in the text. The Lower Blake River assemblage is known as the Hébécourt Formation in Quebec. The area south of the Horne mine block belongs to the Rouyn–Pelletier Formation. Pontiac and Ossian townships will be mapped by OGS personnel in 2007 and an equivalent area will be examined by Géologie Québec personnel in Quebec, in addition to ongoing mapping projects in the Blake River (locations not shown). Note: not all faults are displayed and some are incomplete.

MEGATEM® II SURVEY

A combined magnetic and electromagnetic survey (MEGATEM® II) will be flown during the fall of 2006 over the Bartlett Dome (*see* Figure 4.1). The results of a total of 5920 km of flight lines are expected to be published early in 2007. The previous EM survey for this area was released in 1988 and had north-south–oriented flight lines, a poor orientation for much of the southern portion of the new survey area, which is now being flown east to west, orthogonal to the strike of the geological units. The EM component of the new survey will generate a significant number of exploration targets for base metals, whereas the high-resolution magnetic component will help to better define the regional geology of the area, outline key lithological units and possible identify structural targets for gold mineralization.

Blake River Assemblage

The Upper Blake River assemblage of Quebec and Ontario (Péloquin et al. 2001; Ayer et al. 2005a; Figure 4.3) is a prime target for VMS exploration. This is demonstrated by the >200 Mt of known base metals and the >25M ounces of known gold, most notably within the Horne deposit (production of 53.7 Mt at 6.1 g/t Au, 2.2% Cu, 13 g/t Ag; Gibson, Kerr and Cattalini 2001) and the LaRonde deposit (production, reserves and resources totalling 58.4 Mt at 4.39 g/t Au, 2.7% Zn, 0.33% Cu, 50 g/t Ag; Dubé et al. 2004; Mercier-Langevin et al. 2004). Despite the fact that a sizable portion of the Upper Blake River assemblage is also present in Ontario, large deposits have so far been restricted to the Quebec portion. A multi-disciplinary integrated project has been initiated to better understand the geology of the Blake River, the parameters controlling the formation of mineral deposits at the scale of the assemblage and to help the mineral industry explore for base metals. The project includes township-scale mapping, volcanology, structure, geochronology, alteration and mineral deposit (including Horne and Quemont deposits, Doyon–Bousquet–LaRonde district), geochemistry, isotope geochemistry, as well as two-dimensional seismic and 3D modelling.

VOLCANOLOGY, STRATIGRAPHY, STRUCTURE, STABLE ISOTOPES, BEDROCK MAPPING AND GEOCHRONOLOGY

Volcaniclastic Rocks outside the Noranda Camp

(Participant: P.-S. Ross)

This study is taking place in Quebec and Ontario. Overall, it aims to improve our understanding of the stratigraphy, volcanic history, and volcanic architecture of the Upper Blake River assemblage to help base metal exploration. It includes the interpretation and documentation of major occurrences of volcaniclastic rocks (including pyroclastic rocks).

In the Noranda camp, work by de Rosen-Spence (1976), followed up by Gibson (1989), and others, has allowed the identification of an irregular, graben-like subsidence structure, traditionally referred to as the Noranda cauldron. The giant Horne deposit lies just south of the southern boundary of this cauldron, but most of the "Noranda-type" VMS occurrences in the camp are found within it. The recent suggestion by Pearson (2005) of a much larger "megacaldera" in the Blake River Group, which he names the Misema caldera, has important implications for exploration and reconstruction of the volcanic architecture of the region. The proposed Misema caldera has been delineated using inferred ring faults; carbonate alteration zones; mafic dike patterns; and volcaniclastic deposits. The latter are not well known as they have not been systematically studied. Therefore, a systematic documentation of the distribution, grain size, sorting, type and proportion of fragments, structure, and geochemistry of volcaniclastic rocks outside the Noranda camp (in both Quebec and Ontario) will be a significant contribution to understanding of the evolution of the

Blake River Group. This will result in a consistent inventory of these rock types using a unified nomenclature scheme; as this type of information is not presently available. The most interesting and well-exposed occurrences will then be mapped in detail with the aim of interpreting the mode of fragmentation and the mode of transport of these rocks. Previous mapping efforts relevant to this study on the Ontario side include those of Jensen (1975a, 1975b) and Péloquin and Piercey (2005); compilation maps by Ayer, Berger and Trowell (1999) and Ayer and Trowell (2000) are also useful.

Work to date was mostly done on the Quebec side (including the Stadacona Tuff, the d'Alembert Tuff, and the Monsabrais area). The d'Alembert Tuff, located in the northern Blake River Group in Quebec (Tassé, Lajoie and Dimroth 1978; Dimroth and Demarcke 1978) is the archetypal "Misema caldera" intermediate volcaniclastic unit, of possible pyroclastic origin. It consists of a sequence of tuff-breccias, lapilli-tuffs and tuffs which can be traced for over 15 km laterally and that is at least 300 m in stratigraphic thickness. Both the intermediate lithic fragments and the matrix are generally rich in plagioclase crystals. Fragment vesicularity varies: some "pumice" (very vesicular clasts) are seen on wet slabs and non-vesicular clasts also exist. Work on the Ontario side for summer 2006 was limited to reconnaissance mapping in Ossian Township, mostly in the Lake Labyrinth area, and visits to Ben Nevis and Katrine townships (*see* Figure 4.2). The initial interpretation is that no volcaniclastic units equivalent to the d'Alembert Tuff have been encountered, most volcaniclastic units appearing monogenic, of limited lateral extent, and not especially plagioclase-phyric. With the exception of one area in Katrine Township, the clastic rocks observed this summer originated as flow breccias, pillow breccias, hyaloclastite, etc., but not as submarine pyroclastic deposits (e.g., Photo 4.2). Polygenic volcaniclastic rocks in Katrine Township, described by Péloquin and Piercey (2005, p.8), are of uncertain origin. More work is clearly needed before any definitive statements can be made about the lack of d'Alembert Tuff correlatives on the Ontario side of the Blake River Group.

Photo 4.2. Intermediate fragmental unit on the Larder Lake Station road in Ben Nevis Township (location: UTM 597989E 5352550N, NAD83, Zone 17). Massive lava is seen to grade into the volcaniclastic rock, strongly suggesting local fragmentation because of autobrecciation of the flow and/or interaction with seawater.

Stable Isotopes

(Participants: B.E. Taylor, P.-S. Ross, C. Dion, P. Mercier-Langevin)

In parallel with the volcanology study, 10 samples were collected from Ossian Township for whole-rock oxygen isotope analysis. More extensive isotopic sampling took place in Quebec (Doyon–Bousquet–LaRonde camp, and other areas of lesser coverage). Samples will be processed at the Light Stable Isotope Lab, GSC–Ottawa. The results will be integrated into an oxygen isotope map of the whole Blake River Group based on both compiled and new data. The purpose of this large-scale study is to document hydrothermal systems in areas of known mineralization as well as in areas poorly known for mineralization. The Ontario sampling will be greatly extended in 2007, especially in Ossian and Pontiac townships, which lie between areas of better isotopic coverage, that is, Clifford–Ben Nevis townships to the west (Taylor and Timbal 2002a) and the Noranda camp to the east (e.g., Taylor and Timbal 2002b).

Structural Studies

(Participants: J.A. Percival, J. Goutier)

A structural study of the entire Blake River Group was initiated. This subproject will build on the existing synthesis by adding structural detail that will help illustrate the structural characteristics of the Blake River Group and the reconstruction of volcanic features prior to regional deformation. In particular, variations in strain level across the area will be incorporated into a geometric model to allow palinspastic reconstruction. The work will result in a more accurate representation of the primary volcanic architecture, including distribution and orientation of strata, dikes, sills, alteration and mineralized zones. Three-dimensional GIS tools will be used to aid data management, interpretation and visualization.

The main goals of the study are to:

1. define the structural geometry and tectonic evolution of the Blake River Group in Quebec and Ontario;
2. reconstruct the primary volcanic architecture of the Blake River Group prior to regional deformation; and
3. define the subsurface distribution of stratigraphic units, particularly strata prospective for VMS mineralization.

A regional structural study was initiated in 2006 in the Rouyn–Pelletier formation of the Blake River Group, near Rouyn–Noranda. The submarine volcanic formation consists of a lower tholeiitic basalt section, including a unit of “fish-roe” rhyolite and stratigraphically higher units including the Stadacona Tuff, Glenwood Rhyolite and pillowed andesitic flows. It is bounded to the south by the Cadillac fault and to the north by the Andesite fault. Several structural domains were identified on the basis of the style, orientation and kinematic sense of structures in these variably deformed, low-grade metamorphic rocks. From south to north, the domains include

1. an approximately 2 to 3 km wide zone characterized by narrow, moderately (20 to 50°) north-dipping deformation zones, generally focussed within pillow breccia units and exhibiting normal kinematic sense. These structures correspond to a suite recognized to the south in Granada (Timiskaming-type) conglomerates and Pontiac metasediments, and attributed to an “exhumation” deformational stage by Daigneault, Mueller and Chown (2002). Brittle–ductile transcurrent movement on the Cadillac fault postdates this generation of structures;

2. an approximately 2 km wide, upright anticline-syncline pair including the Rouyn syncline, associated with a steep, east-northeast-striking axial planar cleavage. Sporadic steeply dipping shear zones within the central Rouyn–Pelletier formation may relate to this folding event; and
3. a zone of overprinting, east-striking cleavage and localized narrow shear zones indicating sinistral transcurrent sense. These are most prominent in the north and possibly related to deformation along the Andesite fault.

Age relationships among the structures in these domains are apparent on a local scale. Further work in progress will define the structural sequence and geometry of the Rouyn–Pelletier formation as part of a broader project aimed at describing the structural evolution and 3D distribution of units throughout the Blake River Group.

Geochronology and Bedrock Mapping

(Participants: V.J. McNicoll, C. Dion, M. Legault, P.-S. Ross)

A U/Pb geochronology sample was collected from the west shore of Lake Labyrinth in Ossian Township (location: UTM 609639E 5343936N, NAD83, Zone 17). The rock to be analyzed is a massive silicic lava belonging to the major east-trending felsic unit in the township (*see* Figure 4.1). The zircon yield is encouraging, but no age is available at this time. This felsic unit is shown as dominantly fragmental on the map accompanying Jensen's (1975b) report and hosts the former Ossian gold mine. We hope to better characterize this unit in the gold mine area next year.

This geochronological sample is part of a suite collected in the Upper Blake River assemblage in 2006, mainly on the Quebec side, to help solve a number of problems including stratigraphic issues. Many of these samples were collected to complement 1:20 000-scale bedrock mapping and compilation by Géologie Québec geologists.

Mafic Dikes Project

(Participants: P.C. Thurston, J. Goutier, J.A. Ayer)

Archean mafic to intermediate dikes and sills cutting the Upper Blake River assemblage have a close spatial relationship to VMS mineralization in the Noranda camp; some dikes appear, in part, related to development of the subsidence structure containing the mineralization in that their distribution is subparallel to the margin of the Noranda cauldron (Gibson and Watkinson 1990). The dikes in the Noranda camp include several types ranging from pre-mineralization gabbro-quartz diorite to post-mineralization units related to reverse faults. The dikes extend throughout the Upper Blake River assemblage and define radial and concentric patterns. Pearson (2005) used these patterns, amongst other evidence, to suggest that the assemblage as a whole represents an imbricated caldera complex composed of an early Misema caldera representing almost the whole of the assemblage, followed by development of a newly recognized New Senator caldera and, lastly, the classic Noranda cauldron, confined to the central part of the camp.

What is currently known is that the dikes in the Noranda region represent at least 5 geochemical types (Lagraa 1994): A – tholeiitic, B – tholeiitic, C – calc-alkaline, C1 – transitional, D – transitional. Suites A and B are enriched in TiO_2, Al_2O_3, CaO and Fe_2O_3. Rare earth element (REE) patterns are fractionated with suite D representing the most differentiation with strong negative Eu anomalies. The tholeiitic suites (A, C1, and D) are enriched in incompatible elements (Nb, Zr, Y, Rb, Hf, Th, U and REE). Suites A, B, and D are not co-magmatic and ratios such as Zr/Nb vary from suite to suite. Petrogenesis of suites A, B, D and C1 involves both fractionation and partial melting with suite C involving magma mixing. Lagraa (1994) did not

deal with field relations amongst the various dike types or provide geochronological constraints. This complexity clearly indicates much work remains to establish the field relations, structural setting, and absolute ages of these types in Quebec and to extend the work to Ontario.

As a result of the close spatial association and possible linkage with caldera development in the Noranda camp and the Upper Blake River assemblage as a whole, TGI-3 developed a "Mafic Dykes" project. The goals of the project, which is being done in collaboration with the Mineral Exploration Research Centre at Laurentian University, are to

- establish the field relations of the various sets of mafic to intermediate dikes and sills cutting the Upper Blake River assemblage;
- establish the structural setting of the various sets;
- establish the absolute age of the intrusions by U/Pb geochronology;
- establish the petrography, geochemistry and petrogenesis of the various sets.

To date, we have sampled many of the mafic dikes and sills cutting the Blake River Group in Ossian, Pontiac, Tannahill, Clifford and Ben Nevis townships of Ontario (*see* Figure 4.3). Composition ranges from quartz diorite through diorite to hornblende gabbro. The preliminary sampling done thus far will be expanded to include Quebec (where the pegmatitic phase of one dike is being dated by V.J. McNicoll) by the close of the field season. Subsequent work on the project in 2007 will involve a MSc student emphasizing mapping, petrography, geochemistry and petrogenesis of the dikes.

Future Work in the Blake River Assemblage

Activities planned in the Blake River assemblage for field season 2007 include 1:20 000-scale bedrock mapping of 2 townships (Ossian and Pontiac, near the Quebec border, *see* Figure 4.3) by the OGS and mapping of an equivalent area at the same scale on the other side of the border by Géologie Québec. This simultaneous and co-ordinated bedrock mapping effort should eliminate the border fault and contribute to a better stratigraphic and structural understanding of the Blake River assemblage. Additionally, the aforementioned studies of the volcanology, structure, mineral deposits and specific mineralized-altered stratigraphic horizons, geophysics, stable isotopes, and geochronology of the Blake River assemblage will continue. The ongoing geophysical surveys and compilations (3D model by E. de Kemp; 2D seismic lines by G. Bellefleur), the metallogenic synthesis of the Doyon–Bousquet–LaRonde district (P. Mercier-Langevin, B. Dubé, P. Gosselin, C. Dion), along with other VMS showing characterization (P. Mercier-Langevin. P.-S. Ross, C. Dion), and synthesis will all have impact on exploration in Ontario as it will provide a better knowledge of the favourable criteria for VMS and gold-rich VMS deposits formation in the entire Blake River, and elsewhere as well.

Geophysics

GRAVITY COMPILATION

(Participants: P. Keating, P. Brouillette)

Bouguer anomaly data from the GSC, OGS and Géologie Québec have been integrated into a homogeneous grid that covers the Abitibi greenstone belt from west of Timmins to Chibougamau. The new map will be available in digital format, as well as a paper GSC Open File at a scale of 1:750 000. This gravity map will contribute to a better understanding of the three-dimensional structure of the region.

SEISMIC REFLECTION: TRIAL PROCESSING OF HORIZONTAL COMPONENT SEISMIC REFLECTION DATA – SHILLINGTON LINE

(Participants: D.B. Snyder, W. Bleeker)

The Discover Abitibi Initiative acquired 153 line-kilometres of seismic reflection data in 2004 and processed only the vertical component before producing interpretative reports (Reed at al. 2005) and a upcoming paper to be published in *Economic Geology* (Snyder et al., in press). These interpretations identified reflector geometries characteristic of thrust and fold belts within the upper crust in the Timmins region of the Abitibi greenstone belt. The implied repetition of stratigraphy as a result of these tectonic processes has important implications for the recently established regional stratigraphy of the greenstone belt (Ayer et al. 2005a). Thus, field checking of key outcrops during the 2007 OGS field season will be required in order to reconcile fold and thrust patterns implied by the seismic reflection geometries with mapped rock attitudes.

In early 2006, as part of the first year of the TGI-3 Abitibi Project, the remaining 2 (horizontal) components of one of the seismic profiles were processed by Sensor Geophysical Ltd., the same commercial contractor that did the initial processing. Similar reflection geometries were identified, but, significantly, these represent reflections of S-waves, whereas the original processing used P-waves. By contrasting the 2 sections, new physical rock properties can be estimated. In addition, tomographic sections of the top 1.5 km are being produced that provide bulk estimates of P- and S-wave speeds in the crust (as contrasted with reflectivity properties discussed above). To date, all specialized processing was concentrated on the Shillington Line crossing of the Porcupine–Destor deformation zone. Similar work in the future will focus on the line going through the Kidd Creek Mine site where we hope to "map" stratigraphy as well as identify anomalous seismic properties that might be associated with massive sulphide mineralization by using the 4 types of seismic wave properties now available. In collaboration with colleagues from Geoscience Australia, comparisons between results from the Abitibi greenstone belt will be made with those from the Yilgarn craton in Australia.

Quaternary

MERGING MULTI-SCALE SURFICIAL GEOLOGY MAPS FOR THE TRANS-FRONTIER QUEBEC–ONTARIO ABITIBI AREA

(Participant: S.J. Paradis)

The trans-frontier Quebec–Ontario Abitibi area has been mapped at various scales over the years by numerous Quaternary scientists (a few scientists on the Quebec side and about 10 different scientists on the Ontario side). This multi-author mapping strategy caused numerous discrepancies along the different map margins (especially at the Quebec–Ontario frontier) and legend units descriptors, etc. This new final uniform scale (1:250 000 or 1:500 000) map and legend will resolve those problems and, at the same time, will improve our understanding of the different regional ice-flow movements and their respective regional associated morphological features.

To do so, we will program and apply surface, length, width, density, etc. algorithms on maps at 1:50 000, 1:100 000 and 1:250 000 scales for the entire Quebec–Ontario Abitibi area. We also propose to automate the process of unit (polygon) generalization using a cell-based method (Cellular Automata (CA)).

Presently, work is being done using the Chibougamau maps (1:50 000 and 1:100 000) as a test area. Next year, the Abitibi (Quebec) area will be submitted to the CA method and field verification will be extended to the northern part of the Abitibi (Ontario) sector. The work will be necessary to upgrade and compare the actual mapping existing for the Abitibi (Ontario) area with what exists on the Abitibi (Quebec) side.

CONCLUSION

In summary, the Abitibi and Deep Search TGI-3 projects are multi-disciplinary projects designed to improve and expand the geoscience knowledge of established mining districts by collecting new data, undertaking new interpretations and developing improved geological and mineral deposit model(s), and exploration methods. A significant effort was invested in determining client needs, defining the projects and developing close collaboration with the various participants. The projects range from Abitibi-scale compilation to mineral deposit-scale detailed mapping focussed on the economically important parts of the belt with an emphasis on finding new base metal deposits. Discussions are underway to closely collaborate with the Phase V of Discover Abitibi Initiative (DAI) in a number of geoscience projects in order to develop synergy between the TGI-3 program and DAI, and help the industry renew mineral resources in the Abitibi area.

Many exciting new advances in our understanding of the geology of the Abitibi greenstone belt are being made demonstrating the merits of a diverse, but balanced, approach to Abitibi area geology using the traditional strengths of the OGS and Géologie Québec bedrock mapping, the thematic and multi-disciplinary strengths of the GSC, the research skills of university geology departments, and the comprehensive understanding of the ore deposits by the mining companies working in the area. We feel our integrated approach to applied research is needed to advance our understanding of the geology and its relationship to mineral deposits in the geologically complex, but highly prospective, parts of the Abitibi area. We also feel confident that the maps, reports and theses resulting from this comprehensive program will provide many new ideas and concepts that are, and that will continue to be, directly applicable to exploration for new mineral deposits.

REFERENCES

Ayer, J., Amelin, Y., Corfu, F., Kamo, S., Ketchum, J., Kwok, K. and Trowell, N. 2002. Evolution of the southern Abitibi greenstone belt based on U-Pb geochronology: autochthonous volcanic construction followed by plutonism, regional deformation and sedimentation; Precambrian Research, v.115, p.63-95.

Ayer, J., Berger, B.R., Hall, L.A.F., Houlé, M.G., Johns, G.W., Josey, S., Madon, Z., Rainsford, D., Trowell, N.F. and Vaillancourt, C. 2005. Geological compilation of the central Abitibi greenstone belt: Kapuskasing structural zone to the Quebec border; Ontario Geological Survey, Preliminary Map P.3565, scale 1:250 000.

Ayer, J.A., Berger, B.R. and Trowell, N.F. 1999. Geological compilation of the Lake Abitibi area, Abitibi greenstone belt; Ontario Geological Survey, Preliminary Map P.3398, scale 1:100 000.

Ayer, J.A. and Calhoun, R. 2005. The Abitibi greenstone belt: an update on the Precambrian Geoscience program and the results of the Discover Abitibi Initiative; *in* Summary of Field Work and Other Activities 2005, Ontario Geological Survey, Open File Report 6172, p.4-1 to 4-11.

Ayer, J.A., Thurston, P.C., Bateman, R., Dubé, B., Gibson, H.L., Hamilton, M.A., Hathway, B., Hocker, S.M., Houlé, M.G., Hudak, G., Ispolatov, V.O., Lafrance, B., Lesher, C.M., MacDonald, P.J., Péloquin, A.S., Piercey, S.J., Reed, L.E. and Thompson, P.H. 2005a. Overview of results from the Greenstone Architecture Project: Discover Abitibi Initiative; Ontario Geological Survey, Open File Report 6154, 146p.

Ayer, J.A., Thurston, P.C., Bateman, R., Gibson, H.L., Hamilton, M.A., Hathway, B., Hocker, S.M., Hudak, G., Lafrance, B., Ispolatov, V., MacDonald, P.J., Péloquin, A.S., Piercey, S.J., Reed, L.E., Thompson, P.H. and Izumi, H. 2005b. Digital compilation of maps and data from the Greenstone Architecture Project in the Timmins–Kirkland Lake region: Discover Abitibi Initiative; Ontario Geological Survey, Miscellaneous Release—Data 155.

Ayer, J.A. and Trowell, N.F. 2000. Geological compilation of the Kirkland Lake area, Abitibi greenstone belt; Ontario Geological Survey, Preliminary Map P.3425, scale 1:100 000.

Ayer, J.A., Trowell, N.F. and Josey, S. 2004. Geological compilation of the Abitibi greenstone belt; Ontario Geological Survey, Miscellaneous Release—Data 143.

Bleeker, W. 1995. Surface geology of the Porcupine camp: Geological Survey of Canada, Open File 3141, p.13-47.

——— 1999. Structure, stratigraphy, and primary setting of the Kidd Creek volcanogenic massive sulphide deposit: a semiquantitative reconstruction; *in* The giant Kidd Creek volcanogenic massive sulfide deposit, western Abitibi Subprovince, Canada, Society of Economic Geologists, Monograph 10, p.71-122.

Bleeker, W., Parrish, R.R. and Sager-Kinsman, S. 1999. High precision U-Pb geochronology of the Late Archean Kidd Creek deposit and surrounding Kidd volcanic complex; *in* The giant Kidd Creek volcanogenic massive sulfide deposit, western Abitibi Subprovince, Canada, Society of Economic Geologists, Monograph 10, p.43-69.

Daigneault, R., Mueller, W.U. and Chown, E.H. 2002. Oblique Archean subduction: accretion and exhumation of an oceanic arc during dextral transpression, southern volcanic zone, Abitibi Subprovince, Canada; Precambrian Research, v.115, p.261-290.

de Rosen-Spence, A.F. 1976. Stratigraphy, development and petrogenesis of the central Noranda volcanic pile, Noranda, Quebec; unpublished PhD thesis, University of Toronto, Toronto, Ontario, 116p.

Dimroth, E. and Demarcke, J. 1978. Petrography and mechanism of eruption of the Archean d'Alembert tuff, Rouyn–Noranda, Quebec, Canada; Canadian Journal of Earth Sciences, v.15, p.1712-1723.

Dubé, B., Mercier-Langevin, P., Hannington, M.D., Davis, D.W. and Lafrance, B. 2004. Le gisement de sulfures massifs volcanogènes aurifères LaRonde, Abitibi, Québec : altération, minéralisation, genèse et implications pour l'exploration; Ministère des Ressources Naturelles, Faune et Parcs, Québec, MB 2004-03, 112p.

Galley, A., Bailes, A., Hannington, M., Holk, G., Katsube, J., Paquette, F., Paradis, S., Santaguida, F. and Taylor, B. 2002. Database for CAMIRO Project 940E07: Interrelationships between subvolcanic intrusions, large-scale alteration zones and VMS deposits, Ontario, Manitoba, Quebec and Sweden; Geological Survey of Canada, Open File 4431, 1 CD-ROM.

Gibson, H.L. 1989. The Mine sequence of the Central Noranda Volcanic Complex: geology, alteration, massive sulfide deposits and volcanological reconstruction; unpublished PhD thesis, Carleton University, Ottawa, Ontario, 800p.

Gibson, H.L., Kerr, D.J. and Cattalini, S. 2001. The Horne mine: history, influence on genetic models, and a comparison to the Kidd Creek mine; Exploration and Mining Geology, v.9, p.91-111.

Gibson, H.L. and Watkinson, D.H. 1990. Volcanogenic massive sulphide deposits of the Noranda Cauldron and shield volcano, Quebec; *in* The northwestern Quebec polymetallic belt: a summary of 60 years of mining exploration, Canadian Institute of Mining and Metallurgy, Special Volume 43, p.119-132.

Goutier, J. 1997. Géologie de la région de Destor (SNRC 32D/07); Ministère des Ressources naturelles et de la Faune, Québec, RG 96-13, 37p.

Hannington, M.D., Bleeker, W. and Kjarsgaard, I. 1999. Sulfide mineralogy, geochemistry, and ore genesis of the Kidd Creek deposit: Part 1. North, central, and south orebodies; *in* The giant Kidd Creek volcanogenic massive sulfide deposit, western Abitibi Subprovince, Canada, Society of Economic Geologists, Monograph 10, p.163-224.

Haus, M. and Pauk, T. 1993. PETROCH lithogeochemical data; Ontario Geological Survey, Open File Report 5855, 18p.

Huston, D. and Taylor, B.E. 1999. Genetic significance of oxygen and hydrogen isotope variations at the Kidd Creek volcanic-hosted massive sulfide deposit, Ontario, Canada; *in* The giant Kidd Creek volcanogenic massive sulfide deposit, western Abitibi Subprovince, Canada, Society of Economic Geologists, Monograph 10, p.335-350.

Jensen, L.S. 1975a. Geology of Clifford and Ben Nevis townships, District of Cochrane; Ontario Geological Survey, Report 132, 55p.

———1975b. Geology of Pontiac and Ossian townships, districts of Cochrane and Timiskaming; Ontario Geological Survey, Report 125, 40p.

Lagraa, K. 1994. Pétrographie et géochimie des dykes de diorites du Groupe de Blake River, Abitibi, P.Q.; unpublished MSc thesis, Département de Géologie, Université de Montréal, Montréal, Québec, 81p.

Mercier-Langevin, P., Dubé, B., Hannington, M.D., Davis, D. and Lafrance, B. 2004. Contexte géologique et structural des sulfures massifs volcanogènes aurifères du gisement LaRonde, Abitibi; Ministères des Resources naturelles de la faune et des parcs, Étude ET2003-03, 60p.

Pearson, V. 2005. The Blake River Group: an imbricated caldera complex: Québec Exploration 2005, Program and Abstracts, Québec, 2005, p.105.

Péloquin, A.S. and Piercey, S.J. 2005. Geology and base metal mineralization in Ben Nevis, Clifford and Katrine townships: Discover Abitibi Initiative; Ontario Geological Survey, Open File Report 6161, 86p.

Péloquin, A.S., Verpaelst, P., Ludden, J.N., Dejou, B. and Gaulin, R. 2001. La stratigraphie du Groupe du Blake River ouest, ceinture de l'Abitibi, Québec; Ministère des Ressources Naturelles du Québec, Étude ET98-03, 37p.

Pilote, P., Moorhead, J. and Mueller, W. 2000. Développement d'un arc volcanique, la région de Val-d'Or, ceinture de l'Abitibi : volcanologie physique et évolution métallogénique; Ministère des Ressources naturelles et de la Faune, Québec, MB 2000-09, p.1-20.

Reed, L.E., Snyder, D.B. and Salisbury, M.H. 2005. Two-dimensional (2D) reflection seismic surveying in the Timmins–Kirkland Lake area, northern Ontario: acquisition, processing, interpretation: Discover Abitibi Initiative; Ontario Geological Survey, Open File Report 6169, 96p.

Scott, C.R., Mueller, W.U. and Pilote, P. 2002. Physical volcanology, stratigraphy, and lithogeochemistry of an Archean volcanic arc: evolution from plume-related volcanism to arc rifting of SE Abitibi greenstone belt, Val d'Or, Canada; Precambrian Research, v.115, p.223-260.

Snyder, D.B., Bleeker, W., Reed, R.E., Ayer, J.A., Houlé, M.G. and Bateman, R. in press. Tectonic and metallogenic implications of the Discover Abitibi regional seismic profiles in the Timmins mining camp; Economic Geology.

Tassé, N., Lajoie, J. and Dimroth, E. 1978. The anatomy and interpretation of an Archean volcaniclastic sequence, Noranda region, Quebec; Canadian Journal of Earth Sciences, v.15, p.874-888.

Taylor, B.E. and Huston, D.L. 1999. Regional ^{18}O zoning and hydrogen isotope studies in the Kidd Creek volcanic complex, Timmins, Ontario; *in* The giant Kidd Creek volcanogenic massive sulfide deposit, western Abitibi Subprovince, Canada, Society of Economic Geologists, Monograph 10, p.351-378.

Taylor, B. and Timbal, A. 2002a. Regional stable isotope studies in the Clifford–Ben Nevis area; *in* Database for CAMIRO Project 940E07: Interrelationships between subvolcanic intrusions, large-scale alteration zones and VMS deposits, Ontario, Manitoba, Quebec and Sweden; Geological Survey of Canada, Open File 4431.

——— 2002b. Regional stable isotope studies in the Noranda volcanic complex; *in* Database for CAMIRO Project 940E07: Interrelationships between subvolcanic intrusions, large-scale alteration zones and VMS deposits, Ontario, Manitoba, Quebec and Sweden; Geological Survey of Canada, Open File 4431.

Vaillancourt, C. and Hall, L. 2003. Lithogeochemical data for the Timmins west area: Carscallen, Denton, Bristol, Ogden and Deloro townships; Ontario Geological Survey, Miscellaneous Release—Data 123.

5. Project Unit 06-001. The Kidd–Munro Assemblage Project in Ontario: A Project under the Targeted Geoscience Initiative III

B.R. Berger[1]

[1]Precambrian Geoscience Section, Ontario Geological Survey

INTRODUCTION

The Kidd–Munro assemblage project is part of the Abitibi Targeted Geoscience Initiative III (TGI-3) program. This program is a collaborative effort between the Geological Survey of Canada (GSC), the Ontario Geological Survey (OGS) and Géologie Québec. As part of the TGI-3 program, the Kidd–Munro project is a multi-year effort intended to extend the stratigraphy of the assemblage beyond the Kidd Creek copper-zinc mine (*see* Bleeker 1999), erect structural sections across various parts of the assemblage, examine the geochemistry and chemostratigraphy, provide reconnaissance stable isotope mapping, and examine the geochemistry of graphitic argillites and interflow metasedimentary units within the assemblage. In Ontario, OGS personnel are involved with every aspect of the project, but are most directly involved with geological mapping of areas not recently mapped or that are deemed critical to understanding the Kidd–Munro assemblage (Figure 5.1).

BACKGROUND

The Kidd–Munro assemblage was first defined by Fyon and Jackson (1990) and described by Jackson and Fyon (1991). On the basis of new compilation maps and improved geochronological sampling densities, Ayer et al. (2002) refined the limits of the assemblage to better reflect the increased knowledge and understanding of the Abitibi greenstone belt in Ontario, and it is this definition that is currently applied to the Kidd–Munro assemblage (*see* Figure 5.1). Ayer et al. (2002) also recognized Kidd–Munro assemblage units west of the Kidd Creek Mine, in the Swayze and Shining Tree greenstone belts, but these areas are not included in the current TGI-3 program. The part of the Kidd–Munro assemblage included in the program in Ontario extends from the Kidd Creek Mine, in the west, to the Quebec boundary, and is composed of komatiitic, tholeiitic and calc-alkaline metavolcanic rocks and related subvolcanic intrusive rocks (*see* Figure 5.1). One characteristic of the Kidd–Munro assemblage is the presence of high silica rhyolites that contain a high abundance of yttrium and zirconium and are geochemically classified as F-III type rhyolites (Lesher et al. 1986). Uranium-lead (U/Pb) zircon geochronology of these rocks from several locations between the Kidd Creek Mine and Munro Township yielded U/Pb zircon ages of 2717 to 2710 Ma and, thus, constrain the age of the assemblage (Ayer et al. 2002; Bleeker, Parrish and Sager-Kinsman 1999).

A stratigraphic column constructed at the Kidd Creek Mine (Figure 5.2, Prior et al. 1999; Bleeker, Parrish and Sager-Kinsman 1999) was extended 3 km to the north by De Wolfe (2004). Detailed mapping by the OGS, combined with the construction of structural cross sections, will extend the stratigraphy

Summary of Field Work and Other Activities 2006,
Ontario Geological Survey, Open File Report 6192, p.5-1 to 5-6.

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within the assemblage eastward to the Quebec border and examine various aspects of the geology in relation to base metal mineralization. In particular, an MSc student from the University of Ottawa will study the volcanic facies and geochemistry of the F-III felsic metavolcanic rocks at various locations in the assemblage. The structural cross sections will further serve to examine the contact relationships with other assemblages, reveal the internal structure of the assemblage, test the stratigraphic column and look

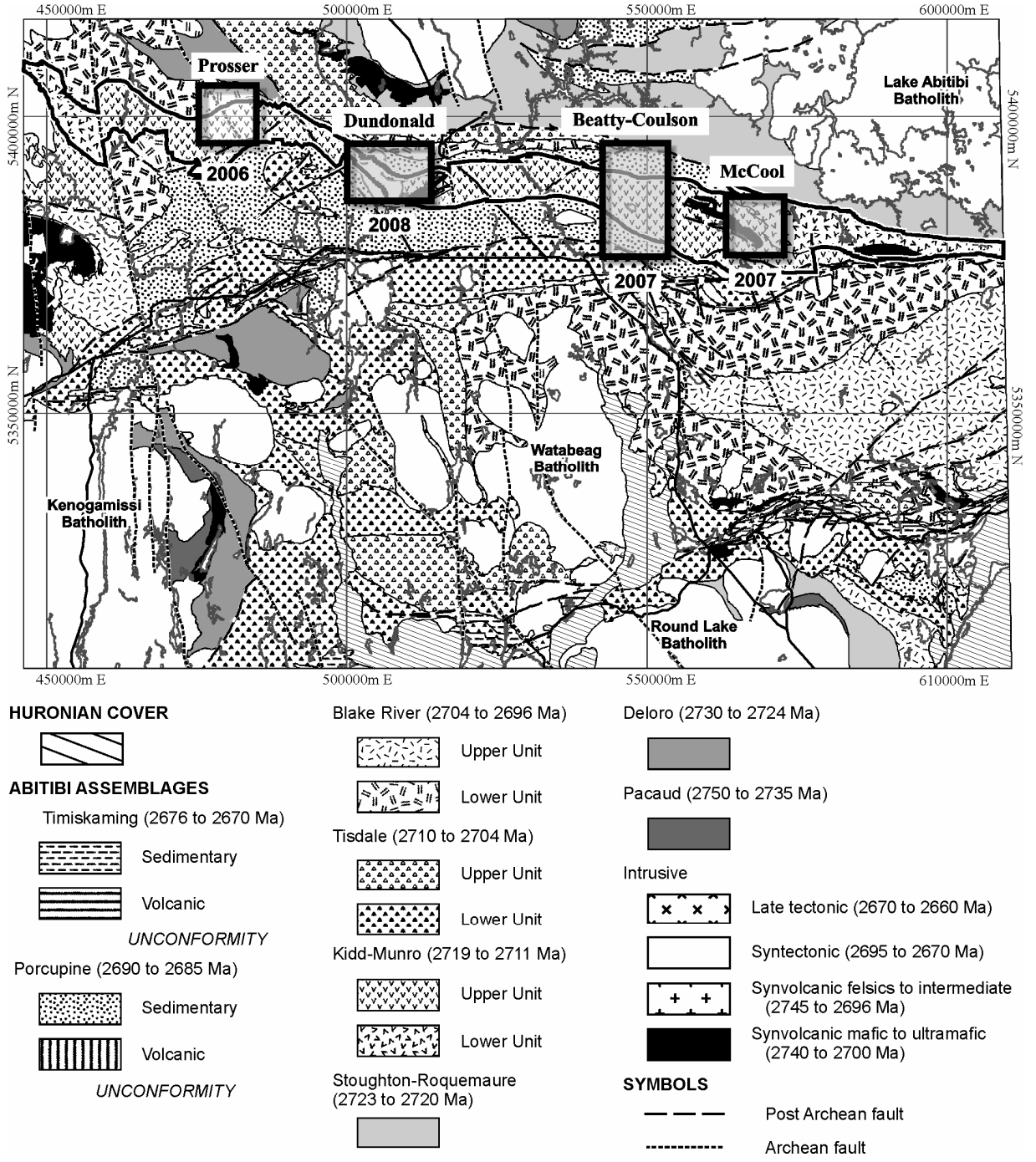

Figure 5.1. Location map and proposed OGS mapping for the Kidd–Munro assemblage as part of the TGI-3 Abitibi Project.

at along-strike variations, thereby building a more complete picture of the Kidd–Munro assemblage. Closely linked to the mapping and structural cross sections is the completion of a geographic information system (GIS) based geochemical compilation of the Kidd–Munro assemblage. Completion of the compilation will identify areas for more lithogeochemical sampling and permit extensive testing of the chemostratigraphy of the assemblage.

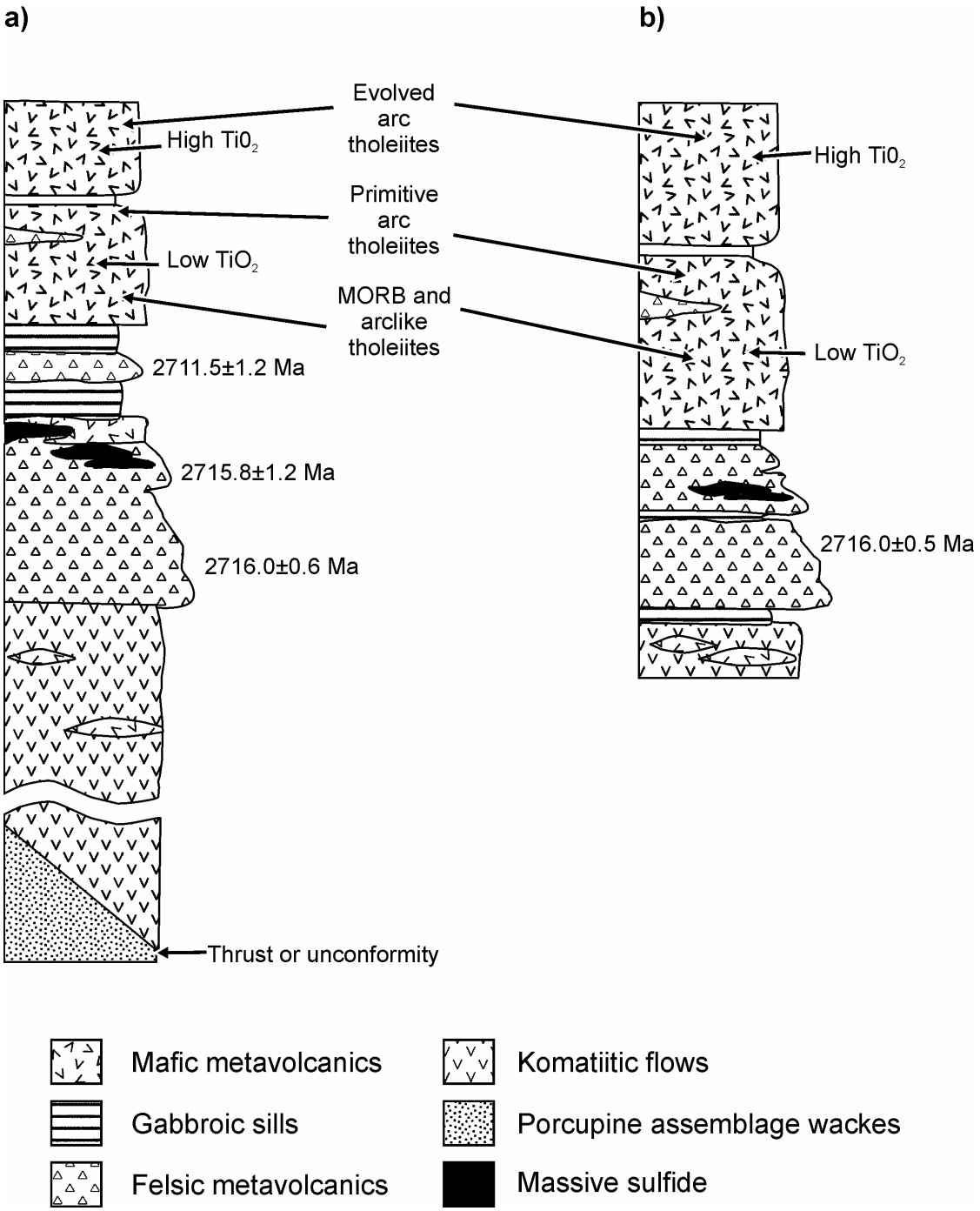

Figure 5.2. Stratigraphic columns for the Kidd–Munro assemblage from the Kidd Creek Mine (left) and the north rhyolite (right). *Modified after* De Wolfe (2004).

Stable isotope geochemistry at the Kidd Creek Mine demonstrated that the base metal mineralization was correlated with high $\delta^{18}O$ values (Taylor and Huston 1999). Continuation of this work will provide isotopic characterization of the Kidd–Munro assemblage and hopefully identify areas with anomalously high $\delta^{18}O$, that are prospective for base metal mineralization. Peter and Goodfellow (2003) demonstrated that the geochemistry of hydrothermal sedimentary rocks could be used to aid exploration for concealed base metal deposits and Barrie (2005) sampled graphitic argillite units within the Kidd–Munro Stable isotope geochemistry at the Kidd Creek Mine demonstrated that the base metal mineralization was correlated with high $\delta^{18}O$ values (Taylor and Huston 1999). Continuation of this work will provide isotopic characterization of the Kidd–Munro assemblage and hopefully identify areas with anomalously assemblage proximal to base metal and gold hydrothermal alteration systems. Thus, further identification of "fertile" metasedimentary units can provide an important vector to mineralization in other parts of the assemblage.

GEOLOGY OF PROSSER TOWNSHIP

Prosser Township, located approximately 8 km northeast of the Kidd Creek Mine, was mapped at 1:20 000 scale this summer. Outcrop that covers less than 1% of the township was mapped and sampled in early June. Diamond-drill core stored at the Timmins drill core library was examined as were the geological and geophysical data stored in files at the Timmins Resident Geologist's Office. The township has been the focus of extensive exploration over the last 40 years by Falconbridge Exploration Incorporated (now Xstrata Copper) and several zinc and copper occurrences were discovered. Diamond-drill core from 66 holes that were drilled at various locations throughout Prosser Township, which are now owned by Xstrata Copper and stored at the Kidd Creek Mine site in Timmins, were examined and the data from these core examinations are currently being compiled into a database along with data from an additional 30 drill logs. Two diamond drill holes recently completed by Vismand Exploration Incorporated were examined as well. The compiled data will be melded with airborne geophysical and geochemical data to derive a new geological map of the area.

Preliminary observations indicate that much of Prosser Township is underlain by massive, pillowed and brecciated mafic flows. Carbonate and quartz-filled amygdules are common; varioles and tuffaceous deposits are rare. Ultramafic metavolcanic rocks are restricted to the south part of the township and are most commonly composed of massive, cumulate-textured flows. Spinifex-textured komatiites and talc-carbonate schist are common; varioles and komatiitic basalts are rare. Felsic metavolcanic rocks underlie parts of central and east-central Prosser Township. Massive, flow laminated and autobrecciated flows are common. Tuff and lapilli tuff are widespread and commonly occur interbedded with clastic metasedimentary rocks. Quartz porphyritic felsic rocks that may be intrusive occur throughout the felsic units, but are most common in the east part of the township. Heterolithic breccia occurs in several places within the felsic units. The breccia is dominated by rhyolitic clasts, but mafic metavolcanic and sulphide clasts to 50 cm in size are common. These rocks appear to be debris flows deposited on the flanks of felsic volcanic edifices.

Intermediate metavolcanic rocks are rare, but geochemical data from Xstrata Copper indicate that icelandite with between 52 and 60% SiO_2 content occur in several places in Prosser Township. In addition, several diorite dikes with between 50 and 58% SiO_2 content intruded the volcanic stratigraphy at various locations in Prosser Township.

Clastic and chemical metasedimentary rocks occur at various locations throughout the township. Wacke, siltstone, argillite and graphitic argillite deposited as turbidites underlie the southeast portion of the area and are correlated with the Porcupine assemblage (Bleeker 1999; Berger 1999). Metasedimentary rocks composed of graphite, graphitic argillite, wacke, sulphide-facies iron formation, and rare magnetite-

chert iron formation occur as interflow units throughout Prosser Township and account for a great many of the electromagnetic conductors tested by the diamond-drill holes. The interflow units are commonly interlayered with metavolcanic flows and tuffaceous rocks and the intermixing of graphitic argillite with these rocks creates a distinctive breccia referred to by the author as graphite breccia. Graphite breccia, also referred to as "*in situ*" breccia in several diamond-drill logs is interpreted by the author as a peperite resulting from the mixing of hot volcanic rocks with unconsolidated graphitic argillite (Photo 5.1). Phreatic and phreatomagmatic brecciation of the volcanic rocks causes the distinctive "jig-saw" texture and mixing of the rocks.

A granodiorite, with an age of 2663±3.3 Ma, intrudes the Kidd–Munro assemblage in the southwest part of Prosser Township (Bleeker 1999). This intrusion is equigranular to feldspar porphyritic, pink to red weathering and is weakly foliated to massive. Geochemistry indicates the intrusion has a sodic alkaline affinity similar to that of the albitite intrusions associated with gold mineralization along the Porcupine–Destor deformation zone (Berger 2002).

Sulphide mineralization occurs throughout Prosser Township as sulphide-facies iron formation, disseminations, veins and replacement fillings in several locations. Narrow chalcopyrite veins and red to honey coloured sphalerite occurs as disseminations and veinlets in graphitic argillite, mafic and felsic graphite breccia in west central Prosser Township where assays up to 64 000 ppm Zn were returned over narrow intervals in diamond-drill holes. This area has been extensively diamond drill tested by Xstrata without encountering economic mineralization.

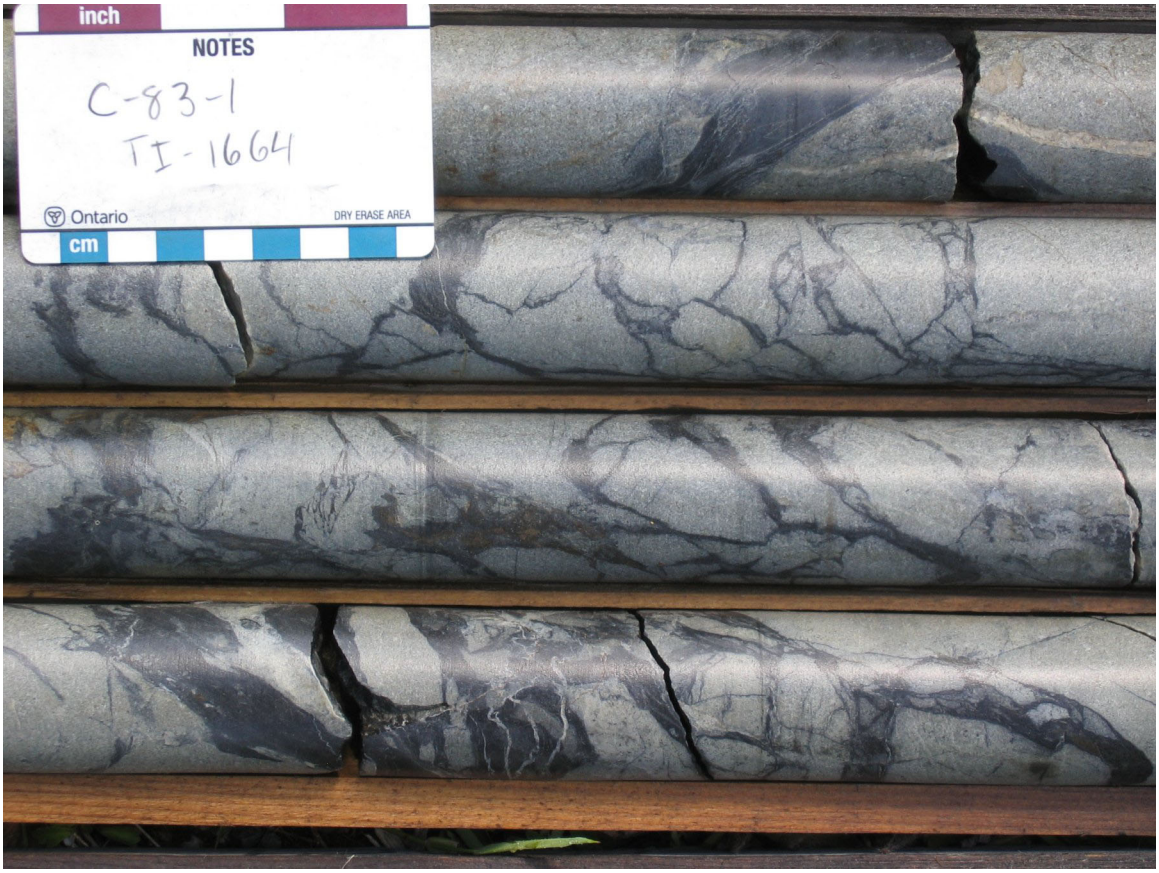

Photo 5.1. Graphite or "*in situ*" or "jig saw" breccia is commonly developed throughout the Kidd–Munro assemblage and is interpreted by the author as a mixing of hot magma with unconsolidated graphitic argillite (peperite).

REFERENCES

Ayer, J., Amelin, Y., Corfu, F., Kamo, S., Ketchum, J., Kwok, K. and Trowell, N. 2002. Evolution of the southern Abitibi greenstone belt based on U–Pb geochronology: autochthonous volcanic construction followed by plutonism, regional deformation and sedimentation; Precambrian Research, v.115, p.63-95.

Barrie, C.T. 2005. Geochemistry of exhalites and graphitic argillites near VMS and gold deposits; Ontario Geological Survey, Miscellaneous Release—Data 173.

Berger, B.R. 1999. Geology of Murphy and Wark townships, District of Cochrane; Ontario Geological Survey, Open File Report 5994, 64p.

——— 2002. Geological synthesis of the Highway 101 area, east of Matheson, Ontario; Ontario Geological Survey, Open File Report 6091, 124p.

Bleeker, W. 1999. Structure, stratigraphy and primary setting of the Kidd Creek volcanogenic massive sulfide deposit: a semiquantitative reconstruction; *in* The giant Kidd Creek volcanogenic massive sulfide deposit, western Abitibi Subprovince, Canada, Economic Geology Monograph 10, p.71-122.

Bleeker, W., Parrish, R.R. and Sager-Kinsman, A. 1999. High-precision U-Pb geochronology of the Late Archean Kidd Creek deposit and Kidd volcanic complex; *in* The giant Kidd Creek Volcanogenic massive sulfide deposit, western Abitibi Subprovince, Canada, Economic Geology Monograph 10, p.43-70.

DeWolfe, Y.M. 2004. Volcanic reconstruction of the Archean north rhyolites, Kidd Creek Mine, Timmins, Ontario, Canada; unpublished MSc thesis, Laurentian University, Sudbury, Ontario, 149p.

Fyon, A. and Jackson, S. 1990. District geology - central Abitibi greenstone belt; *in* Geology and ore deposits of the Timmins district, Ontario, 8th International Association of the Genesis of Ore Deposits (IAGOD) symposium, Ottawa, Ontario, Field Trip 6 Guidebook, Geological Survey of Canada, Open File 2161, p.13-21.

Jackson, S.L. and Fyon, J.A. 1991. The western Abitibi Subprovince of Ontario; *in* Geology of Ontario; Ontario Geological Survey, Special Volume 4, Part 1, p.405-484.

Lesher, C.M., Goodwin, A.M., Campbell, I.H. and Gorton, M.P. 1986. Trace-element geochemistry of ore-associated and barren, felsic metavolcanic rocks in the Superior Province, Canada; Canadian Journal of Earth Sciences, v.23, p.222-237.

Peter, J.M. and Goodfellow, W.D. 2003. Hydrothermal sedimentary rocks of the Heath Steele Belt, Bathurst mining camp, New Brunswick: Part 3. Application of mineralogy and mineral and bulk compositions to massive sulphide exploration; *in* Massive sulfide deposits of the Bathurst mining camp, New Brunswick, and northern Maine, Economic Geology Monograph 11, p.417-433.

Prior, G.J., Gibson, H.L., Watkinson, D.H. and Cook, R.E. 1999. Anatomy, lithogeochemistry, and emplacement mechanisms for the QP rhyolites, Kidd Creek Mine, Timmins, Ontario; *in* The giant Kidd Creek volcanogenic massive sulfide deposit, western Abitibi Subprovince, Canada; Economic Geology Monograph 10, p.123-142.

Taylor, B.E. and Huston, D.L. 1999. Regional ^{18}O zoning and hydrogen isotope studies in the Kidd Creek volcanic complex, Timmins, Ontario; *in* The giant Kidd Creek volcanogenic massive sulfide deposit, western Abitibi Subprovince, Canada; Economic Geology Monograph 10, p.331-378.

6. Project Unit 06-002. Geological and Mineral Potential of McArthur Township in the Bartlett Dome, Abitibi Greenstone Belt

M.G. Houlé[1]

[1]Precambrian Geoscience Section, Ontario Geological Survey

INTRODUCTION

In 2006, the Precambrian Geoscience Section (PGS) of the Ontario Geological Survey (OGS) started a multi-year project of bedrock geological mapping of the Bartlett Dome as part of an ongoing project to update geological mapping in the Timmins mining camp. This past summer, the 1:20 000 scale bedrock mapping was focussed on McArthur Township, located about 40 km south of the City of Timmins (Figure 6.1: Block 1). Other areas, including all or parts of Fripp, Douglas, Musgrove, Bartlett, Geikie, Beemer, English and Zavitz townships, will be mapped over the next few years.

The goals of this multi-year project are fivefold: 1) to update the geological mapping south of Timmins; 2) to clarify and characterize the major lithologic units; 3) to better understand the stratigraphy of the Bartlett Dome and its correlation with the Shaw Dome; 4) to evaluate the mineral potential of the area; and 5) to improve our understanding of the relationship of geophysical features to bedrock geology.

The Bartlett Dome mapping project is part of the core program of the PGS and represents an in-kind contribution to the Targeted Geoscience Initiative III (TGI III), a multidisciplinary collaboration with the Geological Survey of Canada (GSC) and Géologie Québec. This collaborative effort will aid the OGS in achieving the above goals.

NEW GEOPHYSICAL SURVEY

A new geophysical survey is an important component of the Bartlett Dome project. Geophysics provides additional tools to geologists to help interpret the bedrock geology and to outline targets for mineral exploration. Under the TGI III Initiative, the GSC has provided funding and technical supervision for a new time-domain electromagnetic airborne survey (MEGATEM® II) that will cover not only most of the Bartlett Dome, but also the southern and western part of the Shaw Dome area (*see* Figure 6.1). The products of this geophysical survey will include the digital data and hard-copy maps with EM anomalies, apparent conductance, time-constant maps, residual total magnetic field, and second vertical derivative of the magnetic field and are planned for released in early 2007. For more information about this geophysical survey, please contact P. Keating at the GSC in Ottawa (Pierre.Keating@nrcan-rncan.gc.ca).

Summary of Field Work and Other Activities 2006,
Ontario Geological Survey, Open File Report 6192, p.6-1 to 6-14.

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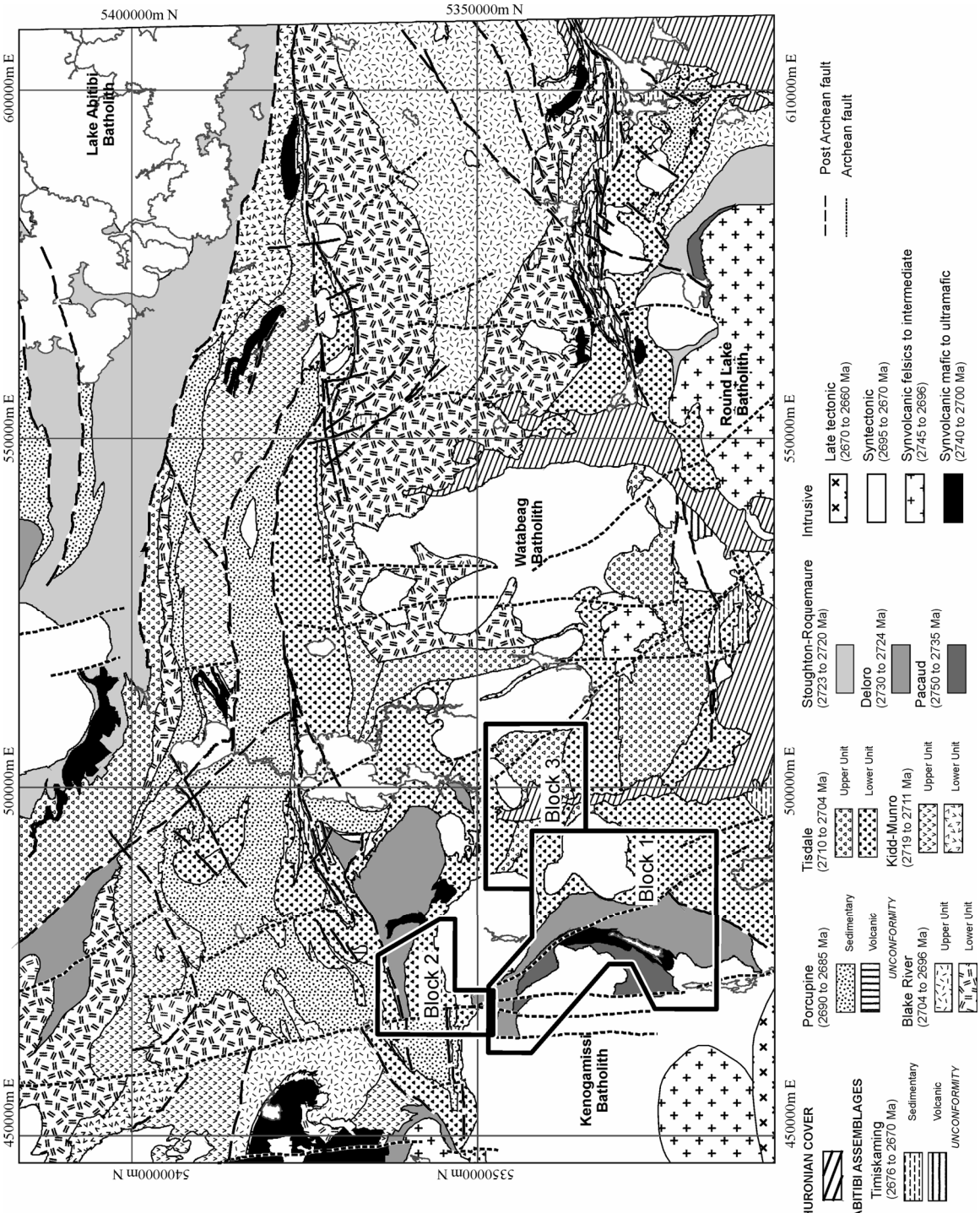

Figure 6.1. Distribution of lithotectonic assemblage in the Timmins and Kirkland Lake area showing the location of study areas (*modified from* Ayer et al. 2005). Blocks 1, 2 and 3 refer to new geophysical surveys in the area. Block 1: Bartlett Dome; Block 2: western part of the Shaw Dome; Block 3: southern part of the Shaw Dome.

PREVIOUS WORK

The most recent bedrock mapping surveys completed by the OGS in the Bartlett Dome area were conducted in the 1960–1970s. Bright (1968a, 1968b, 1968c) mapped the southern portion (Beemer, English and Zavitz townships) in 1967, whereas Pyke (1978a) mapped the northern and central portions during the summer of 1970, 1971 and 1972. Following this work, Pyke (1978b) compiled the Peterlong Lake area (Map 2345 at 1:50 000 scale) based on past detailed mapping (1:15 840, 1:31 680 scales) and on semi-detailed and reconnaissance mapping (1:47 520, 1:126 720 scales). The Bartlett Dome has had a variety of exploration activity in the past with several companies searching for asbestos, copper-zinc, gold as well as nickel. Numerous exploration companies have worked in the area and the reader is referred to Pyke (1978a, 1978b) and Bright (1974) for a complete listing of previous workers in the Bartlett Dome area. Since then, other exploration companies have worked in McArthur Township. The main work in McArthur Township was undertaken by United Kingdom Energy Incorporated (1986: geological, magnetic, VLF and electromagnetic surveys), and Inco Gold Management Inc. (1988: geological, magnetic and electromagnetic surveys) who both focussed their exploration program on gold. BHP Minerals (1990–1992: geological, magnetic, HLEM, and VLF surveys combined with lithogeochemical and soil sampling) and Mustang Minerals (2004: magnetic and electromagnetic surveys) also worked in this area and focussed their exploration program on nickel. Further work was also conducted south of the map area in Bartlett and Geikie townships at the Texmont Mine, which is a komatiite-associated nickel sulphides deposit that contains several mineralized zones of disseminated to blebby sulphides (Coad 1979).

REGIONAL SETTING

The Abitibi Subprovince of the Superior Province consists of a stratigraphically continuous succession of Archean metavolcanic and metasedimentary rocks that developed in an ensimatic basin (Ayer et al. 2002). These rocks have been subdivided into 8 temporally constrained lithotectonic assemblages (Ayer et al. 1999a, 1999b). In these assemblages, 6 are dominantly volcanic and 2 are dominantly sedimentary. Figure 6.1 shows the distribution of the lithotectonic assemblage that occurred in the Bartlett Dome area in this vicinity.

Two volcanic cycles have been recognized previously by Pyke (1978a, 1978b) where each is composed of a lower unit of ultramafic metavolcanic rocks, an overlying unit of mafic metavolcanic rocks, and an upper unit of intermediate to felsic metavolcanic rocks. The volcano-sedimentary succession in the Bartlett Dome is intruded by intrusions of a wide range of compositions (ultramafic, mafic and felsic). Of specific relevance to this project, the volcanic sequence is composed of a lower sequence of calc-alkalic intermediate to felsic volcanic rocks, a central sequence of komatiitic rocks, and an upper sequence of tholeiitic mafic volcanic rocks, respectively, interpreted to be a part of the Pacaud, the Deloro and the Tisdale assemblages. Proterozoic diabase dikes observed in the mapped area are attributed to the Abitibi, Sudbury, and Matachewan swarms.

GEOLOGY OF McARTHUR TOWNSHIP

Ultramafic Metavolcanic Rocks

Ultramafic volcanic rocks are confined to one stratigraphic interval in McArthur Township (Figure 6.2). Relative to many other lithologies in the area, the ultramafic rocks are fairly well exposed and coincide with some of the higher topographic relief within McArthur Township.

The komatiitic sequence in McArthur Township is dominated by *sensu stricto* komatiites flows with subordinate komatiitic basalt flows. Ultramafic flows were recognized during the mapping, but "typical" komatiites flows with all internal subdivisions defined by Pyke, Naldrett and Eckstrand (1973) were not found in this area. Instead, komatiite flows occur mainly as sheet flows that exhibit a lower olivine cumulate or olivine-phyric zones and an upper zone of randomly oriented olivine spinifex textured, or as flattened pillows (Photo 6.1). Thicker komatiites flows are generally characterized by cumulate texture comprised of olivine pseudomorphs. Polysuturing defined by polygonal jointing is common to most of the komatiites mapped as lava flows. Locally, spinifex-textured sills intrude ultramafic flows.

The Serpentine Mountain area in McArthur Township has spectacular preservation of primary cooling and crystallization features in the komatiitic rocks. Numerous flows have been identified in an approximately 350 m thick sequence of komatiites exposed in the area. Individual flows range in thickness from 1 to 8 m, however, the exact number of flows within the sequence and the maximum thickness are uncertain because of the thick overburden that covers much of the outcrop. None of the komatiitic flows have the internal zonation characteristic of classic komatiite flows such as those at Pyke Hill in Munro Township. Here, the flows only contain fine- to coarse-grained random olivine spinifex zones that overlie an olivine cumulate zone. Several outcrops contain flows with subconcordant spinifex-textured sills that crosscut the host olivine cumulate.

Mafic Metavolcanic Rocks

Mafic volcanic rocks occur mainly in 2 stratigraphic intervals in the area (*see* Figure 6.2). The lower sequence crops out in the southwest corner of McArthur Township, whereas the upper sequence is largely confined to the central part of the area along the contact with the Adams pluton. However, some mafic volcanic rocks also occur sporadically intercalated with the ultramafic volcanic rocks.

The mafic metavolcanic rocks that occur in the lower sequence have a tholeiitic affinity (Pyke 1978a) and display a medium to pale green weathered surface with medium green fresh surfaces. Pillowed and massive flows are the 2 main volcanic facies in this package of rocks with massive flows being dominant. Medium-grained gabbroic texture is commonly observed within the massive facies suggesting slower cooling within the thicker lava flow units. Pillowed flows generally composed of elongate pillows locally exhibit some concentric cooling fractures.

The mafic metavolcanic rocks that occur in the upper sequence have also a tholeiitic affinity (Pyke 1978a), but exhibit a distinct characteristic. These rocks are mylonitized and amphibolitized with dark and pale green "streaks" due to the relative abundance of hornblende and epidote (Photo 6.2A). These rocks are interpreted to be pillowed (Photo 6.2B) and massive mafic metavolcanic rocks that are intruded by porphyritic felsic dikes in the vicinity of the Adams pluton.

Intermediate to Felsic Metavolcanic Rocks

Intermediate to felsic volcanic rocks are restricted to one stratigraphic interval in McArthur Township. Most of the sequence is entirely composed of volcaniclastic rocks ranging from tuff to pyroclastic-breccia. Lapilli-tuff and tuff-breccia are prominent facies observed in the intermediate to felsic volcaniclastic rocks. Weathered surfaces are generally light grey to light green, whereas fresh surfaces are light to medium grey. Most of the volcaniclastic rocks do not show well-developed bedding, but, where observed, it is on a scale of tens of metres. Tuff-breccias are monomictic to polymictic, matrix-supported (Photo 6.3) and contain commonly 50 to 60% of angular to subrounded clasts up to 1 m. The dominant fragments are light grey, aphyric to plagioclase-phyric intermediate to felsic volcanic rocks with lesser layered felsic tuff, mafic volcanic rocks, chert, iron formation, sulphidic argillite, and quartz

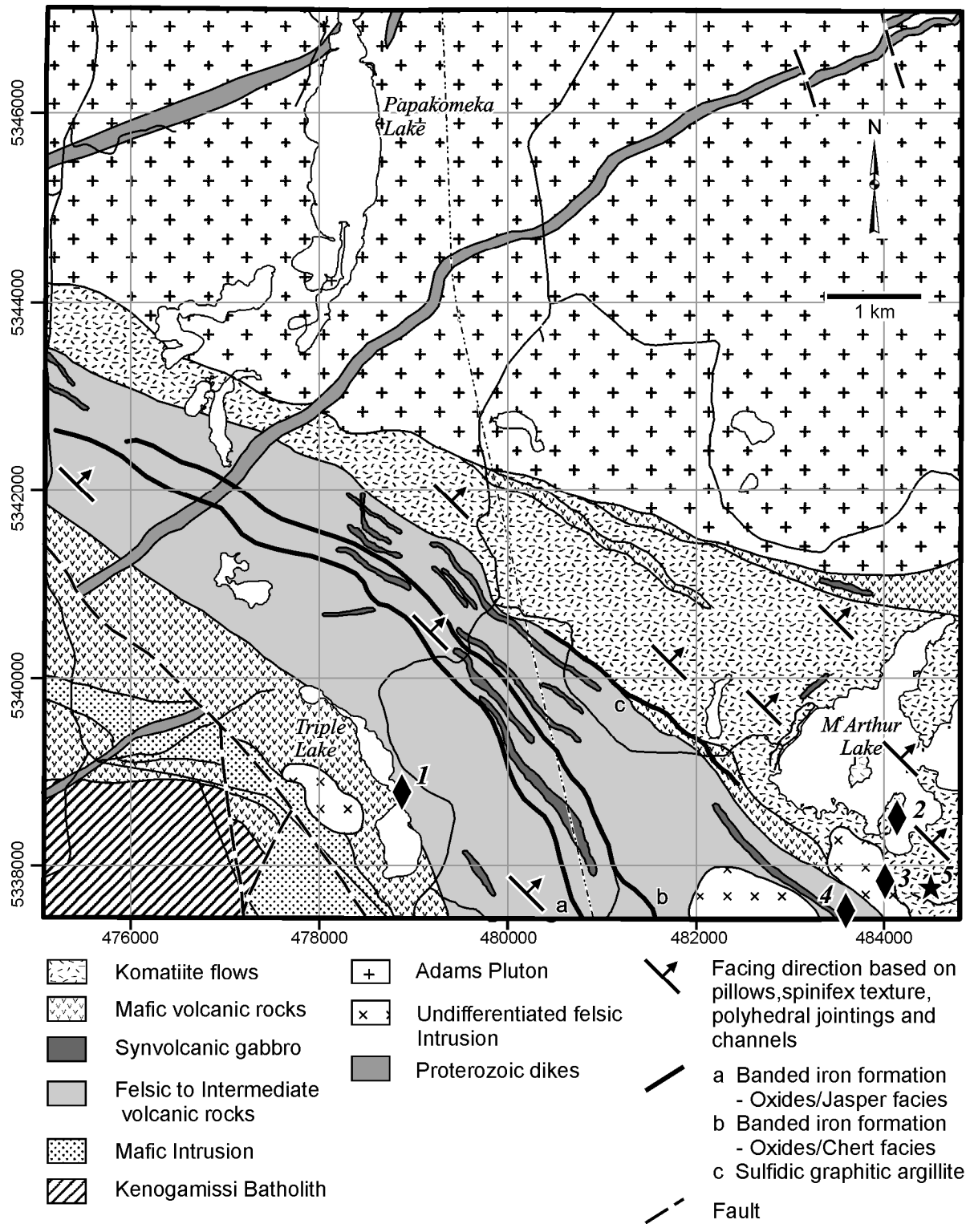

Figure 6.2. Simplified geological map of McArthur Township in the Bartlett Dome area. Black diamonds and black star show, respectively, the general distribution of gold showings and sulphides occurrences in the area: 1) Triple Lake; 2) Steel vein; 3) Ogilvie vein, Couinard vein, Portage vein, Andover porphyry and Westport Porcupine occurrence #2; 4) Westport Porcupine occurrence #1, Hewitt shaft; 5) sulphides occurrence.

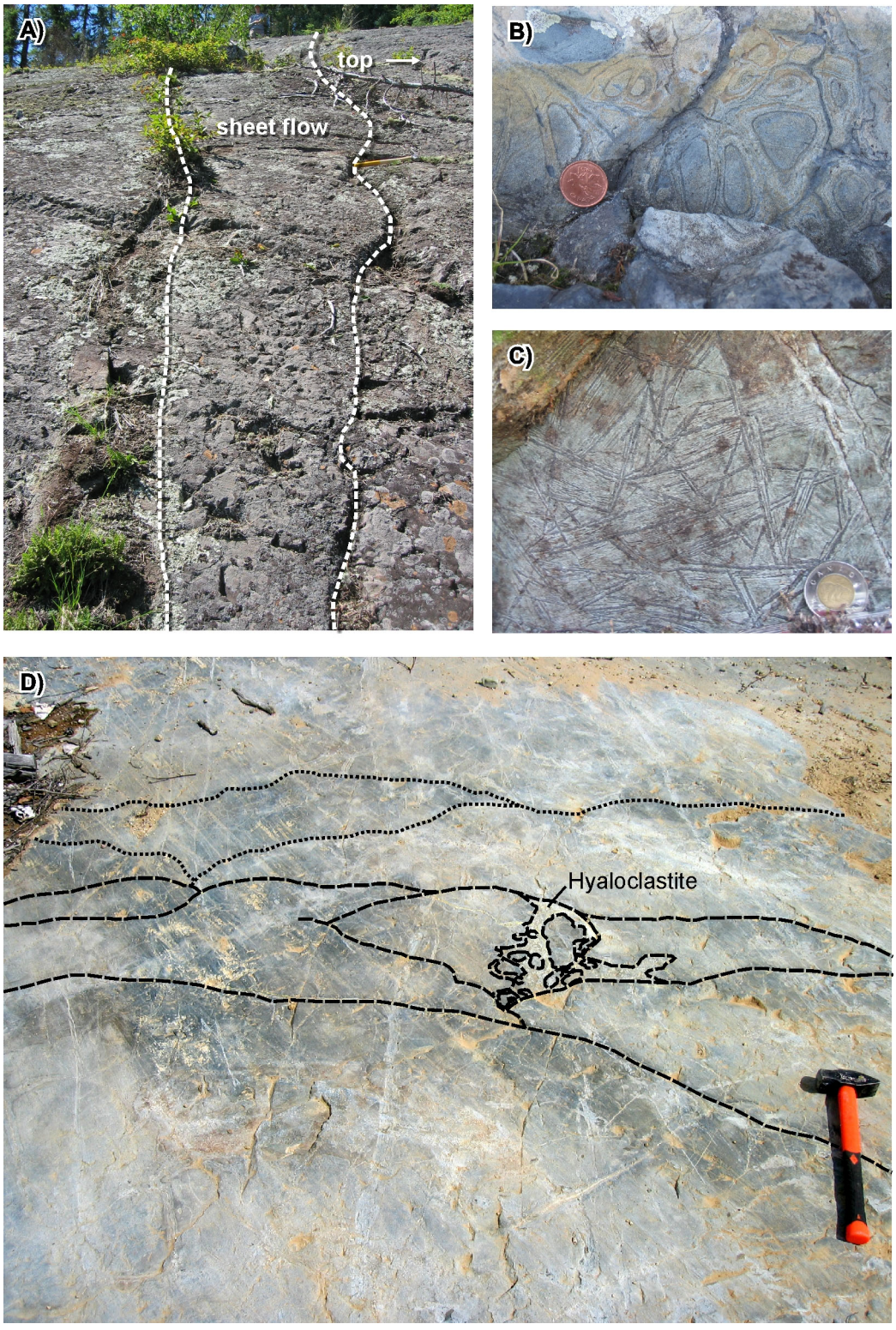

Photo 6.1. A) Komatiite sheet flows with well-developed polyhedral jointing at the upper contact. Arrow indicate the younging direction. B)Typical polyhedral jointing in komatiite flows. C) Randomly oriented olivine spinifex in komatiite. D) Several morphofacies within komatiite flows from the base to the top: sheet flow, lobate sheets/flattened pillows, sheet flow. Arrow indicate the younging direction.

veins fragments. The matrix is generally a light grey felsic tuff or a light grey felsic lapilli tuff. Despite poor exposure, especially within the lower section (stratigraphically below the banded iron formation (BIF) in the middle horizon), the lower volcaniclastic sequence appears to be dominated by monomictic clasts, whereas the upper sequence appears to be dominated by polymictic clasts.

Metasedimentary Rocks

Several bands of sedimentary rocks, which can be generalized into 3 main horizons, are present within the intermediate to felsic volcanic rocks.

The lower horizon is a relatively thin banded iron formation (0.5 to 5 m) that occurs in the middle of the intermediate to felsic volcanic rocks and extends over 8 km across McArthur Township. It is composed mainly of several magnetite-rich bands that range in thickness from 1 to 10 cm with felsic tuff. Locally, this banded iron formation consists of interlayered magnetite-rich and red chert (jasper) bands (Photo 6.4A).

The middle horizon is a thick banded iron formation (5 to 40 m) that occurs in the upper third of the intermediate to felsic volcanic rocks and extends over 7 km across McArthur Township. It consists mainly of interlayered thin magnetite-rich and thicker chert-rich bands. Commonly, the upper section of this iron formation also exhibits some sulphide±magnetite-rich bands intercalated within the typical banded iron formation (Photo 6.4B).

The upper horizon consists of a thin unit (metre-scale) dominated by a graphitic and sulphidic argillite with subordinate intercalation of chert bands located at the contact between the intermediate to felsic volcanic rocks and the ultramafic volcanic rocks. This horizon extends over 2 km in the central part of McArthur Township.

Archean Mafic Intrusions

Mafic intrusions are common in the map area. The dominant mafic intrusion is a massive, medium-grained equigranular to ophitic melanocratic gabbro with subordinate phases of quartz gabbro. This intrusion is part of the Peterlong Lake mafic to ultramafic intrusion, a sill-like body that extends over several townships south of the map area. Quartz stockworks hosted in a medium-grained gabbro were observed at 2 localities along the Scott Lakes fault and it splays trending north to south in Bartlett Township.

Numerous synvolcanic sills and dikes are also present in the map area. These mafic intrusions are weakly foliated medium- to fine-grained and equigranular gabbros. Foliation developed within these sills is generally subparallel to the one observed in adjacent volcanic rocks. These gabbroic sills are emplaced within most of the volcanic rocks in the area. The lower mafic volcanic rocks in the southeastern corner of the township are the only ones that are not intruded by those sills. The gabbroic synvolcanic sills are abundant within the upper section, whereas they are relatively uncommon within the lower section intermediate to felsic volcanic rocks (*see* Figure 6.2).

Archean Felsic to Intermediate Intrusions

Three main types of felsic intrusive rocks occurred in McArthur Township: 1) a large granodioritic pluton (Adams pluton); 2) a small lobe of intermediate intrusive rocks, which forms the eastern margin of the extensive Kenogamissi batholith; and 3) a number of small tonalitic stocks.

Photo 6.2. A) Deformed pillowed mafic volcanic rocks within the upper sequence. B) Highly deformed mafic volcanic rocks intruded by porphyritic (plagioclase) tonalite dikes within the upper sequence near the contact with the Adams pluton.

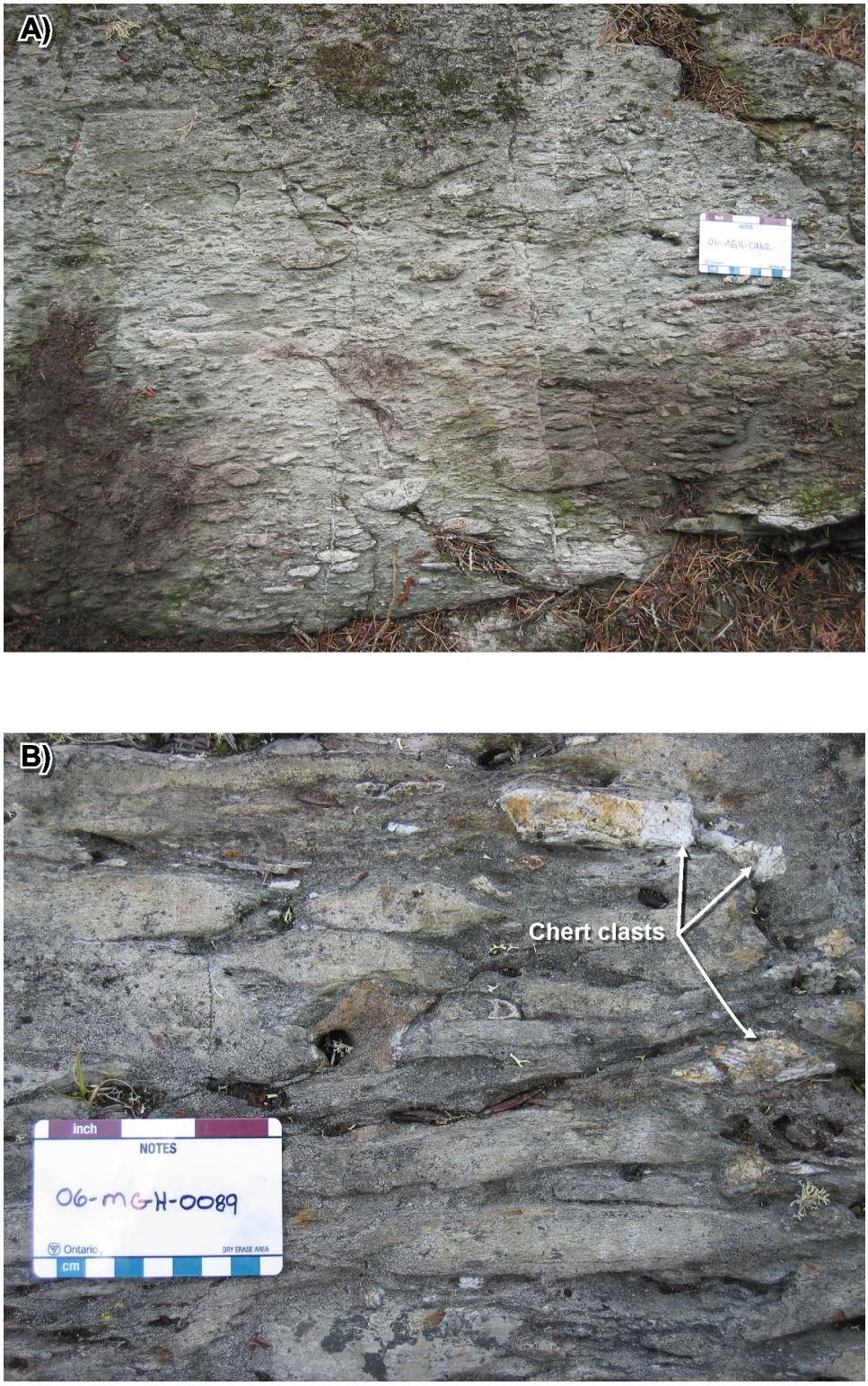

Photo 6.3. A) Monomictic felsic to intermediate lapilli-tuff within the lower section. B) Polymictic felsic to intermediate tuff-breccia containing exotic chert clasts within the upper section.

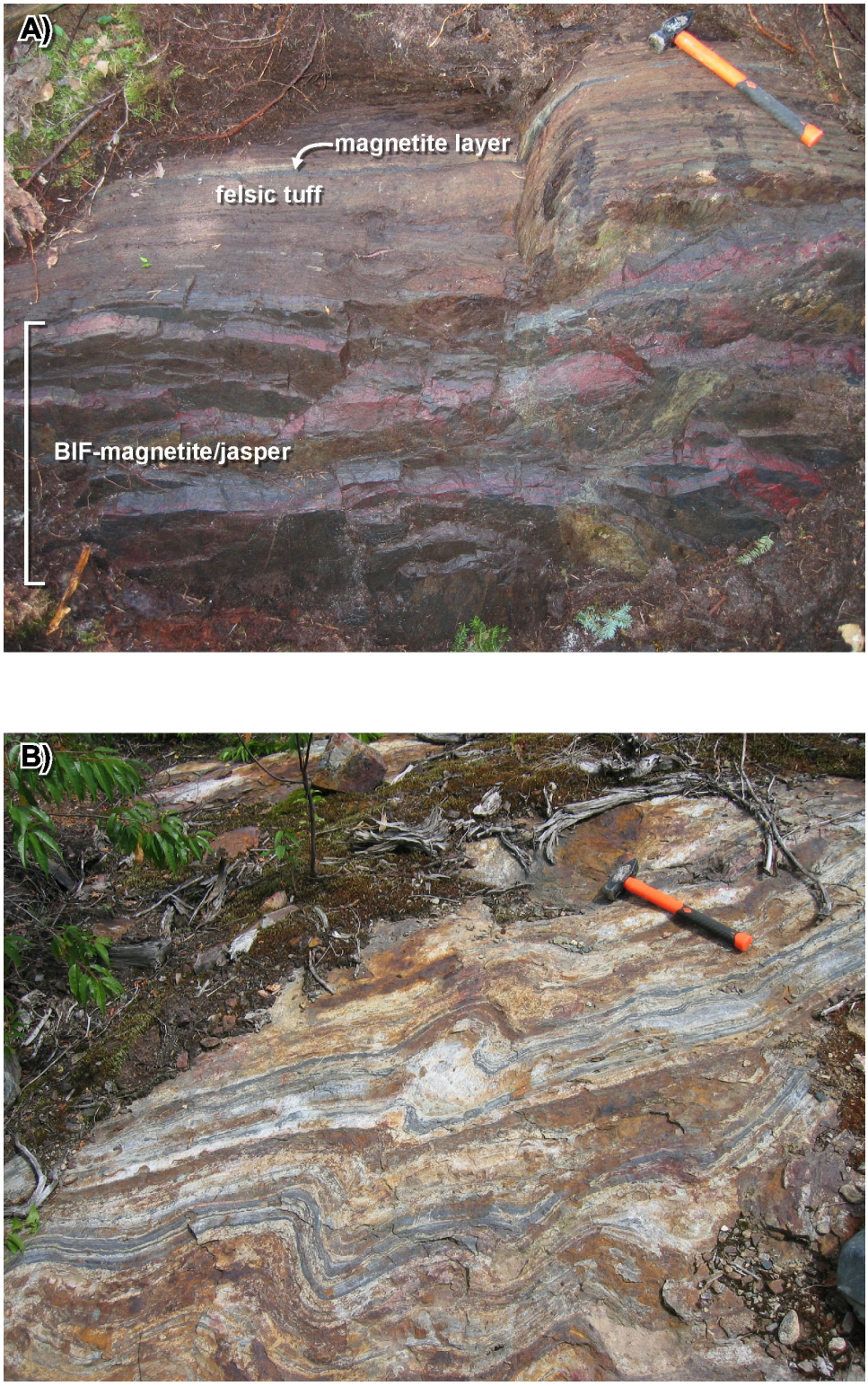

Photo 6.4. A) Banded iron formation exhibiting alternation of magnetite layers and jasper layers from the lower horizon. B) Banded iron formation exhibiting altenationss of magnetite layers, magnetite/sulphides layers, and chert layers from the middle horizon.

ADAMS PLUTON

The Adams pluton is a large felsic intrusion occupying much of Adams Township, and extending into parts of Ogden, Deloro, Price, Eldorado, McArthur and Douglas townships. The pluton is typically a light grey-pink granodiorite on weathered and fresh surfaces. The granodiorite is medium grained, massive to weakly foliated, and generally porphyritic (up to 15%). The phenocrysts range from 0.5 to 3 cm and are composed of potassium feldspar that locally appears to have zones of inclusions consisting of albite and quartz. Accessory minerals include abundant hornblende, epidote, limited intergrowths of biotite with hornblende and locally euhedral, orange titanite. Small dioritic inclusions are relatively abundant and distributed throughout the pluton that might represent a minor, early to coeval, intermediate phase of the pluton. Another similar pluton (Geikie pluton) occurs in the eastern part of McArthur Township, but it is poorly exposed in the current map area and was not observed by the author during the field work.

EASTERN LOBE OF THE KENOGAMISSI BATHOLITH

The eastern margin of the Kenogamissi batholith is dominated by massive, medium-grained diorite, quartz diorite with lesser melanocratic diorite to amphibolite. These phases are composed of different proportions of plagioclase, hornblende and quartz. The hornblende is variably altered to actinolite and chlorite. The colour index is commonly 30 to 40% giving a mottled white and green colour on the weathered surface. However, some phases exhibit a colour index of 60% or more is provides a greenish weathered surface colour (i.e., melanocratic diorite, amphibolite). Contacts between the diorite and the quartz diorite are generally gradual and difficult to observe as they reflect small changes in the proportion of quartz (only up to 5%). Melanocratic diorite and amphibolite occur as enclaves or a large mass within diorite (quartz diorite). Contacts between these are sharp and highly irregular. The variability of the colour index within the eastern lobe of the batholith could be related to varied contamination of the diorite by adjacent mafic volcanic rocks as proposed by Pyke (1978a) or by the presence of distinct intrusive stages with differing compositions. Several quartz veins occur locally within the eastern lobe.

TONALITIC STOCKS

Several tonalite stocks are exposed in the southern part of McArthur Township extending into the northern part of Bartlett Township. These intrusions are fine- to medium-grained tonalite composed of plagioclase, quartz, and hornblende (up to 10%). Some porphyritic phases are locally observed where plagioclase and/or quartz formed millimetre-scale phenocrysts. White weathered and fresh surfaces are generally characteristics of the tonalite. The tonalite stock emplaced near the base of the ultramafic volcanic rocks in the vicinity of McArthur Lake exhibits a pinkish marginal zone of very fine-grained tonalite reflecting intense and pervasive carbonatization along the tonalite and ultramafic volcanic rock contact.

Proterozoic Dikes

Several diabase dikes observed in the mapped area are attributed to the Matachewan swarm (NNW), the Sudbury swarm (WNW) and the Abitibi swarm (ENE).

In the map area, only a few Paleoproterozoic Matachewan dikes were observed and these were not easily delineated because of their limited thickness. The Matachewan dikes exhibit a distinctive orange-brown colour and are positive weathering with elongation parallel to the trend of the dike. Green saussuritized plagioclase phenocrysts or glomerocrysts up to 2 to 3 cm across are rarely observed.

The Paleoproterozoic Sudbury dike swarm crops out mainly in the southern part of McArthur Township. These dikes are fine- to medium-grained orange brown olivine gabbro that contains disseminated sulphides. Intrusions commonly follow pre-existing structures and zones of weakness, but are observed to bifurcate. Local small swarms of aphanitic to porphyritic dikelets extend laterally from the main body of a dike taking advantage of the main fabric in the country rock.

The Mesoproterozoic Abitibi dikes crop out in the map area in several localities, but are generally constrained to the northern part of McArthur Township. These fine- to medium-grained ophitic textured, olivine gabbro or rarely quartz gabbro dikes weather readily, resulting in the presence of coarse orange coloured sand around exposures. Abitibi dikes are typically 20 to 50 m wide and are moderately magnetic, yielding distinctive geophysical trends.

STRUCTURE

The character of the deformation preserved in the rocks of the map area is varied reflecting the diverse competency of the lithologies. All units exhibit north-northeast younging based on pillows (mafic metavolcanic rocks), possible erosion channel (felsic volcaniclastic rocks), spinifex textured, and polyhedral jointing (ultramafic metavolcanic rocks) suggesting an homoclinal sequence without any major folds in McArthur Township. Open parasitic folds were locally observed within finer volcaniclastic units and banded iron formations exhibiting a "Z" sense of asymmetry, thus, suggesting that they could be located on the same limb of a larger fold structure. Most deformation is recorded within the intermediate to felsic volcaniclastic rocks and the upper mafic metavolcanic rocks along the contact with the Adams pluton. All units in the area dip steeply to the northeast at 70 to 80°. Tectonic foliation is not everywhere parallel to the layering in the metavolcanic rocks (cf. Pyke 1978a).

The Scott Lakes fault is the most extensive northwest-trending fault in the McArthur area. It is accompanied by the presence of extensive quartz veining within some gabbroic exposure along this structure. Shear zone exposure in this area also suggests the presence of north-trending splays of the Scott Lakes fault. Some minor fault zones were also recognized in the mapped area. Thus far, most of the faulting seems to be located subparallel to the volcanic stratigraphy in the area.

ECONOMIC GEOLOGY

Diverse commodities were reported in McArthur Township following bedrock mapping and mineral exploration programs conducted since the early 1900s. Numerous pits, trenches and small shafts are located throughout McArthur Township (15 occurrences). Half of those are gold occurrences (8) and occurred near the south shore of McArthur Lake and on the east shore of Triple Lake (1 occurrence) (*see* Figure 6.2). Table 6.1 summarizes the main characteristics of the gold showings. Other mineral occurrences include iron, gold, copper and zinc associated with iron formations, copper and gold associated with mafic intrusions and nickel associated with komatiites.

Recommendation for Explorations

Few mineral occurrences have been found to date in McArthur Township. However, a number of favourable geological settings representing a variety of mineralization types may be present in this area.

Table 6.1. Main characteristic of gold showings in McArthur Township.

Occurrence	Best Historic Value	Hosted Units
Ogilvie vein	Up to 12 g/t Au 1.68% and 2.26% Cu	Quartz vein hosted by tonalite and associated with feldspar porphyry
Chouinard vein	Up to 1 oz/t Au	Quartz vein hosted by tonalite
Steel vein	Visible gold	Quartz vein hosted by komatiite and associated with feldspar porphyry
Portage vein	Unknown	Quartz vein hosted by komatiite and associated with feldspar porphyry
Andover porphyry showing	Visible gold	Quartz stringer hosted in a feldspar porphyry
Hewitt shaft	Visible gold	Quartz stringer occupying cross fractures in iron formation
Westport Porcupine occurrence #1	Visible gold occur in pannings	Quartz veinlets hosted by felsic to intermediate breccia
Westport Porcupine occurrence #2	Up to 10 g/t Au	Iron formation associated with feldspar porphyry
Triple Lake showing	Unknown	Quartz vein hosted by felsic metavolcanic rocks

The reader is referred to Pyke (1978a) and Clark (1989) for a more detailed description on these occurrences.

The contact between the tonalite stocks and the surrounding metavolcanic and sedimentary rocks south of McArthur Lake is a prospective zone for gold mineralization. Several showings at, or near, this contact indicate the entire zone along the felsic intrusion should be re-examined. The association between gold and iron formation is also well established in greenstone belts. The Carshaw–Malga Mine in the Shaw Dome area represents a good example of this type of association between gold and iron formation. Numerous and relatively continuous iron formations in McArthur Township could represent an interesting target for this type of mineralization. Furthermore, rusty zones on exposures of the middle iron formation horizon observed during the mapping should be tested for gold and base metal content.

A close spatial relationship between komatiites and sedimentary rocks (banded iron formation and sulphidic graphitic argillite), abundant olivine cumulates, and spinifex-textured sills hosted within komatiite flows in the map area, provides a favourable location for nickel sulphide mineralization associated with the komatiites. Observations during mapping indicate high volumes of magma were associated with these komatiites and, thus, are potentially sufficient to dissolve sulphur and precipitate sulphide minerals that carry the nickel, copper and platinum group elements. During this bedrock mapping project, a small gossan was observed southeast of McArthur Lake. It exhibits some disseminated, blebby and millimetre-scale sulphides veinlets (pyrrhotite, pyrite) (*see* Figure 6.2). Furthermore, the komatiites in the map area are along strike from the former Texmont Mine, a komatiite-associated nickel sulphide deposit.

ACKNOWLEDGMENTS

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REFERENCES

Ayer, J.A., Amelin, Y., Corfu, F., Kamo, S., Ketchum, J., Kwok, K. and Trowell, N. 2002. Evolution of the southern Abitibi greenstone belt based on U-Pb geochronology: autochthonous volcanic construction followed by plutonism, regional deformation and sedimentation; Precambrian Research, v.115, p.63-95.

Ayer, J.A., Thurston, P.C., Bateman, R., Dubé, B., Gibson, H.L., Hamilton, M.A., Hathaway, B., Hocker, S., Houlé, M.G., Hudak, G., Lafrance, B., Lesher, C.M., Ispolatov, V., MacDonald, P.J., Péloquin, A.S., Piercey, S.J., Reed, L.E. and Thompson, P.H. 2005. Overview of results from the Greenstone Architecture Project: Discover Abitibi Initiative; Ontario Geological Survey, Open File Report 6154, 146p.

Ayer, J.A., Trowell, N.F., Amelin, Y. and Corfu, F. 1999a. Geological compilation of the Abitibi greenstone belt in Ontario: toward a revised stratigraphy based on compilation and new geochronology results; *in* Summary of Field Work and Other Activities 1998, Ontario Geological Survey, Miscellaneous Paper 169, p.14-24.

Ayer, J.A., Trowell, N.F., Madon, Z., Kamo, S., Kwok, Y.Y. and Amelin, Y. 1999b. Compilation of the Abitibi greenstone belt in the Timmins–Kirkland Lake area: revisions to stratigraphy and new geochronological results; *in* Summary of Field Work and Other Activities 1999, Ontario Geological Survey, Open File Report 6000, p.4-1 to 4-14.

Bright, E.G. 1968a. Beemer Township, District of Sudbury; Ontario Division of Mines, Preliminary Map P.453, scale 1:15 840.

——— 1968b. English Township, District of Sudbury; Ontario Division of Mines, Preliminary Map P.454, scale 1:15 840.

——— 1968c. Zavitz Township, District of Sudbury; Ontario Division of Mines, Preliminary Map P.455, scale 1:15 840.

——— 1974. English and Zavitz townships, District of Sudbury; Ontario Division of Mines, Map 2290, scale 1:31 680.

Clark, R. 1989. Geological and geophysical surveys, Norwin project, Ontario, McArthur and Bartlett townships, Inco Gold Management Inc.; Timmins Resident Geologist's office, NTS 42 A/03, assessment file AFRI# 42A03NE0027, 71p.

Coad, P.R. 1979. Nickel sulphides deposits associated with ultramafic rocks of the Abitibi belt and economic potential of mafic-ultramafic intrusions; Ontario Geological Survey, Study 20, 84p.

Pyke, D.R. 1978a. Geology of the Redstone River area, District of Timiskaming; Ontario Division of Mines, Geological Report 161, 75p. Accompanied by Map 2363 and Map 2364, scale 1:31 680.

——— 1978b. Geology of the Peterlong Lake area, districts of Timiskaming and Sudbury; Ontario Division of Mines, Geological Report 171, 52p. Accompanied by Map 2345, scale 1:50 000.

Pyke, D.R., Naldrett, A.J. and Eckstrand, O.R. 1973. Archean ultramafic flows in Munro Township, Ontario; Geological Society of America Bulletin, v.84, p.955-978.

7. Project Unit 00-012. Tectonic Significance of the Pukaskwa Batholith and its Contact Relationships with the Hemlo and Mishibishu Greenstone Belts

G.P. Beakhouse[1] and S. Lin[2]

[1]Precambrian Geoscience Section, Ontario Geological Survey
[2]Department of Earth Sciences, University of Waterloo, Waterloo, Ontario N2L 3G1

INTRODUCTION

Previous investigations of the Hemlo greenstone belt and Hemlo gold deposit have established a chronological framework for the deposition, deformation, metamorphism, intrusive activity and gold mineralization associated with the Hemlo greenstone belt (Lin 2001; Davis and Lin 2003; Beakhouse 2001; Beakhouse and Davis 2005). Subsequent investigations in other portions of the Superior Province (Lin 2005; Beakhouse 2005, in press) have suggested that synchronous vertical and horizontal tectonic processes may have operated during the later stages of greenstone belt development. The interplay of these vertical and horizontal tectonic processes may explain the characteristic sequence and pace of tectonic development of the Superior Province and have implications for gold metallogeny (Beakhouse 2005, in press; Lin, Parmenter and Parks 2005).

The character of large belt-bounding batholiths and their contact relationships with adjacent greenstone belts offer one means of testing several important aspects of the synchronous horizontal and vertical tectonic model. With this goal in mind, a brief reconnaissance of the Pukaskwa batholith and its contact relationship with the Mishibishu and Hemlo greenstone belts was carried out. In addition to field relationships discussed here, further investigations of microstructures in oriented thin sections and paleopressures utilizing the Al-in-hornblende geobarometer are planned.

SYNCHRONOUS HORIZONTAL AND VERTICAL TECTONISM

Models for the tectonic development of the Archean crust have historically invoked either dominantly vertical tectonic processes or dominantly horizontal tectonic processes. Earlier studies dominantly advocated vertical tectonism due to density inversion with denser overlying greenstone sequences sinking (sagduction) and underlying granitoids buoyantly rising (diapirism), whereas many more recent models have advocated dominantly horizontal tectonic processes generally attributed to collisional and transcurrent plate interactions within a broadly uniformitarian plate tectonic paradigm (Lin 2005 and references therein).

Several common characteristics of Archean greenstone belts in the Superior Province suggest that both horizontal and vertical tectonic processes must have been operative. Evidence for large-scale vertical processes is seen in the observations that many greenstone belts define arcuate synclinal keels and are dominated by subvertical stretching lineations, whereas intervening granitoids batholiths have the form of structural domes. Local evidence for thrust faulting (Davis, Sutcliffe and Trowell 1988), regional-scale recumbent folds (Beakhouse, Stott and Sutcliffe 1983; Arias and Helmstaedt 1990) and

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large-scale transcurrent faulting attests to large-scale horizontal processes. The pace of development of the sequence of deformational and metamorphic events that characterizes most Archean greenstone belts is such that all of these processes must have developed within a restricted time interval suggesting that any tectonic model must be consistent with a characteristic sequence of depositional, deformational, metamorphic and intrusive events with the near synchronous association of large-scale vertical and horizontal tectonic processes (Beakhouse 2005, in press).

Vertical and horizontal tectonism can operate synchronously because the driving forces are different. Vertical tectonics is driven by body forces (gravity) acting on a density inversion such as is represented by dominantly mafic greenstone sequences structurally overlying intermediate to felsic granitoid crust. The sagduction and diapirism processes may be triggered by a perturbation (e.g., thickness variation in either layer due to primary or deformational processes) if the viscosity of the rocks is sufficiently low.

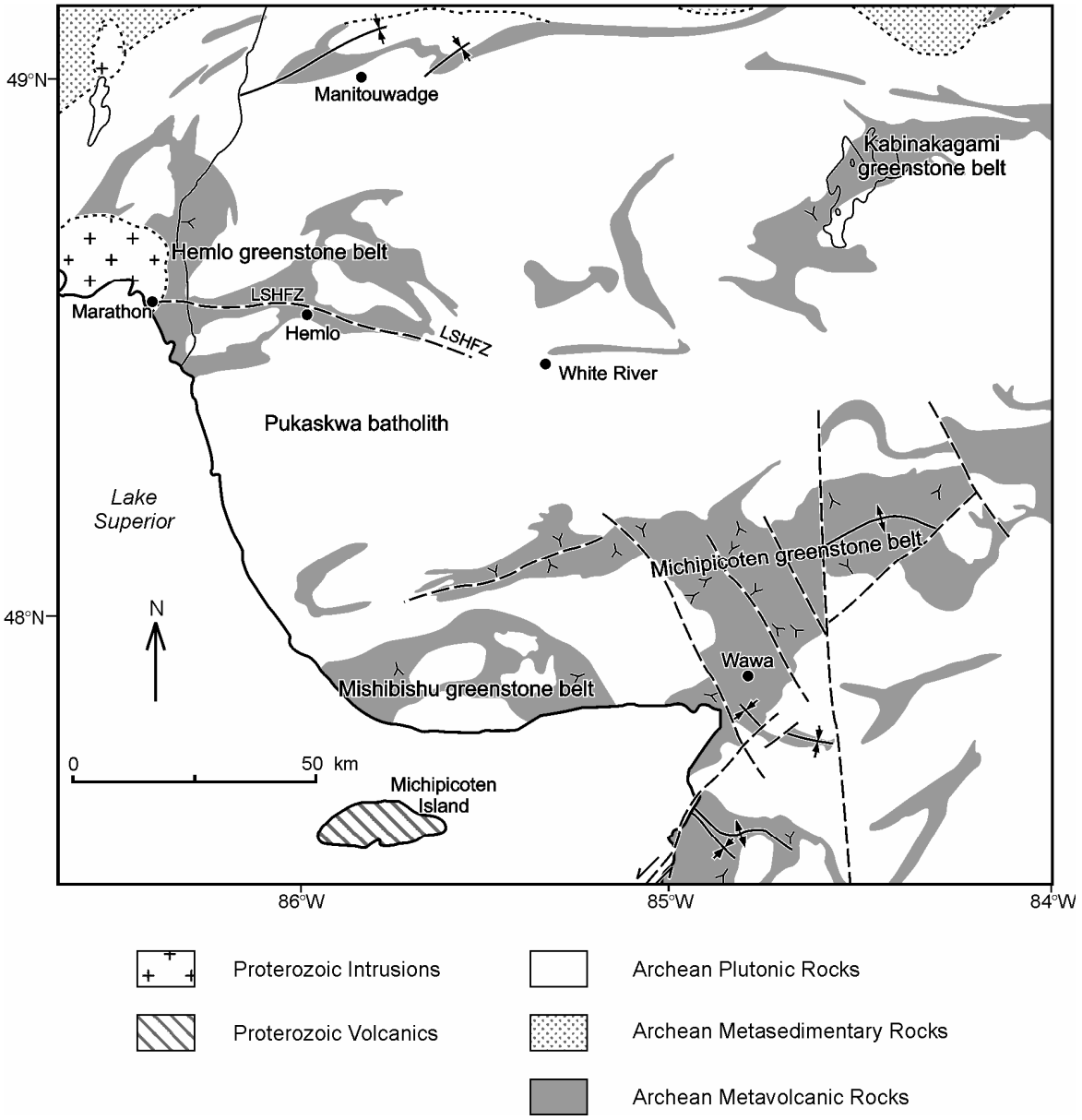

Figure 7.1. Generalized geological map illustrating the setting of the Pukaskwa batholith. Abbreviation: LSHFZ, Lake Superior–Hemlo fault zone.

Horizontal tectonics is ultimately driven by vertical processes (upwelling of hot, less dense asthenospheric mantle at spreading centres and sinking of old, colder oceanic crust and lithospheric mantle at subduction zones). However, the structures preserved in continental crust relating to this process are produced in response to boundary forces (orthogonal to oblique collision and transcurrent movement) relating to lateral movement of plates on the earth's surface. Consequently, both horizontal and vertical tectonic processes may operate simultaneously to produce structures at a variety of scales.

Lin (2005) and Parmenter, Lin and Corkery (2006) proposed that the structural geometry and kinematics of granitoid–greenstone contacts provide a means to test for the simultaneous operation of vertical and horizontal tectonic processes. Lin (2005) presents evidence that the narrow Carrot River greenstone belt in the northwest Superior Province is a synclinal keel between two granitoids domes and that a high-strain zone coincident with the greenstone belt records a greenstone-down and granitoid-up dip-slip component that developed synchronously with a dextral strike-slip component. Similar geometry and kinematics have been observed at the Cross Lake greenstone belt, indicating a similar process (Parmenter, Lin and Corkery 2006). Lin, Parmenter and Parks (2005) and Parmenter, Lin and Corkery (2006) further suggests that late unconformable ("Temiskaming-type") sequences are deposited in the synclinal keels as they developed and that the resulting structures may play a role in the localization of gold mineralization.

THE PUKASKWA BATHOLITH AND ITS CONTACT RELATIONSHIPS

The Pukaskwa batholith is a large, poorly understood, heterolithic granitoid complex occurring within the Wawa Subprovince. It is bounded to the north by the Hemlo and Kabinakagami Lake greenstone belts, which are connected by semi-continuous greenstone septa and, to the south, by the Mishibishu and Michipicoten greenstone belts (Figure 7.1). Results reported here are based largely on observations along the well-exposed Lake Superior shoreline, which represents a transect from the Hemlo greenstone belt, across the Pukaskwa batholith to the northern portion of the Mishibishu greenstone belt.

The Pukaskwa batholith is lithologically complex and only a broad characterization is possible within the scope of this investigation. Three general rock associations, each displaying considerable internal variation, predominate within the Pukaskwa batholith. The oldest of these are gneissic, well-foliated tonalitic to granodioritic rocks (Photo 7.1a) that locally contain entrained amphibolitic units that represent both included basaltic country rock and deformed mafic dikes. Biotite is the predominant mafic mineral phase. A second rock association is represented by foliated granodiorite to quartz monzodiorite. These units intrude the gneissic tonalite to granodiorite and locally crosscut the gneissic fabric (Photo 7.1b) although they themselves are weakly to moderately foliated. The foliation within these units is generally subparallel to parallel to that within the gneisses. The dominant mafic minerals within these units are biotite and hornblende. The youngest of the 3 rock associations consists of relatively leucocratic, granodioritic to granitic units that range from large, relatively homogeneous plutons to small dikes. The larger plutons of this younger rock association within the batholith are characterized by uniform, medium-grained, equigranular to potassium feldspar megacrystic textures with foliation being weak or absent. The smaller dike phases display more compositional variation and include medium- to coarse-grained equigranular as well as pegmatitic and aplitic granitic phases that commonly display complex, crosscutting intrusive relationships (Photo 7.1c). The dikes are mostly little deformed; however, in some cases, they are affected by late deformation.

The distribution of these 3 rock associations imparts a crude symmetry to the Pukaskwa batholith. The gneissic tonalite association is most abundant in the northern portion of the batholith where it generally contains only minor amounts of later crosscutting phases. The proportion of foliated granodiorite to quartz monzodiorite increases to the south of the mouth of the White River and in the

Photo 7.1. a) Folded gneissic tonalite. b) Foliated granodiorite cutting gneissic tonalite. c) Diverse late granitic to granodioritic dikes with complex crosscutting relationships.

central portion of the batholith, the younger granodioritic to granitic phases predominate. These younger phases are well represented in the southern portion of the batholith; however, the character of inclusions and local coherent units of the older phases suggests that the pattern of marginal gneissic tonalite and interior foliated granodiorite to quartz monzodiorite phases observed in the north is repeated in the south. Consequently, the Pukaskwa batholith appears to be crudely symmetrical with gneissic tonalitic margins giving way to interior foliated granodiorite to quartz monzodiorite with a welt of later granitic phases dominating the core and portions of the southern part of the batholith.

Interpretations of the structure of the batholith are similarly limited by the reconnaissance nature of this investigation, but some generalizations are possible. Near both margins of the pluton, the foliation and lineation are well developed with consistent orientations similar to those observed within the greenstone belts near the contact. The dips of foliations near the margins are generally moderate to steep. The foliation in the interior portions of the batholith is more variable in intensity and orientation with folding resulting in dips ranging from vertical to horizontal.

Contact Structural Relationships

In the vicinity of the Pukaskwa batholith–Hemlo greenstone belt contact, a strong foliation dips moderately to the north with well-developed lineations (stretching, mineral and ridge-in-groove striations) plunging 35 to 45° to the northwest and indicating oblique movement along the contact (Photo 7.2a). Shear sense indicators (Photo 7.2b) consistently indicate that this oblique movement has a north (greenstone)-side-down–south (granite)-side-up dip-slip component and a sinistral strike-slip component. Within the northern margin of the Mishibishu greenstone belt, the foliation dips moderately to the north with a well-developed lineation plunging 40 to 45° to the northeast. Back-rotated boudins with shear bands indicate a shear sense with north (granite)-side-up–south (greenstone)-side-down dip-slip component and a sinistral strike-slip component (Photo 7.2c). The data indicate that the Pukaskwa batholith moved up relative to the greenstone belts on both sides while both contacts were undergoing sinistral shearing.

DISCUSSION

The observations described above are consistent with the interpretation that regional-scale sinistral transcurrent (horizontal tectonic) deformation acted in concert with diapiric and sagduction (vertical tectonic) processes. This hypothesis is similar to that developed for the northwest Superior Province (Lin 2005; Parmenter, Lin and Corkery 2006) and further suggests that synchronous vertical and horizontal tectonism may be a common feature of Neoarchean terranes.

Geochronological constraints indicate that the complex deformational and/or metamorphic evolution of the Hemlo greenstone belt proceeded rapidly with the belt achieving something approximating its final tectonometamorphic configuration within approximately 10 million years of deposition of the youngest supracrustal rocks (Davis and Lin 2003; Beakhouse and Davis 2005). This rapid pace of development is attributed to collision and southward accretion of the Superior Province, which resulted in abrupt termination of arc-type magmatism and rapid tectonic thickening followed shortly by slab roll-back or delamination leading to influx of hot asthenospheric mantle and extensional orogenic collapse (Beakhouse 2005). We speculate that regional sinistral transcurrent displacement is a far-field effect of continuing oblique convergence along the southern flank of the Superior craton and that vertical deformational components (diapirism and sagduction) can be attributed to density inversion during extensional orogenic collapse. The diapirism and sagduction may have been triggered by crustal thinning and changes in the rheology of the crust due to influx of hot asthenospheric mantle during extensional orogenic collapse.

Photo 7.2. a) Ridge-in-groove striations indicative of oblique movement in the vicinity of the northern contact of the batholith. b) Asymmetric back-rotated boudins indicative of north-side-down dip-slip component in the vicinity of the northern contact of the batholith. c) Back-rotated boudins with shear bands indicative of a south-side-down dip-slip component in the vicinity of the southern contact of the pluton.

Estimates of the timing of these tectonic processes are similar to that for formation of Archean lode gold deposits suggesting that these processes may play a role in metallogeny. Specifically, major shear zones developed in greenstone belts preserved in synclinal keels in response to the interplay of horizontal and vertical tectonic processes. In addition, the crust was undergoing extension and thinning above hot mantle that may have been a source of late mantle-derived magmas and auriferous fluids. As such, the overall tectonic setting may be responsible for generating both the mineralizing fluids and the plumbing system required to focus the flow of fluids and form an economic gold deposit.

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REFERENCES

Arias, Z.G. and Helmstaedt, H. 1990. Structural evolution of the Michipicoten (Wawa) greenstone belt, Superior Province: evidence for an Archean fold and thrust belt; *in* Geoscience Research Grant Program, Summary of Research 1989–1990; Ontario Geological Survey, Miscellaneous Paper 150, p.107-114.

Beakhouse, G.P. 2001. Nature, timing and significance of intermediate to felsic intrusive rocks associated with the Hemlo greenstone belt and implications for the regional geological setting of the Hemlo gold deposit; Ontario Geological Survey, Open File Report 6020, 248p.

——— 2005. Tectonic setting of late plutonism and Archean lode gold deposits in the Superior Province; Geological Society of America, Abstracts with Programs, v.37, no.7, p.95.

——— in press. Magmatic hydrothermal model for Archean lode gold deposits: a working hypothesis; Ontario Geological Survey, Open File Report 6193.

Beakhouse, G.P. and Davis, D.W. 2005. Evolution and tectonic significance of intermediate to felsic plutonism associated with the Hemlo greenstone belt, Superior Province, Canada; Precambrian Research, v.137, p.61-92.

Beakhouse, G.P., Stott, G.M. and Sutcliffe, R.H. 1983. Geological studies in the Kenora–Cedar Lake area; *in* Summary of Field Work, 1983; Ontario Geological Survey, Miscellaneous Paper 116, p.5-10.

Davis, D.W. and Lin, S. 2003. Unraveling the geologic history of the Hemlo Archean gold deposit, Superior Province, Canada: a U-Pb geochronological study; Economic Geology, v.98, p.51-67.

Davis, D.W., Sutcliffe, R.H. and Trowell, N.F. 1988. Geochronological constraints on the tectonic evolution of a Late Archean greenstone belt, Wabigoon Subprovince, northwest Ontario, Canada; Precambrian Research, v.39, p.171-191.

Lin, S. 2001. Stratigraphic and structural setting of the Hemlo gold deposit, Ontario, Canada; Economic Geology, v.96, p.477-507.

——— 2005. Synchronous vertical and horizontal tectonism in the Neo-Archean: kinematic evidence from a synclinal keel in the northwestern Superior Craton, Canada; Precambrian Research, v.139, p.181-194.

Lin, S., Parmenter, A. and Parks, J. 2005. Synchronous vertical and horizontal tectonism at the late stage of Archean cratonization: an important process in gold mineralization?; *in* Mineral deposit research: meeting the global challenge, Springer Verlag, Proceedings of the 8th Biennial SGA Meeting, Beijing, China, August 18–21, 2005, v.1, p.20-32.

Parmenter, A.C., Lin, S. and Corkery, M.T. 2006. Structural evolution of the Cross Lake greenstone belt in the northwestern Superior Province, Manitoba: implications for relationship between vertical and horizontal tectonism; Canadian Journal of Earth Sciences, v.43, p.767-787.

8. Project Unit 05-009. Intermediate to Felsic Intrusive Rocks in the Abitibi Subprovince

G.P. Beakhouse[1] and K.F. Cassidy[2]

[1]Precambrian Geoscience Section, Ontario Geological Survey, 933 Ramsey Lake Road, Sudbury, Ontario P3E 6B5
[2]Geoscience Australia, c/o Geological Survey of Western Australia, 100 Plain St., East Perth, Western Australia 6004

INTRODUCTION

Intermediate to felsic intrusive rocks in the Ontario portion of the Abitibi Subprovince are poorly understood relative to the more thoroughly investigated metavolcanic and metasedimentary rocks (Ayer et al. 2002). Moderately detailed investigations of intrusive rocks have been carried out in several areas where the plutons are spatially associated with mineralization (e.g., Rowins, LaLonde and Cameron 1991; Rowins et al. 1993; Pigeon 2003; MacDonald, Piercey and Hamilton 2005) and general frameworks for Abitibi granitic plutonism based in part on selected units from the Ontario portion of the subprovince have been developed (Feng and Kerrich 1992a, 1992b; Sutcliffe et al. 1993). General frameworks have also been presented for the Quebec portion of the Abitibi Subprovince (Rivé, Pintson and Ludden 1990; Chown, Harrap and Moukhsil 2002).

This project was initiated as a collaborative research agreement between the Ontario Geological Survey and Placer Dome Inc. (now Goldcorp) with the objective of providing a high-quality petrologic and geochemical database for Abitibi Subprovince intermediate to felsic intrusive rocks and interpreting the tectonic and metallogenic significance of these rocks. This database and derived interpretations will be compared with results from other Archean greenstone terranes (Red Lake, western Wabigoon, Hemlo and portions of the Yilgarn craton of Western Australia) as part of a broader evaluation of the potential application of granite studies to predictive metallogeny.

Field work was initiated in September and October of 2005, with additional field work being carried out in June and August of 2006. Geochemical data for 131 samples from the first phase of this work are being released this year and processing of 102 samples from the second phase of this work is underway.

PRELIMINARY OBSERVATIONS

This work relies heavily on petrographic, geochemical and mineral chemical data that are not available at the time of writing; however, some preliminary observations based on field observations are possible. Field observations are consistent with the broad pattern of earlier (pre- to syntectonic), predominantly tonalitic, batholiths with later (late to posttectonic), generally minor intrusions ranging in composition from quartz diorite to syenite (Feng and Kerrich 1992a, 1992b; Sutcliffe et al. 1993). Most of the large batholiths (Round Lake, Kenogamissi and the poorly exposed Lake Abitibi batholiths) are complex, polyphase intrusions with the earliest and predominant phases generally having a fairly restricted compositional range (tonalite, leuco-tonalite, granodiorite) and being characterized by the presence of a weakly to strongly developed tectonic foliation (Photo 8.1a). Individual outcrops

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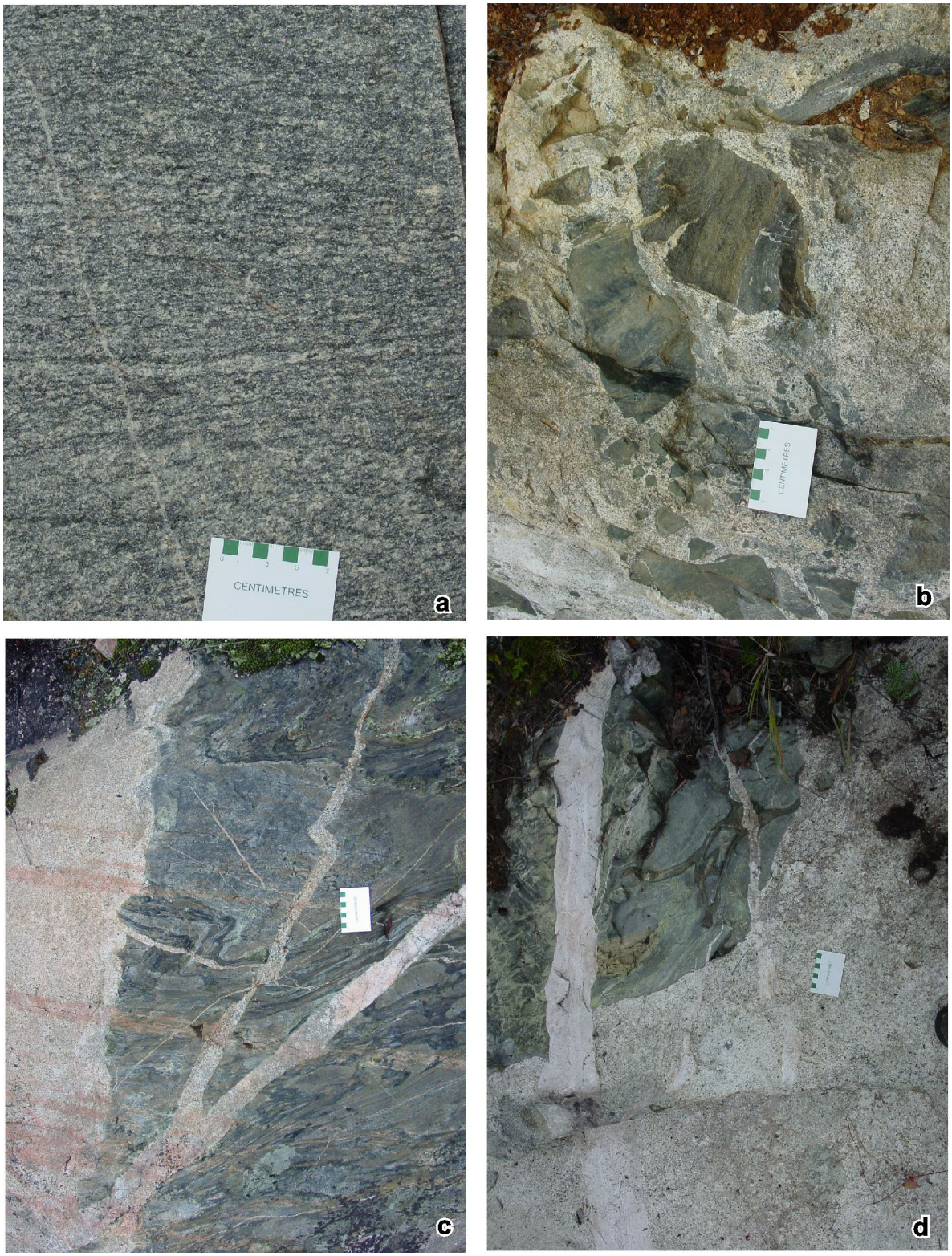

Photo 8.1. a) Well-foliated to gneissic tonalite (Kenogamissi batholith). b) Randomly oriented blocks of well-foliated country rock included in the margin of the Geikie pluton. c) Well-developed foliation deformed by folding with development of an axial planar fabric which is crosscut by the Blackstock intrusion. d) Crosscutting relationship between strong fabric and both main intrusion and dikes at the north contact of the Adams pluton.

commonly display considerable heterogeneity due to variation in composition and fabric development in the main phases as well as the presence of amphibolitic inclusions and variously deformed minor phases ranging in composition from gabbro to granite. Pegmatitic and aplitic leuco-granitic phases are generally the most abundant and conspicuous minor phases. Some relatively large, weakly foliated, homogeneous intrusions of granodioritic or, less commonly, quartz dioritic composition occur within these batholiths (particularly the Kenogamissi batholith). It is not clear if these represent a discrete magmatic event or if they could possibly be related to the late- to posttectonic intrusions occurring elsewhere within the greenstone belt.

The most enigmatic larger intrusions are those occurring in the west-central portion of the main Abitibi belt, including the Watabeag batholith and the Blackstock, Fallon, Adams and Geikie plutons. These units are comprised predominantly of relatively homogeneous hornblende granodiorite to quartz monzodiorite. Discrete plutons are sometimes also differentiated by variations in magnetite content. Exposures at the contacts of several of these intrusions (Blackstock, Adams, Geikie) indicate emplacement comparatively late in the tectonic evolution of the Abitibi Subprovince (Photos 8.1b to 8.1d). Weak foliations observed locally are either possible magmatic fabrics or extremely localized and related to late minor shearing. On this basis, these intrusions are provisionally interpreted to be late tectonic. Uranium-lead (U/Pb) zircon ages reported for several of these units span a considerable age range (2676 to 2699 Ma: Frarey and Krogh 1986), overlapping that of both the late- to posttectonic syenitic plutons discussed below and the youngest volcanism and tonalitic plutonism. Additional U/Pb age determinations are required to evaluate the absolute timing of these units relative to others in the Abitibi Subprovince.

Syenitic intrusions have attracted considerable interest due to their common spatial association with gold mineralization (Robert 2001). They also tend to be most abundant along major ‘breaks’, as for example in the Kirkland Lake–Larder Lake and Harker–Holloway areas; however, some syenite intrusions are more distal from major known structures. In Powell Township, a series of small syenite intrusions define a north-trending zone that diverges notably from that of the Cadillac–Larder Lake deformation zone in this area (Berger and Préfontaine 2005). Other examples of syenites occurring well removed from major known deformation zones include the Iris and Casey Mountain syenites. An additional problem to be addressed as part of this study is whether some minor dioritic to granodioritic intrusions (e.g., Millie Lake intrusion and several minor intrusions in Argyle and Hincks townships) may be temporally or genetically associated with the syenitic magmatism.

Numerous minor intrusions are widely distributed within the greenstone belt and the affinity of most of these to any of the magmatic associations discussed above is uncertain and will be investigated as part of this study. A high proportion of these minor intrusions occur within mineralized and/or higher strain zones. Although this apparent distribution may be influenced by the more detailed nature of investigations carried out in mineralized deformation zones, observations made during this investigation support the notion that there is a spatial (and perhaps temporal and genetic) association of magmatic, deformational and gold mineralization processes.

REFERENCES

Ayer, J., Amelin, Y., Corfu, F., Kamo, S., Ketchum, J., Kwok, K. and Trowell, N. 2002. Evolution of the southern Abitibi greenstone belt based on U-Pb geochronology: autochthonous volcanic construction followed by plutonism, regional deformation and sedimentation; Precambrian Research, v.115, p.63-95.

Berger, B.R. and Préfontaine, S. 2005. General geology of Powell Township, district of Timiskaming; *in* Summary of Field Work and Other Activities 2005, Ontario Geological Survey, Open File Report 6172, p.5-1 to 5-10.

Chown, E.H., Harrap, R. and Moukhsil, A. 2002. The role of granitic intrusions in the evolution of the Abitibi belt, Canada; Precambrian Research, v.115, p.291-310.

Feng, R. and Kerrich, R. 1992a. Geochemical evolution of granitoids from the Archean Abitibi southern volcanic zone and the Pontiac Subprovince, Superior Province, Canada: implications for tectonic history and source regions; Chemical Geology, v.98, p.23-70.

Feng, R. and Kerrich, R. 1992b. Geodynamic evolution of the southern Abitibi and Pontiac terranes: evidence from geochemistry of granitoids magma series (2700–2630 Ma); Canadian Journal of Earth Sciences, v.29, p.2266-2286.

Frarey, M.J. and Krogh, T.E. 1986. U-Pb ages of late internal plutons of the Abitibi and eastern Wawa subprovinces, Ontario and Quebec; *in* Current Research, Part A, Geological Survey of Canada, Paper 86-1A, p.43-48.

MacDonald, P.J., Piercey, S.J. and Hamilton, M.A. 2005. An integrated study of intrusive rocks spatially associated with gold and base metal mineralization in the Abitibi greenstone belt, Timmins area and Clifford Township: Discover Abitibi Initiative; Ontario Geological Survey, Open File Report 6160, 190p.

Pigeon, L. 2003. Mineralogy, petrology and petrogenesis of syenitic rocks of the Porcupine–Destor fault zone near Matheson, Ontario; unpublished PhD thesis, University of Ottawa, Ottawa, Ontario, 285p.

Rivé, M., Pintson, H. and Ludden, J.N. 1990. Characteristics of Late Archean plutonic rocks from the Abitibi and Pontiac subprovinces, Superior Province, Canada; *in* The northwestern Quebec polymetallic belt, The Canadian Institute of Mining and Metallurgy, Special Volume 43, p.65-76.

Robert, F. 2001. Syenite-associated disseminated gold deposits in the Abitibi greenstone belt, Canada; Mineralium Deposita, v.36, p.503-516.

Rowins, S.M., LaLonde, A.E. and Cameron, E.M. 1991. Magmatic oxidation in the syenitic Murdock Creek intrusion, Kirkland Lake, Ontario: evidence from the ferromagnesian silicates; Journal of Geology, v.99, p.395-414.

Rowins, S.M., Cameron, E.M., LaLonde, A.E. and Ernst, R.E. 1993. Petrogenesis of the Late Archean syenitic Murdock Creek pluton, Kirkland Lake, Ontario: evidence for an extensional tectonic setting; The Canadian Mineralogist, v.31, p.219-244.

Sutcliffe, R.H., Barrie, C.T., Burrows, D.R. and Beakhouse, G.P. 1993. Plutonism in the southern Abitibi Subprovince: a tectonic and petrogenetic framework; Economic Geology, v.88, p.1359-1375.

9. Project Unit 06-003. Geology of the Hamlin and Wye Lakes Area, Shebandowan Greenstone Belt, Thunder Bay District

T.R. Hart[1] and D-A. Trebilcock[2]

[1]Precambrian Geoscience Section, Ontario Geological Survey, Sudbury, Ontario
[2]RR#1 Kam-Current Road, Kaministiquia, Ontario P0T 1X0

INTRODUCTION

Mapping of the Hamlin–Wye lakes area (Figure 9.1), located on the southwestern Shebandowan greenstone belt, was conducted to evaluate the position of the supracrustal and associated intrusive rocks of the map area within the tectonostratigraphic framework of Shebandowan greenstone belt. The project will characterize the metavolcanic and intrusive rocks of the map area and their relationship to gold and base metal mineralization. Past exploration has concentrated on the potential for gold mineralization, but the recent discovery of massive copper-zinc volcanogenic massive sulphide (VMS) mineralization indicates a potential for different styles of mineralization within this portion of the Shebandowan greenstone belt.

ACCESS AND PREVIOUS WORK

The Hamlin–Wye lakes map area is located approximately 115 km west of Thunder Bay, along the eastern boundary of Quetico Park. Access is provided by the logging road network extending south from the Swamp Road, which is located along Highway 11 about 16 km west of Kashabowie (*see* Figure 9.1). Previous geological mapping by Harris (1970) covered most of the map area at a scale of 1:31 680. The southern edge of the map area was previously mapped by Harris (1968) at 1:31 680 scale. The Shebandowan greenstone belt, including this map area, was covered by airborne magnetic and electromagnetic surveys (Ontario Geological Survey 2003).

Exploration in the late 1950s resulted in discovery of a number of copper showings in the Hamlin and Wye lakes area (Harris 1970), and exploration activity was intermittent until the early 1970s. Advanced exploration at the Ardeen and Moss Lake mines, located northeast of the map area, led to sporadic exploration throughout the area from the mid-1980s until the present time. A number of companies are currently examining the potential for gold and copper mineralization in the northern portion of the map area, including a copper-gold occurrence north of Hamlin Lake (East West Resource Corp. 2005). Exploration for gold in the Wye Lake area resulted in the discovery of massive to semi-massive sphalerite and chalcopyrite mineralization with grades up to 12.49% Cu and 10.01% Zn (Freewest Resources Canada Inc. 2005). Ground geophysical surveys, trenching, geological mapping and diamond drilling have been completed, and currently these data are being evaluated to determine the next stage in exploration.

Summary of Field Work and Other Activities 2006,
Ontario Geological Survey, Open File Report 6192, p.9-1 to 9-9.

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GENERAL GEOLOGY

The map area is underlain by Archean rocks of the Shebandowan greenstone belt in the southwestern portion of the Wawa Subprovince (*see* Figure 9.1). Mafic to intermediate metavolcanic rocks occur as tuffs, lapilli tuffs, and debris flows, with less abundant massive to pillowed flows. The intermediate to felsic metavolcanic rocks consist of tuff, lapilli tuffs, and debris flows, and less commonly massive flows. Oxide-facies iron formation and cherts are interbedded with the metavolcanic rocks throughout the map area, and fine clastic metasedimentary rocks are present on the south side of the area. Lamprophyre dikes intrude, and have been deformed with, the metavolcanic rocks. Scattered gabbro bodies intrude the metavolcanic rocks, and may be in part the core of thicker flows. Small peridotite bodies intrude the

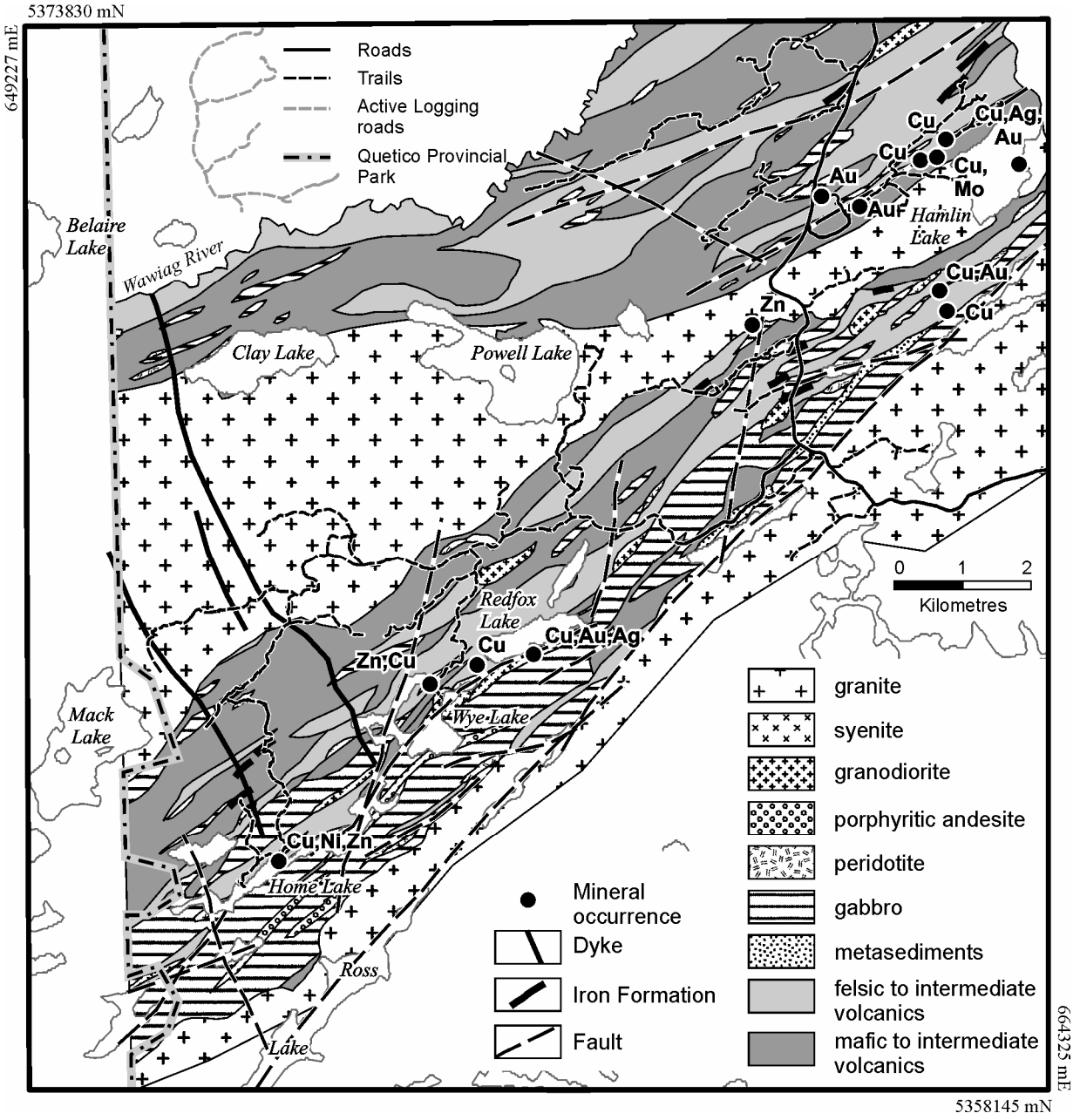

Figure 9.1. Location and general geology of the Hamlin and Wye lakes area.

metavolcanic rocks, and are more common along the south arm of the belt. Granodiorite sills intrude the metavolcanic rocks throughout the map area, and intrude some gabbros in the southern portion of the area. The hornblende granite Powell Lake intrusion separates the greenstone belt into a north and south arm. The north arm is bounded to the north by fine clastic metasedimentary rocks of the Quetico Subprovince. To the south, the Myrt Lake biotite granite separates the south arm from the Saganagons Lake area metavolcanic rocks to the southeast. A number of north- to northwest-trending mafic dikes intrude the metavolcanic and felsic intrusive rocks of the map area.

Mafic to Intermediate Metavolcanic Rocks

Mafic to intermediate metavolcanic rocks occur as tuffs, lapilli tuffs, and debris flows, with less abundant massive to pillowed flows. Tuffs are well foliated, medium green-grey, and aphanitic to very fine grained, with some units containing medium-grained subhedral crystals of feldspar. Lapilli tuffs are medium green to grey-green, moderately well-foliated chloritic tuff matrix, with mafic lapilli to occasionally block-size clasts. The ability to distinguishing the lapilli tuffs from debris flows depends on the quality of the exposure. Debris flows consist of a mafic matrix containing block- to lapilli-size clasts that are predominantly mafic in composition, with varied intermediate to felsic and chert clast content. The flows are weakly to moderately well foliated with subangular to subrounded clasts elongated along the foliation. Mafic to intermediate flows are massive to weakly foliated, medium grey-green to green, aphanitic, and occasionally containing up to 0.5 cm quartz-filled amygdules. Some units have fine-grained, disseminated feldspar that could indicate an andesitic composition. Pillowed flows are medium grey-green to green, aphanitic to very fine grained, occasionally amygdaloidal along the margins, with dark green, 1 to 2 cm chloritic selvages and no visible interpillow hyaloclastite. Flattening of the pillows due to deformation means that top directions are indeterminant.

Intermediate to Felsic Metavolcanic Rocks

The intermediate to felsic metavolcanic rocks consist of tuff, lapilli tuffs, and debris flows, and less commonly massive flows. Tuffs are well to moderately well foliated, medium to light grey, and aphanitic to very fine grained, with most units containing varied amounts of medium-grained, anhedral to subhedral quartz and lesser feldspar. In some locations along the north side of the south volcanic arm, tuffs occur in 5 to 10 cm beds interbedded with coarser fragmental or medium brown aphanitic units probably composed of a mixture of ash and mud. Northwest of Hamlin Lake, an intermediate tuff with up to 60% subhedral feldspar crystals is interbedded with mafic lapilli tuff in a few exposures. The tuffs may have gradational contacts with lapilli-tuffs. Lapilli-tuffs are composed of monolithic clasts in a fine- to medium-grained, weakly to moderately well-foliated tuff matrix. Clasts range from aphanitic to quartz porphyritic, predominantly lapilli (with occasional blocks) size, subrounded to subangular that are flattened along the foliation. The quartz content of the tuff matrix of some lapilli-tuffs varies on an outcrop scale. Debris flows are composed of block, with lesser lapilli, size clasts ranging from monolithic to predominantly intermediate to felsic composition with a lesser number of mafic to intermediate or chert clasts. Clasts are subrounded to subangular and flattened to different extents, as the flows are moderately to well foliated. The matrix is generally intermediate to felsic tuff to crystal-rich tuff that has varied chlorite or sericite alteration. Debris flows are typically matrix supported, but some units are clast supported and display a crude variation over a few metres that may represent originally bedding. Massive flows are massive to weakly foliated, medium to light grey, aphanitic groundmass generally containing fine-grained anhedral to subhedral, light grey to blue quartz phenocrysts. In the area of the Wye Lake massive sulphide occurrence, the northern hanging-wall flows contain blue quartz phenocrysts, and the footwall flows are aphanitic to fine grained (D. Maclean, Freewest Resource Canada Inc., personal communication, 2006).

Metasedimentary Rocks

Metasedimentary rocks consist of chemical sediments interbedded with the metavolcanic rocks throughout the map area, and fine clastic sediments in the southern portion of the area. Chemical sediments consist of cherts and banded oxide-facies iron formations. A chert unit was not observed during the mapping project, but has been reported to be present in the area north of Hamlin Lake (A. Shute, Laurentian University–East West Resource Corp., personal communication, 2006). However, chert is a common clast type in heterolithic volcanic debris flows and monolith soft sediment slump deposits. The oxide-facies iron formation, in a small number of exposures, occur as well-banded, chert and magnetite-rich layers in beds up to 2 m thick interbedded with the metavolcanic rocks. One unit located north of Home Lake is interbedded with fine clastic metasedimentary rocks. More commonly, the iron formation is boudinaged forming 5 to 30 cm long isoclinally folded, cherty black, magnetite-rich lenses varying from 1 to 20 cm in thickness and hosted by well-foliated mafic to intermediate metavolcanic rocks. Clastic metasedimentary rocks consist of finely bedded to laminated, medium to dark grey mudstones occurring in a discontinuous band interbedded with the metavolcanic rock along the southern side of the map area. An approximately 60 m thick sequence, apparently in conformable contact with metavolcanic rocks to the north, is exposed in a trench north of Home Lake. However, abundant fine isoclinal folds within the sequence suggest that the original stratigraphic thickness was much less.

Gabbro

Gabbro bodies intrude the metavolcanic rocks throughout the map area, with the number of bodies increasing towards the south. To the north, the gabbro typically occurs as isolated sills less than a hundred metres thick and up to a few hundred metres long, intruding along the foliation of the metavolcanic rocks. In the southern portion of the map area, gabbro may be up to a few hundred metres thick and up to a kilometre in length, but the greater size may be partially a result of overlapping small sills, varying from sill-like to more irregularly shaped bodies, although the irregular shapes may be the result of deformation. The sills are usually composed of massive, medium- to coarse-grained, plagioclase and hornblende, with up to 1% fine- to medium-grained magnetite. Occasional, irregularly shaped, very coarse-grained patches with up to 2% quartz are present in some of the southern sills. A sill, 350 to 450 m thick intrudes the metavolcanic rocks north of Home Lake, and varies from gabbro to hornblendite with less than 30% plagioclase. A portion of this sill has crude centimetre-scale rhythmic layering. Similar compositional variations may occur in other sills, but was only observed in this sill as a result of greater exposure along an all-terrain vehicle trail.

A distinctive coarse plagioclase porphyritic andesite up to a few hundred metres wide occurs over a distance of at least 10 km along the south side of the map area, closely associated with the gabbro sills. The andesite is composed of a fine-grained to aphanitic, dark green groundmass with subhedral, white to light green plagioclase, up to 2 cm in diameter. The plagioclase phenocrysts are irregularly distributed within the body and may vary between 15 and 50% over distances of a few metres. Although interpreted to be intrusive, thick mafic flows with similar irregular phenocryst contents and distributions are common in other greenstone belts of northwest Ontario. Mapping south of Home and Wye lakes suggests that there may be more than one of these units, unless there is a structural repetition of a single body.

Lamprophyre Dikes

Lamprophyre dikes intrude the metavolcanic rocks along either northeast or northwest directions in the Hamlin and Wye lakes areas, and are also exposed to the east of the current map area. The dikes are medium to coarse grained, dark green to brownish green and distinguished by the presence of up to 25%

reddish brown biotite. In all cases, the dikes have highly irregular forms suggesting emplacement prior to the main phase of deformation.

Peridotite Sills

Peridotite sills occur as scattered bodies intruding the metavolcanic rocks of the southern side of the map area. The exact dimensions of the sills are difficult to determine, but appear to be about 25 m in width and a few hundred metres in length, although a sill up to 150 m in width and 800 m in length is located along the east side of Wye Lake. All sills are massive, fine to medium grained, and dark green. Serpentinization is varied with many sills being moderately altered, but some have very low magnetic susceptibilities suggesting a very low degree of serpentinization such as in the peridotite intruding along the zinc-copper massive sulphide horizon in the discovery outcrop northeast of Wye Lake. Harris (1970) suggested that these sills may be the residual products of the fractionation process that formed the gabbro, as many of the peridotites are closely associated with gabbro sills; however, whole rock geochemistry is required to test this interpretation.

Granodiorite Sills

A number of intermediate to felsic bodies intrude the metavolcanic rocks and some of the gabbros of the map area. In the area north of the Wawiag River, these bodies consist of medium-grained, massive quartz, feldspar and biotite sills intruding along the foliation of the metavolcanic rocks with narrow contact zones containing occasional pebble- to cobble-size rounded xenoliths of the surrounding rocks. Along the southern side of the map area, the granodiorite bodies occur as more irregular-shaped sills intruding both the metavolcanic rocks and, less commonly, the gabbros. The southern bodies are massive, medium-grained, often with coarse-grained, porphyritic feldspar and quartz.

Felsic Plutonic Rocks

The felsic plutonic rocks have a range of composition including the hornblende granite of the Powell Lake intrusion, the biotite granite of the Myrt Lake batholith and syenite sills and dikes intruding the metavolcanic rocks. The Powell Lake intrusion is composed of medium- to coarse-grained, light grey to white, massive hornblende to hornblende-biotite granite that intrudes the metavolcanic rocks, separating the belt into a north and south arm. Previous work indicates that this granite is part of a large batholith centred to the west of the map area. Medium- to coarse-grained, light grey to pinkish grey, biotite granite of the Myrt Lake batholith intrudes along the southern side of the metavolcanic rocks. This granite varies from massive in the interior to weakly foliated and weakly epidotized along the contacts with the metavolcanic rocks.

Syenite dikes and sills intrude the metavolcanic rocks in both the north and south arms of the belt. The dikes are very poorly exposed and only 2 examples were observed during the current mapping project where exposed along the sides of sharply defined 20 to 25 m wide valleys that follow the foliation of the metavolcanic rocks. However, the width and strike length of these dikes is not known. The dikes are composed of aphanitic to fine-grained, reddish pink feldspar with 10 to 15%, fine-grained, dark green hornblende. Immediately adjacent to the dikes, the metavolcanic rocks are intensely altered, with the alteration diminishing in intensity away from the dikes and northeast-trending valleys. Two syenite sills, less than 100 m in width and a few hundreds of metres in length, intrude the metavolcanic rocks on the northwest shore of Wye and Home lakes. These sills are composed of fine-grained, reddish pink feldspar and 10 to 15% fine-grained hornblende.

Structure

The metavolcanic rocks are weakly to moderately foliated with strikes ranging from 240 to 255° and dips of 70 to 90° in the area north of the Powell Lake intrusion. The metavolcanic and metasedimentary rocks in the southern portion of the map area are moderately to well foliated with strikes ranging from 050 to 070° and dips of 70 to 90°. Determination of stratigraphic top directions is difficult owing to deformation and lack of well-defined depositional structures. Tight isoclinal folding observed in the metasedimentary rocks north of Home Lake and the iron formations throughout the south arm suggest that there are probably multiple reversals in stratigraphy as well as shearing subparallel to the axial plane. Lineations in the metavolcanic and metasedimentary rocks, particularly of the south arm, plunge consistently 10 to 20° southwestward, but doubly plunging fold closures are exposed in the metasedimentary rocks north of Home Lake.

Brittle structures consist of fractures striking either to the northeast or the northwest. The northeast-trending structures include the Knife Lake fault that passes through McGinnis and Windblown lakes marking the contact between the Myrt Lake batholith to the south and the supracrustal and associated intrusive rocks to the north. Small-scale displacements along fractures subparallel to the Knife Lake fault are exposed in the metasedimentary rocks to the north, and display sinistral displacements. A second fracture set, striking approximately 085°, may represent splays off the fault, and display dextral displacements. Northwest-trending structures include fractures with apparent dextral offsets, and a spaced cleavage observed in some exposures which may be related to the same event that formed the fractures.

Metamorphism and Alteration

Metamorphism in the map area is generally a regional style confined to the supracrustal rocks and associated intrusive rocks. There are 2 types of alteration: one appears to be related to an early synvolcanic event evident in the metavolcanic and metasedimentary rocks and the other to a late, possibly intrusive-related event evident in both the supracrustal and younger granites.

The supracrustal and associated intrusive rocks have been metamorphosed to middle greenschist facies, with localized upper greenschist to lower amphibolite facies along the contacts with the Powell Lake and Myrt Lake granites. Contact metamorphism associated with the intrusion of the gabbro and granodiorite sills into the metavolcanic rocks is not generally evident, or is limited to very narrow zones of a few tens of centimetres, probably obscured in part by the later regional metamorphism. Weak epidote alteration of feldspar occurs sporadically in both the Myrt Lake and Powell Lake granites, but is moderate in strength along the contacts with the metavolcanic rocks.

Early synvolcanic alteration appears to be related to the hydrothermal event that also deposited the base metal sulphide mineralization, and includes chlorite, epidote, and cordierite alteration. Intense chlorite and garnet alteration is well developed in felsic debris flows west of Hamlin Lake, west of the Nelson Road in the southern metavolcanic arm, and northeast of Redfox Lake. The felsic tuffaceous matrix can be nearly totally replaced by chlorite and garnet, with a progressive replacement of the smaller lapilli-size clasts and development of alteration rims on the remaining blocks resulting in angular to sub-angular quartz porphyritic blocks in a dark green to black-green chlorite and garnet matrix. This style of chlorite alteration appears to be conformable, is up to 8 m thick and, west of Hamlin Lake, it can be traced for about 400 m along strike. Epidote and cordierite alterations are limited in extent, and appear to be closely related to zones associated with base metal sulphide mineralization. Epidote alteration is generally weak and most evident in the mafic to intermediate flows and tuffs. The best example of cordierite alteration is exposed in the trenches south of the Wye Lake occurrence as disseminated, coarse grains in an intermediate flow.

An alteration resulting in varied, but often intense, red pink to mauve, is commonly associated with joints and fractures and may have associated epidote and magnetite. This alteration could be the result of either hematite or potassium, but, since whole rock analyses and thin sections are currently pending, it has been referred to in this report as hematite alteration. Intense development of the hematite alteration is best exposed in the metavolcanic and intrusive rocks along the north side of the Powell Lake intrusion and from north of Redfox Lake to north of Home Lake through the north arm of Wye Lake. This alteration is associated with a moderate to high degree of fracturing of the host rock, and, in the area west of Hamlin Lake, with a series of northeast-trending, possibly fault-controlled, valleys and syenite dikes. In the same area, patches of magnetite up to 15 cm in diameter and disseminated epidote are associated with the hematite. Less intense and scattered development of this type of alteration was also noted north of Powell Lake. Similar alteration also occurs as fracture and joint haloes in both the Powell Lake and Myrt Lake granites suggesting this style of alteration is a relatively late event.

Mineralization

The map area hosts copper (-gold), copper-zinc, and gold (-copper) mineralization, with the copper and copper-zinc mineralization hosted by the metavolcanic and metasedimentary rocks, whereas the gold (-copper) mineralization is not restricted to a single rock type. A number of new occurrence have been identified by the companies working in the area. These occurrences are often associated with historic showings, but form part of previously unidentified larger mineralized systems.

COPPER (-GOLD)

Copper mineralization was identified northwest of Hamlin Lake by Ray Smith in 1956, and subsequently explored by a number of companies (*see* Figure 9.1) (Harris 1970). Mineralization is hosted by intermediate to felsic debris flows that are highly fractured to brecciated, and hematite altered, with occasional magnetite as patches and occurring along the same fractures as the intense pink to mauve hematite alteration. The brecciated zone trends about 060° with a width of about 100 m over a length of about 800 m as defined by diamond drilling (East West Resource Corp. 2005). Pyrite and chalcopyrite occur as disseminated grains and concentrated along fractures, and occasional bornite and molybdenite has also been reported. The best results reported have been 2.65% Cu, 23.1 g/t Ag, and 1.43 g/t Au over 1 m in a chip sample from surface. A second zone, located 300 m north of the breccia, consists of disseminated pyrite in felsic metavolcanic rocks, an analysis of which returned 5.4 g/t Au over 2.0 m in drill hole HAM06-42 (East West Resource Corp. 2006).

The Redfox Lake occurrence is located between Redfox and Wye lakes, and was initially explored by Cominco Ltd. in 1957 (*see* Figure 9.1) (Harris 1970). Harris (1970) reported that chalcopyrite and pyrite are disseminated or hosted by fractures in a medium-grained porphyritic dacite intruding the metavolcanic rocks, with the best intersection being 0.7% Cu over 1.8 feet. A number of the granodiorite bodies in the Redfox and Wye lake area contain up to 3%, fine-grained, subhedral, disseminated pyrite. These bodies intrude the metavolcanic rocks hosting the Zn-Cu VMS mineralization at Wye Lake. A number of samples of different sills in the area were collected and submitted for analyses, but results are pending.

A zone of intense hematite alteration occurs in the metavolcanic rocks extending from north of Windblown Lake to north of Home Lake through the north arm of Wye Lake, a distance of about 6 km (*see* Figure 9.1). The fracturing and style of alteration is very similar to the alteration hosting the copper (-gold) mineralization north of Hamlin Lake suggesting the zone has the potential to host a similar copper and gold mineralization. Small syenite sills are located on the north shore of Wye and Home lakes, but it is not clear if they are directly related to the alteration. Results for samples collected in this zone are pending.

COPPER AND ZINC

Freewest Resources Canada Inc. discovered massive copper-zinc sulphide mineralization in the area north of Wye Lake in March 2005 (Freewest Resources Canada Inc. 2005), and subsequent work has identified a number of areas of mineralization occurring as a conformable to semi-conformable horizon (*see* Figure 9.1). The discovery was the result of a Beep-Mat © survey, and grab samples returned up 12.49% Cu and 10.01% Zn (Freewest Resources Canada Inc. 2005). Subsequent diamond drilling returned intersections of up to 5.09% Zn and 0.75% Cu over 2.15 m in massive to stringer sulphide mineralization and the drill results have been interpreted to indicate a number of zones plunging shallowly to the southwest along the same direction as the regional (Freewest Resources Canada Inc. 2006). Mineralization consists of massive, semi-massive, to stringer mineralization composed of sphalerite, chalcopyrite, pyrite, pyrrhotite and magnetite hosted by fine-grained, intermediate to felsic tuffs and lapilli-tuffs that are strongly chlorite and sericite altered, with local silicification. The mineralization trends about 030°, and is up to 15 m wide, but is isoclinally folded and intruded by a peridotite. The footwall is strongly altered with chlorite developed in some metasedimentary beds and cordierite in the mafic to intermediate metavolcanic rocks. Gabbro and granodiorite intrusions are located in the footwall metavolcanic and metasedimentary rocks, and have been interpreted to be subvolcanic and possible heat sources for the hydrothermal system forming the mineralization (D. Maclean and D. Hoy, Freewest Resources Canada Inc., personal communication, 2006). The eastern extension of the mineralization is not clear, but, to the west, the zone can be traced for approximately 4.5 km to the Island Lake area. It is not evident whether the western extension may be located to the northwest or southwest of Island Lake.

GOLD (-COPPER)

The close association between gold and copper in the area north of Hamlin Lake is common throughout the map area, but some occurrences host gold-, rather than copper-, dominant mineralization (*see* Figure 9.1). White, quartz veins occur in northeast-trending joints within the northeastern portion of the Powell Lake intrusion, and the veins are exposed in trenches along the east side of the Nelson Road, and both east and west side of Hamlin Lake (*see* Figure 9.1). The veins contain trace to 2% fine-grained, irregularly distributed pyrite and chalcopyrite, and trace malachite. Hematite alteration occurring as partial to pervasive joint and fracture haloes is common in the same trenches. Assay results for sampling completed this year are currently pending.

PLATINUM GROUP ELEMENTS

There are no known occurrences of platinum group elements in the map area. However, up to 1% pyrrhotite and pyrite was observed in 2 locations hosted by the occasional, very coarse-grained patches within the southern gabbro sills located south of Home and Redfox lakes. Since gabbro bodies of similar composition host mineralization in other areas of northwestern Ontario, samples were submitted for analyses; however, results are pending.

REFERENCES

East West Resource Corporation 2005. Hamlin–Shebandowan: 49m of 0.68% copper equivalent in hole HAM-05-35; copper-silver-gold-molybdenum zone; news release, December 6, 2005, http://www.eastwestres.com/main.asp?section=news&page=20051206 [accessed May 25, 2006].

——— 2006. New gold zone in Hamlin; news release, May 4, 2006, http://www.eastwestres.com/main.asp?section=news&page=20060504 [accessed May 25, 2006].

Freewest Resources Canada Incorporated 2005. Freewest obtains up to 12.49% copper and 32.80% zinc in new base metal discovery in the Shebandowan greenstone belt, northwestern Ontario; news release, March 16, 2005, http://www.freewest.com/press/%2003-16-2005/index.html [accessed May 25, 2006].

——— 2006. Annual Report 2005; Freewest Resources Canada Incorporated, 32p. http://www.freewest.com/ *see* under "Financial Reports" [accessed October 30, 2006].

Harris, F.R. 1968. Saganagons Lake area, District of Thunder Bay; Ontario Geological Survey, Map 2149, scale 1:31 680.

——— 1970. Geology of the Moss Lake area, District of Thunder Bay; Ontario Geological Survey, Geological Report 85, 61p.

Ontario Geological Survey 2003. Ontario airborne geophysical surveys, magnetic and electromagnetic data, Shebandowan greenstone belt; Ontario Geological Survey, Geophysical Data Set 1021.

10. Project Unit 06-007. Precambrian Geology of the East-Central Caribou Lake Greenstone Belt

C.A. MacDonald[1]

[1]Precambrian Geoscience Section, Ontario Geological Survey

INTRODUCTION

The Caribou Lake greenstone belt (CLGB) is located approximately 230 km northeast of Thunder Bay and 15 km north of Lake Nipigon (Figure 10.1). Recent exploration activity for several commodities including gold, copper-nickel-platinum group elements (PGE), and rare metal pegmatites signifies an increased interest in the economic potential of the CLGB (Smyk et al. 2005, 2006). Smyk et al. (2006) also point to the significant potential for the CLGB to host copper-zinc volcanogenic massive sulphide (VMS) deposits. Increased interest, combined with recent improvements in road access and new outcrop exposures, led in part to the proposal and initiation of the current mapping project. This mapping is also intended to complement an ongoing Quaternary mapping and sampling project that encompasses all or part of the CLGB (Barnett 2005; Barnett, this volume).

The CLGB ranges from 3.5 to 15 km wide and extends roughly easterly for 80 to 100 km where it merges along strike with the Onaman–Tashota greenstone belt (Stott et al. 2002; Percival et al. 2002). Owing to time and access limitations, the map area was constrained to an area roughly 60 km long eastward and 30 km wide northward (Figure 10.2) and was highly dependant on road and lake accessible outcrops. The goals of this project are

- to map the east-central CLGB on a regional scale (1:50 000 scale) including areas that have never been mapped or have not been mapped in 40 to 65 years
- to delineate lithologic units of economic interest that were not recognized on previous maps
- to determine if units within the east-central part of the CLGB can be correlated with units recognized in more recent mapping to the east by Berger (1992a), Stott and Parker (1996), Stott et al. (1996), Parker and Stott (1998a, 1998b), Stott and Straub (1999), Straub, Stott and Phillips (2000) and Pye (1966, 1968)
- to determine if units and lithologies present within the east-central part of the CLGB can be correlated with earlier mapping by Sutcliffe (1983a, 1983b) in the Funger and Fletcher lakes areas, respectively, to the west
- to use lithological and structural mapping, geochemistry and possibly geochronology in the east-central CLGB to work within the existing framework of lithostratigraphic assemblages identified by previous mappers (i.e., Berger 1992a, 1992b; Stott et al. 2002; Percival et al. 2002) in the eastern part of the CLGB and adjoining Onaman–Tashota greenstone belt; with the ultimate goal of identifying these assemblages in the east-central CLGB and correlating stratigraphy westward into an area previously mapped by Sutcliffe (1983a, 1983b)

Summary of Field Work and Other Activities 2006,
Ontario Geological Survey, Open File Report 6192, p.10-1 to 10-17.

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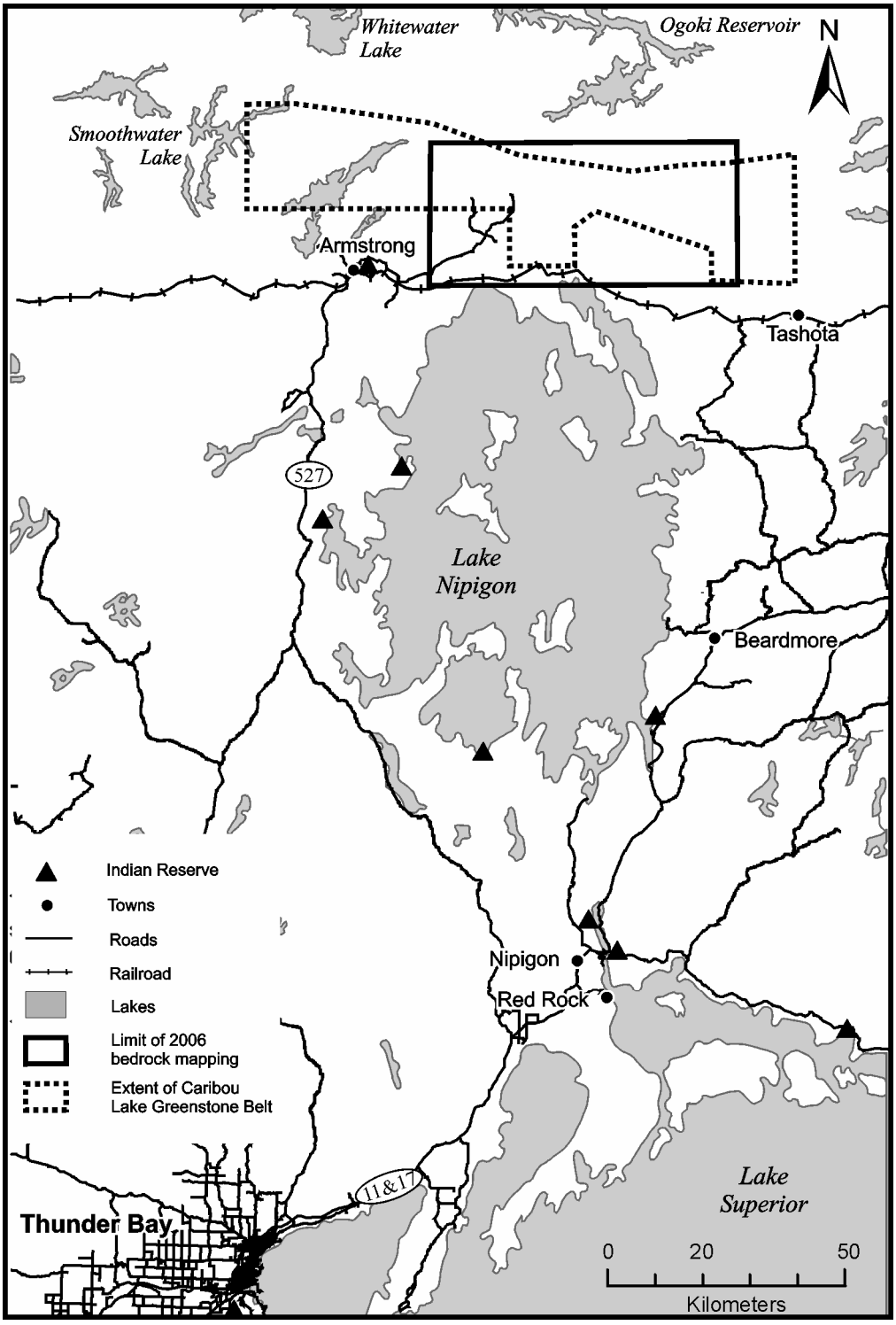

Figure 10.1. Lake Nipigon area showing location of the Caribou Lake greenstone belt and location of 2006 bedrock mapping.

Field work for this project, completed during 9 weeks from early June to mid August 2006, covered the east-central CLGB and surrounding area to the north and south where road access permitted (*see* Figure 10.2). The map area covers approximately 50% of the CLGB including surrounding gneisses of the English River Subprovince to the north and Winnipeg River terrane (Percival et al. 2006) to the south (Figure 10.3). Several areas to the north and south of the belt including the Major Lake–Roaring Lake area, the Pavlava Lake area, northeast Linklater Lake area and southwest Pikitiguishi area have never been mapped as they were not included in most recent mapping by Gussow (1942) and Pye (1966, 1968).

ACCESS AND PREVIOUS WORK

The east-central part of the CLGB is accessed by the main Airport Road or Jackfish Logging Road east of Armstrong. Numerous secondary logging roads and trails that branch north and south off the main Jackfish Road provide good access and outcrop exposure. Lack of trails in the Crescent–Zig Zag lakes area, Falcon–Tape lakes area, Toset Lake area and southwest Linklater Lake area would necessitate access by float-equipped plane or helicopter.

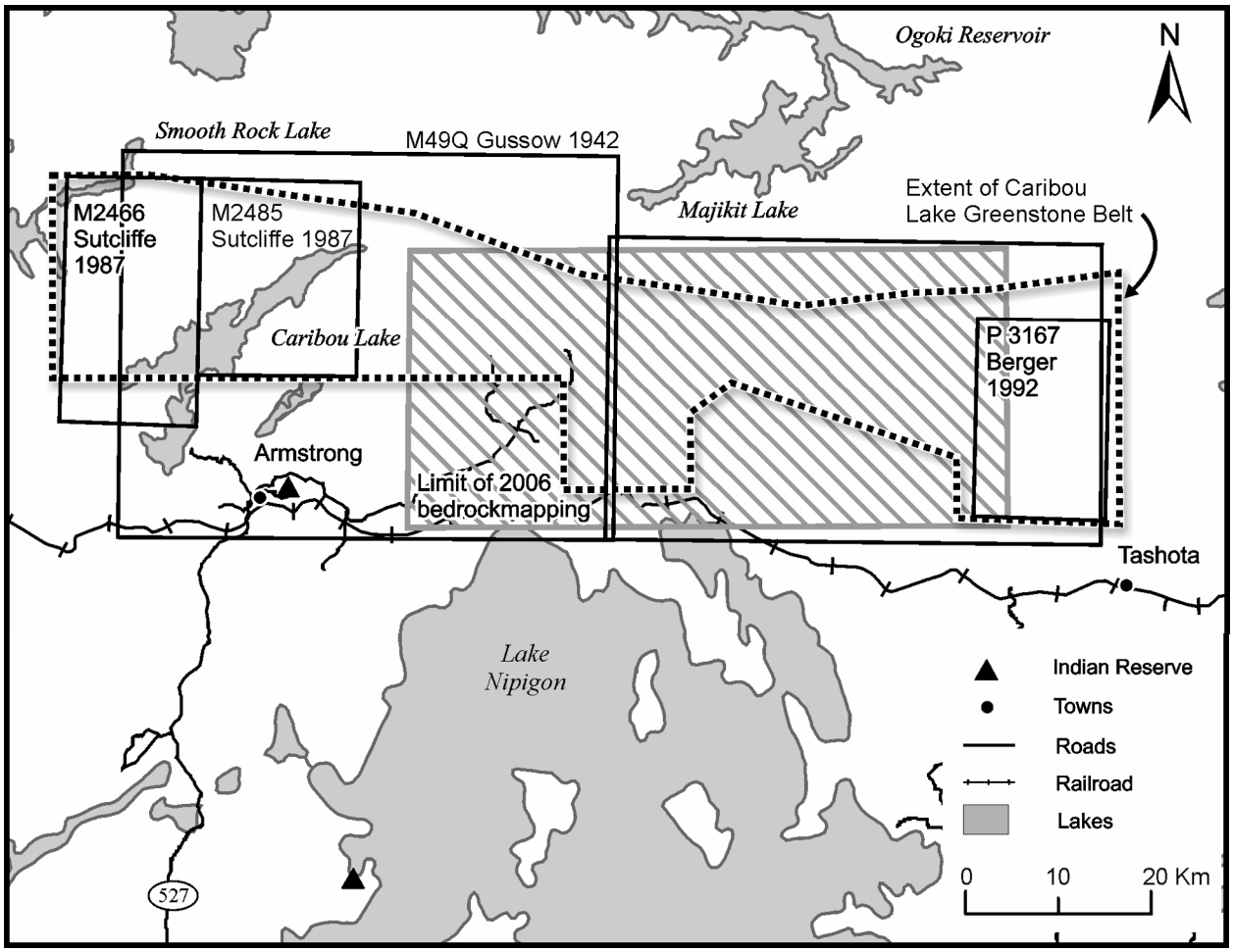

Figure 10.2. North Lake Nipigon area showing the extent of the Caribou Lake greenstone belt, the limit of 2006 bedrock mapping, and areas covered by previous mapping.

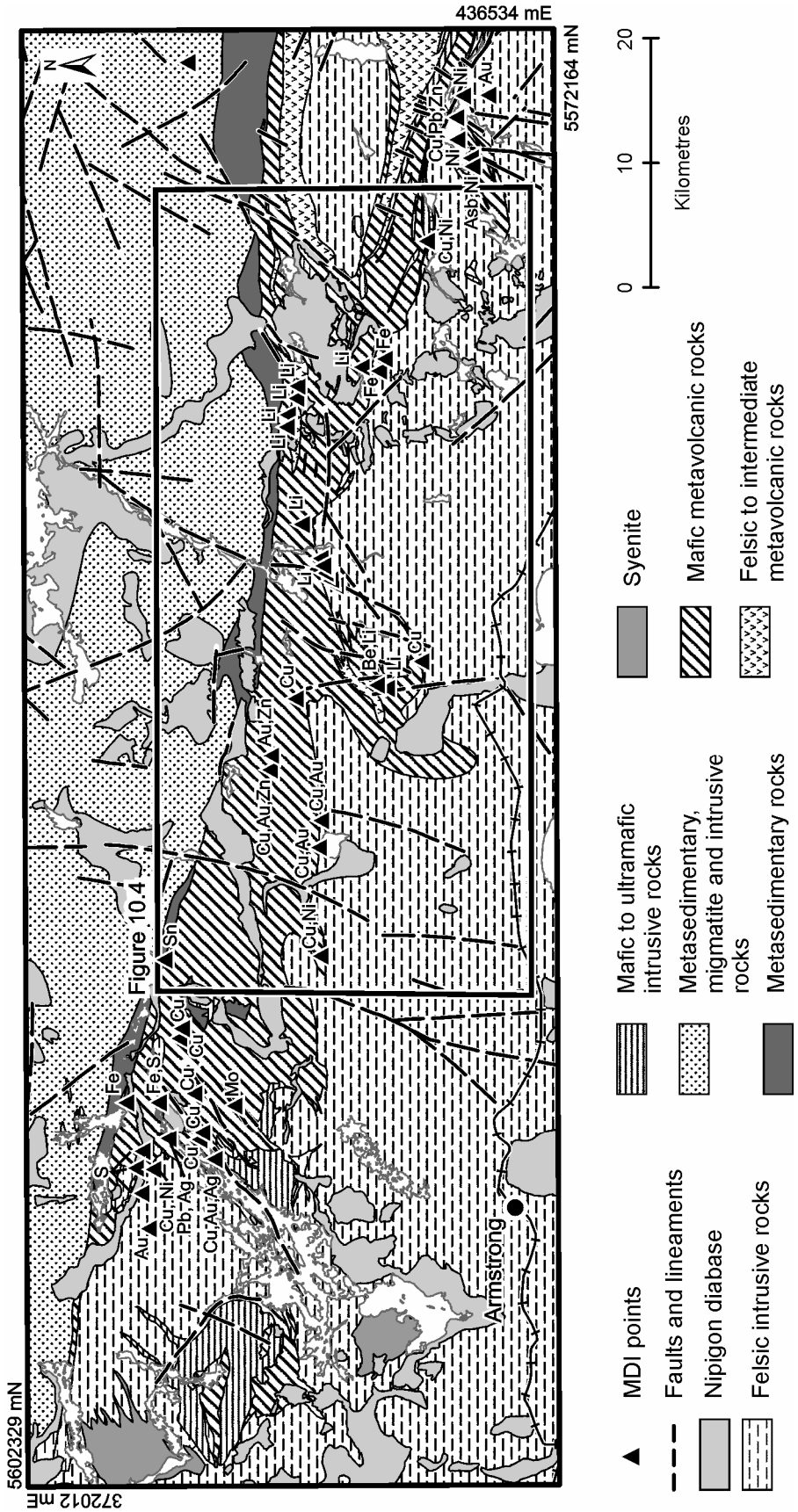

Figure 10.3. Simplified geological map of the Caribou Lake greenstone belt (*modified from* Lemkow et al. (2005), Percival et al. (2002) and Stott et al. (2002)). Boxed area shows limit of 2006 mapping and extent of Figure 10.4. Mineral occurrences are from the mineral deposit inventory (MDI) database (Ontario Geological Survey 2004).

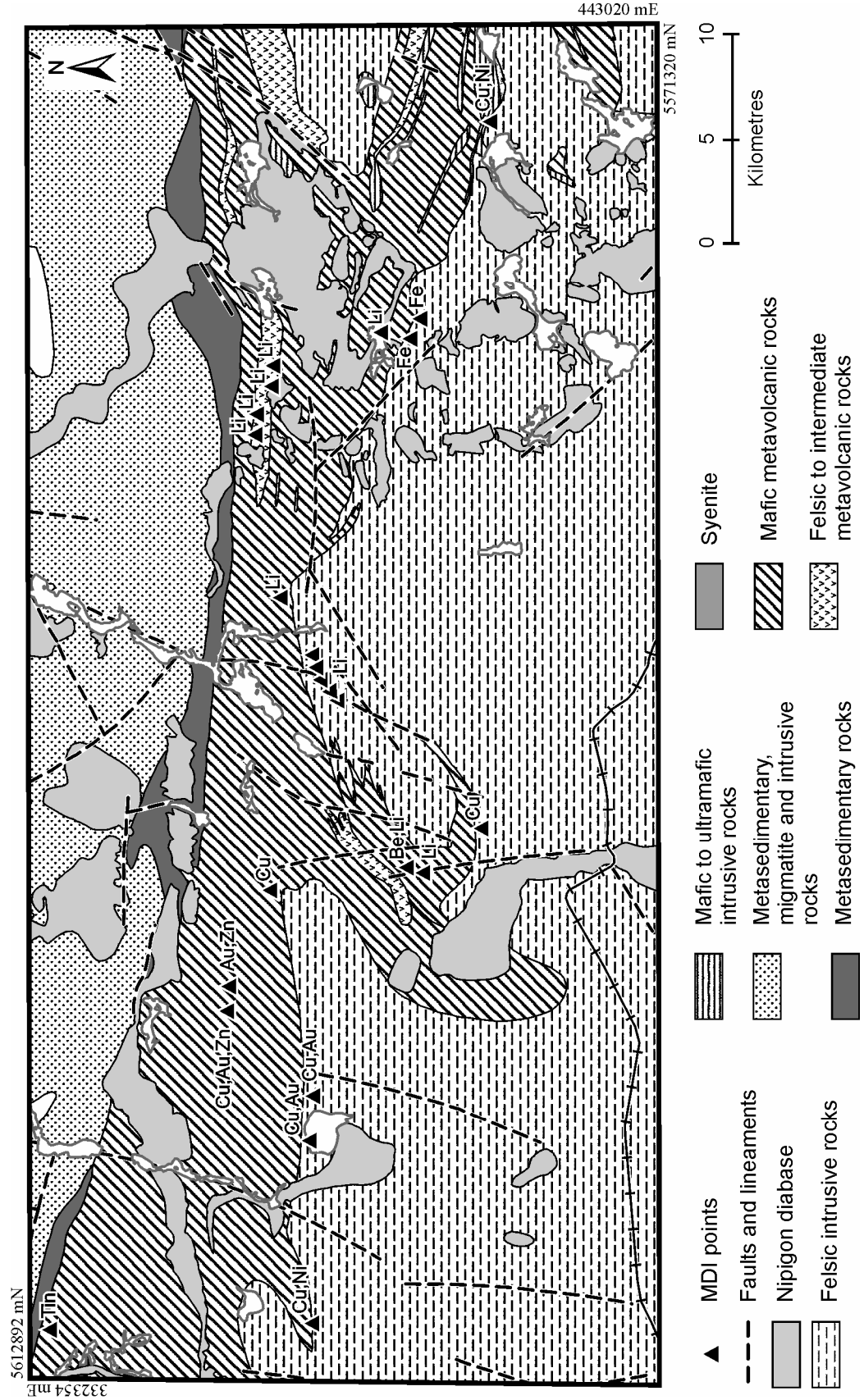

Figure 10.4. Simplified geological map of the west-central Caribou Lake greenstone belt (*modified from* Lemkow et al. (2005), Percival et al. (2002) and Stott et al. (2002)). The area encompassed by Figure 10.4 is the limit of 2006 mapping. Mineral occurrences are from the mineral deposit inventory (MDI) database (Ontario Geological Survey 2004).

The earliest geological mapping in the east-central CLGB was completed by Collins (1908) as part of a reconnaissance survey along the transcontinental railway north of Lake Nipigon. This 1:253 440 scale mapping covered parts of the Caribou Lake and Pikitigushi Lake areas. Maps produced by Hopkins (1916, 1917) and Kindle (1931) of the Kowkash and Kowkash–Ogoki areas at 1:126 720 and 1:253 440 scale, respectively, occur mainly on the eastern periphery of the 2006 map boundary. Reconnaissance mapping projects by Thurston, Carter and Riley (1969), Sage et al. (1974) did not focus on the CLGB and mostly included areas peripheral to the belt. Compilation projects by the Geological Survey of Canada (1935), Pye and Harris (1965), and Stott (1984) have included large portions of the CLGB, but are based on data from older maps.

A geological survey by Gussow (1940), at 1:63 360 scale, covered an area extending from the west end of Caribou Lake to just east of the Pikitigushi River (*see* Figure 10.2). This mapping (Gussow 1940, 1942) focussed directly on the west-central part of the CLGB and mainly defined areas of outcrop and the overall extent of metavolcanic and metasedimentary rocks compared to the surrounding gneisses and granitoid rocks. Pye (1966, 1968) mapped the central to eastern part of the CLGB and its eastern extent into the Onaman–Tashota greenstone belt at 1:63 360 (*see* Figure 10.2). Although regional scale in scope, Pye's (1966, 1968) mapping delineated several metasedimentary and possibly felsic to intermediate metavolcanic units within the east CLGB and west Onaman–Tashota greenstone belt. Berger (1992a) completed detailed mapping (1:15 840) near the eastern end of the CLGB in the Toronto Lake area (*see* Figure 10.2). This mapping allowed Berger (1992b) to successfully subdivide metavolcanic and metasedimentary rocks from the area into 2 lithostratigraphic groups: the Toronto Lake Group and the Marshall Lake Group.

Mapping projects east of the CLGB in the Onaman–Tashota greenstone belt including Stott et al. (1996), Stott and Parker (1996), Parker and Stott (1998a, 1998b), Stott and Straub (1999), Stott, Straub and Fortin (1999), and Straub, Stott and Phillips (2000) led to construction of a tectonostratigraphic framework for the eastern Wabigoon Subprovince (Stott et al. 2002; Percival et al. 2002).

GENERAL GEOLOGY

Archean

ULTRAMAFIC INTRUSIONS OR ULTRAMAFIC METAVOLCANIC ROCKS

Several outcrops of moderate to strongly magnetic, rusty orange-white talcose material occur along the main Jackfish Road at Landore Resource nickel-copper Carrot Top Zone as well as on trails north of Lamaune Lake. These outcrops are generally strongly foliated to schistose with most primary textures obliterated by a combination of high strain and intense alteration. The lack of any relict textures (e.g., spinifex texture) and inconclusive contact relationships between the talcose schist outcrops and adjacent lithologies prevents us from distinguishing whether this unit is intrusive or extrusive.

Massive medium-grained, relatively unaltered orthocumulate peridotite was observed in 3 outcrops north of Juneau Lake. The peridotite is generally weakly to non-magnetic, yellow-white weathered and dark green on fresh surface. This massive peridotite unit is proximal to at least one highly altered talc-serpentine rich outcrop in the Lamaune Lake area and, thus, could represent an unaltered equivalent. Contact relationships with adjacent lithologies were not observed.

MAFIC METAVOLCANIC ROCKS

Mafic metavolcanic rocks are the dominant lithology in the CLGB (*see* Figures 10.3 and 10.4). In the southeastern part of the belt, these rocks generally consist of blue green to green weathered, massive to pillowed flows. Pillows typically range from less than 10 cm to greater than 5 m in diameter, are locally variolitic, feldspar phyric, and commonly display well-developed interpillow hyaloclastite. These pillowed flows consistently show top indicators to the north (Photo 10.1A) with pillow flow-top breccias locally marking the tops of flow units. Evidence of both a regional, semiconformable, sericite-epidote alteration event and an inhomogeneous amphibolite-grade metamorphic event are recorded in the cores and selvages of some of the pillow basalts in this area. Medium- to coarse-grained, gabbroic textured pillows (amphibole + plagioclase) are also common particularly where in proximity to gabbroic intrusions and later felsic dikes that crosscut the pillows at a moderate angle (Photo 10.1B). Mafic metavolcanic rocks further to the north and southeast of Zig Zag Lake tend to have thinner pillowed flows, larger amounts of mafic tuff and/or massive flows, and few to no feldspar phenocrysts or varioles within the pillowed flows. The amount of intercalated felsic to intermediate tuff also increases within the northern parts of the CLGB. Mafic metavolcanic rocks in the southeastern part of the CLGB and may be part of either the 2740 Ma Willet assemblage (Stott et al. 2002) or the 2922 Ma Toronto assemblage (Stott et al. 2002; Berger 1992b). Mafic volcanic rocks to the north with significantly more intercalated felsic material may be part of an older Caribou East assemblage (Stott et al. 2002).

FELSIC TO INTERMEDIATE METAVOLCANIC ROCKS

There are 3 to 5 felsic to intermediate metavolcanic units within the CLGB. The northernmost unit occurs in the area southeast of Tape Lake and consists of bedded heterolithic lapilli tuff, tuff breccia, and crystal tuff to fine tuff (Photos 10.1C and 10.1D). Tuff beds in this area commonly contain white, locally quartz and feldspar phyric, lapilli in a fine- to medium-grained, dark green (amphibole + garnet) recrystallized matrix. The dark green matrix records an iron enrichment hydrothermal alteration event that preferentially flooded the groundmass of the lapilli tuff. Amphibolite-grade metamorphism, subsequently overprinted these rocks, resulting in the current (garnet + amphibole) assemblage. These lithologies and alteration overprint are similar to those observed in felsic to intermediate tuff of the 2739 Ma Marshall assemblage (Stott et al. 2002; Straub 1999). This sequence may also be capped by a 10 to 15 m wide, strongly magnetic, oxide-facies iron formation with abundant secondary sulphide minerals (pyrite + pyrrhotite).

The southernmost felsic to intermediate metavolcanic unit was observed in several outcrops north of Juneau Lake and consists of crystal tuff, lapilli tuff to tuff breccia, and fine tuff (Photo 10.1E). The upper contact of this unit is a 2 to 4 m wide chert-magnetite iron formation. This felsic to intermediate tuff and oxide-facies iron formation are traceable for up to 10 km along the southeast margin of the belt and may represent an extension of the Toronto Lake Group (Berger 1992b), which is part of the Toronto assemblage of Stott et al. (2002).

Felsic to intermediate tuff horizons in the centre of the CLGB tend to be thin, metre-scale, variably folded, discontinuous beds dominated by fine tuff to crystal tuff that is intercalated with the mafic volcanic rocks. The exception is felsic to intermediate fine tuff to crystal tuff that occurs immediately east of Zig Zag Lake and may reach several hundred metres thickness (*see* Figure 10.4).

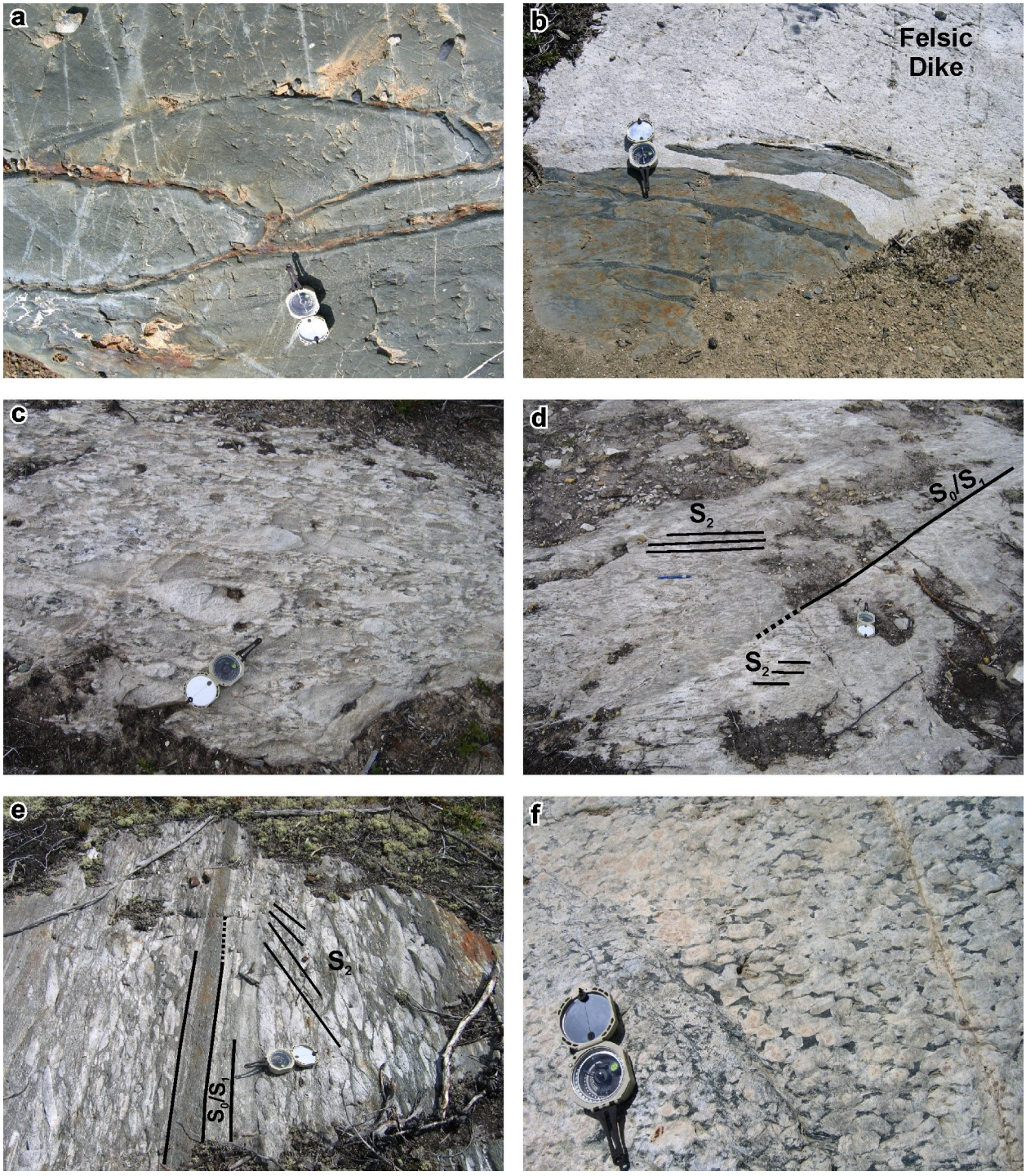

Photo 10.1. Photographs of the geology from the east-central Caribou Lake greenstone belt. a) Archean mafic pillowed flow showing stratigraphic tops to north, Juneau Lake area; compass points north for scale. b) Archean mafic pillowed flow crosscut by felsic dike, Juneau Lake area; compass points north for scale. c) Felsic to intermediate lapilli tuff to tuff breccia, southeast Tape Lake area; compass points north for scale. d) Bedded felsic to intermediate lapilli tuff, southeast Tape Lake area; compass points north for scale. e) Bedded felsic to intermediate lapillit tuff to tuff breccia, Juneau Lake area; compass points north for scale. f) Anorthositic phase of the Grassy Pond sill, Juneau Lake area; compass points north for scale.

OXIDE-FACIES IRON FORMATION

Oxide-facies (chert-magnetite) iron formation occurs in several areas of the CLGB. They are generally finely laminated, less than 1 mm wide laminations to banded, greater than 10 cm and locally strongly replaced by secondary sulphides. Oxide-facies iron formation caps at least 2 felsic horizons within the CLGB.

SYNVOLCANIC MAFIC TO ULTRAMAFIC INTRUSIONS

Grassy Pond Sill

The Grassy Pond sill occurs in the area north of Juneau Lake. It consists of a 5 to 6 km long and 100 to 550 m thick (McTavish 2004) subvolcanic gabbro to anorthosite body that intrudes and crosscuts the surrounding mafic metavolcanic rocks. Four main phases of the sill were recognized during 2006 mapping: medium- to coarse-grained gabbro to melagabbro, coarse- to very coarse-grained anorthosite (Photo 10.1F), minor pyroxenite, and a pegmatitic to varitextured phase. The base of this sill is known to host several Ni-Cu-PGE occurrences (McTavish 2004). This sill and its associated Ni-Cu-PGE mineralization will be the focus of an undergraduate thesis at Lakehead University during the 2006–2007 school year.

Swole Lake Gabbro

Outcrops similar to the gabbro to melagabbro phase in the Grassy Pond sill occur in the Swole Lake area. Originally mapped as 3 to 4 outcrops on and west of Swole Lake by Pye (1966, 1968), new exposures to the southeast will extend the size of this unit. Minor disseminated and fracture-controlled pyrite and pyrrhotite were observed in one outcrop on Claude's Road, west of Swole Lake.

MAFIC DIKES (NEOARCHEAN?)

Medium- to coarse-grained, dark green grey weathered, intergranular and locally plagioclase porphyritic gabbro dikes were observed to occur in several parts of the map area. These dikes typically range from 1 to 10 m wide, are moderately magnetic, and are most obvious where they crosscut the gneissic foliation and banding near the southern margin of the CLGB (Photo 10.2A). The dikes are in turn folded with the gneissic banding by a D_2 or D_3 deformation event (Photo 10.2B). Locally, where finer grained, these mafic dikes may display a weak cleavage development (S_2 or S_3) (Photo 10.2C).

ULTRAMAFIC DIKES

Fine- to medium-grained mafic to ultramafic dikes were observed to crosscut the felsic to intermediate lapilli tuffs to crystal tuffs in at least 3 parts of the map area. These dikes tend to be dark green on weathered and fresh surfaces, are moderately to strongly magnetic and range from 10 to 25 cm wide.

Photo 10.2. Photographs of the geology from the east-central Caribou Lake greenstone belt. a) Biotite tonalite crosscut by Archean and Proterozoic mafic dikes, Lamaune Lake area; hammer points north for scale. b) Biotite tonalite crosscut by Archean mafic dike, North Jackfish Road; handheld digital computing device and compass for scale. c) Biotite tonalite gneiss crosscut by Archean mafic dike, North Jackfish Road; pencils for scale. d) Biotite granodiorite with biotite tonalite xenoliths crosscut by a pegmatite dike, Seymour Lake area; hammer points north for scale. e) Biotite tonalite gneiss crosscut by pegmatite dike, Major Lake area; compass for scale. f) Mafic metavolcanic rocks and bedded (S_0) felsic to intermediate tuffs folded (F_2) by D_2 deformation event, Lamaune Lake area; hammer for scale.

FELSIC TO INTERMEDIATE INTRUSIVE ROCKS

Syenite

Three outcrops of medium- to very coarse-grained, hornblende syenite were observed in the Pikitiguishi Lake area. This lithology was not observed elsewhere in the map area and may represent a small, less than 1 km diameter, poorly exposed plug.

Summit Lake Intrusion

Biotite tonalite to granodiorite of the Summit Lake intrusion crops out in the eastern part of the map area (*see* Figure 10.4). The rock is generally white to light grey, medium to coarse grained inequigranular and massive to moderately well foliated. Locally present are porphyritic phases with light blue quartz phenocrysts up to 1 cm diameter, which intrude the surrounding pillow basalts. Results of the 2006 mapping will possibly extend the contact of the Summit Lake intrusion further west and southwest of Swole Lake where it may be difficult to distinguish from felsic metavolcanic rocks southeast of Tape Lake.

Felsic Dikes

Fine- to medium-grained, inequigranular dikes of granodioritic to tonalitic composition were commonly observed in the southeastern part of the CLGB. They are typically white to light pink on weathered surface and light grey blue on fresh surface, are biotite bearing, trend between 110 and 125° and are less than 1 to 5 m wide. The dikes are massive to moderately well foliated by the same regional S_0–S_1 fabric present in the mafic metavolcanic rocks, but also cut the pillow basalts at a low angle indicating they postdate their emplacement (*see* Photo 10.1B). Toward the east end of the map area, the dikes become progressively wider and more abundant suggesting along with their trends that they may be related to either the Summit Lake intrusion or the Robinson Lake pluton. Petrographic and geochemical comparisons between these intrusions may indicate possible offshoots of either the Summit Lake or Robinson Lake plutons.

Biotite Granodiorite to Tonalite

Numerous outcrops of light grey to light pink, massive to weakly foliated, medium- to coarse-grained, biotite granodiorite occur in the Seymour Lake area. This intrusion locally contains 2 cm to greater than 25 cm long, lens-shaped to elongate xenoliths of coarse-grained, medium grey, tonalite to gabbro. The size and abundance of the xenoliths generally increases toward the south and in part defines a weak to moderate foliation (Photo 10.2D). Due to textural and compositional similarities, as well as proximity, these xenoliths are inferred to be derived from a gneissic complex located immediately to the south. An intrusion breccia with tonalite to gabbro and amphibolite fragments in a granodioritic matrix locally marks the contact between the granodiorite intrusion and tonalite gneiss. Rarely, this intrusion breccia also contains fine-grained to very fine-grained ultramafic xenoliths with a 1 to 3 cm reaction rim.

The granodiorite intrusion and the tonalite gneiss are commonly crosscut by pegmatite and aplite dikes in this area (*see* Photo 10.2D). Contacts between the granodiorite and metavolcanic rocks of the CLGB to the north were not observed.

Pegmatites

Rare earth element pegmatites are known to occur along both the southern and northern margins of the CLGB (Pye 1968; Breaks, Selway and Tindle 2003). Crosscutting relationships indicate these pegmatites postdate emplacement of both the southern tonalite gneiss and the late granodiorite intrusion along the southern margin of the CLGB (*see* Photos 10.2D and 10.2E). Pegmatites also crosscut and thus postdate English River paragneisses along the northern margin of the CLGB. In outcrop, both dike and irregular pod-like morphologies are common with bodies ranging from less than 10 cm to several metres wide. Grain size is generally coarse to very coarse grained with local fine-grained sugary textured phases that may contain abundant garnets, green muscovite and magnetite. Typical mineralogy of the coarser grained more massive phases include white, pink and locally blue perthitic and non-perthitic potassium feldspar, quartz, biotite, and white muscovite. Green muscovite, tourmaline, apatite and garnet may be present locally as well as graphic intergrowths of quartz and potassium feldspar and tourmaline and quartz. Less commonly, these pegmatites may contain tantalite, fluorite, and spodumene. The latter 3 minerals were not recognized in pegmatites observed during the 2006 field season; however, all pegmatite samples collected will be closely examined prior to submission for whole rock and trace element geochemistry. Metavolcanic rocks of the CLGB will also be analyzed for lithium, a proximity indicator element for the presence of fertile pegmatites.

GNEISSIC SUITES

English River Subprovince

The northern margin of the CLGB is bounded by metasedimentary rocks and derived metatextites of the English River Subprovince. Immediately north of the CLGB, in the area west of Falcon Lake, the contact between mafic metavolcanic rocks and quartzofeldspathic wackes of the English River Subprovince is marked by the presence of a valley and a large gap in outcrop exposure. In the areas north of Lee Lake and east of Linklater Lake, this boundary is less abrupt possibly forming a transitional contact between metavolcanic rocks of the CLGB and metasedimentary rocks of the English River Subprovince. Therefore, the nature of this contact may vary along the length of the CLGB from an abrupt, possibly faulted contact to a more gradual transitional contact between the metavolcanic rocks to the south and metasedimentary rocks to the north. In the area east of Funnel Lake, the metasedimentary rocks range from brown, fine- to medium-grained, biotite-rich metawackes with some visible elements of bedding preserved to metawacke with varying amounts of lensoid to podiform granite and pegmatitic granite. Northward, the amount of granitic interlayers and pods increase.

The presence of andalusite and possibly cordierite was noted in at least 2 areas. In one area southeast of Pavlava Lake, possible cordierite forms subcircular 0.5 to 3 cm diameter porphyroblasts with greenish grey rims and possible relict sector twinning in relatively muscovite-rich migmatized metasedimentary rocks. Bedded, brownish, biotite-quartz-feldspar metawackes to metasandstones with local porphyroblasts of bluish grey and light pink minerals were observed in a northeast-trending segment south of Tape Lake. X-ray diffraction analyses of these minerals confirmed the presence of andalusite (M.C. Smyk, OGS, personal communication, 2006).

Wabigoon Subprovince–Winnipeg River Terrane

BIOTITE TONALITE GNEISS

Rocks south of the CLGB generally consist of moderately foliated to gneissic biotite tonalite to granodiorite. In outcrop, the gneiss generally ranges from white to light pink on weathered surface and light grey to grey pink fresh surface with prominent millimetre- to metre-scale gneissic banding. There are 3 dominant rock types or phases within this gneissic suite: 1) massive to moderately foliated, coarse- to very coarse-grained biotite tonalite; 2) fine- to medium-grained, massive to moderately foliated biotite tonalite; and 3) biotite-rich, fine- to medium-grained melanosome that forms the darker bands in the gneiss. All phases of the gneiss contain or are crosscut by fine- to coarse-grained and locally pegmatitic, 2 cm to 5 m wide granodiorite to granite pods, lenses and dikes; fine- to coarse-grained mafic dikes less than 1 to 10 m wide; and 1 to 10 cm wide, pink aplite dikes.

Proterozoic

NIPIGON DIABASE

Outcrops of Nipigon diabase occur in approximately 5 to 10% of the map area (*see* Figure 10.4). Erosional remnants of these typically undulatory sill-like bodies form the rusty brown mesa-like cliffs that dominate the topography in several parts of the map area. In hand sample, the diabase is typically dark grey green, medium-grained, intergranular to subophitic gabbro. Local textural variations include coarse grained, magnetite rich, fine grained to aphanitic, and oikocrystic to ophitic. Fine-grained to aphanitic chill margins are locally observed where in contact with the Archean bedrock. Whole rock and trace element analyses of this unit will be used to determine if it is part of the Inspiration-type of diabase sill that occurs northwest of Lake Nipigon (MacDonald and Tremblay 2004).

MARATHON DIKES AND PROTEROZOIC DIKE SWARMS

In several areas, outcrops of moderately to strongly magnetic, massive, medium-grained, inequigranular and intergranular textured gabbro occur. These gabbro outcrops are virtually indistinguishable from outcrops of the Nipigon diabase in hand sample. Rather, they are distinguished by their dike-like morphology that is apparent from their strong, generally north-trending, and narrow linear aeromagnetic signatures (Ontario Geological Survey 2003a, 2003b, 2003c). One approximately north-trending diabase dike was observed to crosscut tonalite gneiss along the main Jackfish Road north of Lamaune Lake and southwest of Boras Lake (*see* Photo 10.2A).

STRUCTURAL GEOLOGY

At least 2 phases of deformation affect the east-central CLGB area. The first phase (D_1) is recorded as a regional-scale, penetrative foliation (S_1) that subparallels primary volcanic and sedimentary bedding (S_0) where observed. For this reason, in most areas, it forms a composite S_0–S_1 fabric that generally parallels the overall northwest to west trend of the CLGB. Stratigraphic facings, where observed from pillowed volcanic flows and graded bedding during the 2006 field season were consistently to the north (*see* Photo 10.1A). Pye (1968) documented several anticline and syncline structures, that trend parallel to the regional foliation directions in the CLGB, based on reversals in stratigraphic facing and foliation dip

directions. He interpreted these structures as a result of an upright, isoclinal folding (F_1) event that presumably formed the S_0–S_1 foliation. S_1 foliation in the metavolcanic rocks was observed to generally dip steeply to the north with minor local dip reversals. S_1 foliation or gneissosity in the southern biotite tonalite gneiss generally displays shallow 30º dips that become progressively shallower to the south.

A second phase of deformation is recorded locally with the development of an S_2 fabric, particularly near the margins of the CLGB where it may have been produced by the intrusion of granodiorite to tonalite bodies (*see* Photos 10.2B, 10.2C and 10.1D). This phase (D_2) is also observed in moderate to steeply plunging, close folds (F_2), particularly along the southern margin of the CLGB (*see* Photo 10.2E).

Shear sense indicators, where observed, were typically dextral. Biotite-rich metawackes along the northern margin of the CLGB, in the Pavlava Lake area, locally display counter clockwise-rotated quartz vein boudins with dextral sigma tails. In a 20 to 50 m wide west-trending shear zone near the southern margin of the belt, dextral shear sense indicators are also common.

ALTERATION AND METAMORPHISM

Metamorphic grade in the CLGB ranges from mid-greenschist facies to middle amphibolite facies. The most prevalent metamorphic mineral assemblages present within the volcanic sequences include 1) amphibole + plagioclase and 2) amphibole + garnet. The first assemblage is present locally in the mafic metavolcanic rocks in the southeastern part of the map area where medium- to coarse-grained gabbroic-textured pillow basalts (hornblende + plagioclase) occur. The metamorphism is mostly inhomogeneous and sometimes patchy at a scale of tens of metres. This may be reflective of either an alteration event prior to regional metamorphism and/or possibly a contact metamorphic effect. Amphibole + plagioclase gabbroic texture in the mafic metavolcanic rocks is particularly pronounced where in proximity to the 1 to 5 m wide felsic dikes mentioned in a previous section. The amphibole + garnet assemblage was observed in the matrix to felsic to intermediate tuff to lapilli tuff and tuff breccia occurring in the areas southeast of Tape Lake, west of Seymour Lake, and northwest of Juneau Lake. In the adjacent Marshall Lake greenstone belt, this similar combination of mineral assemblage and lithologies has been interpreted to represent an early iron enrichment hydrothermal alteration event that has been overprinted by amphibolite-grade metamorphism (Straub 1999).

Other types of alteration present in the volcanic lithologies include a regional, semiconformable, sericite-epidote and a fracture- to vein-controlled iron-carbonate event. Both types of alteration occur in pillow basalts from northwest of Juneau Lake to north of Ketchikan Lake. Sericite-epidote alteration particularly affects the pillow basalt cores. Vein- and fracture-controlled iron-carbonate alteration is a local phenomenon only observed at the outcrop scale. Minor vein-controlled potassic and epidote alteration is observed locally in the granodioritic and tonalitic lithologies.

RECOMMENDATIONS FOR EXPLORATION

The CLGB has the potential to host several different types of mineralization. The presence of felsic to intermediate metavolcanic rocks with garnet-amphibole hydrothermal alteration southeast of Tape Lake and south of Swole Lake should be further investigated. If these units are equivalent to the Marshall assemblage of Stott et al. (2002), then these areas may hold significant potential for the discovery of VMS deposits (Smyk et al. 2006). Semiconformable, sericite-epidote hydrothermal alteration recorded in the pillow basalts extending from east of Boras Lake to the Ketchikan Lake area may also be indicative of a regional-scale VMS-related hydrothermal system.

Trace disseminated pyrite and pyrrhotite were noted in medium- to coarse-grained gabbro west of Swole Lake. If this gabbro intrusion is correlative with the Grassy Pond sill, it may hold potential to host nickel-copper-PGE mineralization. Samples collected from this unit will be submitted for assay.

A new pegmatite occurrence was found south of Tape Lake at the contact between biotite-rich metawackes and mafic metavolcanic rocks. No unusual minerals were noted during field work and sample collection; however, samples of the pegmatite and adjacent metavolcanic rocks will be submitted for whole rock and trace element analysis. Metavolcanic rocks of the CLGB will also be analyzed for lithium, a proximity indicator element for the presence of fertile pegmatites.

Several possible new sulphide mineral occurrences were noted during the 2006 field season including rusty boulders southwest of Ratte Lake, a rusty sulphidic outcrop south of Lee Lake, and rusty sulphide-bearing boulders and outcrop southeast of Tape Lake. Each of these occurrences are located within or in proximity to volcanic or metasedimentary rocks. Samples collected will be submitted for assay.

REFERENCES

Barnett, P.J. 2005. Reconnaissance till sampling in the Caribou Lake greenstone belt area, northwestern Ontario; *in* Summary of Field Work and Other Activities 2005, Ontario Geological Survey, Open File Report 6172, p.20-1 to 20-5.

Berger, B.R. 1992a. Precambrian geology, Toronto Lake area; Ontario Geological Survey, Preliminary Map P.3167, scale 1:15 840.

——— 1992b. Geology of the Toronto Lake area, District of Thunder Bay; Ontario Geological Survey, Open File Report 5784, 145p.

Breaks, F.W., Selway, J.B. and Tindle, A.G. 2003. Fertile peraluminous granites and related rare-element pegmatite mineralization, Superior Province, northwest and northeast Ontario: Operation Treasure Hunt; Ontario Geological Survey, Open File Report 6099, 179p.

Collins, W.H. 1908. Explored routes in a portion of northwestern Ontario traversed by the national transcontinental railway between Lake Nipigon and Sturgeon Lake; Geological Survey of Canada, Map No. 993, scale 1:253 440.

Geological Survey of Canada. 1935. Lake Nipigon sheet, Ontario; Geological Survey of Canada, Map No. 308A, scale 1:506 880.

Gussow, W.C. 1940. Caribou–Pikitigushi area; Ontario Department of Mines, Map No. 49q, scale 1:63 360.

——— 1942. Geology of the Caribou–Pikitigushi area; Ontario Department of Mines, Annual Report 1940, v.49, pt.6, p.1-12. Accompanied by Map 49g, scale 1:63 360.

Hopkins, P.E. 1916. Kowkash gold area, District of Thunder Bay; Ontario Department of Mines, Map No. 25a, scale 1:253 440.

——— 1917. Kowkash gold area, District of Thunder Bay; Ontario Department of Mines, Map No. 26a, scale 1:126 720.

Kindle, L.F. 1931. Kowkash–Ogoki gold area, District of Thunder Bay, Ontario; Ontario Department of Mines, Map No. 40f, scale 1:126 760.

Lemkow, D.R., Sanborn-Barrie, M., Stott, G.M., Percival, J.A., Stone, D., Tomlinson, K.Y., Skulski, T., McNicoll, V., Davis, D.W., Whalen, J.B. and Hollings, P. 2005. GIS compilation of geology and tectonostratigraphic assemblages, Wabigoon–Winnipeg River–Marmion transect, western Superior Province, Ontario; Geological Survey of Canada, Open File 4971; Ontario Geological Survey, Miscellaneous Release—Data 187, scale 1:250 000.

MacDonald, C.A. and Tremblay, E. 2004. Lake Nipigon Region Geoscience Initiative: Results of bedrock mapping in the northern part of the western Nipigon Embayment, northwestern Ontario, Canada; oral presentation abstract *in* Institute on Lake Superior Geology, Proceedings, v.50, pt.1, Programs and Abstracts, p.102-103.

McTavish, A.D. 2004. Diamond drilling report, BAM and B4-7 zones, Junior Lake property 2003: Junior Lake, Falcon Lake and Toronto Lake areas, Thunder Bay North Mines and Minerals Division, Ontario, NTS 42 L/05NW and SW, 52 I/08NE and SE, for Landore Resources Inc., February 20, 2004; Landore Resources Inc., Technical Report, filed February 23, 2005, with SEDAR®, *see* Sedar Home Page, 32p.

Ontario Geological Survey 2004. Mineral Deposit Inventory Version 2 (MDI2), October 2004 Release; Ontario Geological Survey.

——— 2003a. Ontario airborne geophysical surveys, magnetic data, Armstrong–Caribou Lake area; Ontario Geological Survey, Geophysical Data Set 1027.

——— 2003b. Ontario airborne geophysical surveys, magnetic data, Geraldton–Tashota area northwest; Ontario Geological Survey, Geophysical Data Set 1031.

——— 2003c. Ontario airborne geophysical surveys, magnetic data, Geraldton–Tashota area southeast; Ontario Geological Survey, Geophysical Data Set 1032.

Parker, J.R. and Stott, G.M. 1998a. Precambrian geology, O'Sullivan Lake area (west half), northeastern Onaman–Tashota greenstone belt, eastern Wabigoon Subprovince; Ontario Geological Survey, Preliminary Map P.3377, scale 1:20 000.

——— 1998b. Precambrian geology, O'Sullivan Lake area (east half), northeastern Onaman–Tashota greenstone belt, eastern Wabigoon Subprovince; Ontario Geological Survey, Preliminary Map P.3378, scale 1:20 000.

Percival, J.A., Sanborn-Barrie, M., Skulski, T., Stott, G.M., Helmstaedt, H. and White, D.J. 2006. Tectonic evolution of the western Superior Province from NATMAP and Lithoprobe studies; Canadian Journal of Earth Sciences, v.43, p.1085-1117.

Percival, J.A., Whalen, J.B., Tomlinson, K.Y., McNicoll, V. and Stott, G.M. 2002. Geology and tectonostratigraphic assemblages, north-central Wabigoon Subprovince, Ontario; Geological Survey of Canada, Open File 4270; Ontario Geological Survey, Preliminary Map P.3447, scale 1:250 000.

Pye, E.G. 1966. Crescent Lake area, Thunder Bay District; Ontario Department of Mines, Map 2100, scale 1:63 360.

——— 1968. Geology of the Crescent Lake area, District of Thunder Bay; Ontario Department of Mines, Geological Report 55, 72p.

Pye, E.G. and Harris, F.R. 1965. Mojikit Lake sheet, Thunder Bay District; Ontario Geological Survey, Preliminary Map P.267, scale 1:126 720.

Sage, R.P., Breaks, F.W., Stott, G.M., McWilliams, G. and Bowen, R.P. 1974. Operation Ignace–Armstrong, Pashkokogan–Caribou lakes sheet, District of Thunder Bay; Ontario Division of Mines, Preliminary Map P.962, scale 1:126 720.

Smyk, M.C., White, G.D., Magee, M.A. and Komar, C.L. 2005. Report of Activities, 2004, Resident Geologist Program, Thunder Bay North Regional Resident Geologist Report: Thunder Bay North District; Ontario Geological Survey, Open File Report 6147, 37p.

——— 2006. Report of Activities, 2005, Resident Geologist Program, Thunder Bay North Regional Resident Geologist Report: Thunder Bay North District; Ontario Geological Survey, Open File Report 6181, 43p.

Stott, G.M., Davis, D.W., Parker, J.R., Straub, K.J. and Tomlinson, K.Y. 2002. Geology and tectonostratigraphic assemblages, eastern Wabigoon Subprovince, Ontario; Ontario Geological Survey, Preliminary Map P.3449, or Geological Survey of Canada, Open File 4285, scale 1:250 000.

Stott, G.M., McConnell, C.D. and Mason, J.K. 1984. Mojikit Lake sheet, Thunder Bay District; Ontario Geological Survey, Preliminary Map P.267 (revised); scale 1:126 720.

Stott, G.M., Morrison, D., Gale, V. and Wachowlak, N. 1996. Precambrian geology of south-central Onaman–Tashota greenstone belt; Ontario Geological Survey, Preliminary Map P.3352, scale 1:50 000.

Stott, G.M. and Parker, J.R. 1996. Precambrian geology, Metcalfe Lake area, central Onaman–Tashota greenstone belt, eastern Wabigoon Subprovince; Ontario Geological Survey, Preliminary Map P.3365, scale 1:20 000.

Stott, G.M. and Straub, K.H. 1999. The Marshall Lake volcano on the northern margin of eastern Wabigoon Subprovince, northwestern Ontario; *in* Summary of Field Work and Other Activities 1999, Ontario Geological Survey, Open File Report 6000, p.23-1 to 23-13.

Stott, G.M., Straub, K.H. and Fortin, D. 1999. Precambrian geology, Willet–Gledhill lakes area, Onaman–Tashota greenstone belt; Ontario Geological Survey, Preliminary Map P.3390, scale 1:30 000.

Straub, K.H. 1999. Mineralization and alteration within the Marshall Lake intermediate to felsic volcanic centre, east Wabigoon Subprovince; *in* Summary of Field Work and Other Activities 1999, Ontario Geological Survey, Open File Report 6000, p.24-1 to 24-10.

Straub, K.H., Stott, G.M. and Phillips, J. 2000. Precambrian geology, Marshall Lake area, Onaman–Tashota greenstone belt; Ontario Geological Survey, Preliminary Map P.3424, scale 1:20 000.

Sutcliffe, R.H. 1983a. Funger Lake; Ontario Geological Survey, Map 2466, scale 1:31 680.

——— 1983b. Fletcher Lake; Ontario Geological Survey, Map 2485, scale 1:31 680.

Thurston, P.C., Carter, M.W., and Riley, R.A. 1969. Attwood–Caribou lakes sheet, districts of Kenora (Patricia portion) and Thunder Bay; Ontario Department of Mines, Preliminary Map P.564, scale 1:126 720.

11. Project Unit 95-014. Revised Tectonic Domains of the South-Central Wabigoon Subprovince

D. Stone[1] and D.W. Davis[2]

[1]Precambrian Geoscience Section, Ontario Geological Survey
[2]Department of Geology, University of Toronto, Toronto, Ontario M5S 3B1

INTRODUCTION

The recognition of large lithotectonic subprovinces and terranes combined with the application of accretionary tectonic models for the assembly of these elements have been critical to recent advances in understanding the tectonic history of the Superior Province (Card 1990; Stott 1997). The assembly of the various subprovinces and terranes into the Superior Province occurred mainly during the Kenoran Orogeny at circa 2.7 Ga, although some of the component blocks had formed hundreds of millions of years earlier and existed perhaps as micro-continents.

The magmatic and tectonic history of the old (<2.73 Ga) terranes is somewhat less well understood than that of crust developed during the Kenoran Orogeny because the old rocks have been deformed and assimilated during the younger magmatic and deformational events. The Marmion terrane is one of the older crustal blocks situated in the central Wabigoon area of the southwestern Superior Province, approximately 150 km west of Thunder Bay, Ontario. The 3.0 Ga Marmion terrane has been interpreted by Tomlinson et al. (2004) as an old continental fragment that was assembled, along with a variety of other crustal fragments, volcanic arcs and sedimentary prisms, into the Superior Province. New mapping and geochronology have defined several domains within the Marmion terrane, each of which appears to represent a unique magmatic event. Below, we attempt to describe the domains and interpret the evidence for evolution of the Marmion terrane from 3.0 to 2.7 Ga. Interestingly from an historic perspective, the central Wabigoon area is the prime locality where geologists began the task of subdividing Archean rocks over a century ago. The discussion begins with a review of developments and terminology used in the classification of rocks of the western Superior Province.

TERMINOLOGY

The following definitions reflect usage in this report; these are modified from Thurston (1991).

- **Chronostratigraphic series**: Supracrustal or plutonic rock units whose relative ages are established on the basis of stratigraphic superposition or crosscutting relations, with respect to rock units in adjacent chronostratigraphic series.
- **Domain**: A volume of rock, bounded by compositional or structural discontinuities, within which there is structural and chronologic homogeneity. A domain may contain both plutonic and supracrustal rocks, is generally smaller than a subprovince and may be either allochthonous or autochthonous with respect to adjoining geologic units.

Summary of Field Work and Other Activities 2006,
Ontario Geological Survey, Open File Report 6192, p.11-1 to 11-18.

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Table 11.1. Chronostratigraphic subdivisions of Precambrian rocks in the Atikokan–Lake Superior area (*after* Lawson 1912).

Series	Rock Type
Keweenawan	Metavolcanic rocks and intrusions
Animikie	Metasedimentary rocks
Algoman	Granitic intrusions
Seine	Conglomerate
Steep Rock	Metasedimentary and metavolcanic rocks
Laurentian	Felsic plutonic and gneissic rocks
Keewatin	Metavolcanic rocks
Coutchiching	Metasedimentary rocks

- **Greenstone belt**: Elongate or belt-like, variably tapered or bifurcated, kilometre-scale areas of supracrustal rocks with tectonic or intrusive contacts. Greenstone belts may consist of one or more assemblages.
- **Subprovince**: A locally fault-bounded, medium- to large-scale region characterized by similar rock types, structural style, isotopic age, metamorphic grade and mineral deposits.
- **Terrane**: A fault-bounded package of strata that is allochthonous with respect to, and has a geologic history distinct from, the adjoining geologic units.
- **Tectonic assemblage**: Stratified volcanic and/or sedimentary rock units built during a discrete interval of time in a common depositional or volcanic setting. The rock units typically share a common or dominant lithofacies; they may also share some additional attributes, such as structural, metamorphic, geochemical and geophysical features.

A BRIEF HISTORY OF SUBDIVISIONS OF ARCHEAN ROCKS IN NORTHWEST ONTARIO: SERIES, GROUPS, SUBPROVINCES AND TERRANES

Buoyed by the success of subdividing Paleozoic sedimentary rocks throughout Europe and North America on the basis of lithology, paleontology and stratigraphy, geologists in the late nineteenth century turned their attention to the classification of complex Precambrian supracrustal and plutonic sequences. By 1863, Logan et al. (1863) recognized a basement complex of granites and gneisses overlain by supracrustal rocks at Lake Timiskaming and on the north shore of Lake Huron. The basement complex and overlying supracrustal rocks later became known as the Laurentian and Huronian Series.

In 1885, A.C. Lawson noted that deformed volcanic schists, which he termed the "Keewatin Series" at Lake of the Woods must be older than the intrusive Laurentian Series (Lawson 1885). Later, Smyth (1891) identified a rare example of an Archean unconformity at Steep Rock Lake where conglomerate, limestone and volcanic ash of the Steep Rock Series overlie the Laurentian Series. By 1912, Lawson had defined the sedimentary Coutchiching and Seine Series at their type localities in the Rainy Lake area and adopted a subdivision of the Laurentian Series into an early suite of gneisses (Laurentian Series) and a late suite of massive granites (Algoman Series). The chronostratigraphic subdivision of Lawson (1912; Table 11.1) was applied widely to Archean rocks of northwest Ontario in the early part of the twentieth century, but led to considerable controversy because workers in various parts of the area saw conflicting evidence for the relative ages of various series such as the Seine, Keewatin and Coutchiching (*see* summary of Stone, Kamineni and Jackson 1992).

Debate over the relative ages of Lawson's chronostratigraphic series led to the gradual abandonment of this terminology in the mid-twentieth century. Lithostratigraphic terminology was applied to some supracrustal sequences and, for example, the Steep Rock and Seine Series became known as the Steep Rock and Seine Groups (Jolliffe 1955, 1966). The Steep Rock Group was later subdivided into 4 formations including the basal Wagita Formation (conglomerate), Mosher Formation (carbonate), Jolliffe Formation (ironstone) and Dismal Formation (ultramafic lapilli tuff; Wilks and Nisbet 1988). Unfortunately, although various formations of Archean supracrustal strata are defined locally, few can be traced for more than kilometre-scale distances or correlated from greenstone belt to greenstone belt. This has resulted in limited application of lithostratigraphic terminology to Archean supracrustal strata.

The gradual accumulation of regional geologic data for the Superior Province focussed attention on the spatial subdivision of Archean rocks—a style of subdivision that has been generally more successful than the chronostratigraphic or lithostratigraphic methods. Large-scale areas of Archean rocks that were variously termed belts, superbelts, blocks, and ultimately subprovinces were recognized on the basis of distinct lithofacies, structural fabric and metamorphic grade (Stockwell 1964, 1982; Douglas 1973; Goodwin 1978). Card and Ciesielski (1986) subsequently defined 4 principal types of subprovinces including volcano-plutonic, metasedimentary, plutonic and high-grade gneiss varieties. The Wabigoon and Quetico subprovinces, which occur in the present study area, are examples of volcano-plutonic and metasedimentary subprovinces, respectively.

The refinement of radiometric dating techniques in the latter part of the twentieth century provided the ability to obtain absolute ages of igneous rocks and led to further advances in the subdivision of Archean rocks as well as understanding of the tectonic evolution of the Superior Province. At a local scale, many greenstone belts that were previously thought to represent homoclinal packages were shown to be composed of several sequences of volcanic rocks varying in age by hundreds of millions of years (e.g., Corfu and Wallace 1986). These supracrustal packages comprising parts of greenstone belts became known as tectonic assemblages (Ontario Geological Survey 1992; Thurston 1991) and it was recognized that at least some assemblages must have been tectonically juxtaposed. At a regional scale, variations in ages of up to 500 million years from 3.2 to 2.7 Ga were found between rocks within certain subprovinces and from one subprovince to another (*see* summary of Corfu and Davis 1992). The Superior Province was interpreted to have grown by accretion of early crustal blocks, island arcs and sedimentary prisms (Percival and Williams 1989; Williams 1990; Card 1990; Stott 1997). Within the context of accretionary models, the subprovinces and various parts of subprovinces were interpreted as tectonic terranes. For example, Thurston, Osmani and Stone (1991) recognized a 3.0 Ga crustal block (North Caribou terrane) in the central western Superior Province. The North Caribou terrane was regarded as a continental nucleus against which a succession of island arcs, sedimentary prisms and crustal fragments of divergent ages were accreted progressively southward from 2.71 to 2.69 Ga.

Further U/Pb age determinations and Nd isotopic studies (*see* Tomlinson et al. 2003, 2004; Rayner and Stott 2005; Stone 2005b and references therein) led to refinement of the large-scale subprovinces and terranes of the northwest Superior Province (Figure 11.1). Within the central Wabigoon area, the Wabigoon Subprovince is subdivided into the Marmion and Western Wabigoon terranes, which are juxtaposed with the Winnipeg River terrane and Quetico Subprovince on the north and south, respectively. The Marmion terrane is a 3.0 Ga tonalite-greenstone sequence interpreted by Tomlinson et al. (2003) to represent an early continental block. Greenstone sequences of the Western Wabigoon terrane are 2.71 to 2.73 billion years old and are isotopically juvenile, probably representing oceanic material obducted onto the Marmion and Winnipeg River terranes at about 2.7 Ga. The Winnipeg River terrane contains vestiges of older crustal material. Although dominated by Neoarchean felsic plutonic rocks, U/Pb age determinations of inherited zircon grains and Nd isotopic studies by Tomlinson et al. (2004) show that rocks of the Winnipeg River terrane have incorporated circa 3.4 Ga basement. The sedimentary Quetico Subprovince represents a prism of detritus eroded from and rapidly accreted to the southern margin of the Superior craton during the later stages of assembly of the Superior Province at about 2.69 Ga (Davis, Pezzutto and Ojakangas 1990).

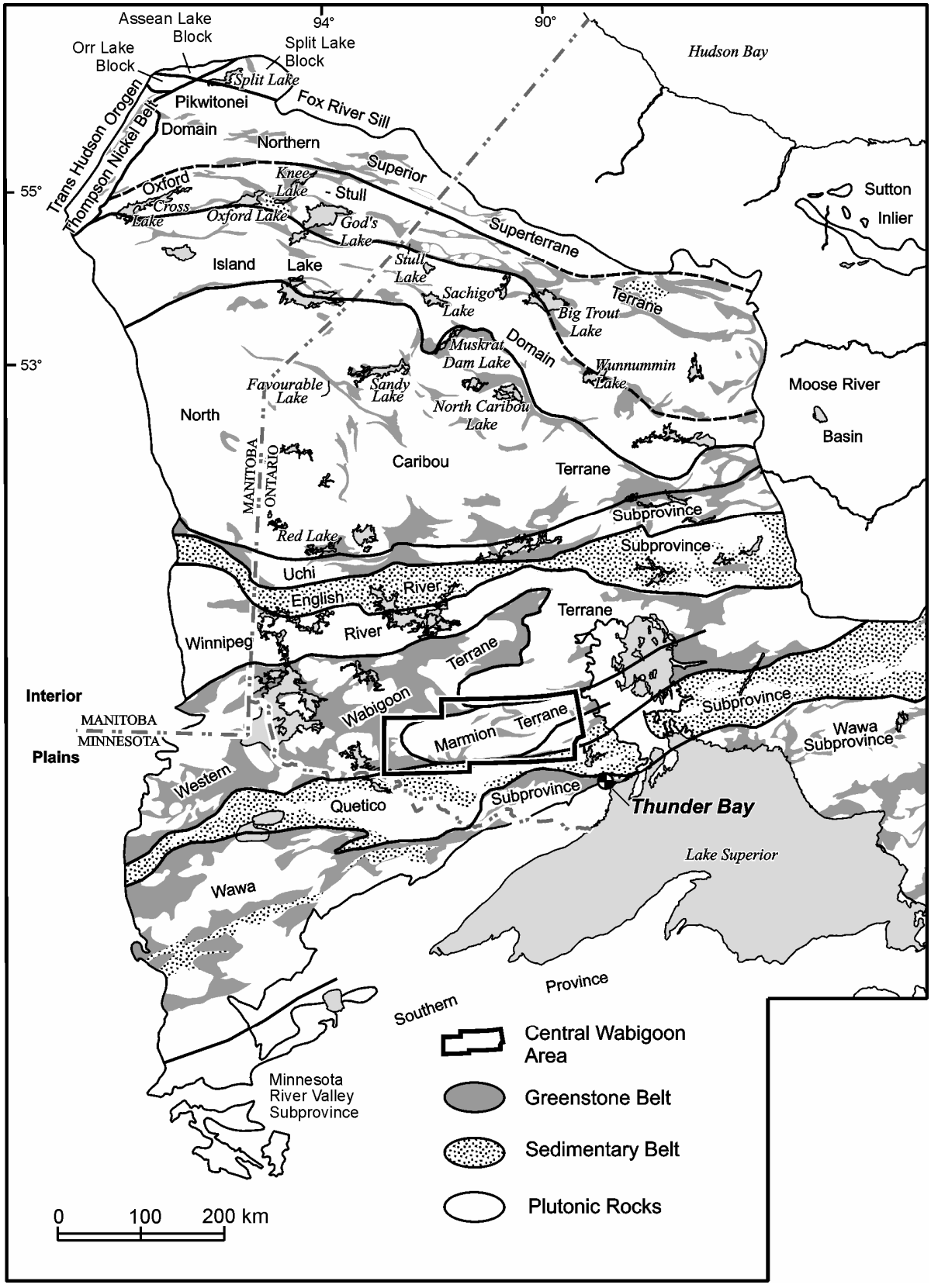


Figure 11.1. Regional subdivisions of the western Superior Province.

GEOLOGY OF THE CENTRAL WABIGOON AREA

The central Wabigoon area extends 30 to 270 km west of Thunder Bay in northwest Ontario and includes the towns of Upsala, Ignace, Atikokan and Mine Centre. Typical of granite-greenstone areas in the Wabigoon Subprovince, it is underlain by thin, bifurcated and anastomosed greenstone belts separated by large, commonly oval masses of felsic plutonic rocks. The greenstone belts, named on Figure 11.2, are composed primarily of mafic volcanic rocks with lesser components of intermediate to felsic volcanic rocks, gabbro and sedimentary rocks. A large gabbro-anorthosite intrusion occurs southwest of Mine Centre and gabbro represents a major component of the greenstone belt extending from Sapawe to Lac des Mille Lacs (*see* Figure 11.2). The supracrustal strata are typically foliated, subvertical and variably metamorphosed from greenschist to amphibolite facies.

Well-bedded wacke siltstone sequences (Quetico sedimentary sequences) of the Quetico Subprovince extend along the south margin of the central Wabigoon area. Metamorphic grade increases southward in the Quetico Subprovince where the sedimentary sequences become progressively migmatized giving way to plutons of peraluminous granite. Coarse conglomerates of the Seine sequence occur in the Shoal Lake area and as small, well foliated units along the Quetico–Wabigoon boundary.

To the north, the Marmion terrane is suggested to be in contact with granitoid rocks of the Winnipeg River terrane, an extension of the Winnipeg River Subprovince. The boundary is cryptic, but is thought to lie between the Heaven Lake and Garden Lake greenstone belts because Paleoarchean Nd model ages similar to those in the Winnipeg River Subprovince have been found to the north, but not to the south in the Marmion terrane (Tomlinson et al. 2003).

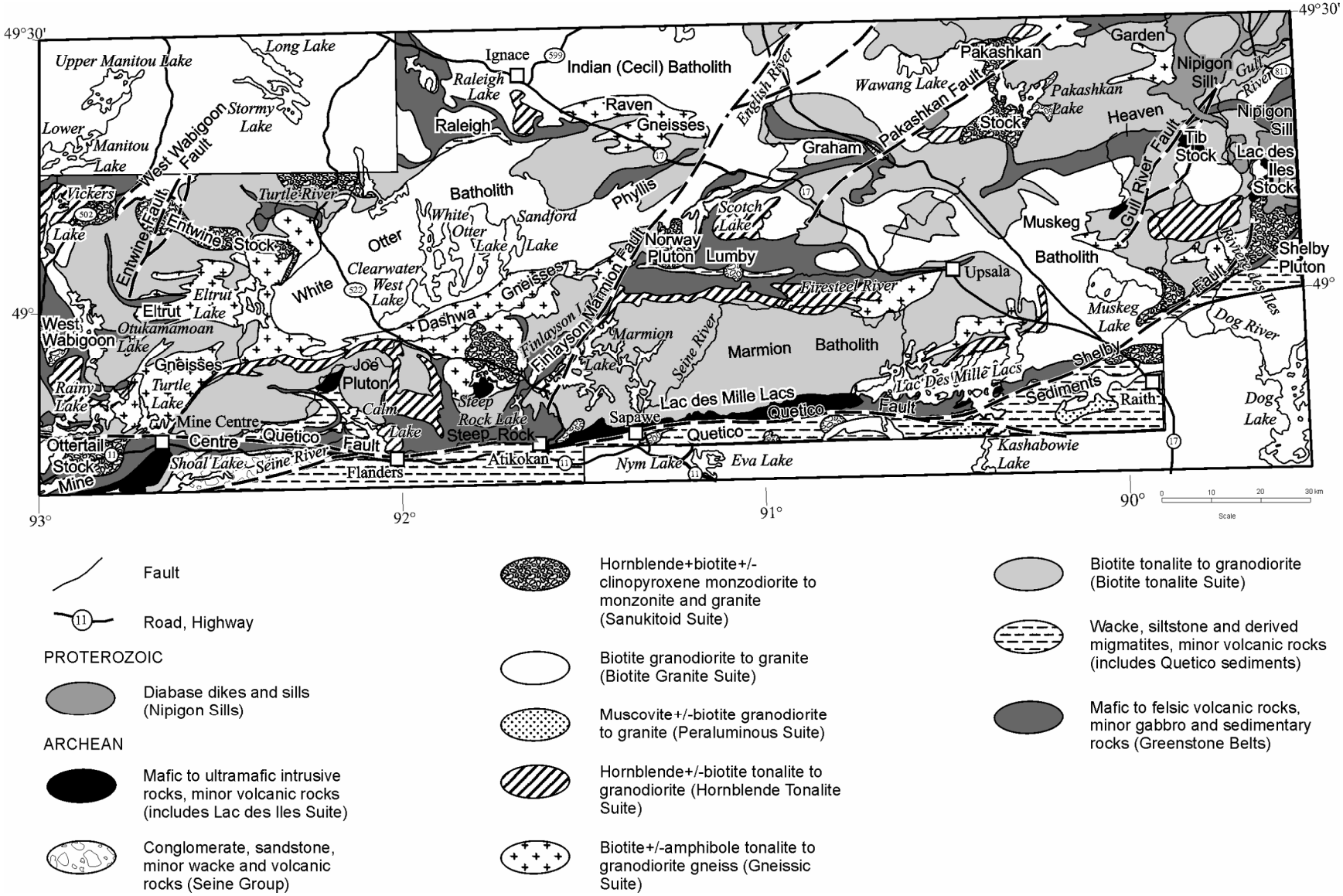
Seven major suites of felsic to intermediate and mafic plutonic rocks occur in the central Wabigoon area. Among the oldest plutonic rocks are intrusions of the biotite tonalite and gneissic suites, examples of which include the Marmion batholith and Eltrut, Dashwa and Raven gneiss complexes (*see* Figure 11.2).

Coarse-grained hornblende tonalite to granodiorite belonging to the hornblende tonalite suite constitute a few percent of the central Wabigoon area and occur as oval to elongate masses at scattered localities. Muscovite±biotite granite of the peraluminous suite occurs as dikes, masses and plutons in the Quetico Subprovince and as rare, small units in greenstone belts of the Wabigoon Subprovince.

Late, massive and mainly posttectonic intrusive rocks include the biotite granite, sanukitoid and Lac des Iles suites. Pink biotite granite to granodiorite of the biotite granite suite is the most common rock in the area occurring in forms ranging from dikes and stocks to large batholiths, examples of which include the White Otter, Cecil and Muskeg batholiths. Oval plutons of the sanukitoid suite occupy up to 10% of the central Wabigoon area. The sanukitoid plutons are heterogeneous and are variably composed of diorite, monzodiorite, monzonite and granite with gabbroic to hornblendite inclusions. Gabbroic to pyroxenitic and peridotitic dikes and stocks of the Lac des Iles suite, many of which are too small to be shown in Figure 11.2, occur within a broad band extending from south of Atikokan to Lac des Iles. Larger examples of this suite include the Tib and Lac des Iles stocks at Lac des Iles. The Mine Block intrusion, which adjoins the southern Lac des Iles stock, is currently being mined for palladium and platinum.

Archean rocks of the central Wabigoon area are cut by Proterozoic diabase dikes and sills. The larger masses of Proterozoic diabase are associated with the Nipigon sill complex and occur in the eastern part of the area.

Two major sets of subvertical, transcurrent faults of late Archean age transect the area. The dextral Quetico and Shelby Lake faults extend easterly along the Quetico–Wabigoon boundary and are marked by zones of schist and mylonite up to 1 km in width. Northeast- to north-northeast-trending faults



Fault

Road, Highway

PROTEROZOIC

Diabase dikes and sills (Nipigon Sills)

ARCHEAN

Mafic to ultramafic intrusive rocks, minor volcanic rocks (includes Lac des Iles Suite)

Conglomerate, sandstone, minor wacke and volcanic rocks (Seine Group)

Hornblende+biotite+/-clinopyroxene monzodiorite to monzonite and granite (Sanukitoid Suite)

Biotite granodiorite to granite (Biotite Granite Suite)

Muscovite+/-biotite granodiorite to granite (Peraluminous Suite)

Hornblende+/-biotite tonalite to granodiorite (Hornblende Tonalite Suite)

Biotite+/-amphibole tonalite to granodiorite gneiss (Gneissic Suite)

Biotite tonalite to granodiorite (Biotite tonalite Suite)

Wacke, siltstone and derived migmatites, minor volcanic rocks (includes Quetico sediments)

Mafic to felsic volcanic rocks, minor gabbro and sedimentary rocks (Greenstone Belts)

Figure 11.2. Geology of the central Wabigoon area. (Note, the following names are abbreviated: "Heaven" is Heaven Lake greenstone belt, "Garden" is Garden Lake greenstone belt, "Lumby" is Lumby Lake greenstone belt, "Raleigh" is Raleigh Lake greenstone belt.)

include the Entwine, Marmion, Pakashkan and Gull River faults. At its southern end within the Marmion batholith, the Marmion fault broadens to a complex braided zone of fault segments, some of which are mineralized with gold.

DOMAINS OF THE CENTRAL WABIGOON AREA

The somewhat simple geologic description in preceding paragraphs belies a complex distribution of lithotectonic domains as indicated by numerous sets of radiometric ages for the supracrustal and plutonic sequences of the central Wabigoon area. More than 85 samples that are representative of a broad range of Archean rocks in the central Wabigoon area have had ages determined using the U/Pb method, mainly at the Jack Satterly Laboratory in Toronto. The age determinations for the central Wabigoon and adjacent areas (Table 11.2) show as many as a dozen magmatic events ranging between 3000 and 2670 Ma as illustrated in Figure 11.3. Conversely, many parts of the Superior Province show ages clustered within one or two narrow ranges and provide a less extended record of Archean magmatism.

In some instances, the age determinations or clusters of age determinations correspond with greenstone-belt assemblages, although the majority of age clusters span a variety of intrusive and extrusive magmatic rocks and are considered to represent distinct sub-blocks or domains of the central Wabigoon area. Each domain appears to have a unique geographic extent as well as a unique magmatic history, although, in many instances, the boundaries of domains are poorly constrained and tectonic relations with neighbouring domains, whether they be allochthonous or autochthonous, are unknown. Nine major domains and several assemblages are recognized within the central Wabigoon area (Table 11.3; Figure 11.4) with other clusters of age determinations representing neighbouring terranes such as the Winnipeg River and Western Wabigoon terranes and Quetico Subprovince. The youngest age determinations in Table 11.2 correspond to suites of posttectonic plutonic rocks that appear to have been emplaced after development of the domain architecture. In some areas, such as at White Otter Lake and Ignace, posttectonic biotite granite batholiths have possibly intruded as large sills and preclude definition of the domains.

The various domains of the central Wabigoon area appear to represent products of a succession of magmatic events. In some instances, the magmatic events seen in the central Wabigoon area are recognized widely. For example, volcanic and plutonic rocks with ages in the range of 2.74 to 2.67 Ga are characteristic of the Kenoran Orogeny and are widespread in other terranes of the western Superior Province (Corfu and Davis 1992). Likewise, the spectrum of circa 3.0 Ga ages in the Marmion domain is similar to that of the North Caribou terrane (*see* compilation of Stone 2005a). In contrast, the magmatism associated with other domains including the Whitton, Central Wabigoon, Hillyer, Marmion South Margin, Pinecone–Savoy and Dog is less widely represented.

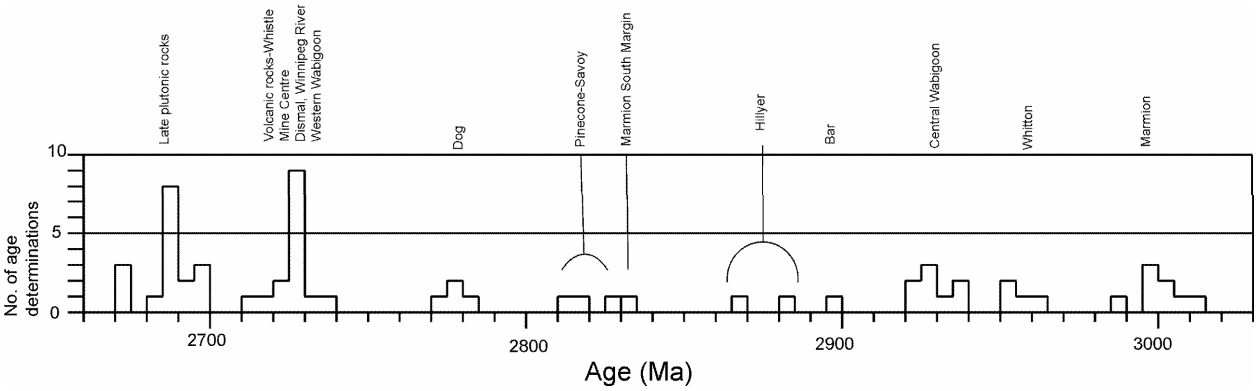


Figure 11.3. Distribution of U/Pb ages in the central Wabigoon and adjacent areas.

Table 11.2. Uranium-lead (U/Pb) age data for volcanic, plutonic and sedimentary units of the central Wabigoon area (numbers keyed to Figure 11.4). For additional notes, see end of table.

No.	UTM Easting	UTM Northing	Rock Type	Crystallization Age	Detrital Grain Age [max. depositional age (in bold)]	Inherited Age	Metamorphic Age	Ref.
Marmion domain								
1	624430	5427561	tonalite gneiss	3009±8				1
2	598425	5408925	mafic (hornblende) tonalite	3001.6 +3.4/–2.3				1
3	596880	5409971	sandstone		**2997.1±0.9**			3
4	601040	5414724	conglomerate, sandstone		3002, 3001, 3001, 2999, 2999, **2997**			2
5	593580	5405780	quartz feldspar porphyry dacite or subvolcanic intrusion	2999.4±0.7				4
6	621029	5432763	felsic tuff	2999.4±2.9				5
7	623930	5432549	rhyolite	3001.1±1.1				1
8	632109	5432335	quartz porphyry	2999.1±2.0				5
9	645328	5441694	rhyolite	3013.6±1.3				1
10	622735	5461789	tonalite gneiss	2989 +5/–3				6
Whitton domain								
15	756394	5476046	felsic dike	2953.1±1.6				1
16	757844	5475642	felsic tuff	2953.7±1.3				1
17	643036	5440069	felsic tuff	2963.3±4.5		3016±5		1
18	620809	5454850	felsic tuff	2955.8±0.8				1
Central Wabigoon domain								
22	742745	5486637	biotite tonalite	2924.1±9			2690 titanite lower intercept	8
23	733130	5474740	tonalite gneiss with wacke and gabbro	2937.1±1.2*			2722 (monazite)	7
24	659562	5465150	biotite tonalite	2929±4				4
25	604450	5420873	felsic tuff	2931.4±2				1
26	602020	5424440	biotite tonalite	2936				9
27	597830	5424500	tonalite gneiss	2928				9
28	577155	5405380	felsic volcanic fragmental	2925.6±1.2				1
29	519920	5409812	tonalite gneiss	2924±2				6
Bar assemblage								
35	629412	5434560	felsic tuff	2897.6±2.1		2903 to 2999		1
Hillyer domain								
40	577300	5405566	hornblende tonalite	2883±2				10
41	541452	5415004	hornblende tonalite	2869±4				6
Marmion South Margin domain								
45	693300	5412160	felsic volcanic fragmental	2830.2±1.1				1
46	653680	5410603	conglomerate		3007, 3006, 3004, 3002, 2981, **2927**			7
47	599316	5409238	tonalite cobble in conglomerate		**2994**			9
Pinecone-Savoy domain								
50	637385	5437320	felsic tuff in komatiite	2828.3±1.8				1
51	650020	5462475	biotite tonalite	2814.0±1.2				4
52	630017	5457740	biotite tonalite	2817 +4/–2			2694 (titanite)	4

Table 11.2. continued

No.	UTM Easting	UTM Northing	Rock Type	Crystallization Age	Detrital Grain Age [max. depositional age (in bold)]	Inherited Age	Metamorphic Age	Ref.
Dog domain								
55	685620	5418565	hornblende tonalite	2780.7±1.8				1
56	736906	5440575	tonalite gneiss	2773.6±1.2				4
57	723380	5445360	biotite tonalite to granodiorite	2777±3				4
58	?	?	tonalite gneiss	2775±8			2722±3	11
Whistle domain								
60	763285	5469530	felsic tuff	2729±2		2813		1
61	762323	5467740	quartz+feldspar porphyry intrusion	2727.8±1.6		2758 to 2779		1
62	760980	5454350	dacite tuff	2727.8±1.3				1
63	745093	5452405	hornblende tonalite	2727.8±1.5				11
73	687712	5432346	biotite tonalite	2716.8±1.0			2707±37 (titanite)	7
Mine Centre domain *(includes Witch Bay and Puffy Pillow assemblages)*								
64	692750	5409820	dacite breccia	2725.0±1.1				4
65	600330	5403550	leucogabbro	2735.2±.8				4
66	594058	5402278	quartz porphyritic tonalite	2729.7±1.9		2865		4
67	599490	5406790	sandstone		**3002.6±1.4**			12
69	569210	5399360	felsic volcanic	2722.3 +1.3/–1.1				13
70	533350	5399380	quartz-phyric volcanic rock	2727.0±1.2				13
71	520420	5398310	tonalite	2728.1 +1.8/–1.3				13
72	519320	5399550	quartz porphyritic rhyolite	2727.8 +4/–2.6				13
Dismal assemblage								
68	599320	5407880	ultramafic lapilli tuff			2997, 2995, 2780		1
Winnipeg River Subprovince								
75	714296	5484615	rhyolite	2725.5±1.3				1
76	687280	5482630	tonalite gneiss	2712±2				10
Western Wabigoon terrane								
80	537761	5436468	tonalite gneiss	2732				10
81	605622	5454407	hornblende tonalite	2721.3±1				6
Quetico Subprovince								
90	765886	5452545	conglomerate		**2696**			14
91	604211	5397904	wacke		3009, 3009,3004, 3004, 2701, **2698**			15
92	602950	5398943	wacke		**2707**			15
93	602610	5397940	wacke		**2704**			15
94	602064	5398020	wacke		**2739**			15
95	600812	5398020	wacke		2901**, 2701**			15
96	599510	5398130	wacke		**2796**			15
97	594866	5399500	wacke		2768, **2706**			15
98	592060	5398600	wacke		2719, **2709**			15
99	588187	5398384	wacke		**2792**			15
100	573300	5397680	wacke		2709**, 2704**			15
101	567275	5397826	wacke		2913, 2787, **2704**			15
102	566962	5397558	wacke		2724, 2705**, 2700**			15
103	565867	5398206	wacke		**2788**			15

Table 11.2. continued

No.	UTM Easting	UTM Northing	Rock Type	Crystallization Age	Detrital Grain Age [max. depositional age (in bold)]	Inherited Age	Metamorphic Age	Ref.
104	538409	5399392	tonalite clast in conglomerate	2696.1 +5/–3	**2696**			13
105	504500	5395650	wacke		3059, 3057, 3056, 2940, 2830, 2726, 2721, 2714, 2712, 2704, **2704**			13
106	605242	5455570	conglomerate		2718, 2710, 2707, **2700**			6
107	501770	5395540	felsic sill in Coutchiching sediments			2717, 2825		13
Late plutonic rocks								
Biotite Granite suite								
110	707560	5423735	potassium-feldspar megacrystic granite	2686±2		2690		4
111	587900	5432889	coarse grained biotite granite	2685±2			2667 (titanite)	16
112	613745	5488309	biotite granite	2671				10
Sanukitoid suite								
115			monzonite	2697				10
116	747519	5447943	hornblende diorite	2690±0.9			2674, 2667 (titanite)	8
117	622784	5402685	quartz monzonite	2688±4				15
118	595442	5417355	biotite-hornblende granite	2684±25**			2665 (titanite)	17
119	509600	5397240	quartz monzodiorite	2686.1 +1.5/–1.4				13
Tonalite Gneiss suite								
125	726017	5411947	tonalite to granodiorite gneiss	2673.0±1.1			2657 (titanite)	7
Lac des Iles suite								
130	733478	5458252	gabbro pegmatite	2685.9±1.6				11
131	747853	5452420	gabbro pegmatite	2693.3±1.3				18
132	746668	5451861	gabbro pegmatite	2689.0±1.0				11
133	346305***	5504619	gabbro	2699.0±0.9				18
134	335900***	5485503	gabbro	2687.6±1.2				18
135	315182***	5492528	gabbro	2686.1±2.2				18
136	331113***	5453513	gabbro	2671±11				18

References

1 Tomlinson et al. (2003)
2 Fralick and King (1996)
3 P. Fralick, unpublished data (2001)
4 Davis (2006)
5 Davis and Jackson (1988)
6 Tomlinson et al. (2001)
7 Davis (2005)
8 Kamo (2004)
9 D. Davis, unpublished work *in* Stone, Kamineni and Jackson (1992)
10 K.Y. Tomlinson, unpublished data *in* Tomlinson et al. (2004)
11 Davis (2003)
12 D. Davis, unpublished work (1986) *in* Stone, Kamineni & Jackson (1992)
13 Davis, Poulsen and Kamo (1989)
14 D. Davis, unpublished work (1994)
15 Davis, Pezzutto and Ojakangas (1990)
16 Davis (1993)
17 Zartman and Kwak (1990)
18 Heaman and Easton (2006)

Additional Notes

* the dated zircon grains are rounded and probably are derived from the sedimentary component of the rock
** U/Pb whole rock age
UTM co-ordinates are in metres for Zone 15, NAD83
*** UTM co-ordinates are in Zone 16, NAD83 and are mainly east of the present study area

Evidently, the central Wabigoon area records a broad spectrum of late Mesoarchean to Neoarchean magmatism and, therefore, gives insight into the tectonic evolution of a key part of the Superior Province. In this area, the Marmion domain possibly represents a continental block developed at 3.0 Ga by emplacement of the Marmion batholith and coeval volcanic rocks into an oceanic arc, vestiges of which are found in 3.01 Ga volcanic sequences of the northern Lumby Lake belt. Parts of several greenstone belts including the Phyllis, Lumby Lake and Heaven Lake belts represent the Whitton domain along the north side of the Marmion domain and are dominated by mafic volcanic sequences with ages of 2.95 to 2.96 Ga. These may represent magmatic arcs that developed on or near the proto-continental margin or oceanic material obducted onto the continental margin. Mafic to felsic volcanic rocks and felsic plutonic rocks of the Central Wabigoon domain occur within a broad, discontinuous belt north of the Whitton domain and have ages of 2.92 to 2.94 Ga. Plutons of the Central Wabigoon domain intrude volcanic sequences of the Whitton and Marmion domains and imply that the Central Wabigoon domain developed as a continental magmatic arc on the north side of the Marmion proto-continent.

The Hillyer domain represents suites of hornblende tonalite and gneissic rocks intruded by posttectonic biotite tonalite plutons (e.g., Joe pluton) occupying an oval embayment in the southern Central Wabigoon domain (*see* Figures 11.2 and 11.4). The 2.88 Ga hornblende tonalite at the northern margin of the Hillyer domain is highly strained and has unusually high crystallization pressures for plutonic rocks of the region. The Hillyer domain may be a part of the Central Wabigoon domain that was intruded by 2.88 Ga magmas and was subsequently uplifted. Alternatively, the Hillyer domain may represent an exotic crustal fragment that has indented and been partially thrust onto the south margin of the Marmion continent. The time of uplift or accretion of the Hillyer domain is pre-2.73 Ga, the age of onlapping volcanic sequences of the Mine Centre domain.

The Marmion continent was rifted apart as indicated by lithologies characteristic of a rift-margin developed within a linear zone at the south side of the Marmion batholith. Within this zone, the Marmion South Margin domain, a conglomerate unit is overlain by felsic volcanic rocks, which are cut by extensive gabbro dikes. The basal conglomerate unit of the Steep Rock Group in the Atikokan area was possibly deposited during the early stages of rifting. The age of the rifting event is constrained by a single age on the felsic volcanic rocks (2.83 Ga). Further geochronologic work is required to establish the age of gabbro dike emplacement. Northern parts of the Marmion continent may have also been rifted at about the same time as the south margin. The 2.83 Ga mafic to ultramafic volcanic sequences and associated sedimentary rocks of the Pinecone assemblage occupy a central band possibly representing a rift in the Lumby Lake greenstone belt. Somewhat younger biotite tonalite plutons with ages of 2.81 to 2.82 Ga occur in the Savoy domain north of the Lumby Lake greenstone belt. Although the extent of the Savoy domain and the tectonic significance of the 2.82 to 2.81 Ga plutonic rocks are unclear, the plutonism of the combined Pinecone–Savoy domain shows a temporal similarity with the rifting event proposed for the southern Marmion continent.

A magmatic arc, represented by intrusions of biotite tonalite, tonalite gneiss and hornblende tonalite of the Dog domain developed in the eastern Marmion terrane at 2.78 Ga. Subsequently, volcanic rocks with ages of 2.73 to 2.72 Ga erupted at or near the south margin of the central Wabigoon area. These include mafic to felsic sequences of the Mine Centre domain and mafic sequences of the Witch Bay and Dismal assemblages at Atikokan and the Puffy Pillow assemblage at Lac des Mille Lacs. These pillowed sequences appear to represent remnants of oceanic magmatic arcs and ocean floor, although Tomlinson et al. (1999) suggested, on the basis of geochemistry, that the ultramafic lapilli tuff of the Dismal assemblage possibly originated in a mantle plume. Whatever the origin, the volcanic rocks were joined to the Marmion continent prior to the deposition and accretion of the Quetico sedimentary sequences at approximately 2.69 Ga. The Whistle domain is characterized by mafic to felsic volcanic sequences and felsic plutonic rocks of 2.72 to 2.73 Ga age in the eastern part of the central Wabigoon area. Although its extent is poorly known, the Whistle domain possibly represents a continental magmatic arc that developed in this area concurrent with offshore volcanism such as that of the Witch Bay assemblage, to the west.

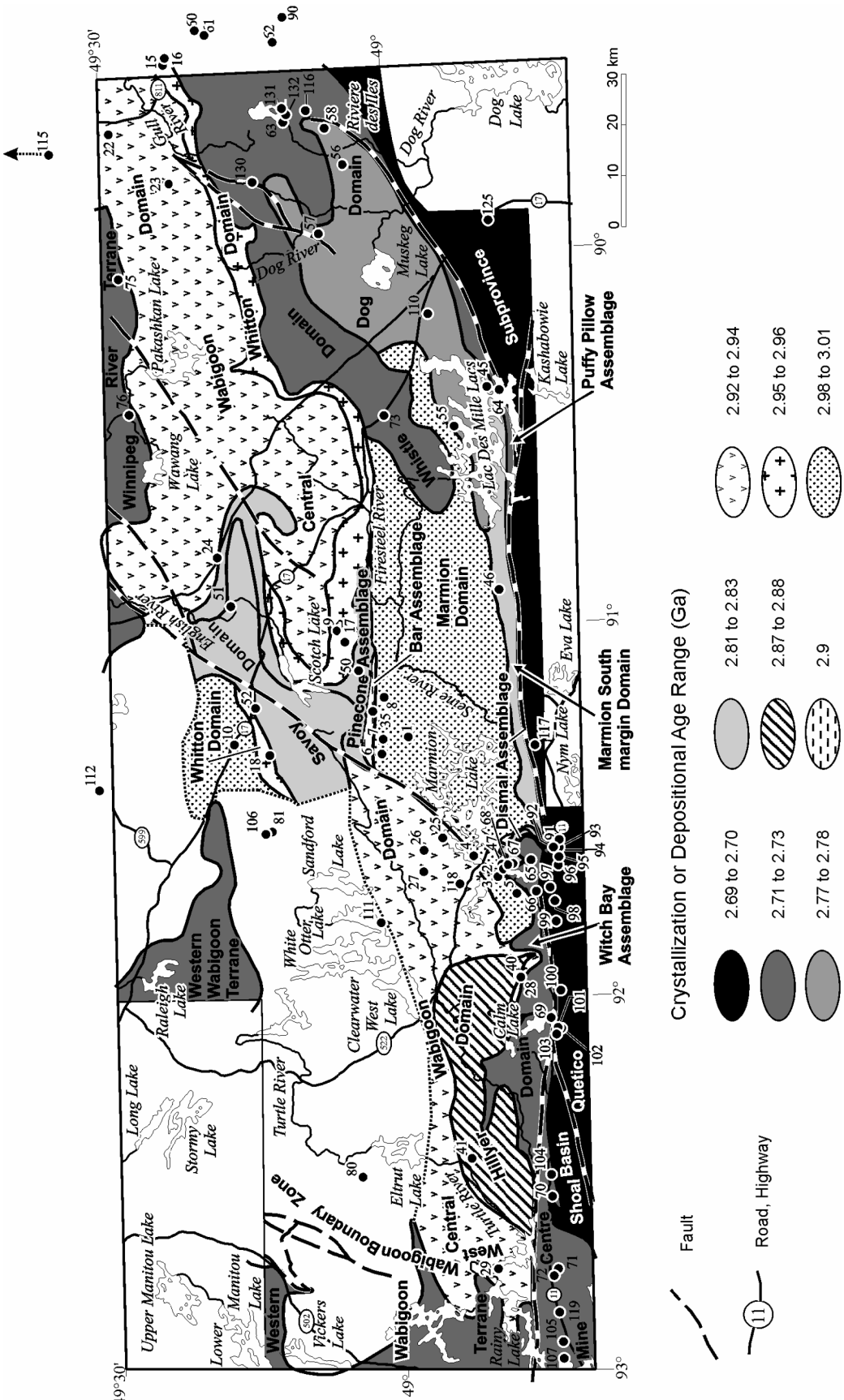


Figure 11.4. Domains and assemblages of the central Wabigoon area. Numbers refer to age determinations in Table 11.2. Posttectonic batholiths and a lack of age determinations preclude definition of domains within the blank areas.

Table 11.3. Crustal domains of the central Wabigoon Subprovince.

Domain	Shape and Contact Relations	Rock Types	Magmatic Ages (Ma)	Crystallization Pressure of Hornblende-bearing Plutonic Rocks (kilobars)	Possible Tectonic Affinity
Marmion	Fragmented block 30 × 100 km; rifted on north and south; intruded by younger plutons	Biotite tonalite; tonalite gneiss; mafic greenstone belts	2889 to 3013	4.8 to 6.1	An early continental block possibly developed in a magmatic arc
Whitton	Fragmented 10 × 100+km belt; locally rifted on south and intruded by younger plutons on north and south	Dominantly mafic greenstone sequences	2953 to 2963	—	Continental margin arc or obducted oceanic material
Central Wabigoon	Elongate 50 × 300+km; fragmented; intrudes Whitton	Biotite tonalite; tonalite gneiss mafic greenstone sequences	2924 to 2936	4.5 to 9.2 increasing easterly	Dominantly felsic continental magmatic arc
Hillyer	Oval 20 × 70 km with sheared margins	Biotite tonalite; tonalite gneiss; hornblende tonalite	2869 to 2883	4.2 to 8.3 increasing easterly	Uplifted continental margin or accreted indenter
Marmion South Margin	Elongate 10 × 100 km; Unconformably overlies Marmion to north and in fault contact with Quetico to south	Conglomerate, felsic volcanic, diorite and gabbro dikes	2830	—	Rift margin
Pinecone–Savoy	Irregular, bifurcated and tapered block 60+ km long; cuts Whitton and Marmion	Biotite tonalite; hornblende tonalite; mafic to ultramafic volcanics; clastic sediments	2814 to 2828	3.7 to 8.0	Rift and rift-related plutonism?
Dog	Elongate 30 × 100 km; intrudes Marmion	Biotite tonalite; tonalite gneiss; hornblende tonalite	2773 to 2780	4.8 to 8.3	Continental magmatic arc
Whistle	Elongate 50 × 100+ km; intrudes Dog	Biotite tonalite, hornblende tonalite, mafic to felsic volcanic sequences	2716 to 2729	5.6 to 8.0 increasing westerly	Continental magmatic arc
Mine Centre	Discontinuous, elongate 20 × 200+ km; locally in fault contact with older domains to north	Mainly mafic to felsic volcanic sequences	2722 to 2735	—	Accreted continental margin arc

IMPLICATIONS FOR MINERAL EXPLORATION

The central Wabigoon area hosts a variety of mineral deposit types including lode gold, volcanic-associated zinc-copper-lead massive sulphide (VMS) deposits, mafic to ultramafic intrusion–associated nickel-copper-palladium-platinum deposits and rare-metal (Li, Cs, Be, Ta) pegmatites. In some instances, the domain architecture and associated evidence for multiple episodes of magmatism and deformation can provide a regional framework within which to focus exploration for these deposit types. For example, Fyon et al. (1992) have shown that mineral deposits tend to be concentrated in younger (post 2.73 Ga) volcanic and plutonic sequences as opposed to older rocks. To some extent, this holds true for the central Wabigoon area, although other factors such as the age of mineralizing events are also important.

Gold is concentrated mainly along the Quetico–Wabigoon boundary such as at Mine Centre and Calm Lake and through Sapawe to Lac des Mille Lacs (Poulsen 2000; Stone 2005a). The gold showings are situated mainly within post-2.73 Ga strata such as that of the Mine Centre domain, although many occurrences in the Sapawe area lie within gabbro-tonalite sequences of the Marmion South Margin domain, which is probably circa 2.83 Ga in age. Furthermore, numerous gold occurrences in the Atikokan area (Schnieders and Dutka 1985; Wilkinson 1982) are situated within the 3.0 Ga Marmion domain and Mesoarchean strata of the western Lumby Lake greenstone belt. Despite the variability in age of host rocks, a common characteristic of many gold occurrences is a close spatial association with late-tectonic shear zones. Hence, the host-rock age may be a less important influence on gold mineralization than the effects of late deformation associated with collisional accretion of domains and transpressive shearing.

Although few gold occurrences are situated within the main Quetico and Shelby Lake faults, these late transpressive structures provide a regional guide for gold exploration because most gold occurrences are situated within a few kilometres of these structures, typically within subsidiary or secondary faults. New mapping also reveals places such as between Arnold and Calm lakes (west of Atikokan) where gold is associated with domain boundaries. In this area, mineralized deformation zones occur marginal to klippe of the Witch Bay assemblage that rest on older mafic to felsic sequences of the Marmion and Central Wabigoon domains. The fault boundaries between these sequences of divergent age developed in a pre-transpressive, accretionary event at about 2.69 to 2.72 Ga and are potential new targets for gold exploration.

Base-metal showings, broadly correlative with VMS-style mineralization are identified in volcanic strata of the Mine Centre domain (Poulsen 2000), at scattered localities in the Raleigh Lake belt of the western Wabigoon terrane and in the southern Lumby Lake greenstone belt (Jackson 1985). Whereas volcanic strata of the Mine Centre domain and presumably the Raleigh Lake greenstone belt are circa 2.72 Ga, the mineralized sequences of the southern Lumby Lake greenstone belt are part of the 3.0 Ga Marmion domain. Hence, base metal mineralization occurs in domains of varied age, although little is known about the time at which economic minerals were concentrated within host-rocks at these localities. Possibly, the Lumby Lake greenstone belt records an early mineralizing event not broadly recognized in the western Superior Province.

Nickel-copper and platinum-group-element (PGE) mineralization are identified within at least 3 suites of mafic to ultramafic rocks. These include layered mafic intrusions of the Mine Centre domain (Poulsen 2000), plutons such as the Entwine intrusion of the sanukitoid suite (Stone 2000) and mafic to ultramafic intrusions of the Lac des Iles suite (Lavigne and Michaud 2001). The Dismal assemblage, which contains the ultramafic lapilli tuff with associated pyrite lenses at Steep Rock Lake (Jolliffe 1955) and also probably the Atikokan Iron Mine (magnetite deposits) at Sapawe, is a potential source of nickel-copper and PGE mineralization. In all cases, the host rocks and mineralization appear to be post 2.73 Ga in age although the mafic to ultramafic intrusions can occur in domains of varied age. For example,

although most intrusions of the Lac des Iles suite occur in the Whistle domain, others have been emplaced into the Quetico Subprovince, Marmion South Margin and Marmion domains. Hence, the domain architecture may provide little control on localization of mineralization associated with posttectonic plutons.

Rare metal pegmatites are identified in the Raleigh Lake greenstone belt (Breaks 1993) and at scattered localities in the Quetico Subprovince. These were emplaced as fractional products of peraluminous granite magmas at a late stage in the evolution of the central Wabigoon area. Rare metal pegmatites appear to be absent from early tonalite-dominated plutonic domains of the area.

CONCLUSIONS

New mapping combined with geochronology has helped to define lithotectonic domains within the Marmion terrane of the central Wabigoon Subprovince. Up to 9 domains are recognized and each appears to represent a distinct magmatic event, which generated new crustal material. These events are spaced throughout a 300 million year period from 3.0 to 2.7 Ga. Although some magmatic events, such as the circa 2.7 Ga Kenoran Orogeny are recognized throughout the western Superior Province, others are much less widely observed. Hence, the central Wabigoon area appears to contain an exceptional record of late Mesoarchean to Neoarchean magmatism.

The series of magmatic events combined with the lithostructural characteristics of the domains produced by each event are a basis for speculation on the tectonic evolution of the central Wabigoon area. The evolution appears to have involved progressive growth of the 3.0 Ga Marmion micro-continent through multiple additions of magmatic and crustal material in continental arcs and possibly through accretion of exotic material. At least one rifting event affected the Marmion micro-continent before it was assembled with other terranes into the Superior craton at 2.7 Ga.

The domain architecture and domain boundary relations provide some useful guidance for mineral exploration. The majority of, but by no means all, known mineral showings occur in younger domains and posttectonic plutons. Although gold is associated mainly with late transcurrent faults, somewhat earlier faults that have thrust volcanic sequences of the Witch Bay assemblage onto older strata west of Atikokan, are also mineralized with gold. These deformed thrust faults provide new exploration targets for gold. Also, the mafic to ultramafic and iron-rich Dismal assemblage that extends from Atikokan to Sapawe has potential for copper-nickel and PGE mineralization.

The domain subdivisions and evolutionary sequence proposed here for the central Wabigoon area, must be considered preliminary. As pointed out by Card and Ciesielski (1986), “No subdivision can be permanent; as new data appear, and basic concepts evolve, so too will ideas about meaningful geologic subdivisions.”

REFERENCES

Breaks, F.W. 1993. Granite-related mineralization in northwestern Ontario: 1. Raleigh Lake and Separation Rapids (English River) rare-element pegmatite fields; *in* Summary of Field Work and Other Activities 1993; Ontario Geological Survey, Miscellaneous Paper 162, p.104-110.

Card, K.D. 1990. A review of the Superior Province of the Canadian Shield, a product of Archaean accretion; Precambrian Research, v.48, p.99-156.

Card, K.D. and Ciesielski, A. 1986. Subdivisions of the Superior Province of the Canadian Shield; Geoscience Canada, v.13, p.5-13.

Corfu, F. and Davis, D.W. 1992. A U-Pb geochronological framework for the western Superior Province, Ontario; *in* Geology of Ontario; Ontario Geological Survey, Special Volume 4, Part 2, p.1335-1348.

Corfu, F. and Wallace, H. 1986. U-Pb zircon ages for magmatism in the Red Lake greenstone belt, northwestern Ontario; Canadian Journal of Earth Sciences, v.23, p.27-42.

Davis, D.W. 1993. Report on U-Pb geochronology in the Atikokan area, Wabigoon Subprovince, Ontario; unpublished report of the Earth Sciences Department, Royal Ontario Museum, 100 Queen's Park, Toronto, Ontario M5S 2C6.

——— 2003. U-Pb geochronology of rocks from the Lac des Iles area, northwest Ontario; unpublished report of the Earth Sciences Department, Royal Ontario Museum, 100 Queen's Park, Toronto, Ontario M5S 2C6.

—— 2005. Geochronology of granitoid rocks in the western Superior Province: applications of abrasion, anneal-leach and garnet-armour techniques to extraction of precise U-Pb ages from altered mineral populations; unpublished report to the Ontario Geological Survey by the Jack Satterly Geochronology Laboratory, Department of Geology, University of Toronto, Earth Sciences Centre, 22 Russell Street, Toronto, Ontario M5S 3B1 (for further information, contact dond@geology.utoronto.ca).

——— 2006. Geochronology of rocks from the Marmion terrane and Hudson Bay Lowland basement, western Superior Province; unpublished report to the Ontario Geological Survey by the Jack Satterly Geochronology Laboratory, Department of Geology, University of Toronto, Earth Sciences Centre, 22 Russell Street, Toronto, Ontario M5S 3B1 (for further information, contact dond@geology.utoronto.ca).

Davis, D.W. and Jackson, M.C. 1988. Geochronology of the Lumby Lake greenstone belt: a 3 Ga complex within the Wabigoon Subprovince, northwest Ontario; Geological Society of America Bulletin, v.100, p.818-824.

Davis, D.W., Pezzutto, F. and Ojakangas, R.W. 1990. The age and provenance of metasedimentary rocks in the Quetico Subprovince, Ontario, from single zircon analyses: implications for Archean sedimentation and tectonics in the Superior Province; Earth and Planetary Science Letters, v.99, p.195-205.

Davis, D.W., Poulsen, K.H. and Kamo, S.L. 1989. New insights into Archean crustal development from geochronology in the Rainy Lake area, Superior Province, Canada; Journal of Geology, v.97, p.379-398.

Douglas, R.J.W. 1973. Geological Provinces, Map 27-28, National Atlas of Canada, 4th Edition: Surveys and Mapping Branch, Department of Energy, Mines and Resources, Canada.

Fralick, P. and King, D. 1996. Mesoarchean evolution of Western Superior Province: evidence from metasedimentary sequences near Atikokan; *in* Western Superior Transect Second Annual Workshop (Oct. 20-21, 1995); Lithoprobe Report #53, Lithoprobe Secretariat, University of British Columbia, Vancouver, British Columbia, p.29-35.

Fyon, J.A., Breaks, F.W., Heather, K.B., Jackson, S.L., Muir, T.L., Stott, G.M. and Thurston, P.C. 1992. Metallogeny of metallic mineral deposits in the Superior Province of Ontario; *in* Geology of Ontario; Ontario Geological Survey, Special Volume 4, Part 2, p.1091-1176.

Goodwin, A.M. 1978. Archean crust in the Superior Geotraverse area: geologic overview*: in* Proceedings of the 1978 Archean Geochemistry Conference; Department of Geology, University of Toronto, Toronto, Ontario, p.73-106.

Heaman, L.M. and Easton, R.M. 2006. Preliminary U-Pb geochronology results from the Lake Nipigon Region Geoscience Initiative; Ontario Geological Survey, Miscellaneous Release—Data 191.

Jackson, S.L. 1985. Geology of the Lumby Lake area, western part, districts of Kenora and Rainy River; Ontario Geological Survey, Open File Report 5534, 178p.

Jolliffe, A.W. 1955. Geology and iron ores of Steep Rock Lake; Economic Geology, v.50, p.373-398.

——— 1966. Stratigraphy of the Steep Rock Group, Steep Rock Lake, Ontario; *in* The relationship of mineralization to Precambrian stratigraphy in certain mining areas of Ontario and Quebec, Precambrian Symposium, Geological Association of Canada, Special Paper 3, p.75-98.

Kamo, S.L. 2004. U-Pb geochronological investigations of rocks from the Lac des Iles area, northwestern Ontario, the Michipicoten greenstone belt, Wawa, and the Tomiko terrane, Mattawa, Ontario; unpublished report of the Jack Satterly Geochronology Laboratory, Department of Geology, University of Toronto, Earth Sciences Centre, 22 Russell Street, Toronto, Ontario M5S 3B1 (for further information, contact skamo@geology.utoronto.ca).

Lavigne, M.J. and Michaud, M.J. 2001. Geology of North American Palladium's Roby Zone deposit, Lac des Iles; Exploration and Mining Geology, v.10, p.1-17.

Lawson, A.C. 1885. Report on the geology of the Lake of the Woods region with special emphasis on the Keewatin (Huronian?) belt of the Archaean rocks; Geological Survey of Canada, Annual Report, 1885, v.1, Report CC, p.5-151.

——— 1912. The geology of Steeprock Lake, Ontario; Geological Survey of Canada, Memoir 28, p.7-15.

Logan, W.E., Murray, A., Hunt, T.S. and Billings, E. 1863. Geological Survey of Canada, report of progress from its commencement to 1863; Geological Survey of Canada, Report of Progress, 1863, 983p.

Ontario Geological Survey 1992. Tectonic assemblages of Ontario, explanatory notes and legend; Ontario Geological Survey, Map 2583.

Percival, J.A. and Williams, H.R. 1989. The Late Archean Quetico accretionary complex, Superior Province, Canada; Geology, v.17, p.23-25.

Poulsen, K.H. 2000. Geologic setting of mineralization in the Mine Centre–Fort Frances area; Ontario Geological Survey, Mineral Deposits Circular 29, 78p.

Rayner, N. and Stott, G.M. 2005. Discrimination of Archean domains in the Sachigo Subprovince: a progress report on the geochronology; *in* Summary of Field Work and Other Activities, 2005; Ontario Geological Survey, Open File Report 6172, p.10-1 to 10-21.

Schnieders, B.R. and Dutka, R.A. 1985. Property visits and reports of the Atikokan Economic Geologists, 1979-1983, Atikokan Geological Survey; Ontario Geological Survey, Open File Report 5539, 512p.

Smyth, H.L. 1891. Structural geology of Steep Rock Lake, Ontario; American Journal of Science, v.42, p.317-331.

Stockwell, H.C. 1964. Fourth report on structural provinces, orogenies and time-classification of rocks of the Canadian Precambrian Shield. Part II. Geological Studies; Geological Survey of Canada, Paper 64-17, 17p.

——— 1982. Proposals for time classification and correlation of Precambrian rocks and events in Canada and adjacent areas of the Canadian Shield, Part I: a time classification of Precambrian rocks and events; Geological Survey of Canada, Paper 80-19, 135p.

Stone, D. 2000. Geology, mineral chemistry and thermobarometry of the Entwine stock, northwest Ontario: base metal, platinum group element and gold mineralization; Ontario Geological Survey, Open File Report 6021, 37p.

——— 2005a. Geology and soil geochemistry of the Crooked Pine and western Steep Rock lakes areas of the Wabigoon Subprovince: implications for gold exploration; *in* Summary of Field Work and Other Activities 2005, Ontario Geological Survey, Open File Report 6172, p.11-1 to 11-11.

——— 2005b. Geology of the northern Superior area; Ontario Geological Survey, Open File Report 6140, 94p.

Stone, D., Kamineni, D.C. and Jackson, M.C. 1992. Precambrian geology of the Atikokan area, northwestern Ontario; Geological Survey of Canada, Bulletin 405, 106p.

Stone, D., Tomlinson, K.Y., Davis, D.W., Fralick, P., Hallé, J., Percival, J.A. and Pufahl, P. 2002. Geology and tectonostratigraphic assemblages, south-central Wabigoon Subprovince, Ontario; Ontario Geological Survey, Preliminary Map P.3348, scale 1:250 000.

Stott, G.M. 1997. The Superior Province, Canada; *in* Greenstone belts, Clarendon Press, Oxford, p.480-507.

Thurston, P.C. 1991. Archean geology of Ontario: introduction; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.73-80.

Thurston, P.C., Osmani, I.A. and Stone, D. 1991. Northwestern Superior Province: review and terrane analysis; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.81-144.

Tomlinson, K.Y., Davis, D.W., Stone, D. and Hart, T.R. 2001. New U-Pb and Nd geochronology from volcanic and granitoid rocks of the central Wabigoon Subprovince; Western Superior Lithoprobe–Western Superior NATMAP 2001 Annual Meeting, Lithoprobe Report #80, Lithoprobe Secretariat, University of British Columbia, Vancouver, British Columbia, p.10-16.

——— 2003. U-Pb age and Nd isotopic evidence for Archean terrane development and crustal recycling in the south-central Wabigoon Subprovince, Canada; Contributions to Mineralogy and Petrology, v.144, p.684-702.

Tomlinson, K.Y., Hughes, D.J., Thurston, P.C. and Hall, R.P. 1999. Plume magmatism and crustal growth at 2.9 and 3.0 Ga in the Steep Rock and Lumby Lake area, western Superior Province; Lithos, v.46, p.103-136.

Tomlinson, K.Y., Stott, G.M., Percival, J.A. and Stone, D. 2004. Basement terrane correlations and crustal recycling in the western Superior Province: Nd isotopic character of granitoid and felsic volcanic rocks in the Wabigoon Subprovince, N. Ontario, Canada; Precambrian Research, v.132, p.245-274.

Wilkinson, S.R. 1982. Gold deposits of the Atikokan area; Ontario Geological Survey, Mineral Deposits Circular 24, 54p.

Wilks, M.E. and Nisbet, E.G. 1988. Stratigraphy of the Steep Rock Group, northwestern Ontario, a major Archean unconformity and Archean stromatolites; Canadian Journal of Earth Sciences, v.25, p.370-391.

Williams, H.R. 1990. Subprovince accretion tectonics in the south-central Superior Province; Canadian Journal of Earth Sciences, v.27, p.383-4023.

Zartman, R.E. and Kwak, L.M. 1990. U-Th-Pb systematics in zircon and titanite; *in* Isotopic studies of the Eye–Dashwa lakes pluton and the long-term integrity of whole-rock and mineral systems, Atomic Energy of Canada Limited, Report AECL-10120, p.25-36. [Available from Scientific Document Distribution Office, Atomic Energy of Canada Limited, Chalk River, Ontario K0J 1J0.]

12. Project Unit 98-005. Regional Structures and their Implications in the Berens River Region, Northwestern Ontario

G.M. Stott[1], S. Buse[1] and S. Préfontaine[1]

[1]Precambrian Geoscience Section, Ontario Geological Survey

INTRODUCTION

Recent studies by several workers in conjunction with the NATMAP and Lithoprobe initiatives have focussed on improving our understanding of the tectonic evolution of Archean crust during the Neoarchean era (2.8 to 2.5 Ga) in particular. However, much of the Mesoarchean history (3.2 to 2.8 Ga) and the nature of Mesoarchean tectonics in northwestern Ontario remain largely unresolved with only local investigations providing new insight (e.g., Skulski et al. 2000; Sanborn-Barrie, Skulski and Parker 2004; Sanborn-Barrie et al. 2004; Bailes and Percival 2005). The Archean Superior Province in Ontario, north of latitude 51°30′, is characterized by comparatively narrower greenstone belts and large, elliptical batholiths with their long axes trending southeast. There are also significantly different foliation trends north of latitude 51°30′ (dominantly southeast trends within the felsic batholiths and plutons, and greenstone belts) than in the southern half of the Superior Province (generally east trends). However, several of the greenstone belts north of the Uchi domain, across the North Caribou terrane (Figure 12.1; *see also* Stott and Rainsford, this volume, Figure 13.1) show north to northeast foliation and bedding trends. This is exemplified by the narrow greenstone belts north of Red Lake—that is, the Berens Lake, McInnes Lake and Hornby Lake belts (*see* Figure 12.1). The Ontario Geological Survey (OGS) has mapped these narrow greenstone belts in 2006 as part of the Far North Geological Mapping Initiative (FNGMI) (*see* Préfontaine, this volume; Buse, this volume, Articles 21 and 22) and the resulting observations permit us to reconsider the broader structural framework encompassing these belts. Accordingly, there are 2 questions that we wish to highlight in this article:

1. Is there evidence of a Mesoarchean tectonic fabric across the North Caribou terrane that differs from the dominantly Neoarchean east trends of bedding and foliation? If so, could this older fabric affect the subsequent Neoarchean tectonic foliation trends?
2. How pervasive is the deformation produced by broad, southeast-directed shortening of the Superior Province in this northern region?

As part of the FNGMI in 2006, Préfontaine (this volume) and Buse (this volume, Articles 21 and 22) have completed detailed geological maps of the areas around McInnes, Frame and Berens lakes, respectively (*see* Figure 12.1). This work, coupled with available aeromagnetic data and age determinations, provides some new insights on the regional structural character encompassing the Hornby, McInnes and Berens lakes belts. As part of a re-interpreted compilation of the Precambrian geology north of latitude 51°30′, this article brings attention to the structural character of a broad region of the Berens River plutonic complex (BRPC), known previously as the Berens River Subprovince, north of Red Lake (*see* Figure 12.1). This is based on aeromagnetic data (Ontario Geological Survey 1999) and observations made by Cortis et al. (1988), and by the authors during 2006 (*see* Préfontaine, this volume;

Summary of Field Work and Other Activities 2006,
Ontario Geological Survey, Open File Report 6192, p.12-1 to 12-10.

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Buse, this volume, Articles 21 and 22). The main point of this article is to bring attention to the presence, across the granitoid region of the BRPC, of southeast-trending mega-shear zones with shear bands and intervening sigmoidal lozenges, and to suggest a) that the McInnes and Hornby greenstone belts are remnants of a once continuous, east-facing stratigraphic sequence preserving a north-striking Mesoarchean tectonic fabric; and b) that a broad north-trending D_2 dextral shear zone, arcing west-northwest, encompasses the Hornby–McInnes–Berens greenstone belts and adjacent, subvertical tonalite-granodiorite sheet-like intrusions. We suggest that this north-trending Hornby–McInnes structural zone forms the eastern flank of an array of northwest-trending mega-shears that dominate the structural and aeromagnetic grain of the Berens River Subprovince.

REGIONAL GEOLOGY

A regional geological survey was previously conducted by Stone (1998) across the Berens River Subprovince. Reconnaissance geological and structural observations were conducted by Cortis et al. (1988) on the McInnes and Hornby greenstone belts. Geochronology of volcanic and plutonic units from samples collected by these 2 studies was reported by Corfu et al. (1998) and Corfu and Stone (1998). These workers recognized that the greenstone belts represented extensions of supracrustal units potentially correlative with strata in the northeastern Red Lake belt. Age determinations (Corfu and Stone 1998) show a progressive younging of strata eastward from the base of the McInnes belt, with an age of 2974 Ma to 2969 Ma, to the top of the sequence, with an age of 2928 Ma. An age of circa 2901 Ma from the Hornby belt is consistent with the overall eastward younging of volcanic strata observed across the combined McInnes and Hornby belts and implies that these belts were once continuous before disruption by intervening Neoarchean felsic intrusions. A north-trending aeromagnetic lineament extending from the Red Lake greenstone belt towards the McInnes belt corresponds to the linear chain of thin greenstone belts, amphibolitic slivers and tabular amphibolite inclusions within sheet-like granitoid bodies that were mapped from south of Berens Lake to McInnes Lake (Préfontaine, this volume; Buse, this volume, Article 22, respectively).

Whereas the bulk of the strata within the McInnes belt show massive to pillowed basaltic flows overlain by dacitic pyroclastic deposits, the Hornby belt is dominated by massive to pillowed mafic to ultramafic flows with intervening ultramafic to mafic sill-like intrusions. Succeeding this is a unit of dacitic pyroclastic breccia up to 400 m thick, which underlies a southeast-facing sequence of sillimanite-bearing wacke and garnet-biotite wacke with minor recrystallized banded chert, argillite and local granular quartz arenite beds (Cortis et al. 1988). The U/Pb zircon age of the dacitic unit is circa 2901 Ma (Corfu et al. 1998). The eastern margin of the Hornby belt is in contact with a strongly deformed biotite tonalite. The deformation can be traced for some distance into the intrusion. Apart from strain aureoles imposed by external felsic plutons to the west and south of the belt, the mineral and stretching lineations across the belt and into the eastern tonalite correspond closely and plunge moderately to the south or southeast.

The felsic plutonic bodies that flank these narrow greenstone belts are generally irregular to elongate in map-view. Tonalite to granodiorite appears to have injected as an irregular, steeply dipping, tabular sheet between the Hornby and McInnes belts. A strong, arcuate, linear aeromagnetic anomaly also extends between the 2 greenstone belts and appears to highlight the sheet-like character of the felsic intrusion.

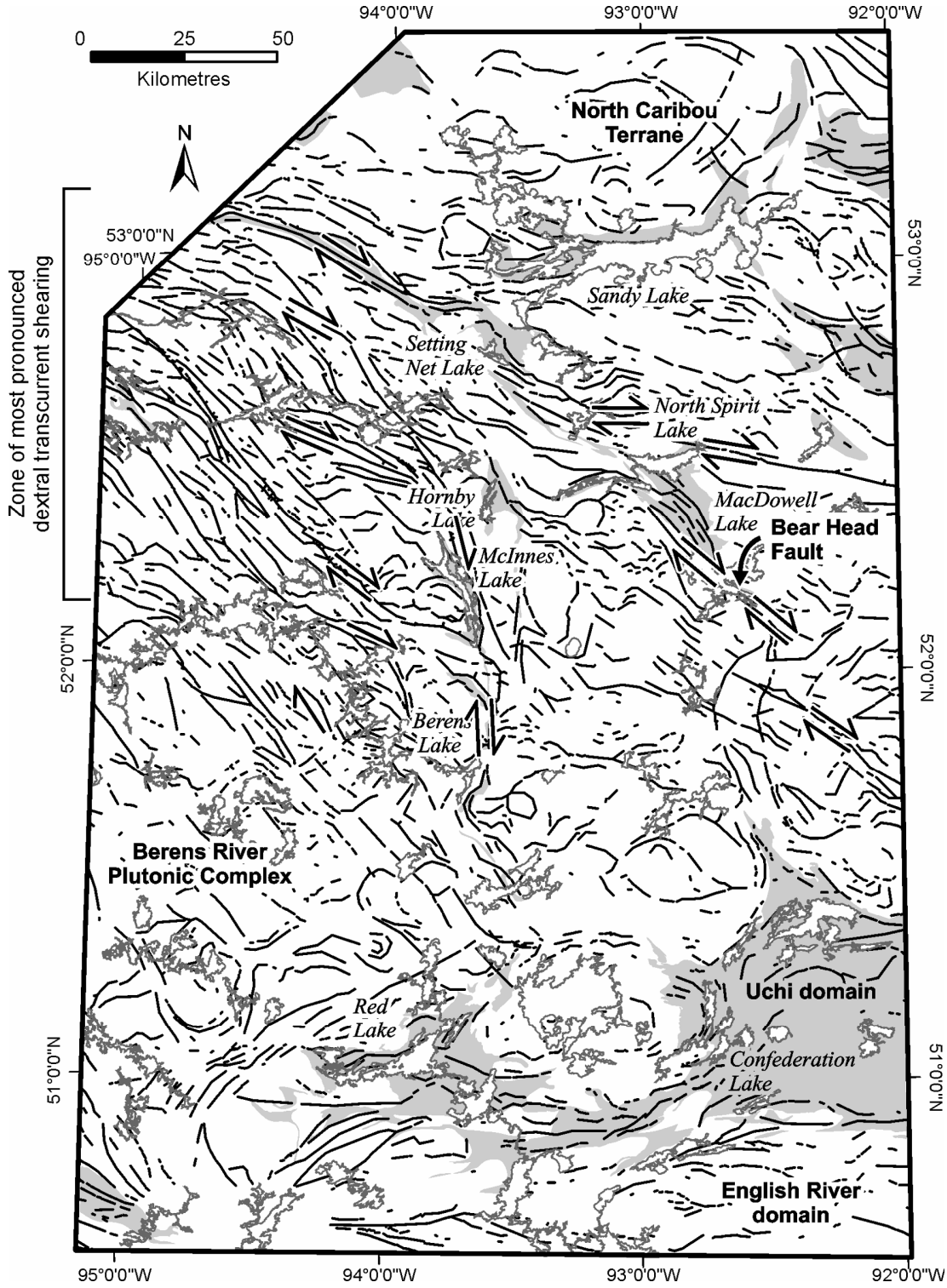

Figure 12.1. Map of the Berens River plutonic complex in the North Caribou terrane showing the Archean greenstone belts (grey) and traces of the aeromagnetic lineaments drawn from the shaded relief map in Figure 12.2. The lineaments west of Hornby, McInnes and Berens lakes show evidence of southeast-trending, dextral shear zones with asymmetric, sigmoidal lozenge-shaped blocks of plutonic rocks bounded by the major shear zones. Several of the major shear zones were observed by Stone (1998). This broad zone of pronounced dextral shearing terminates at the north-trending zone of greenstone belts at Hornby, McInnes and Berens lakes. The remainder of the Berens River plutonic complex is dominated by semi-circular batholiths.

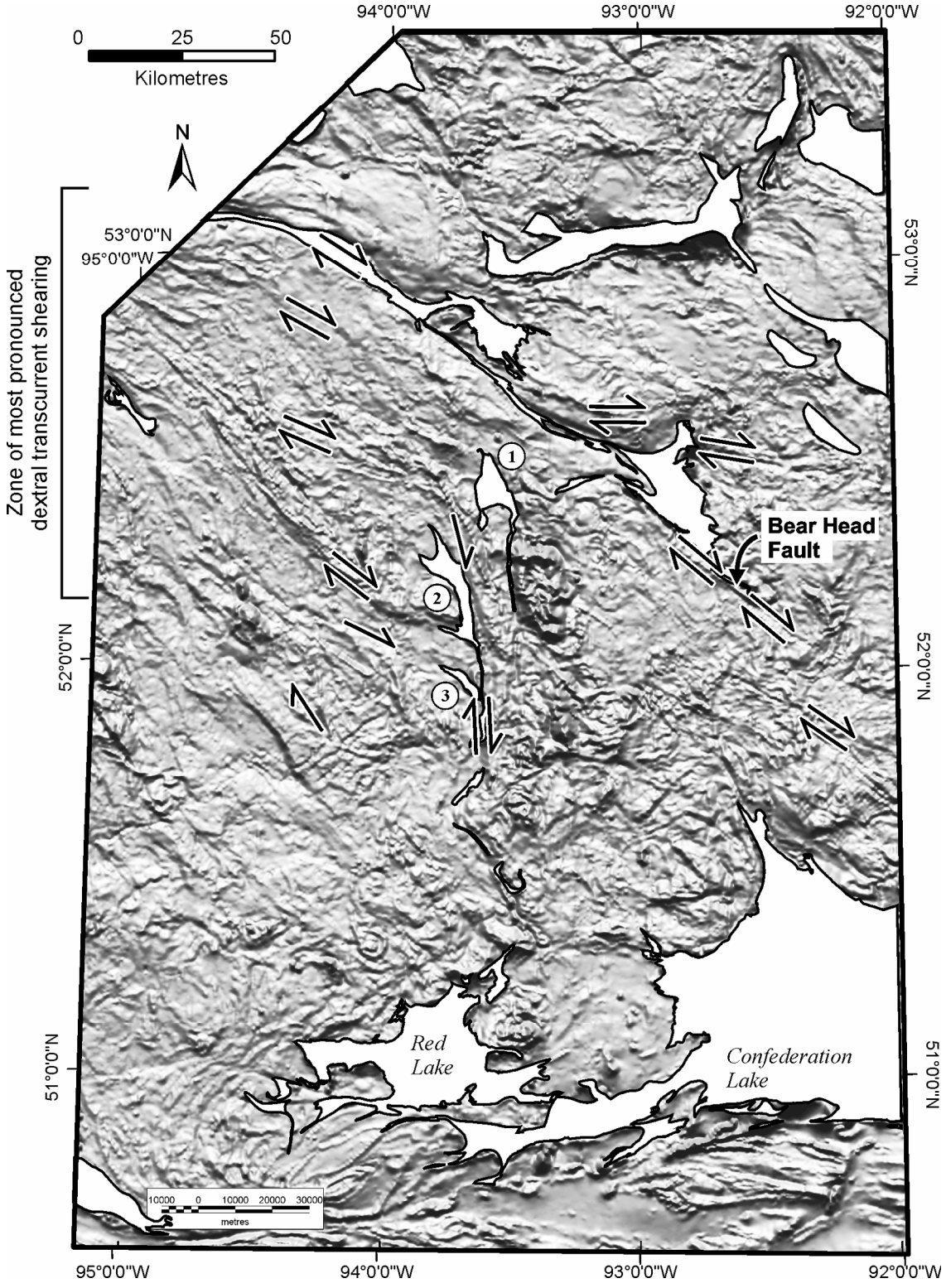

Figure 12.2. Map of the Berens River plutonic complex showing the greenstone belts (white) and the shaded relief image of the first vertical derivative of the regional aeromagnetic survey (*from* Ontario Geological Survey 1999). Dextral shear sense inferred from aeromagnetic image as shown. Numbered greenstone belts are 1) Hornby Lake; 2) McInnes Lake; and 3) Berens Lake chain of small greenstone belt slivers. Note west of Hornby–McInnes–Berens lakes zone is a broad zone of dextral shearing.

STRUCTURAL GEOLOGY

Regional stratigraphic facing directions in the Hornby and McInnes belts is to the east, consistent with the east younging of U/Pb zircon ages of the Mesoarchean felsic metavolcanic units across these belts (*see* Figure 12.1). Structural measurements taken in each of the greenstone belts show strikingly similar features: a dominant foliation parallel to bedding (an $S_{0\text{-}1}$ composite planar fabric), with asymmetric Z folds (F_2) and associated mineral and stretching lineations (L_2) plunging moderately southwards as shown by Cortis et al. (1988), Préfontaine (this volume) and Buse (this volume, Article 22) for the Hornby, McInnes and Berens belts, respectively. The Hornby Lake strata dip to the east in contrast to the McInnes–Berens Lake greenstone belts, which are stratigraphically overturned and dip consistently to the west. Between the Hornby and the McInnes–Berens Lake belts, a major sheet-like intrusive package of tonalite to granodiorite is evident from the aeromagnetic image (Figure 12.2). The earlier D_1 foliation is overprinted by widely observed D_2 dextral shearing, various shear-sense indicators and abundant Z-folds that plunge moderately to the south. This shear fabric also appears to affect the tonalite east of the McInnes and Berens belts and a tonalite intrusion on the eastern flank of the Hornby belt (Cortis et al. 1988). The Z-folding (Photo 12.1) can be seen on all scales, and appears as large open folds of the strata along the length of the McInnes belt and notably along the south-trending length of the eastern metasedimentary sequence in the Hornby belt (*see* Figure 12.1).

On a regional scale, there is evidence of long, curviplanar mega-shear zones separated by asymmetric sigmoidal lozenges that encompass most of the felsic plutonic Berens River Subprovince between Red Lake and the Bear Head fault zone near North Spirit Lake. Figure 12.2 is a shadow-enhanced aeromagnetic image that illustrates the dextral, ductile, transcurrent mega-shear zones anastomosing around regions of less deformed plutonic rocks. Local evidence of ductile to brittle shear in the rocks, corresponding to some of these aeromagnetic linear anomalies, has been observed during regional mapping by Stone (1998). On a broader scale, this style of dextral, transcurrent shear zones bordering, lozenge-shaped areas with sigmoidal fabric, especially in the granitic bodies, is evident from the aeromagnetic data across the breadth of the North Caribou terrane (Ontario Geological Survey 1999).

The region where this feature is most pronounced is west of the McInnes–Berens lakes chain of greenstone belts and amphibolite slivers. The structural and aeromagnetic grain of this western region of felsic plutonic rocks appears to deflect southwards, abutting against this greenstone chain. Extending from the ends of the Hornby and McInnes greenstone belts in particular are some amphibolite tails interfingering and forking between individual granitoid bodies. This deformation appears to predate the emplacement of the Frame Lake intrusion (Buse, this volume, Article 21), from which zircons of the granodiorite core were recovered and an age obtained by Corfu and Ayres (1984) of circa 2696 Ma.

The Hornby and McInnes–Berens belts form the eastern margin of this pronounced domain of shear zones and lozenges accentuated in the shadow-enhanced aeromagnetic image in Figure 12.2. Not surprisingly, these belts form a long structural zone characterized by pronounced dextral shearing and Z-folds on all scales along the length of this greenstone chain. East of these greenstone belts, there is a more symmetric domain of granitoid batholiths, apparent in Figure 12.2, extending from the Trout Lake batholith in the south, separating the Red Lake and Confederation greenstone belts, to the area south of North Spirit Lake and east of the Hornby Lake belt.

In summary, the Hornby–McInnes structural zone, encompassing Hornby and McInnes–Berens lake greenstone belts, trends northward from the Red Lake greenstone belt forming an eastern buttress to the complex of multiple shear zones and lozenges that characterize the structural grain of the main portion of the Berens River Subprovince to the west. A significant change in the structural style occurs across this zone, from a dominantly southeast-trending complex of dextral shear zones, faults and intervening asymmetrical lozenge-shaped crustal blocks on the west side to a prevalence of large, subcircular plutonic

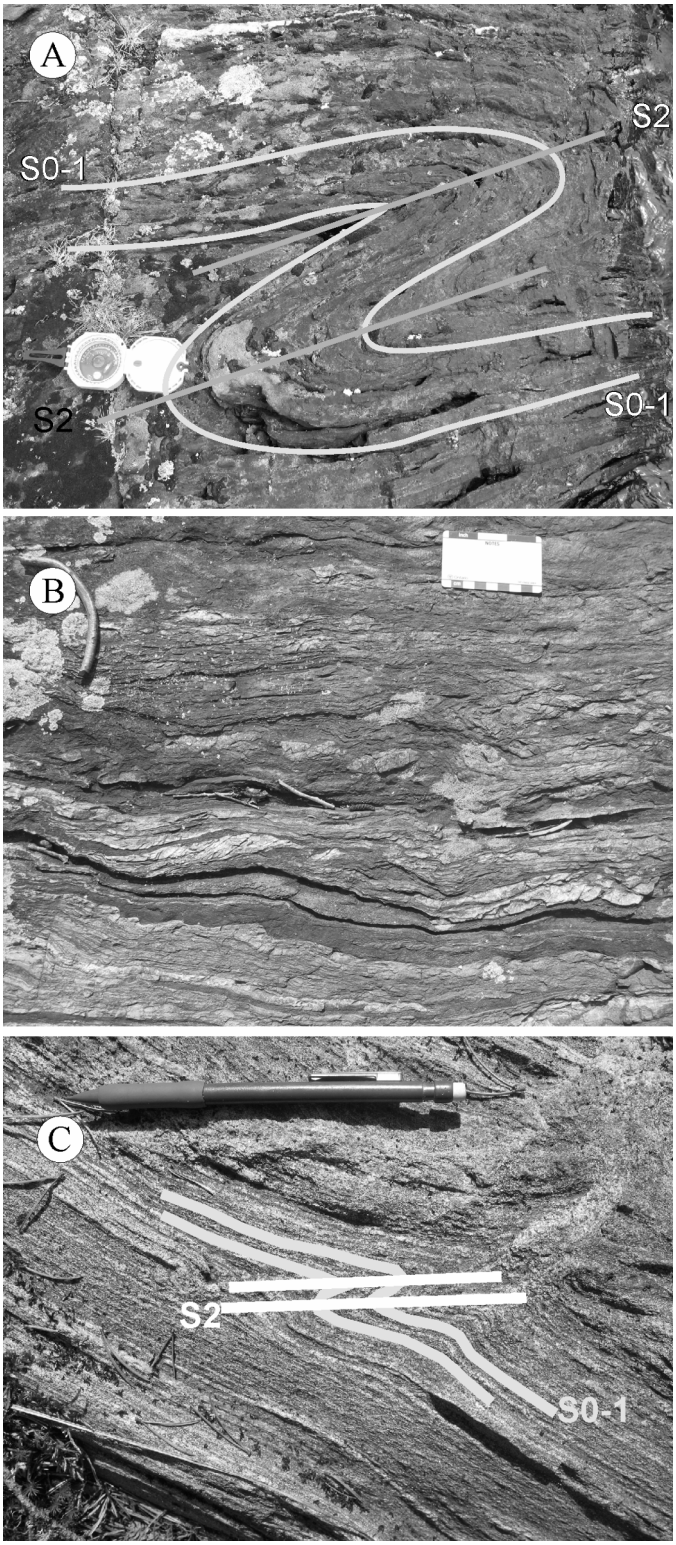

Photo 12.1. a) D_2 Z-fold in D_1 foliated mafic metavolcanic rocks on McInnes Lake; b) thinly bedded garnet-sillimanite-bearing wacke-siltstone and chert with bedding parallel foliation S_0-S_1 with numerous open D_2 Z-folds and counterclockwise-back-rotated chert boudins, on McInnes Lake; c) upper amphibolite-grade metasedimentary rocks showing centimetre-scale D_2 Z folds, southeast of South Berens Lake.

batholiths on the east, from the Trout Lake batholith, east of Red Lake, to a similar batholithic area south of North Spirit Lake belt. The southeast-trending complex of shear zones and lozenges is bounded on the north side by the Bear Head fault (*see* Figure 12.2) and dissipates southward into discrete southeast-trending faults in a batholithic area northwest of the Red Lake greenstone belt.

DISCUSSION

One of the dominant features of the Neoarchean tectonic framework in northwestern Ontario is the prevalent east to east-northeast trend of bedding, foliations and axial traces of folds roughly parallel to the trace of terrane boundaries. This pattern is interpreted to have developed as a consequence of the Neoarchean construction of the Superior Province by episodic, orogenic assembly of terranes (e.g., Percival et al. 2006). Trends of greenstone belts are more complex in the North Caribou terrane, which includes most of the Uchi domain along its southern flank. Most notable are the northward trends observed north of Red Lake and continuing into the Sandy Lake and Muskrat Dam greenstone belts. Since much of the North Caribou terrane contains Mesoarchean supracrustal units and felsic plutons, we would argue that attempts to further characterize the Mesoarchean tectonic history would best succeed with investigations focussed on north- and northeast-trending sets of greenstone belts across the North Caribou terrane beyond the McInnes–Berens belts to the Sandy Lake and Muskrat Dam belts where there is less evidence of Neoarchean plutonism and penetrative deformation.

One of the challenges in deciphering the tectonic history of the Superior Province prior to the Neoarchean record is identifying Mesoarchean structures. We know that the North Caribou terrane harbours relict Mesoarchean structures and metamorphic history. This is illustrated where the arcuate North Caribou greenstone belt is intruded and deformed by the crescent-shaped North Caribou pluton circa 2864 Ma (Davis and Stott 2001), wedged between the 3 billion-year-old greenstone belt and a tonalite gneiss dome (Stott et al. 1989). We argue that the north-trending Hornby–McInnes–Berens chain of greenstone belts reflects, in part, a Mesoarchean structural grain that has been subsequently deformed and sheared during the late Neoarchean.

We would infer from the consistent eastward stratigraphic facing of units ranging in age from 2974 to 2901 Ma (Corfu et al. 1998) that the McInnes–Berens chain of belts was part of a once-continuous Mesoarchean volcanic belt that extended to the Hornby belt. This once-broad volcanic belt (at least 30 km wide) was subsequently disrupted by tonalite to granodiorite sheet-like intrusions, as is evident from recent mapping. Its history of volcanic episodes overlaps with the Ball (circa 2940 to <2925 Ma) and youngest Balmer (2989 to 2964 Ma) assemblages in the Red Lake greenstone belt (summarized in Sanborn-Barrie, Skulski and Parker 2004) and possibly the Narrow Lake assemblage (<2975, >2870 Ma) in the Confederation belt (Rogers 2002).

An interpretation of the aeromagnetic data, shown in Figures 12.1 and 12.2, highlights the presence of multiple shear zones across the northwestern quarter of the BRPC, from west of Red Lake north to the Bear Head fault. These shear zones with sigmoidal trend lines, are right-handed and transcurrent and are most pronounced across the northwest quarter of the BRPC, south of the Bear Head fault. The intervening large lozenge-shaped areas, between curviplanar shear zones and faults, show evidence from the aeromagnetic fabric of local northeast trends rotated towards the southeast. The age of this transpressive deformation is limited by Neoarchean plutons that have been transected by the shearing. Recent mapping of the 2690 Ma Frame Lake pluton (Buse, this volume, Article 21) indicates that it is unaffected by the shear zone encompassing the Hornby–McInnes–Berens belts. However, a monzonite intrusion of 2686±2 Ma age (Corfu and Stone 1998) and the Pakeagama pegmatite with a U/Pb age from columbite-tantalite minerals of 2670±5 Ma (Smith et al. 2004) were sheared by the Bear Head fault to the north, indicating a protracted history of subsequent brittle–ductile fault activity. The chain of Mesoarchean

greenstone belts, Hornby–McInnes–Berens, appears to have served as a buttress to this zone of late Neoarchean dextral shearing that dominates the northwest quarter of the BRPC, deflecting this deformation southwards along the belts and adjacent sheet-like felsic plutons. This appears to have resulted in a significant drop in the number of shear zones east of this chain of belts and preserving the set of batholiths to the east, as evident in Figure 12.2.

If large crustal areas like the northwest quarter of the BRPC in Ontario have been selectively affected by a concentration of late orogenic transcurrent shear zones and deflected south towards the Red Lake greenstone belt, then it reaffirms the argument that a fuller understanding of the structural attractiveness of certain greenstone belts to be enriched in lode gold mineralization requires an evaluation of the constraints on the variability of late orogenic deformation character and intensity across broader parts of the Archean crust beyond individual greenstone belts.

CONCLUSIONS

1. If the eastward trend of volcanic belts within the Uchi domain are largely created and accentuated during a) autochthonous (plus accretionary) growth along this Andean-style boundary on the north side of an Archean subduction zone, plus b) crustal shortening upon collision with Winnipeg River terrane during the Uchian orogeny, and c) widespread transpressive shearing during the late stage of this collision (Stott 1997; Percival et al. 2006), then northward trends of volcanic belts, especially inboard within the North Caribou terrane, might be a composite of Mesoarchean tectonic fabric modified to some degree by later Neoarchean orogenesis. Accordingly, the north-trending chain of Hornby, McInnes and Berens greenstone belts probably represents a relict Mesoarchean tectonic trend in the North Caribou terrane that predated Neoarchean deformation across the Uchi domain (Stott and Corfu 1991), but was subsequently modified by late Neoarchean transpressive deformation prior to 2690 Ma, the age of the posttectonic Frame Lake pluton southeast of Hornby Lake (Corfu and Ayres 1984). This northward trend is otherwise difficult to account for given that the general Neoarchean signature trend of foliation trajectories across northwestern Ontario is east to southeast. This postulated northward Mesoarchean trend appears deflected where it continues across the North Caribou, through the Sandy Lake and Muskrat Dam greenstone belts (*see* Figure 12.1).

2. A significant part of the Berens River portion of the North Caribou terrane, between Red Lake and the Bear Head fault, contains a complex of Neoarchean mega-shear zones and intervening lozenges of deformed plutonic rocks and narrow greenstone belts. This appears to be a much broader zone than was previously thought and a more penetrative zone of deformation than is apparent further north across most of the North Caribou terrane (e.g., Osmani and Stott 1988) where Neoarchean shear zones and faults are more widely spaced. The dominant deformation across the central Uchi domain of greenstone belts is a transpressive D_2 fabric observed by Stott and Wilson (1986) and Stott, Kay and Sanborn (1987) in the Meen–Dempster and Lake St. Joseph areas, and composite D_1-D_2 fabric observed by Dinel, Pettigrew and Gagnon (this volume) in the Bamaji–Fry lakes area. It is characterized by subvertical to steep northward foliation dips, and mineral and stretching lineations plunging moderately to steeply eastward, accompanied by local dextral shearing and Z-folds. This broad D_2 deformation is consistent with the dominant deformation style apparent from the aeromagnetic image of the northwestern quarter of the Berens River plutonic complex (*see* Figure 12.2) and from observations made in the McInnes and Berens lakes areas by Préfontaine (this volume), and Buse (this volume, Article 22), respectively.

3. In the Red Lake greenstone belt, the north- to northeast-striking D_1 foliation and dominant east-striking D_2 foliation are Neoarchean in age as shown by Sanborn-Barrie, Skulski and Parker (2004) who also observed that an earlier non-penetrative deformation involved recumbent folding of the

circa 2.99 Ga Balmer assemblage prior to 2750 Ma and possibly of Mesoarchean age. The arcuate deformation and metamorphism of the North Caribou greenstone belt by the 2870 Ma crescent-shaped North Caribou pluton is the best evidence of Mesoarchean tectonism preserved in northwestern Ontario (Stott et al. 1989). Overall, there is sufficient evidence and encouraging inference of pre-Neoarchean deformation in rocks older than 2.9 Ga to suggest that future investigations of a Mesoarchean tectonic history and tectonic processes might be fruitful especially in the North Caribou terrane where pervasive Neoarchean magmatism and deformation is restricted and Neoarchean deformation is limited to discrete shear zones and faults.

REFERENCES

Bailes, A.H. and Percival, J.A. 2005. Geology of the Black Island area, Lake Winnipeg, Manitoba (parts of NTS 62P1, 7 and 8); Manitoba Industry, Economic Development and Mines; Manitoba Geological Survey, Geoscientific Report GR2005-2, 33p.

Corfu, F. and Ayres, L.D. 1984. U-Pb age and genetic significance of heterogeneous zircon populations in rocks from the Favourable Lake area, northwestern Ontario; Contributions to Mineralogy and Petrology, v.88, p.86-101.

Corfu, F., Davis, D.W., Stone, D. and Moore, M.L. 1998. Chronostratigraphic constraints on the genesis of Archean greenstone belts, northwestern Superior Province, Ontario, Canada; Precambrian Research, v.92, p.277-295.

Corfu, F. and Stone, D. 1998. Age structure and orogenic significance of the western Berens River composite batholiths, western Superior Province; Canadian Journal of Earth Sciences, v.35, p.1089-1109.

Cortis, A.L., Stott, G.M., Osmani, I.A., Atkinson, B. and Thurston, P.C. 1988. A geological re-evaluation of northwestern greenstone belts; *in* Summary of Field Work and Other Activities 1988, Ontario Geological Survey, Miscellaneous Paper 141, p.28-52.

Davis, D.W. and Stott, G.M. 2001. Geochronology of several greenstone belts in the Sachigo Subprovince, northwestern Ontario; Ontario Geological Survey, Open File Report 6070, p.18-1 to 18-13.

Ontario Geological Survey 1999. Single master gravity and aeromagnetic data for Ontario; Ontario Geological Survey, ERLIS Data Set 1036.

Osmani, I.A. and Stott, G.M. 1988. Regional-scale shear zones in Sachigo Subprovince and their economic significance; *in* Summary of Field Work and Other Activities 1988, Ontario Geological Survey, Miscellaneous Paper 141, p.53-67.

Percival, J.A., Sanborn-Barrie, M., Skulski, T., Stott, G.M., Helmstaedt, H. and White, D.J. 2006. Tectonic evolution of the western Superior Province from NATMAP and Lithoprobe studies; Canadian Journal of Earth Sciences, v.43, p.1085-1117.

Rogers, N. 2002. Geology, Confederation Lake, Ontario; Geological Survey of Canada, Open File 4265, scale 1:50 000.

Sanborn-Barrie, M., Rogers, N., Skulski, T., Parker, J., McNicoll, V., and Devaney, J. 2004. Geology and tectonostratigraphic assemblages, East Uchi Subprovince, Red Lake and Birch–Uchi belts, Ontario; Geological Survey of Canada, Open File 4256; Ontario Geological Survey, Preliminary Map P.3460, scale 1:250 000.

Sanborn-Barrie, M., Skulski, T. and Parker, J. 2004. Geology, Red Lake greenstone belt, western Superior Province, Ontario; Geological Survey of Canada, Open File 4594, scale 1:50 000.

Skulski, T., Corkery, M.T., Stone, D., Whalen, J.B. and Stern, R.A. 2000. Geological and geochronological investigations in the Stull Lake–Edmund Lake greenstone belt and granitoid rocks of the northwestern Superior Province; *in* Report of Activities 2000; Manitoba Industry, Trade and Mines Geological Survey, p.117-128.

Smith, S.R., Foster, G.L., Romer, R.L., Tindle, A.G., Kelley, S.P., Boble, S.R., Horstwood, M. and Breaks, F.W. 2004. U-Pb columbite-tantalite chronology of rare-element pegmatites using TIMS and laser ablation – multi collector – ICP-MS; Contributions to Mineralogy and Petrology, v.147, p.549-564.

Stone, D. 1998. Precambrian geology of the Berens River Area, northwest Ontario; Ontario Geological Survey, Open File Report 5963, 116p.

Stott, G.M. 1997. The Superior Province, Canada; *in* Greenstone belts, Oxford Clarendon Press, Oxford Monograph on Geology and Geophysics 35, p.480-507.

Stott, G.M. and Corfu, F. 1991. Uchi Subprovince; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.145-236.

Stott, G.M., Corfu, F., Breaks, F.W. and Thurston, P.C. 1989. Multiple orogenesis in northwestern Superior Province; Geological Association of Canada–Mineralogical Association of Canada, Program with Abstracts, v.14, p.A56.

Stott, G.M., Kay, S.V. and Sanborn, M.M. 1987. Precambrian geology of the Lake St. Joseph area, west half; Ontario Geological Survey, Map P.3050, scale 1:50 000.

Stott, G.M. and Wilson, 1986. Precambrian geology of the Muskegsagagen–Bancroft lakes area; Ontario Geological Survey, Preliminary Map P.3049, scale 1:50 000.

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13. Project Units 98-006 and 98-007. The Precambrian Geology Underlying the James Bay and Hudson Bay Lowlands as Interpreted from Aeromagnetic Data and a Revised Terrane Map for Northwestern Ontario

G.M. Stott[1] and D.R.B. Rainsford[1]

[1]Precambrian Geoscience Section, Ontario Geological Survey

OVERVIEW

This article introduces a new interpretation, from aeromagnetic and limited diamond-drill hole data, of the Precambrian bedrock geology underlying the Paleozoic rocks of the James Bay and Hudson Bay lowlands. In part, as a result of this interpretation, we also present a revision of the Archean Superior Province terrane and domain boundaries in northwestern Ontario (Figure 13.1). The broad Paleozoic cover rocks of the James Bay and Hudson Bay lowlands in Ontario mask the underlying Precambrian rocks. Until high-resolution aeromagnetic surveys became publicly available (Ontario Geological Survey 2003), these cover rocks greatly limited our ability to interpret the Precambrian crustal framework underneath and our ability to correlate major Archean terrane boundaries from Ontario across James Bay to Quebec.

Significant progress has been made over the past 20 years in defining tectonically significant subdivisions in the Superior Province (e.g., Stott 1997; Stott and Corkery 2006; Percival et al. 2006) and moving beyond the mainly lithology-based subprovince subdivisions of the Superior Province. The most significant changes to previous subdivisions occur in northwestern Ontario as a consequence of the geological interpretations of aeromagnetic data across the James Bay and Hudson Bay lowlands plus geochronological and isotopic results (e.g., Skulski et al. 2000; Rayner and Stott 2005). This interpretation of the Archean greenstone belt distributions under the lowlands, and the terrane and domain boundaries has been made from the regional aeromagnetic data (Ontario Geological Survey 1999; Geological Survey of Canada 2003), plus high-resolution data (Ontario Geological Survey 2003) from the James Bay Lowland, and various derivative products, including shadow-enhanced first and second vertical derivatives as illustrated in Figures 13.2 to 13.4. The terrane and domain boundaries shown in Figure 13.1 incorporate and revise previous and current interpretations (e.g., Thurston, Osmani and Stone 1991; Stone 2005; Parks et al. 2006; Stott and Corkery 2006; Percival et al. 2006).

Some terms are defined generally as follows.

Archean tectonostratigraphic *terranes* are considered as crustal blocks with geological histories substantially different from adjacent blocks, although parts of the late history of adjacent terranes typically overlap. They include one or more tectonic (tectonostratigraphic) assemblages and plutonic suites, and at least part of the terrane boundaries are clearly marked by major faults. Those regions with more complex Meso- to Neoarchean orogenic histories are regarded as *superterranes*, thought to comprise at least 2 terranes that generally cannot be physically separated.

Summary of Field Work and Other Activities 2006,
Ontario Geological Survey, Open File Report 6192, p.13-1 to 13-10.

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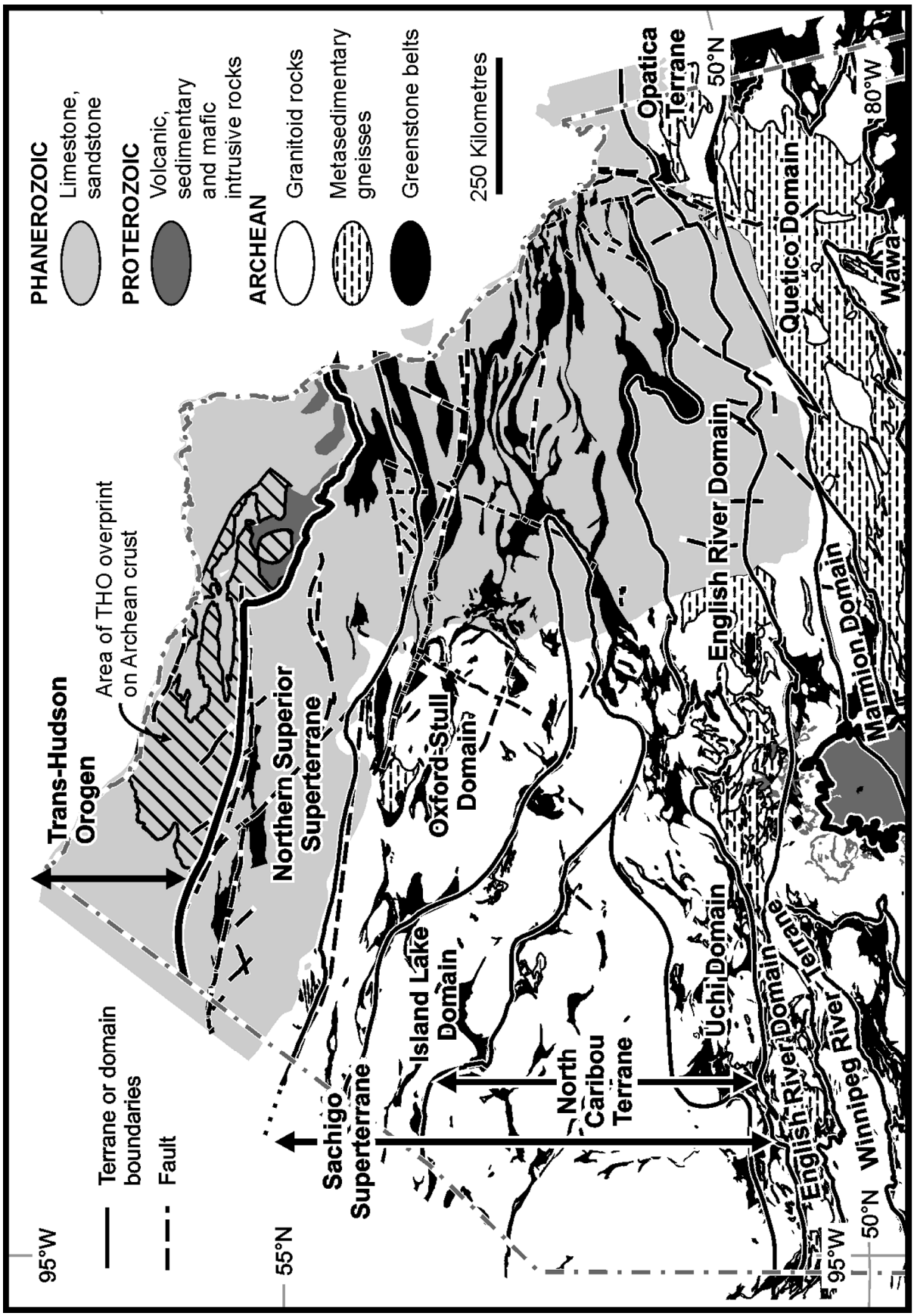
PHANEROZOIC
Limestone, sandstone
PROTEROZOIC
Volcanic, sedimentary and mafic intrusive rocks
ARCHEAN
Granitoid rocks
Metasedimentary gneisses
Greenstone belts
250 Kilometres
Terrane or domain boundaries
Fault
Area of THO overprint on Archean crust
Trans-Hudson Orogen
Northern Superior Superterrane
Oxford-Stull Domain
Island Lake Domain
Sachigo Superterrane
North Caribou Terrane
Uchi Domain
English River Domain
Quetico Domain
Marmion Domain
Opatica Terrane
Wawa
English River Subprovince
Winnipeg River Terrane
95°W
55°N
50°N
80°W

Domains are those marginal parts of terranes or superterranes that are thought to have been largely added autochthonously or for which sparse evidence exists (e.g., Marmion domain) to treat them as separate terranes.

Tectonic assemblages are typically dominated by volcanic or sedimentary rock units deposited during a discrete interval of time in a common depositional or tectonic setting. An assemblage may include one or more groups or formations where they are defined.

METHODOLOGY

A composite image was used for interpreting the regional geology based on the shaded relief of both colour total field and greyscale first vertical derivative of the regional aeromagnetic survey in Ontario (Ontario Geological Survey 1999) plus the colour shaded relief images of first and second vertical derivatives of a high-resolution aeromagnetic supergrid (Ontario Geological Survey 2003) covering a significant part of the James Bay Lowland. After experimenting with various images of the data sets, this provided a reasonable tool for interpreting the Precambrian substrate under the lowland and was compared with the first vertical derivative Bouguer gravity map in assessing the locations of probable greenstone belts in areas outside the high-resolution aeromagnetic supergrid. Most of the interpretations were done on transparent sheets, which were subsequently digitized into geographic information system (GIS) format. The second author is also testing a set of methods for calculating, from aeromagnetic data, the depth to Archean bedrock below the Paleozoic cover rocks in the James Bay Lowland and comparing these with available diamond-drill hole data. The results of these interpretations plus a revision of the drill hole data compilation (McIlraith and Stott 2005) will be published in 2007. The following presents some highlights of the interpretive work. The main highlights of the lowland interpretation are given in the extended caption to Figure 13.1.

Figure 13.1. (facing page) This map displays a composite of the bedrock geology of the northern portion of the Archean Superior Province in Ontario. Some features to note:
- The merging of greenstone belts of Uchi domain and Oxford–Stull domain under the James Bay Lowland;
- A large indentor-like feature underlies the James Bay Lowland, flanked by faults;
- The separation of English River and Quetico metasedimentary domains east of the Wabigoon Subprovince by a ridge of felsic plutonic rocks, with high magnetic field intensity, extending westward from the Opatica gneisses of Quebec. The Opatica terrane might extend to the Winnipeg River terrane where the latter is interpreted to underlie the northern part of the eastern Wabigoon Subprovince;
- The Trans-Hudson Orogen underlies the northern half of the Hudson Bay Lowland;
- Apparent reworked Archean Northern Superior superterrane crust under Hudson Bay Lowland within the Trans-Hudson Orogen;
- Broad areas of pronounced aeromagnetic field intensity characterize large parts of the Northern Superior superterrane under the Hudson Bay Lowland in Ontario and correspondingly resemble the Pikwitonei gneisses, including the Assean and Split Lake blocks on strike in Manitoba.
- Potential correlation of Northern Superior superterrane with the 3.8 Ga Porpoise Cove volcanics (David et al. 2002) in Tikkerutuk domain (Alain Leclair, Geoscientist, Géologie Québec, personal communication, 2006) and the >3.5 Ga Assean gneisses (Böhm et al. 2000).
- Areas interpreted to be part of the Paleoproterozoic Sutton Inlier are outlined where exposed. The Sutton "Inlier", of shallow water platform sedimentary units and overlying gabbro sill, does not appear to be one large area but a set of inliers and should in future be referred to as the Sutton Inliers. The eastern Sutton Inliers with subsurface extensions are shallowly dipping, northward concave and crescent-shaped, based on aeromagnetic patterns, which correspond closely with the distribution of outcrops observed by Bostock (1970). They resemble "klippe" that might have been transported a short distance southwards. Folded strata related to the Sutton Inliers are shown aeromagnetically to extend discontinuously northwards towards the Hudson Bay coast upon apparently reworked Archean crust within the Trans-Hudson Orogen. The Trans-Hudson Orogen, including areas of reworked Archean crust, appears to underlie the northern half of the Hudson Bay Lowland, based on interpretation of aeromagnetic images.

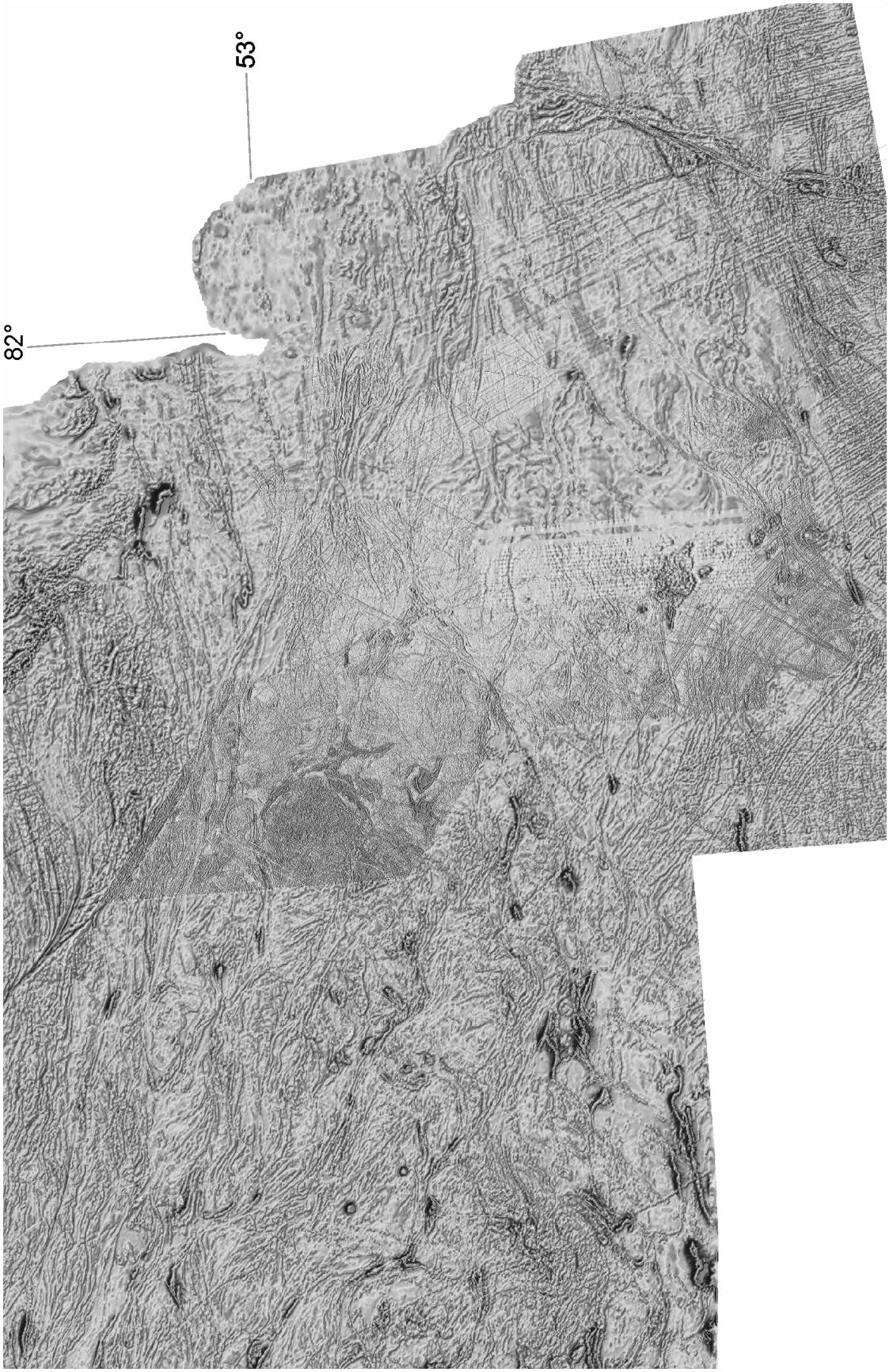

Figure 13.2. The James Bay Lowland region showing a semi-transparent composite, grey-scale relief image of the first vertical derivative of the regional aeromagnetic survey and a portion of the high-resolution aeromagnetic supergrid as a composite of first and second vertical derivatives. This image highlights the greater resolution available for geological interpretation in the western part of the James Bay Lowland.

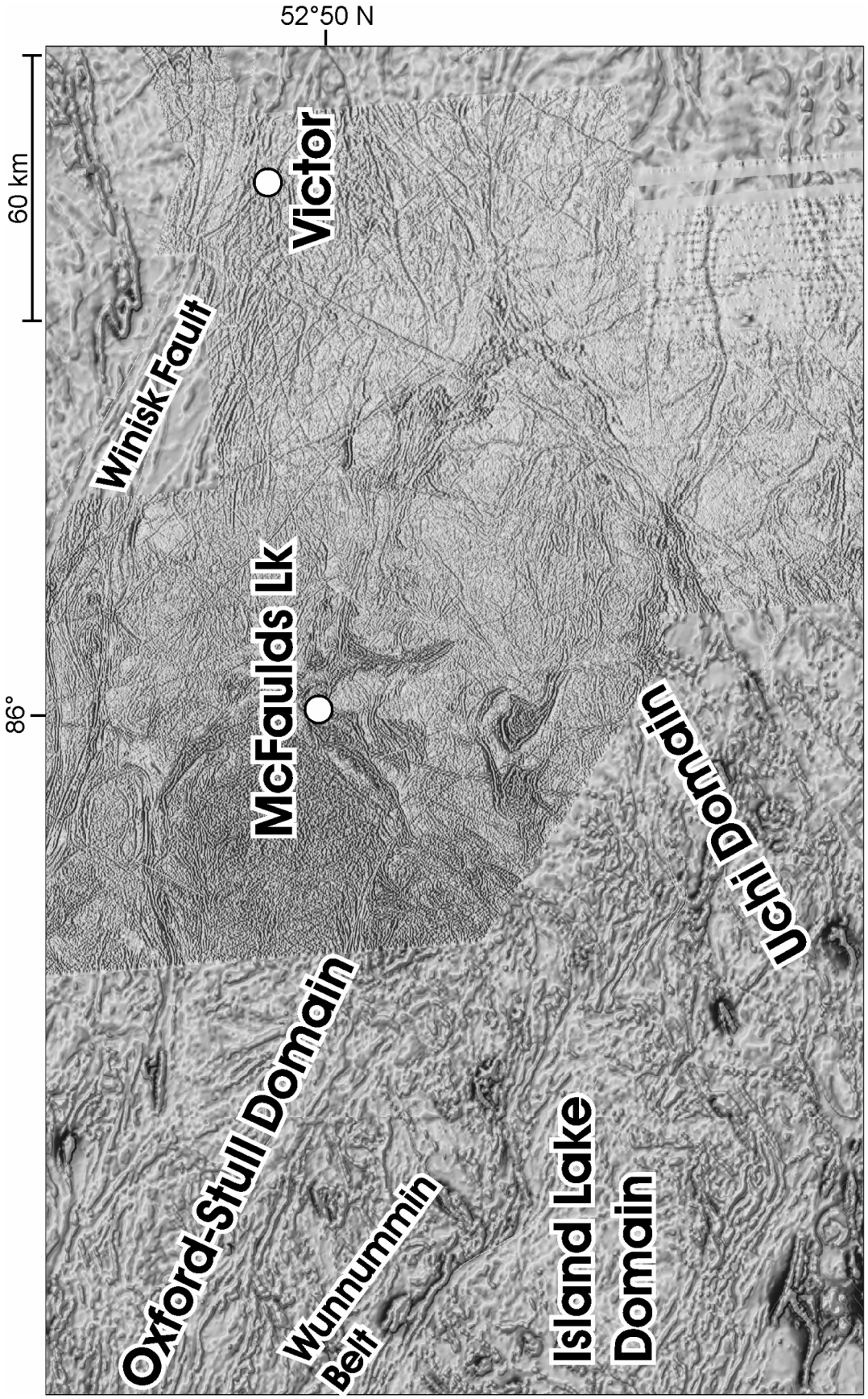

Figure 13.3. Enlargement of Figure 13.2 showing the aeromagnetic expression of greenstone belts of Uchi and Oxford–Stull domains merging and wrapping around the east end of the Island Lake domain portion of the Sachigo superterrane. These domains continue eastward as a common greenstone-granite domain toward the Eastmain domain in Quebec. Location of the McFaulds Lake massive sulphide deposits and the diamond-bearing Victor kimberlite pipe are shown. The age of 2737 Ma for the McFaulds Lake felsic volcanic rocks (Rayner and Stott 2005) in the Oxford–Stull domain corresponds to the age of the Confederation assemblage in the Uchi domain wherein the former South Bay Cu-Zn mine and other massive sulphide mineral occurrences are located.

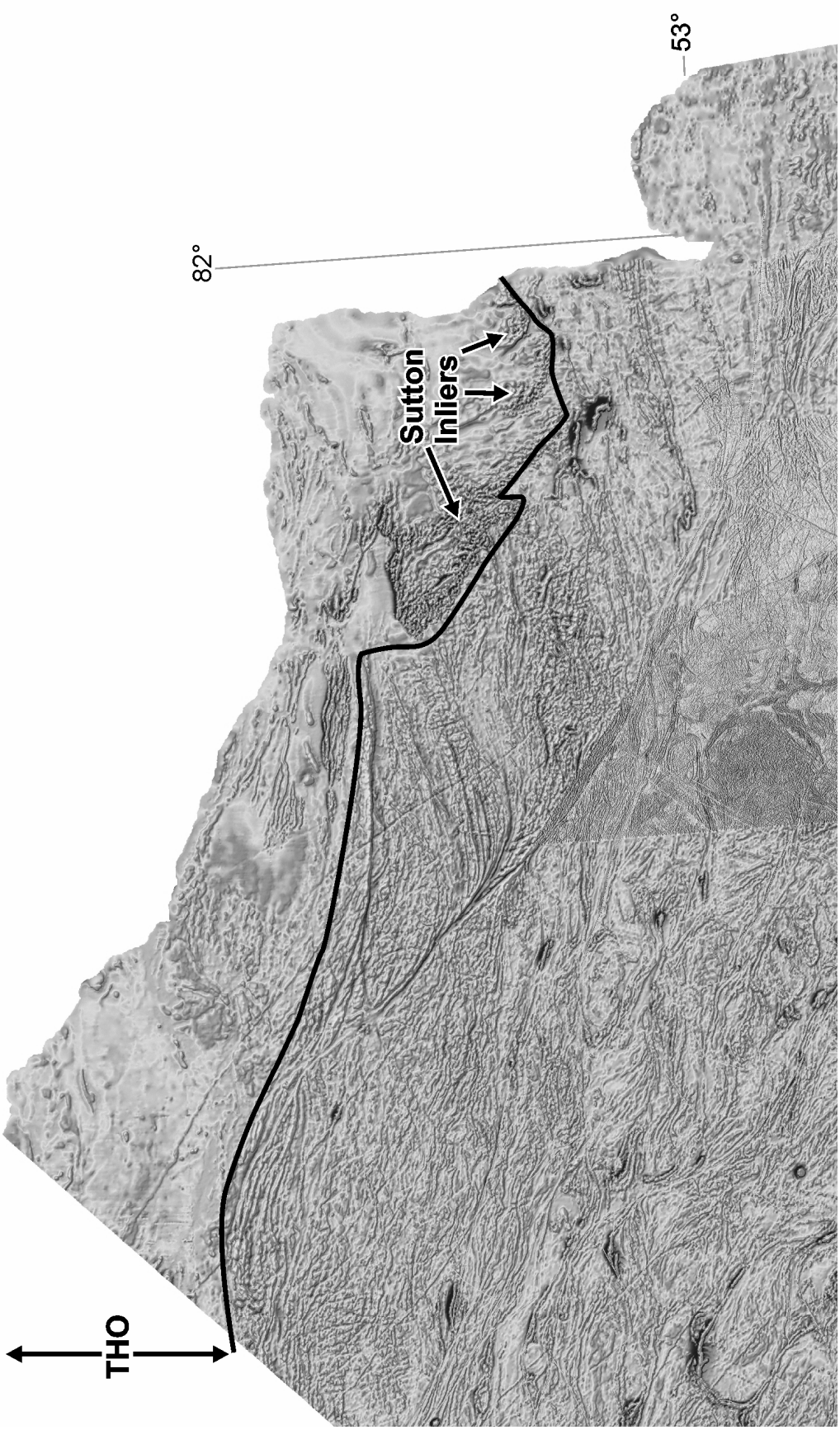

Figure 13.4. The Hudson Bay Lowland region showing a semi-transparent composite, grey-scale relief image of the first vertical derivative of the regional aeromagnetic survey and a portion to the southeast of the high-resolution aeromagnetic supergrid as a composite of the first and second vertical derivatives. Supracrustal components of the Sutton Inlier are clearly discriminated from the underlying Archean crust. The southern limit of the Trans-Hudson Orogen (THO) is interpreted as shown.

JAMES BAY LOWLAND

High-resolution aeromagnetic data (*see* Figure 13.2) (Ontario Geological Survey 2003) and limited diamond-drill hole logs (e.g., McIlraith and Stott 2005) permit a clearer interpretation of the distribution of Archean supracrustal belts and granitic batholiths under the Paleozoic cover of the James Bay Lowland. Perhaps the most striking and significant feature is the aeromagnetic expression (*see* Figure 13.3) of Uchi domain greenstone belts, along the southern flank of the Sachigo superterrane, trending northeast under the James Bay Lowland and wrapping around the eastern end of the Island Lake domain, a portion of the Sachigo superterrane. This greenstone trend merges with the Oxford–Stull domain near the western margin of the James Bay Lowland (*see* Figure 13.3) just east of the McFaulds Lake massive sulphide deposits, currently under exploration by Spider Resources Inc. This combined array of Neoarchean greenstone belts continues east, narrowing under the James Bay Lowland, towards the Eastmain greenstone–granite domain in Quebec.

A northern greenstone limb of the merged Oxford–Stull – Uchi domain, near the boundary with the Northern Superior superterrane, appears to be dextrally offset by the Winisk fault, but on strike towards the northern Eastmain greenstone–granite domain in Quebec.

HUDSON BAY LOWLAND

Northern Superior Superterrane

The Northern Superior superterrane (*see* Figure 13.1) forms a 1000 km long band of distinctively strong magnetic intensity. This superterrane also contains U/Pb zircon ages of 3.2 to 3.1 Ga for plutonic rocks in the Assean Lake block in Manitoba and detrital zircons in metasedimentary rocks up to 3.9 Ga in age (Böhm et al. 2000). Neodymium depleted mantle model ages (TDM: DePaolo 1981) range from 3.4 to 4.1 with ε_{Nd} values to –11 at 2.7 Ga. Mesoarchean (2.846 and 2.814 Ga) and Neoarchean plutonic rocks occur in the limited exposure of the Northern Superior superterrane in Ontario with an inherited age of 3.572 Ga and pre-3.0 Ga Nd model ages (Skulski et al. 2000).

Trans-Hudson Orogen

A marked magnetic discontinuity can be traced eastward roughly midway under the Hudson Bay Lowland between a region of high magnetic relief and complexity that characterizes the Northern Superior superterrane to the south and a region of relatively flat magnetic character that more closely resembles the magnetic signature of the Trans-Hudson Orogen. However, a significant portion of the interpreted Trans-Hudson Orogen resembles an extension of the Northern Superior superterrane and is interpreted as an area of Archean crust that was overprinted by the Trans-Hudson Orogen.

The Sutton Inliers have been reinterpreted by comparing the aeromagnetic data and the outcrops mapped by Bostock (1970). Current regional geology maps of Ontario portray the Sutton Inlier as a single large mass. This new interpretation recognizes a set of ridges forming several crescent-shaped inliers that dip shallowly northward. They appear to be discontinuously related to similar narrow, folded magnetic anomalies within the Trans-Hudson Orogen under the Paleozoic rocks closer to the Hudson Bay coast.

SOME FEATURES OF TERRANES AND DOMAINS

Tectonically significant subdivisions in northern Superior Province across Ontario have been progressively defined from field work, limited geochronology, isotopic studies and aeromagnetic interpretations (e.g., Percival et al. 2006). As in the southern Superior Province, terrane-scale subdivisions, containing supracrustal and plutonic complexes hundreds of kilometres long, are distinguished by lithology, age, isotopic character, geochemistry, and bounding faults. Two sialic terranes, the Northern Superior superterrane and the Sachigo superterrane, each have complex, but distinct, episodic magmatic and tectonic histories. The Northern Superior superterrane contains remnants of a record from Paleo- to Neoarchean and geophysically and isotopically can be linked to the Assean gneisses in Manitoba (Böhm et al. 2000) and the Tikkerutuk terrane (Alain Leclair, Geoscientist, Géologie Québec, personal communication, 2006), encompassing the 3.8 Ga Porpoise Cove volcanic rocks on the western coast of Quebec (David et al. 2002). The Sachigo superterrane with magmatic episodes from Meso- to Neoarchean age, encompasses a core terrane, the North Caribou terrane (NCT), and linear granite–greenstone domains on its south and north flanks that record an outward growth through the Neoarchean.

North Caribou Terrane

The central core of NCT shows limited Neoarchean magmatism, north of the Uchi-associated magmatic arc of the Berens River Subprovince, but it is dominated by Mesoarchean batholiths. However, the Island Lake domain, like the Uchi domain to the south, contains widespread evidence of Neoarchean magmatism and sedimentation. A few remnants of 2.9 to 3.0 Ga supracrustal rocks are preserved in the NCT, notably in the Red Lake and North Caribou Lake greenstone belts. Rift sequences of circa 2.9 Ga age occur locally in the central NCT containing 2.97 to 3.048 Ga detrital zircons and subsequent marine volcanism. Two periods of plutonic and metamorphic activity occur across the NCT at 2.89 to 2.895 Ga and 2.85 to 2.86 Ga. The NCT forms a Mesoarchean core upon which subsequent Neoarchean crust has been added to the north and south margins.

Island Lake Domain

The Island Lake domain is largely plutonic with some Mesoarchean to Neoarchean volcanic belts with geophysical characteristics that show some relationship to the belts within the NCT. The boundaries of the Island Lake domain are probably the least understood and remain the most contentious; modifications to the boundaries proposed by Parks et al. (2006) and Percival et al. (2006) are made in Figure 13.1 based on geochronology and isotopic results of Rayner and Stott (2005) near the James Bay Lowland where the Island Lake domain appears to have incorporated some older crustal contaminants in contrast to the more juvenile Oxford–Stull domain (Rayner and Stott 2005).

Oxford–Stull Domain

At the northern margin of the Sachigo superterrane, the narrower, ribbon-like Oxford–Stull domain (OSD) stretches from Manitoba to the James Bay Lowland (*see* Figure 13.1). In Manitoba, the OSD has been best studied in the Oxford Lake–Knee Lake area where it includes several assemblages (ages are compiled *in* Manitoba Geological Survey 2005) ranging in age from Mesoarchean (2870 to 2830 Ma) to Neoarchean volcanism at 2722 Ma and detrital zircons in overlying sediments as young as 2707 Ma (Corkery et al. 2000). Across the breadth of the OSD, there is a predominance of Neoarchean U/Pb zircon

ages derived through sensitive high-resolution ion microprobe (SHRIMP) analyses near the Manitoba–Ontario border (as young as 2710 Ma) and farther east near the James Bay Lowland in Ontario (2737 to 2696 Ma) of volcanic and plutonic rocks, Neoarchean to Mesoarchean Nd model ages with negative ε_{Nd} values, consistent with relatively juvenile crustal growth (Skulski et al. 2000; Rayner and Stott 2005). The OSD displays some evidence of Mesoarchean mid-ocean ridge basalt (MORB)-like sequences concurrent with continental magmatic growth within Northern Superior superterrane and NCT margins to the north and south, respectively. The southern contact of the OSD with the Island Lake domain of the NCT shows a prevalence of Mesoarchean zircon ages and isotopic evidence for a shared constructive history across the Stull–Wunnummin fault with the OSD.

At the edge of the James Bay Lowland in Ontario, the OSD includes a calc-alkaline metavolcanic sequence containing volcanic-hosted massive sulphide deposits at McFaulds Lake, with a U/Pb zircon SHRIMP age of 2737±7 Ma (Rayner and Stott 2005). This is comparable in age to the Confederation assemblage in the Uchi domain. In this respect, it is noteworthy that a discontinuous chain of greenstone belts, extending from the Uchi domain, wraps around and joins the OSD, east of the McFaulds Lake belt (*see* Figure 13.3). Overall, both the Meso- and Neoarchean supracrustal belts of the OSD appear to be dominated by juvenile, oceanic crust formed without significant input from adjacent older terranes except close to the North Kenyon fault and the Northern Superior superterrane.

Uchi Domain

The Uchi domain forms the southern part of the North Caribou terrane within the Uchi Subprovince where magmatic U/Pb zircon ages and Nd model ages indicate the widespread presence of 2.8 to 2.9 Ga crust, comparable to the Island Lake domain forming the north flank of the NCT. The Uchi domain includes circa 2887 Ma Pembina tonalite on Lake St. Joseph and 2860 Ma Pickle Crow porphyry (Corfu and Stott 1993) in addition to pre-2.8 Ga volcanic assemblages. The Uchi domain was constructed largely by autochthonous, episodic additions of volcanic assemblages and accompanying plutons during the Neoarchean era (Stott and Corfu 1991). Neoarchean assemblages, forming the core of the Uchi Subprovince, appear to have built upon or adjacent to the NCT Mesoarchean crust. The eastern extent of the Uchi domain underlies the James Bay Lowland where, from high-resolution aeromagnetic images, it appears to merge with the OSD. The resulting merged greenstone–granite domain continues eastward under the James Bay Lowland on strike with the Eastmain greenstone–granite domain of Quebec.

ACKNOWLEDGMENTS

Terrane subdivisions continue to be a source of active discussion, largely reflecting our relative lack of data, but also reflecting the significant progress made over the years. Particular appreciation for numerous discussions over the past 18 years on this issue is extended to Tim Corkery of the Manitoba Geological Survey.

REFERENCES

Böhm, Ch. O., Heaman, L.M., Creaser, R.A. and Corkery, M.T. 2000. Discovery of pre-3.5 Ga exotic crust at the northwestern Superior Province margin, Manitoba; Geology, v.28, p.75-78.

Bostock, H.H. 1970. Geological notes on Aquatuk River map-area, Ontario with emphasis on the Precambrian rocks; Geological Survey of Canada, Paper 70-42, 57p.

Corfu, F. and Stott, G.M. 1993. U-Pb geochronology of the central Uchi Subprovince, Superior Province; Canadian Journal of Earth Sciences., v.30, p.1179-1196.

Corkery, M.T., Cameron, H.D.M., Lin, S., Skulski, T., Whalen, J.B. and Stern, R.A. 2000. Geological investigations in the Knee Lake belt (parts of NTS 53L); *in* Report of Activities 2000, Manitoba Industry, Trade and Mines; Manitoba Geological Survey, p.129-136.

David, J., Parent, M., Stevenson, R., Nadeau, P. and Godin, L. 2002. La séquence supracrustale de Porpoise Cove, région d'Inukjuak : un exemple unique de croûte paléo-archéenne (ca 3.8 Ga) dans la Province du Supérieur; Ministère des Ressources naturelles, Québec; DV2002-10, p.17.

DePaolo, D.J. 1981. Crustal growth and mantle evolution: inferences from models of element transport and Nd and Sr isotopes; Geochimica et Cosmochimica Acta, v.44, p.1185-1196.

Geological Survey of Canada 2003. Canadian aeromagnetic data base; Regional Geophysics Section, Geological Survey of Canada, Earth Sciences Sector, Natural Resources Canada.

Manitoba Geological Survey 2005. Manitoba geochronology database; Manitoba Industry, Economic Development and Mines; Manitoba Geological Survey, Open File Report 2005-3, digital Web release.

McIlraith, S.J. and Stott, G.M. 2005. Lowland drill hole data compilation; Ontario Geological Survey, Miscellaneous Release—Data 152.

Ontario Geological Survey 1999. Single master gravity and aeromagnetic data for Ontario; Ontario Geological Survey, ERLIS Data Set 1036.

Ontario Geological Survey 2003. Ontario airborne geophysical surveys, magnetic data, grid data, magnetic supergrids; Ontario Geological Survey, Geophysical Data Set 1037.

Parks, J., Lin, S., Davis, D. and Corkery, T. 2006. New high-precision U-Pb ages for the Island Lake greenstone belt, northwestern Superior Province: implications for regional stratigraphy and the extent of the North Caribou terrane; Canadian Journal of Earth Sciences, v.43, p.789-803.

Percival, J.A., Sanborn-Barrie, M., Skulski, T., Stott, G.M., Helmstaedt, H. and White, D.J. 2006. Tectonic evolution of the western Superior Province from NATMAP and Lithoprobe studies; Canadian Journal of Earth Sciences, v.43, p.1085-1117.

Rayner, N. and Stott, G.M. 2005. Discrimination of Archean domains in the Sachigo Subprovince: a progress report on the geochronology; *in* Summary of Field Work and Other Activities 2005; Ontario Geological Survey, Open File Report 6172, p.10-1 to 10-21.

Skulski, T., Corkery, M.T., Stone, D., Whalen, J.B. and Stern, R.A. 2000. Geological and geochronological investigations in the Stull Lake–Edmund Lake greenstone belt and granitoid rocks of the northwestern Superior Province; *in* Report of Activities 2000, Manitoba Industry, Trade and Mines; Manitoba Geological Survey, p.117-128.

Stone, D. 2005. Geology of northern Superior area, Ontario. Ontario Geological Survey, Open File Report 6140, 94p.

Stott, G.M. 1997. The Superior Province, Canada; *in* Greenstone belts, Oxford Clarendon Press, Oxford Monograph on Geology and Geophysics 35, p.480-507.

Stott, G.M. and Corfu, F. 1991. Uchi Subprovince; *in* Geology of Ontario; Ontario Geological Survey, Special Volume 4, Part 1, p.145-236.

Stott, G.M. and Corkery, M.T. 2006. The terranes of northern Superior Province from Manitoba to Ontario with possible correlations into Quebec; Geological Association of Canada–Mineralogical Association of Canada, Annual Meeting, Program with Abstracts, v.31, p.144.

Thurston, P.C., Osmani, I.A. and Stone, D. 1991. Northwestern Superior Province: review and terrane analysis; *in* Geology of Ontario; Ontario Geological Survey, Special Volume 4, Part 1, p.26-57.

14. Project Unit 06-005. Geology and Mineral Potential of Southern Province Rocks in Baldwin Township

R.M. Easton[1]

[1]Precambrian Geoscience Section, Ontario Geological Survey

INTRODUCTION

Mapping of Baldwin Township at 1:20 000 scale was initiated in 2006, in part because the township provides an easily accessible cross-section through the entire lower Huronian Supergroup stratigraphy and the underlying basement rocks (Figure 14.1). In addition, the area also lies adjacent to Ursa Major's Shakespeare nickel-copper deposit and was a logical southward extension of the mapping program conducted in Porter and Vernon townships, immediately to the north (Easton 2004, 2005, 2006a, 2006b) (*see* Figure 14.1).

Previous Work

Baldwin Township was mapped at 1:12 000 scale by Thomson (1952, 1953), prior to the establishment of the currently used Huronian Supergroup stratigraphy (Robertson, Card and Frarey 1969). Parts of the township were re-examined by Card (1964, 1971, 1978a). Card, Innes and Debicki (1977) describe 3 measured stratigraphic sections from Baldwin Township. The township has been a focus of exploration for copper and uranium mineralization between 1930 and 1970 (e.g., Thomson 1953, 1960; Robertson 1968; Pearson, Bretzlaff and Carrière 1985) and, more recently, for nickel-copper-platinum element group mineralization within Nipissing gabbro intrusions.

This Study

The area is accessible by road from Highway 17, which cuts across the southern part of the map area, and by boat from Agnew Lake (*see* Figure 14.1). The community of McKerrow lies within the map area, and the town of Espanola is located just south of Baldwin Township. The map area has undergone extensive logging over the past 3 decades, making traversing difficult. Thick lichen and vegetative cover, even along the shores of Agnew Lake, renders rock identification of many small outcrops problematic.

Field observations in this report have been augmented by thin section examination, a few preliminary major-element geochemical analyses, and magnetic susceptibility and scintillometer data collected in the field. Easton (2005) first reported on the test of a hand-held scintillometer for rock unit discrimination and evaluation of historic radioactive occurrences, and a similar approach was used in this project. As illustrated in Table 14.1, the scintillometer was effective in discriminating between different rock units in the study area.

Summary of Field Work and Other Activities 2006,
Ontario Geological Survey, Open File Report 6192, p.14-1 to 14-22.

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STRATIGRAPHIC UNITS

Archean Basement

At least 3 main units constitute the Archean basement present within Baldwin Township. All basement rocks are exposed in a block bounded to the north by the Cameron Creek fault and to the south by the Fairbank Lake and Murray faults (Figure 14.2). The first unit, exposed in western Baldwin Township, is a body of foliated, medium-grained, granodiorite to monzogranite that extends into the map area from Shakespeare Township. This granitoid body is part of the Birch Lake granite, and is shown on the maps of Thomson (1952) and Card (1971, 1978a).

The second, and largest, unit of possible basement rock is an area of fine-grained, moderately to highly foliated, buff weathering, blue-green granitoid rock present in western Baldwin Township (*see* Figure 14.2). Thomson (1952) showed these rocks as a body of intermixed granite and diorite, whereas Card (1971, 1978a) mapped the same rocks as felsic volcanic rocks of the Huronian Supergroup, which

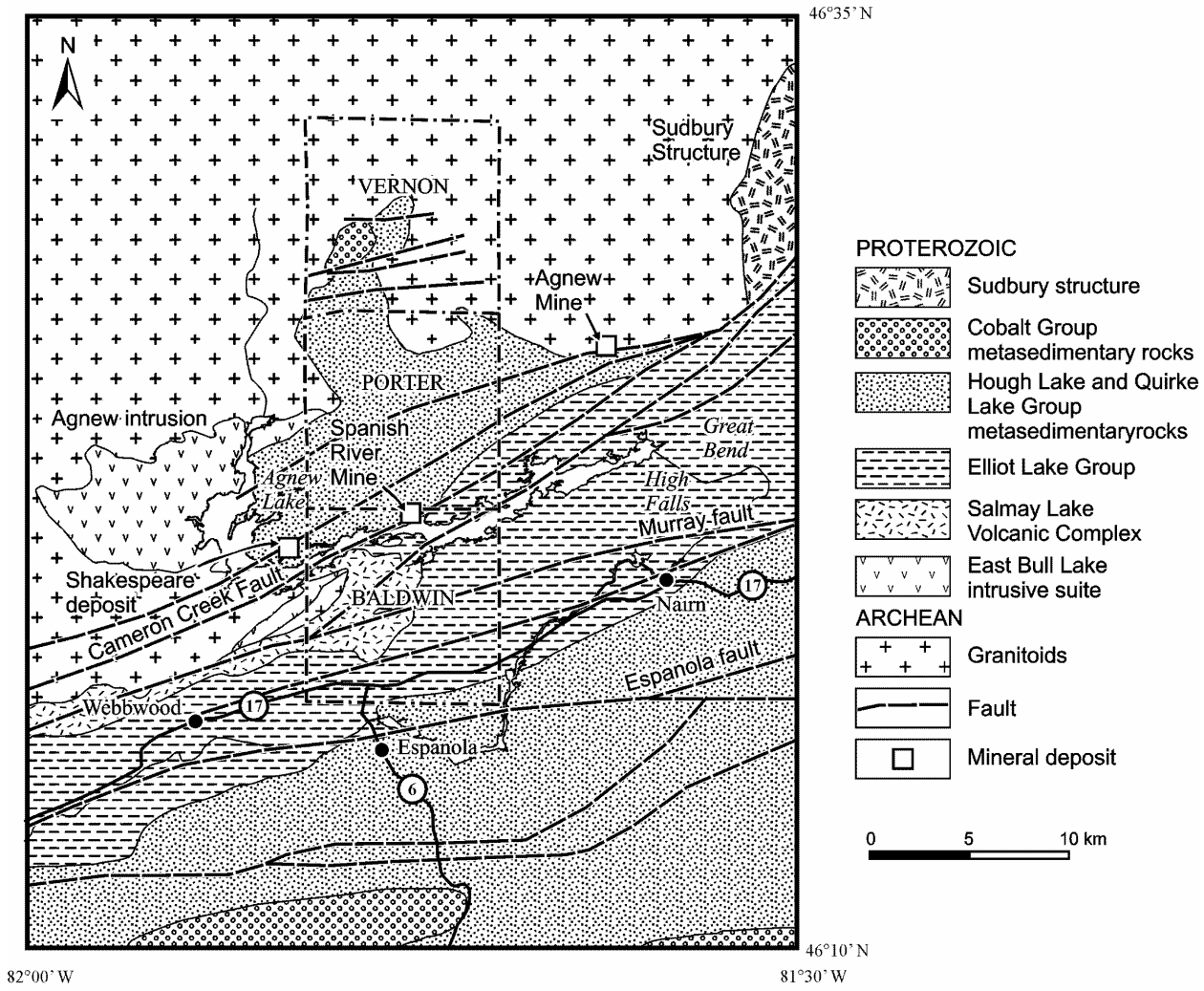

Figure 14.1. Regional geological setting of Baldwin Township (*from* Card and Lumbers 1975). Only major east-northeast-trending faults are shown. Nipissing gabbro intrusions omitted for clarity.

Table 14.1. Scintillometer data for the major rock units in Baldwin Township.

Rock Unit	K_2O (wt %) chemical	K_2O (wt %) scintillometer	U (ppm) scintillometer	Th (ppm) scintillometer	number of stations
Archean granitoid	<0.3	0.5	1.7	9.2	7
Birch Lake granite (Baldwin)	NA	3.0	5.7	26.8	9
Birch Lake granite (Porter–Vernon)	4.0 to 5.5	4.1	6.8	29.1	13
East Bull Lake intrusive suite	<0.4	0.4	0.1	0.5	2
Nipissing gabbro (excluding quartz diorite phases)	<0.5	0.3	0.2	1.9	14
Salmay Lake Volcanic Complex	<0.5	0.4	0.2	1.9	17
Feather amphibolite	1.4 to 1.5	1.3	1.3	6.4	11
Lower Matinenda Formation	NA	4.5	8.5	38.3	19
Upper Matinenda Formation	NA	3.3	1.9	9.9	23
McKim Formation	2.5 to 4.5*	2.7	4.3	13.2	15
Ramsay Lake Formation	~2.0*	1.6	5.9	14.4	5

Abbreviations: NA = not available.
All data were recorded using an Exploranium™ GR-135G MiniSpec gamma-ray spectrometer, serial number 4885, calibrated on February 22, 2006, using an NaI crystal and software version 501GEO. The instrument was stabilized daily, and data were recorded using the assay mode with a 5-minute count time. Quoted accuracy is 0.1% K, 0.4 ppm U, and 0.7 ppm Th for a sample with 2% K, 2 ppm U and 8 ppm Th. Measured K values were converted to K_2O to facilitate comparison with the geochemical data. Asterisk indicates chemical data *from* Card, Innes and Debicki (1977); all other chemical data are from this study or Easton (2006b).

he correlated with the Salmay Lake Formation (Card 1978a). In outcrop, it appears that these rocks were originally a medium- to coarse-grained igneous rock, of broadly granodiorite composition, that has been variably sheared and deformed, and possibly hydrothermally altered. Geochemically, these rocks classify as tonalite, although the high sodium (>5 weight %) and low potassium (<0.3 weight %) could be an indication of alteration of the samples. In thin section, these rocks exhibit a relict medium- to coarse-grained igneous texture that subsequently was sheared and locally grain-size reduced. Both outcrop and thin section observations, as well as the geochemical data, would appear to favour Thomson's (1952) interpretation of these rocks as intrusive in origin. A few samples of fine- to medium-grained granitoid rocks near the margin of this mass of granitoid rocks exhibit a porphyritic texture in thin section, and could represent either hypabyssal intrusions or felsic metavolcanic rocks. Whether or not these porphyritic rocks are Huronian or Archean in age is not easily determined. All of the granitoid rocks in western Baldwin Township, including the porphyritic varieties, are cut by fine-grained mafic dikes. Some of these mafic dikes are plagioclase-phyric and may be part of the Matachewan dike swarm (~2475 Ma). If so, then the granitoid rocks are mostly like Archean in age. The Birch Lake granite is one of the youngest phases of the Ramsay–Algoma gneiss complex of the Superior Province, and it is possible that these granitoid rocks are slightly older Archean basement into which the Birch Lake granite was emplaced.

The third unit occurs in the area south of Agnew Lake and west of Espanola Bay, and consists of a body of foliated, medium- to coarse-grained, monzogranite to syenogranite. These granitic rocks have the high potassium and thorium signature (as determined in the field by scintillometer measurements, *see* Table 14.1) characteristic of the Birch Lake granite, which forms the Archean basement to the Huronian Supergroup in Porter and Shakespeare townships, immediately north and west of the study area, respectively. The Birch Lake granite has a U/Pb age of 2651±1 Ma (Kamo 2006). Thomson (1952)

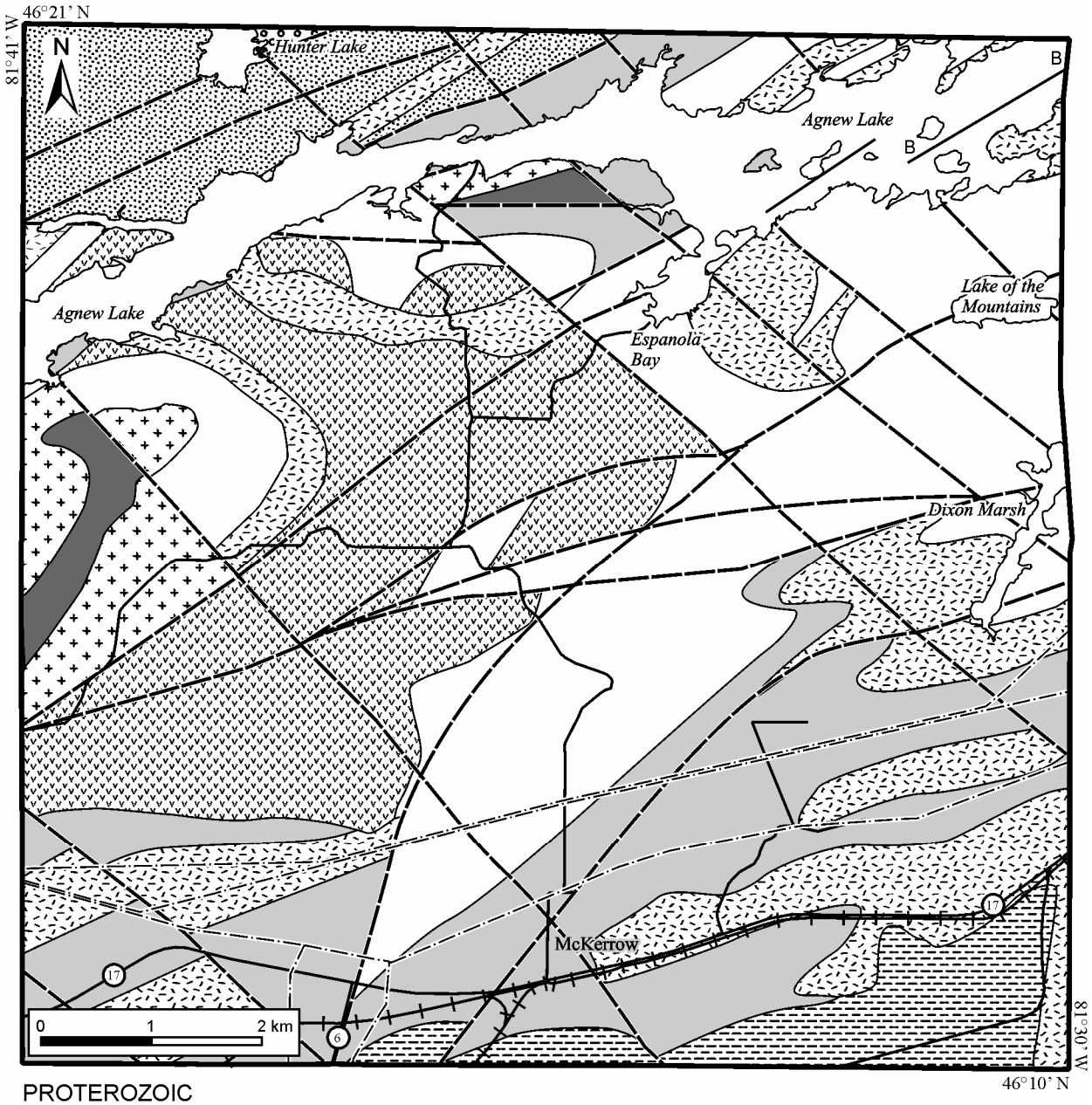

Figure 14.2. Simplified geological map of Baldwin Township showing major stratigraphic units and faults.

shows some outcrops of granite in this area, but this body is not shown on Card (1971) or Card (1978a). Card, Innes and Debicki (1977) considered the granitic rocks to be a felsic differentiate of an East Bull Lake intrusive suite body located in the same area.

Isolated slivers of foliated to gneissic granodiorite, likely Archean basement, occur on several islands within Agnew Lake northeast of Espanola Bay. These slivers lie on strike with the basement exposures described above in western and central Baldwin Township, and their presence suggest that the thickness of the Elliot Lake Group, in the area bounded by the Cameron Creek and Fairbank Lake faults, may be considerably thinner than previously indicated (e.g., Card, Innes and Debicki 1977).

East Bull Lake Intrusive Suite

As noted by Card (1978a), 2 separate bodies are present in the study area, with both bodies located in the block bounded by the Cameron Creek and Fairbank Lake faults (*see* Figure 14.2). Both bodies are dominated by medium-grained gabbroic anorthosite, locally with coarse-grained dendritic-textured zones typically present within the upper part of the larger East Bull Lake intrusive suite intrusions (e.g., Easton, Jobin-Bevans and James 2004). No igneous layering was observed in either intrusion, and no intrusive breccia zones were observed along their margins. The larger intrusion occurs in western Baldwin Township, and appears to have been emplaced along the contact between rocks of the Birch Lake granite and the more deformed Archean granitoid rocks described above. The intrusion located west of Espanola Bay is in fault contact with Huronian Supergroup metasedimentary rocks to the south, and is intruded into Birch Lake granite rocks to the north. In neither area are the bodies in non-tectonic contact with Huronian Supergroup supracrustal rocks.

Huronian Supergroup, Elliot Lake Group

The Elliot Lake Group is the basal unit of the 4 groups that constitute the Huronian Supergroup (e.g., Bennett, Dressler and Robertson 1991). Unlike the overlying 3 groups, which are characterized by a generally "layer cake" stratigraphic succession of conglomerate, mudstone and sandstone, the Elliot Lake Group is characterized by complex interfingering of a variety of metasedimentary and metavolcanic units and facies. In many ways, the various formations of the Elliot Lake Group are more like allostratigraphic rather than lithostratigraphic units (NACSN 2005). The subdivisions of the Elliot Lake Group in the study area, from stratigraphically lowest to highest in a broad sense, are 1) supracrustal rocks of the Salmay Lake Volcanic Complex, 2) metaconglomerate and meta-quartz arenite of the Matinenda Formation, and 3) turbidites of the McKim Formation.

SALMAY LAKE VOLCANIC COMPLEX

Robertson (1966, 1976) defined metavolcanic rocks located along the Murray Fault in the vicinity of Salter, Victoria and May townships as the Salmay Lake Formation and, subsequently, Card (1978a) correlated the metavolcanic rocks in Baldwin Township with the Salmay Lake Formation. It is proposed herein that the Salmay Lake Formation be redefined as the Salmay Lake Volcanic Complex, in accordance with the North American Stratigraphic Code (NACSN 2005), as the unit contains rocks of several classes (volcanic, volcaniclastic, sedimentary and intrusive) rather than rocks of a single class.

In Baldwin Township, the Salmay Lake Volcanic Complex is dominated by monolithic (Photo 14.1a) and heterolithic volcanic conglomerate and debris flows, volcanic sandstones and mudstones (Photo 14.1b), and sulphidic black shales (Photo 14.1c), with occasional dark green weathering, aphanitic flow and dike rocks. Some of the aphanitic flow rocks are amygdaloidal, and clasts derived from

amygdaloidal flows are common in some of the volcanic conglomerate units (Photo 14.1d). Compositionally, most of these units are mafic, likely of basaltic or andesitic composition. Preliminary geochemical results indicate that the mafic volcanic rocks are high-iron tholeiites, with either mid-ocean ridge or continental flood basalt affinities. Amygdaloidal samples tend to have higher silica contents due to the abundance of quartz amygdules, causing them to plot as low-potassium andesites, even though their primary composition is basaltic. Felsic metavolcanic rocks are uncommon. Thomson (1952) showed several localities of pillowed flows near the transition from the uppermost part of the volcanic complex to the Matinenda Formation; however, upon examination, the author was not convinced that these mafic rocks were pillowed, let alone flows. Sparsely plagioclase-phyric mafic rocks are common within the volcanic complex, and represent either thick flows or sills, possibly both. In many respects, rocks of the Salmay Lake Volcanic Complex closely resemble rocks of the volcaniclastic dominated Grimsthorpe Group of the Central Metasedimentary Belt of the Grenville Province (Easton and Ford 1994), albeit the rocks in Baldwin Township are preserved at somewhat higher metamorphic grade.

Photo 14.1. Rocks of the Salmay Lake Volcanic Complex (all UTM locations in NAD83, Zone 17). A) Monomict volcanic breccia. Note vesicular character of the fragments. Complete hammer is 30 cm long. Location: UTM 439790E 5132054N. B) Medium bedded volcanic sandstones. Location: UTM 438375E 5132165N. C) Black shale. Knife is 9 cm long. Location: UTM 437093E 5127889N. D) Amygdaloidal mafic volcanic fragment in volcanic conglomerate. Location: UTM 435994E 5131315N.

In the field, medium- to fine-grained volcaniclastic rocks of the volcanic complex can be distinguished from stratigraphically higher and/or interfingering clastic metasedimentary rocks using a scintillometer, as the volcaniclastic rocks are characterized by near zero values of K, U and Th, similar to the mafic flow and mafic intrusive rocks present in the volcanic complex (*see* Table 14.1).

MATINENDA FORMATION

The transition between the volcanic complex and rocks of the Matinenda Formation is complex, and is complicated by the presence of a wide variety of matrix-supported metaconglomerates within the transition zone. In this study, metaconglomerates with a mafic matrix and dominated by volcanic clasts, and low K, U and Th contents, have been included as part of the Salmay Lake Volcanic Complex (*see* Photo 14.1). Metaconglomerates dominated by quartz pebble and/or granitic clasts have been included within the Matinenda Formation (Photo 14.2).

Photo 14.2. Rocks of the Matinenda Formation (all UTM locations in NAD83, Zone 17). A) Rounded granitoid cobble in matrix-supported conglomerate. Hammer is 30 cm long. Location: UTM 438490E 5130720N. B) Subround to elongate granitic cobble in matrix-supported conglomerate, 20 cm above contact with underlying Archean granitic basement, which was the source of the cobble. Hammer handle is 30 cm long. Location: UTM 437928E 5131505N. C) Conglomerate hosting minor uranium and thorium mineralization, Jellicoe occurrence. Hammer handle is 30 cm long. Location: UTM 441136E 5132775N. D) Sudbury breccia veinlet developed in meta-quartz arenite of the lower Matinenda Formation. Hammer handle is 30 cm long. Location: UTM 440150E 5132673N.

Matinenda Formation metaconglomerate horizons are discontinuous, range from 0.50 to 30 m thick, and occur at different stratigraphic heights. Unlike suggestions by previous authors (Thomson 1953; Card, Innes and Debicki 1977), no single, lateral extensive basal quartz pebble metaconglomerate horizon is present. Examination of diamond-drill logs in the area west of Espanola Bay (Broulan Reef Mines Limited 1967) along the transition zone indicates that the uppermost volcanic and volcaniclastic units of the Salmay Lake Volcanic Complex interfinger with quartz arenites of the Matinenda Formation over a stratigraphic height of up to 80 m, prior to the first appearance of any metaconglomerate horizons. In addition, in western Baldwin Township, some Matinenda Formation metaconglomerate horizons directly overlie Archean granitoid rocks and, in these localities, contain abundant granitic clasts.

In the field, a distinction can be made between the meta-quartz arenites of the lower and upper Matinenda Formation. Lower Matinenda Formation meta-quartz arenites are coarser grained, thick bedded, and have higher K and Th contents, as determined by scintillometer measurements (*see* Table 14.1). The high K and Th contents are consistent with a source region dominated by the Birch Lake granite (*see* Table 14.1), as has long been suggested by some authors (e.g., Thomson 1960; Robertson 1968). Metaconglomerate horizons are common within the lower Matinenda Formation, as are fine-grained mafic dikes similar to those observed within the Salmay Lake Volcanic Complex. The upper Matinenda Formation meta-quartz arenites are medium grained, medium to thick bedded, are more commonly cross-bedded, and metaconglomerate horizons are rare. The Matinenda Formation is thicker, and contains more quartz arenite, in Baldwin Township than areas to the east and west (Card, Innes and Debicki 1977).

McKIM FORMATION

Card, Innes and Debicki (1977) recognized 3 facies within the McKim Formation. The "quartz sandstone" facies of Card, Innes and Debicki (1977) is equivalent to the Matinenda Formation, and represents thin interbeds of meta-quartz arenite and minor metaconglomerate in the 2 other main facies of the McKim Formation. The "greywacke" facies consists of interbedded metawacke, metasiltstone and thin bedded mudstone and siltstone. Ripple marks, cross-laminations, graded beds and Bouma cycles are common in this facies in the northern part of the map area along Agnew Lake. Bedding varies from a few centimetres to 50 cm thick. The "laminated argillite facies" consists of thin-bedded mudstone and siltstone, with occasional beds of fine-grained wacke. Bedding is commonly less than 1 cm, and rarely exceeds 10 cm. As with the "greywacke" facies, sedimentary features are best preserved near Agnew Lake. In the southern and eastern parts of Baldwin Township, metamorphic porphyroblasts develop within rocks of the "laminated argillite" facies, and are best described as metapelites. Similarly, rocks of the "greywacke" facies in the southern and eastern parts of the study area are more aptly described as psammites. The metapelites are characterized by high Al_2O_3 contents (20.0 to 25.0 weight %, this study and Card, Innes and Debicki 1977), and moderate Fe/Mg ratios (~2), which probably explains why metamorphic porphyroblast development in metasedimentary rocks in Baldwin Township is restricted almost exclusively to the "laminated argillite" facies of the McKim Formation.

DEPOSITIONAL ENVIRONMENT

The abundance of volcaniclastic material within the Salmay Lake Volcanic Complex suggests that the rocks present in Baldwin Township were mostly likely deposited on the flanks of volcanic centres, possibly quite distal to the areas of active volcanism. The irregular thickness, varied composition and distribution of the volcanic metaconglomerates may reflect a mixture of both locally and distally derived material. All of these features are consistent with deposition in a valley-fill environment, primarily as debris flows. Transport could have been along the axis of rift valleys, perhaps by braided-stream systems. Interfingering of sandstones of the Matinenda Formation and rocks of the Salmay Lake Volcanic

Complex suggests that, as volcanism waned, detritus from a continental source region (including the Birch Lake granite) became the dominant source of sediment.

The irregular thickness of, and distribution of metaconglomerate horizons within the lower Matinenda Formation, and the presence of many apparently locally derived cobbles, may indicate that they were deposited in a valley-fill environment, from debris flows related to flooding the valleys. Evidence for this is found in the area west of Espanola Bay, where there is considerable relief along the contact between the Salmay Lake Volcanic Complex and the Matinenda Formation, which could reflect original topographic highs and lows. The massive sandstones in the lower Matinenda Formation may represent sheet flood deposits deposited in an overbank or floodplain environment. In general, there is a fining-upward trend from the lower to the upper Matinenda Formation, which is consistent with deposition in a braided-stream system. Although there is a change in source material from the Salmay Lake Volcanic Complex to the Matinenda Formation, the depositional environment need not have changed substantially.

The McKim Formation, which is dominated by mudstones and turbidites, represents a more significant change in depositional regime, and may represent a marine incursion into what were originally subaerial rift valleys.

Huronian Supergroup, Hough Lake and Quirke Lake Groups

Rocks of the Ramsay Lake Formation are restricted to the southernmost part of Baldwin Township, and consist of matrix-supported metaconglomerate and pebbly meta-quartz arenite overlain by a thick sequence of pebbly meta-quartz arenite.

North of the Cameron Creek fault is an extensive area of Mississagi Formation meta-quartz arenite, which continues into Porter Township (Easton 2006a). A thin sliver of Bruce Formation matrix-supported metaconglomerate occurs on the north side of the Cameron Creek fault, which juxtaposes the Mississagi and Bruce Formations against rocks of the McKim Formation. Card (1971, 1978a) assigned this sliver of metaconglomerate to the Ramsay Lake Formation; however, there are no siltstones (Pecors Formation) between the Mississagi meta-quartz arenites and the metaconglomerate, and the metaconglomerate is identical to other exposures of the Bruce Formation located immediately adjacent in Porter Township (Easton 2006a).

Nipissing Gabbro

Nipissing gabbro sills occur at 5 main stratigraphic levels within the Huronian Supergroup in Baldwin Township: 1) at the transition between the Salmay Lake Volcanic Complex and the Matinenda Formation, 2) in the upper Matinenda Formation, 3) in both facies of the McKim Formation, 4) at the McKim–Ramsay Lake formations contact, and 5) within the Mississagi Formation. Easton (2005, 2006a) suggested that there were 2 main structural settings for Nipissing gabbro intrusions in Porter and Vernon Townships: a stratiform setting, coincident with F_1 folding, and a discordant setting, commonly axial planar to F_2 folds. All of the large Nipissing gabbro sills in Baldwin Township belong to the stratiform setting. Areas where the primary igneous mineralogy of the sills is preserved was observed in several localities, in particular in the sill at the top of the Salmay Lake Formation and the sill at the McKim–Ramsay Lake formations contact. In addition, the sill at the McKim–Ramsay Lake formations contact contains abundant orthopyroxene, and locally is close to being ultramafic in composition. The mineralogical preservation within the Nipissing gabbro sills is in marked contrast to the Huronian Supergroup strata, which are pervasively altered to retrograde mineral assemblages containing chlorite and white mica.

Other Units

Sudbury breccia (*see* Photo 14.2d) is best developed in the vicinity of Agnew Lake, and affects all Paleoproterozoic rocks in the study area. It is most abundant along the major easterly to north-easterly trending faults in the area, but also occurs along major stratigraphic contacts.

Two large diabase dikes of the Sudbury diabase dike swarm are present in the southwest corner of the map area. The largest of these dikes was the first dike of the swarm to have an age determined using zircon and baddeleyite, and yielded an age of 1238±4 Ma (Krogh et al. 1987). Smaller dikes occur elsewhere in the township, and can be distinguished by the fact that they have much higher magnetic susceptibility ($>10\times10^{-3}$ SI), compared to almost every other rock unit in the township (generally $<0.8\times10^{-3}$ SI).

FOLDING

The area north of the Fairbank Lake fault is dominated by a dome and basin interference fold pattern, similar to that reported in adjacent Porter Township by Easton (2005, 2006a). The distribution of Archean basement rocks in the fault block located between the Cameron Creek and Fairbank Lake faults reflects this folding pattern, with the granitoid basement rocks being located in the domes, and the larger masses of rocks of the Salmay Lake Volcanic Complex being located in the basins. The Baldwin anticlinorium of Card (1971, 1978a) is the trace of the F_2 responsible for the interference pattern in this area. Two generations of quartz veins occur in this fault block, the early generation is folded, whereas the younger generation veins are axial planar to the F_2 folds. Several high-grade copper occurrences (Thomson 1953; Pearson, Bretzlaff and Carrière 1985) are associated with the younger, axial planar quartz veins. South of the Fairbank Lake fault, although small dome and basins are observed locally (e.g., near Rock Lake in Nairn Township), the regional fold pattern is more sinuous.

FAULTING

Easton (2006a, 2006c) reported the presence of at least 5 major fault sets, 4 of which are post-folding, in the Porter–Vernon townships area. Only the earliest set of north-trending faults appear to be absent from Baldwin Township. East-northeast faults also juxtapose Huronian strata against basement rocks, but are post-F_1 folding, with both vertical and lateral movement. They may be associated with a set of north- to northeast-trending, dominantly normal faults; that may have an older thrust component.

As noted by Thomson (1953), the most significant fault system in terms of map pattern in Baldwin Township, are the east- to east-northeast-trending normal faults, across which major changes in stratigraphic level occur (*see* Figure 14.2). There may be a thrust component to these faults, but, if so, it has been obscured by subsequent vertical movement, and the fact that the east- to east-northeast-trending faults are the loci for the development of extensive zones of Sudbury breccia. The localization of Sudbury breccia along this fault set suggests that it may have developed at ~1850 Ma, due to the Sudbury impact or the peak of the Penokean orogeny, or both. In Baldwin Township, the most significant fault in terms of offset is the Cameron Creek fault, which juxtaposes upper Hough Lake Group and lower Quirke Lake Group strata against Archean basement and rocks of the Elliot Lake Group. Just south of Baldwin Township, the Espanola fault juxtaposes rocks of the McKim and Ramsay Lake formations against rocks of the upper Hough Lake and the Quirke Lake groups, and appears to represent a major metamorphic break.

As in Porter and Vernon townships, significant vertical displacement also occurs along a major set of closely spaced northwest-trending faults, which were not always identified on previous maps (*see* Figure 14.2). These faults parallel the trend of the Sudbury diabase dike swarm, and could be as young as this dike swarm (~1240 Ma).

METAMORPHISM

Previous Studies

Baldwin Township lies just west of the Great Bend in the Spanish River, which is interpreted as a high-grade metamorphic node in the Southern Province (Card 1978b) and which has been the subject of detailed metamorphic studies (Card 1964; Fox 1971). At the Great Bend, both Card (1964) and Fox (1971) report the co-existing assemblage staurolite–chloritoid in metapelitic rocks of the McKim Formation. Fox (1971) also reports the presence of andalusite in some of samples containing staurolite and chloritoid, which would place the assemblage within bathozone 3 of Carmichael (1978) (Figure 14.3). Fox (1971) estimated metamorphic conditions of 500 to 550°C and 4.45 to 4.75 kilobars for this assemblage, which would place the mineral assemblage in the kyanite field (*see* Figure 14.3). This discrepancy is within the error limits of the estimate of Fox (1971). Both Card (1964) and Fox (1971) reported randomly oriented staurolite and chloritoid porphyroblasts that are post-kinematic with respect to the foliation defined by matrix phyllosilicates. As noted previously under "Stratigraphic Units, McKim Formation", the chemistry of these rocks indicates that they are high-aluminum pelites.

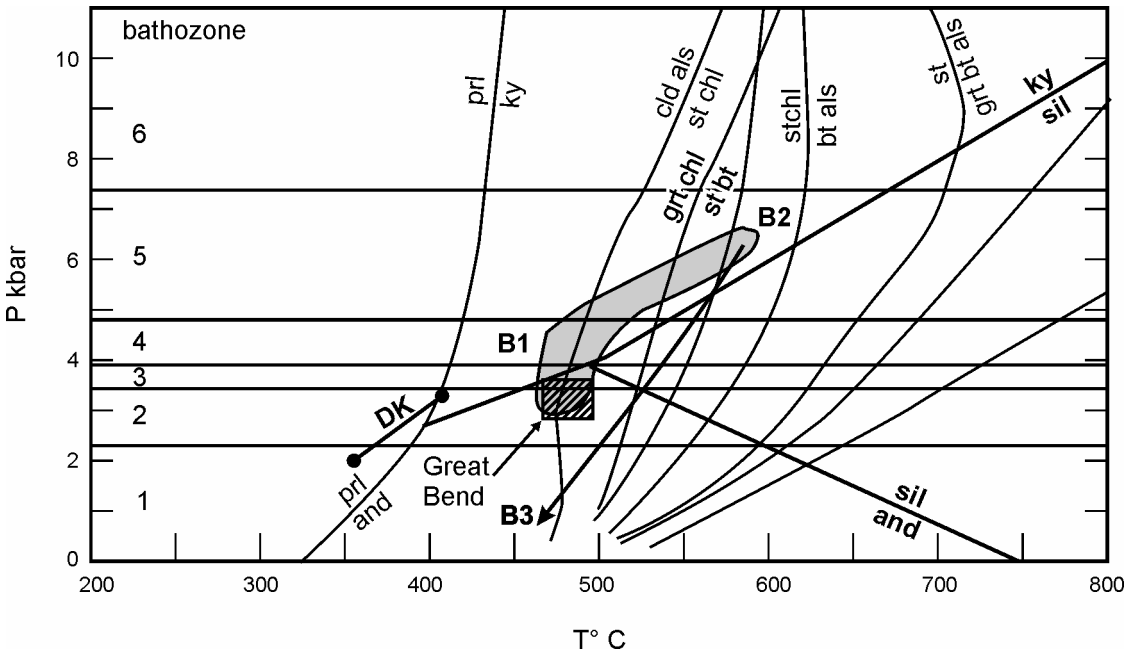

Figure 14.3. Pressure–temperature (*P–T*) grid showing the location of major mineral assemblages in the system KFMASH, *after* Spear (1993). Bathozones *from* Carmichael (1978). Also indicated are possible *P–T* paths for different parts of the Southern Province. Abbreviations: and = andalusite, as = aluminosilicate, bt = biotite, chl = chlorite, cld = chloritoid; crd = cordierite, grt = garnet, kfs = potassium feldspar, ky = kyanite, ms = muscovite, prl = pyrophyllite, qtz = quartz, sil = sillimanite, st = staurolite; B1 = Baldwin initial conditions, B2 = Baldwin peak conditions, B3 = Baldwin retrograde path; DK = diaspore to kyanite path.

Card (1964) shows a general increase in metamorphic grade from southwest to northeast in Baldwin Township, from a biotite-chlorite zone in the southwest to a chloritoid zone in the northeast, with an intervening garnet zone. Furthermore, Card (1964) included Baldwin Township in his structural zone A, which is characterized by post-kinematic growth of metamorphic minerals. The metamorphic zonation shown by Card (1964) implies that all of Baldwin Township is at lower metamorphic grade than at the Great Bend. Although superficially correct, the pattern shown by Card (1964) does not adequately reflect the metamorphic history of Baldwin Township, in part because his pattern includes the effects of both prograde and retrograde metamorphism; not just the effects of a single metamorphic event.

This Study

METASEDIMENTARY ROCKS

The abundance of quartz arenites within Baldwin Township makes it difficult to estimate metamorphic grade across much of the township. Nonetheless, in thin section, annealing of quartz grains was observed in all samples of Matinenda Formation quartz arenite that were examined. This annealing texture has largely obliterated the primary detrital character of the rock, except for the occasional feldspar grain or rock fragment. This widespread development of this annealed texture suggests that the quartz arenites were subjected to high-grade metamorphism, consistent with the metamorphic grade observed in adjacent McKim Formation metapelites. This annealing would not be expected if these rocks had only been subjected to prograde biotite-chlorite–grade metamorphism as suggested by Card (1964).

Metamorphic porphyroblasts other than garnet were only observed in metapelitic rocks of the McKim Formation, which occur mainly in the eastern and southern parts of Baldwin Township. Throughout Baldwin Township, porphyroblasts of garnet, staurolite and chloritoid are all syn-kinematic in character, and are almost always pervasively retrograded to chlorite and white mica. The prominent metamorphic foliation in the metapelitic rocks can easily be mistaken for bedding, which is generally at a high angle (60 to 70°) to the foliation. Mica defining the foliation is medium grained, and all original sedimentary textures have been obliterated. Many of the samples collected for thin sectioning appear to contain the fibrolite form of sillimanite developed in the plane of the foliation; however, in thin section, only white mica was observed in the samples. This could mean that the rocks never grew sillimanite, but it could also mean that any sillimanite that was formed has now been thoroughly retrograded to white mica. Metapelite samples from as far north as the shore of Agnew Lake to as far south as Espanola also contain small, euhedral, generally twinned, randomly oriented kyanite porphyroblasts that are not retrograded to the same extent as the other porphyroblasts, and which developed after the main deformation experienced by these rocks. The presence of kyanite throughout most of Baldwin Township indicates that at a minimum, bathozone 4 conditions (Carmichael 1978; *see* Figure 14.3) were reached.

Even if one disregards the presence of kyanite in these rocks, it is most likely that these rocks were subjected to much higher metamorphic conditions than suggested by Card (1964, 1978b). Although in thin section, the main mineral assemblage is the retrograde mineral assemblage of chlorite-white mica-quartz ± biotite, relict porphyroblasts indicate the presence of staurolite in these rocks and, thus, at a minimum, they were subjected to peak metamorphic conditions of lower amphibolite facies. The possible presence of fibrolite in these rocks suggests even higher metamorphic temperatures were reached. In fact, texturally, the metapelitic rocks in Baldwin Township resemble upper amphibolite facies metapelitic rocks, such as the Flinton Group, studied by the author in the Grenville Province. They are not what one would expect for rocks that had experienced only prograde chlorite-biotite metamorphic conditions, as suggested by Card (1964, 1978b).

PRESSURE–TEMPERATURE PATH

The textures observed in the metapelites can be explained if the rocks followed the prograde metamorphic path illustrated in Figure 14.3. With increasing metamorphic grade, chloritoid would begin forming at above 300°C, followed by the development of andalusite at approximately 400°C. At 480°C, the reaction chloritoid + andalusite to form staurolite + quartz would begin, which would produce the post-kinematic mineral assemblages observed at the Great Bend. In Baldwin Township, these reactions occurred syn-kinematically, likely in conjunction with regional folding. If temperatures continued to rise to 650°C, the reaction staurolite + chlorite + quartz would result in the formation of garnet and abundant kyanite, along with releasing water. This reaction occurred post-kinematically. If this reaction took place near the aluminosilicate triple junction, only a slight increase in temperature would result in the formation of sillimanite, which has been reported from McKim Formation metapelites in May Township (Jackson 2001). Upon reaching peak temperatures, the rocks were cooled quickly to low grade conditions, likely in a fluid-rich environment, which thoroughly retrogressed most minerals, except for the late-formed kyanite. Minerals such as early-formed chloritoid, andalusite and staurolite, were particularly susceptible to retrograde alteration, as they would have already started to break down during the period of increasing temperature.

Tectonic thickening is the most common explanation used to account for the transition from andalusite to kyanite (Kerrick 1990, p.242-243) and also provides an explanation for the syn-kinematic character of the metamorphic porphyroblasts. It also can account for the differences between Baldwin Township and the Great Bend area. As illustrated in Figure 14.4, rocks in Baldwin Township were deformed and metamorphosed near the base of a fold and thrust belt (lower plate), with chloritoid-andalusite-staurolite forming early in the deformation history and at lower pressure. Kyanite formed after thrusting was largely completed, but before unroofing lowered the temperature and pressure in the thrust stack. The rocks at the Great Bend likely formed at a structurally higher level (upper plate), which resulted in metamorphic heating lagging behind deformation. In this scenario, formation of kyanite in rocks in Baldwin Township may have been synchronous with formation of staurolite at the Great Bend. If so, then, regionally, peak metamorphism may have been diachronous, and dependent on the amount of local crustal thickening. Block faulting related to the major easterly and northwesterly faults in the study area has subsequently juxtaposed lower and upper plate rocks adjacent to one another.

The model presented here does serve to explain other metamorphic mineralogical anomalies in the Southern Province. For example, at low temperatures, but similar pressures, the reaction of diaspore to kyanite occurs (*see* Figure 14.3), which would account for the presence of reported occurrences of diaspore and kyanite (Card 1978b; Church 1967; Chandler 1969). It accounts for the folding of metamorphic isograds, as reported by Jackson (2001) for the May Township area. It also provides an alternate explanation for the high-grade metamorphic nodes in the Southern Province other than the presence of focussed heat and fluid zones proposed by Card (1978b). The resulting tectonic history of the Southern Province, that results from the observations in Baldwin Township and the proposed model, represents a considerably more complex metamorphic history for the south-central Southern Province than has been previously envisaged (e.g., Card 1978b; Bennett, Dressler and Robertson 1991).

POST-METAMORPHIC ALTERATION

An approximately 5 km^2 area in central Baldwin Township (Figure 14.5), near the contact between the metavolcanic complex and the overlying metasedimentary sequence dominated by meta-quartz arenites of the Matinenda Formation, is characterized by the widespread development of large, coarse amphibole grains, forming rocks commonly referred to as feather amphibolites (Photo 14.3). These rocks are characterized by coarse-grained, elongate amphibole laths (feathers) in a fine-grained, generally

white, matrix. This texture is commonly observed in the Grenville Province, particularly in mafic dikes hosted within marbles. This alteration zone is also coincident with a Bouguer gravity high (~10 mgal), an aeromagnetic high (~210 gammas), and elevated airborne gamma-ray spectrometric readings for potassium (1.3 to 2.0 percent equivalent potassium (% eK)). These are among the most significant gravity, magnetic, and potassium anomalies in the township.

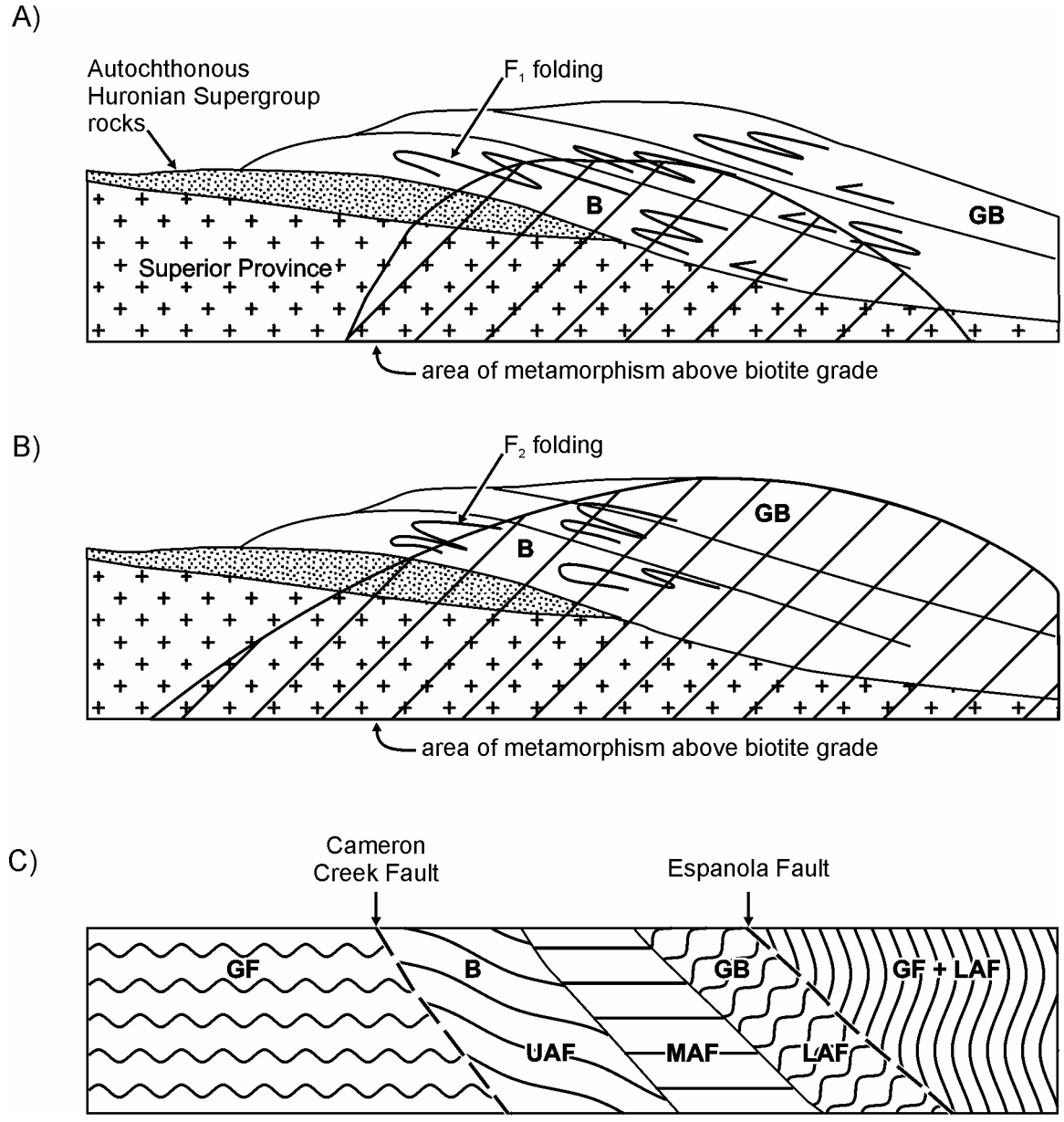

Figure 14.4. Cartoon illustrating the tectonic and metamorphic development of the Southern Province in and around Baldwin Township. A) Early thrusting stage. Baldwin rocks could be located east or west of the décollement, i.e., either in the autochthon or the allochthon. B) Late thrusting stage, coincident with regional metamorphic peak. Nipissing gabbro emplacement probably occurs during both phases A and B. C) Current configuration, following development of east-northeast-trending normal faults at circa 1850 Ma and northwest-trending faults between 1850 and 1240 Ma. Not to scale. Abbreviations: B – Baldwin Township rocks, GB – Great Bend rocks; GF = greenschist facies, LAF = lower amphibolite facies, MAF = middle amphibolite facies, UAF = upper amphibolite facies.

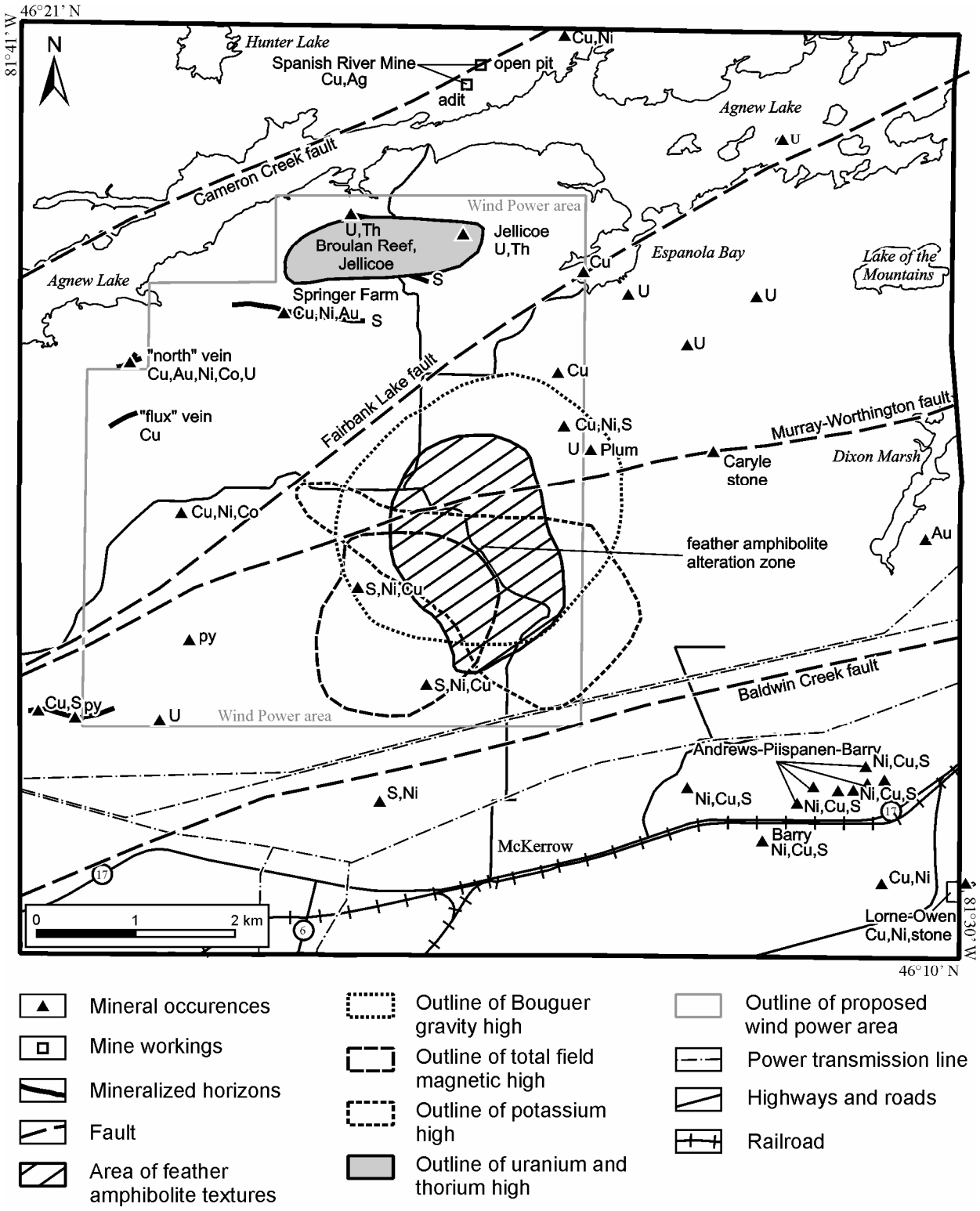

Figure 14.5. Location of alteration zones, geophysical anomalies, past-producing mines, stone quarries and mineral occurrences within Baldwin Township. Only major faults are shown. Abbreviations: Ag = silver, Au = gold, Co = cobalt; Cu = copper, Ni = nickel, py = pyrite, S = sulphide minerals, Th = thorium; U = uranium.

The feather amphibolite texture is not uniformly developed within the 5 km^2 zone. On individual outcrops, metasedimentary rocks are present, sandwiched between rocks exhibiting feather amphibolite texture. Adjacent to recognizable metasedimentary beds, many of the feather amphibolites are layered, and appear to be a replacement texture developed in original sedimentary beds. For the most part, however, the feather amphibolite outcrops are massive, and have the appearance of an igneous rock; in fact, on previous maps, the 5 km^2 zone is shown as a complex mixture of metasedimentary and mafic intrusive rocks (Thomson 1952; Card 1978a). Although the feather amphibolite texture is developed in many metasedimentary rocks, based on observations of the metavolcanic-metasedimentary transition elsewhere in Baldwin Township, it is also likely that the feather amphibolite alteration is also present in the fine-grained mafic dikes that are also common in the metavolcanic–metasedimentary rock package. In outcrop, recognition of altered mafic dikes versus altered metasedimentary rocks is not always possible. As one traverses from the centre to the margins of the 5 km^2 zone, grain size of the amphibole decreases from coarse grained to fine grained, and eventually one passes into metasedimentary or metavolcanic rocks where the texture is absent.

In thin section, it can be seen more clearly that the large amphibole grains overgrow an original sedimentary protolith, even in rocks that outwardly show a massive appearance. The feathery amphiboles are blue-green hornblende, are unaltered, and overgrow an earlier metamorphic foliation. In addition, garnets developed in the adjacent metasedimentary rocks, are equant, contain few inclusions, and also overgrow an earlier metamorphic fabric. The preservation of both the amphiboles and the garnets suggests that the feather amphibolite texture developed after the regional metamorphic retrogression event that affected all other supracrustal rock units in the township. Thus, the feather amphibolite zone formed after regional metamorphism.

Although the feather amphibolite samples show a wide range in silica content (45 to 67 weight %), reflecting derivation from both mafic igneous and metasedimentary protoliths, total alkali contents are remarkably similar (3.6 to 3.9 weight %), as are their Fe/Mg ratios (3.0 to 3.3), suggesting subsequent chemical homogenization of some of the major elements. Lithium is also slightly high (26 to 81 ppm).

Photo 14.3. Feather amphibolite texture developed in a metasedimentary protolith, with relict bedding plane cutting from left to right across the upper part of the photo. Knife for scale, entire knife is 9 cm long. Location: UTM 442556E 5128900N, NAD83, Zone 18.

The reason for this extensive alteration zone is unknown, but the presence of coincident geophysical anomalies suggest that it may be related to fluid release from an underlying pluton, perhaps related to the Cutler and Eden Lake plutons (~1740 Ma).

MINERAL POTENTIAL

Known mineral occurrences in the township are indicated on Figure 14.5. Subsequent to undertaking this mapping program, a 30 km^2 area in central Baldwin Township was withdrawn from staking for the purpose of evaluating the potential for a wind power farm (*see* Figure 14.5). Although this area represents only 30% of the area of the township, it includes 50% of the known mineral occurrences.

The mineral potential of the area of post-metamorphic alteration is currently unknown. It is a zone of high fluid flow and it is associated with several geophysical anomalies. Consequently, the zone may outline a zone of moderate- to deep-seated mineralization.

Uranium

Only low-resolution gamma-ray spectrometric data are available for Baldwin Township (Ontario Geological Survey–Geological Survey of Canada 1978a, 1978b, 1978c). A minor uranium and thorium anomaly occurs in the area south of Agnew Lake, west of Espanola Bay (*see* Figure 14.5), in association with the Jellicoe uranium occurrence (Thomson 1960) and outcrops of syenogranite of the Birch Lake granite. Part of this airborne gamma-ray anomaly likely reflects the Birch Lake granite, which contains elevated thorium contents (Easton 2005; *see* Table 14.1), as well as adjacent meta-quartz arenite beds that also give scintillometer readings in the range of 40 to 91 ppm for thorium.

Uranium and thorium mineralization at the Jellicoe occurrence occurs in a quartz-pebble metaconglomerate horizon (*see* Photo 14.2c), located near the base of the Matinenda Formation. Thickness of the mineralized horizons varies from 2 to 20 m. The best assays reported from drill core were values of 250 to 900 ppm U and 80 to 670 ppm U over widths of 30 to 90 cm (Thomson 1960; values have been converted from weight % U_3O_8 to ppm U). The highest surface exposure scintillometer readings that were measured as part of this study, from quartz-pebble metaconglomerate at the Jellicoe occurrence, were 90 ppm U and 49 ppm Th. H.D. Meyn had collected samples of metaconglomerate and meta-quartz arenite from the Jellicoe occurrence in 1979; these had been analyzed for major elements and a limited number of trace elements. As part of this study, the 1979 powders were re-analyzed, with the metaconglomerate samples assaying between 141 and 259 ppb Au, 44 to 285 ppm Th, and 840 to 1780 ppm U. A meta-quartz arenite sample assayed 136 ppb Au, 140 ppm Th and 381 ppm U. These values are consistent with the historic values reported by Thomson (1960).

Roscoe (1969, p.140-142) proposed a chemical–mineralogical classification of the Huronian Supergroup radioactive conglomerates based on the proportions of U, Ti, Th and Zr. Type 1 were the uraninite-rich conglomerates that were mined at Elliot Lake. Type 4 conglomerates have Ti>Th>Zr>U, no or only minor correlation between Ti, Th, Zr and U contents and iron, and monazite as the main radioactive mineral. The Jellicoe occurrence metaconglomerates are type 4, based on the samples collected by Meyn. This chemical classification is also consistent with the petrographic study of radioactive metaconglomerates from the Agnew Lake area by Young (1962), who only found monazite in the samples from Baldwin Township. In contrast, samples from near the Agnew Lake Mine in Hyman Township contained thorianite and monazite (Young 1962).

Several other small uranium occurrences also occur in the study area (*see* Figure 14.5), and are all associated with thin (<1 m thick) metaconglomerate horizons in the lower Matinenda Formation (Thomson 1960; Robertson 1968). These other occurrences appear to be similar in setting and type to the Jellicoe occurrence. The highest assay values (585 to 1350 ppm U, converted from weight % U_3O_8 as reported in Thomson 1960) were from the Plum occurrence, over intervals of 60 to 90 cm; the thickness of the host metaconglomerate (Thomson 1960). The Plum occurrence is now largely overgrown.

The lack of 1) significant airborne gamma-ray spectrometric targets in the area, 2) the absence of a continuous basal metaconglomerate horizon, 3) the thin, discontinuous, character of the metaconglomerate horizons in the study area, and 4) their classification as type 4 conglomerates, all indicate low potential for uranium and thorium mineralization within Baldwin Township, despite the relative abundance of Matinenda Formation rocks.

Copper

SALMAY LAKE VOLCANIC COMPLEX

The abundance of originally highly permeable volcaniclastic rocks within the Salmay Lake Volcanic Complex is a favourable indicator with respect to mineralization, and these units commonly contain disseminated pyrite and pyrrhotite. In addition, several laterally extensive (1 to 3 km), sulphide-rich volcanic sediment and black shale horizons are located in the township. As shown in Figure 14.5, several historic mineral occurrences, predominantly copper-rich, are located along the trace of these volcanic sediment and black shale horizons. The potential for these rocks to host volcanogenic massive sulphide mineralization is difficult to ascertain, especially given the lack of felsic units within the volcanic complex, and the fact that the supracrustal rocks of the volcanic complex may have been deposited distal to the volcanic centres.

VEIN- AND FAULT-HOSTED COPPER

Two quartz veins in Concession V, Lot 11 contain massive chalcopyrite. Archibald (2003) provides a summary of the exploration history of these veins. Assay samples reported by Thomson (1953) from the "north" vein contained as much as 9.92 and 13.2% Cu, as well as 600 ppm Ni, 2900 ppm Co, and between 0.31 and 2.8 g/t Au. Assay samples reported by Thomson (1953) from the "flux" vein contained 3.69, 4.64 and 7.45% Cu, and up to 2100 ppm Ni. Both these quartz veins are axial planar to the F_2 fold axes in the area, and occur near the contact between the Archean basement and overlying rocks of the Salmay Lake Volcanic Complex and the Matinenda Formation.

Fault-hosted chalcopyrite mineralization occurs along 2 of the major fault systems. The first is known only from drill core, and occurs on the southwest shore of Espanola Bay along the trace of the Fairbank Lake fault. Up to 4.19% Cu is reported over a width of 2.4 m in 1 diamond-drill hole, and assay values of 0.48, 0.65, and 1.01% Cu are reported on core from other holes (Shklanka 1969, p.230-231). More significant is the Spanish River Mine, located along the Cameron Creek fault, which puts McKim Formation metawacke and shales in contact with Mississagi Formation meta-quartz arenites. This mine operated between June 1969 and September 1970, producing 132 735 tonnes or ore, grading 1.20% Cu, 0.06 g/t Au, and 1.30 g/t Ag (Pearson, Bretzlaff and Carrière 1985). A reserve calculation made in 1968 indicated the presence of 992 757 tonnes of ore at a grade of 1.49% Cu (Pearson, Bretzlaff and Carrière 1985; Shklanka 1969, p.230). A 727 kg bulk sample collected in 1995 in association with environmental clean-up of the site assayed 8.77% Cu and 14 g/t Ag (D&H Consulting Inc. 1996). Four grab samples collected from waste piles at the Spanish River Mine by the author assayed between 383 and 1000 ppb Au.

Both the vein-hosted and fault-hosted copper occurrences formed late in the geological history of the area, likely after the metamorphic and deformational peaks. The presence of associated cobalt and silver with these occurrences, suggests linkages with five-element veins systems (e.g., Kissin 1993), such as those associated with Nipissing gabbro intrusions in the Cobalt area. These vein systems are commonly associated with crystalline intrusive rocks as well as metasedimentary rocks, both of which occur in Baldwin Township. The widespread development of chalcopyrite and other copper sulphides, along with pyrite and pyrrhotite, suggests that in Baldwin Township, the paragenetic sequence developed at least to Stage 4 (Sulphide Stage). As in the Cobalt area, crustal heating and development of hydrothermal systems associated with the crustal extension event that led to the emplacement of the Nipissing gabbro intrusions was likely the driving factor behind this style of mineralization.

Historically, the Southern Province west of Sudbury has not been regarded as a host region for five-element vein style mineralization (e.g., Fyon et al. 1992), perhaps because previous attempts to classify vein systems in the Southern Province focussed on metal content rather than on other vein characteristics (e.g., Fyon et al. 1992). If the vein- and fault-hosted copper occurrences in Baldwin Township are indeed related to the five-element vein model, then it is likely that this style of mineralization occurs over a much broader region of the Southern Province west of Sudbury.

On a local scale, application of the five-element vein model to Baldwin Township, would suggest that the best exploration target areas are crosscutting structures (either veins or faults) in areas near the Archean basement–Huronian Supergroup contact, and where sulphide-rich rocks host rocks are present, for example, the Salmay Lake Volcanic Complex. The area between the Cameron Creek and Fairbank faults contains all of these features. Although, to date, most reported mineralization is copper dominant, the possibility also exists for local concentrations of cobalt and silver.

Nickel-Copper-Platinum Group Elements

A large, folded, Nipissing gabbro sill in southeastern Baldwin Township has been extensively explored for nickel-copper-platinum group element mineralization, and contains 2 main occurrences: the Lorne–Owen and Andrews–Piispanen–Barry occurrences (*see* Figure 14.5). Thomson (1953) reported assay values of 1.23% Cu and 1600 ppm Ni from the Lorne–Owen occurrence, and 1.51% Cu and 7400 ppm Ni from the Andrews–Piispanen–Barry occurrence. Barry (2001a) reported Pt, Pd, and Au values from samples collected north of Highway 17 of 10 to 70 ppb, 20 to 80 ppb, and 20 to 40 ppb, respectively. The highest copper and nickel values reported by Barry (2001a) were similar to those reported by Thomson (1953). A sample south of Highway 17 assayed 2.33% Cu, 5600 ppm Ni, trace Pt and Pd, and 30 ppb Au (Barry 2001b). This sill contains orthopyroxene-rich horizons, and may be more compositionally primitive than other sills in the area. Existing assay data suggests greater potential for Ni-Cu mineralization than for PGE mineralization in the map area.

Industrial Minerals

The Lorne–Owen occurrence has also been examined for its dimension stone potential. Stripping took place in 1997 and 1998, and a test block was extracted in 1997 (Cooper 1999). Subsequently, a small aggregate quarry has been developed in medium-grained Nipissing gabbro at this locality. Carlyle Construction Limited has developed a stone quarry in a steep rock face along the trace of the Worthington fault in eastern Baldwin Township (*see* Figure 14.5). The host rock is sheared and fractured meta-quartz arenite of the Matinenda Formation, which is locally strongly hematized.

REFERENCES

Archibald, F.T. 2003. Baldwin–Shakespeare Township Cu-Au occurrence; Sudbury Resident Geologist's Office, Baldwin Township, assessment file Baldwin SP-021, AFRO# 2.27026, 85p.

Barry, A. 2001a. Untitled report and appendixes; Sudbury Resident Geologist's Office, Baldwin Township, assessment file Baldwin SP-016, AFRO# 2.21285, 10p. [Author's Note: if this file is accessed through the Geology Ontario portal, the file image also includes data from file AFRO# 2.24685, for a property in Shakespeare Township, which are not relevant to the work in Baldwin Township.]

——— 2001b. Untitled report; Sudbury Resident Geologist's office, Baldwin Township, assessment file Baldwin SP-017, AFRO# 2.21906, 10p.

Bennett, G., Dressler, B.O. and Robertson, J.A. 1991. The Huronian Supergroup and associated intrusive rocks; *in* Geology of Ontario, Chapter 14, Ontario Geological Survey, Special Volume 4, Part 1, p.549-591.

Broulan Reef Mines Limited. 1967. Diamond drill logs; Sudbury Resident Geologist's office, Baldwin Township, assessment file Baldwin-0050, not paginated.

Card, K.D. 1964. Metamorphism in the Agnew Lake area, Sudbury district, Ontario, Canada; Geological Society of America Bulletin, v.75, p.1011-1030.

——— 1971. Panache Lake area (west part), district of Sudbury and Manitoulin; Ontario Department of Mines, Preliminary Map P.668, scale 1:63 360.

——— 1978a. Sudbury–Manitoulin; Ontario Geological Survey, Map 2360, scale 1:126 720.

——— 1978b. Metamorphism of the Middle Precambrian (Aphebian) rocks of the eastern Southern Province; *in* Metamorphism in the Canadian Shield; Geological Survey of Canada, Paper 78-10, p.269-282.

Card, K.D., Innes, D.G. and Debicki, R.L. 1977. Stratigraphy, sedimentology, and petrology of the Huronian Supergroup in the Sudbury–Espanola area; Ontario Division of Mines, Geoscience Study 16, 99p.

Card, K.D. and Lumbers, S.B. 1975. Sudbury–Cobalt; Ontario Geological Survey, Map 2361, scale 1:253 440.

Carmichael, D.M. 1978. Metamorphic bathozones and bathograds; a measure of the depth of post-metamorphic uplift and erosion on the regional scale; American Journal of Science, v.278, p.769-797.

Chandler, F.W. 1969. Geology of the Huronian rocks of Harrow Township and surrounding area, north shore of Lake Huron, Ontario; unpublished PhD thesis, University of Western Ontario, London, Ontario, 327p.

Church, W.R. 1967. The occurrence of kyanite, andalusite and kaolinite in lower Proterozoic (Huronian) rocks of Ontario; Geological Association of Canada–Mineralogical Association of Canada, Annual Meeting, Kingston, Ontario, Program with Abstracts, p.14.

Cooper, W.G. 1999. Report on assessment work for James Peter Owen, Baldwin–Nairn property; Sudbury Resident Geologist's office, Baldwin Township, assessment file Baldwin SP-007, AFRO# 2.19502, 73p.

D&H Consulting Inc. 1996. Report on bulk sample project (former Spanish River Mine property), Baldwin Township, Sudbury Mining Division; Sudbury Resident Geologist's office, Baldwin Township, assessment file Baldwin SP-007, AFRO# 2.16796, 22p.

Easton, R.M. 2004. Reconnaissance study of the geology and mineral potential of Porter and Vernon townships, Southern Province; *in* Summary of Field Work and Other Activities, Ontario Geological Survey, Open File Report 6145, p.13-1 to 13-13.

——— 2005. Geology of Porter and Vernon townships, Southern Province; *in* Summary of Field Work and Other Activities, 2005, Ontario Geological Survey, Open File Report 6172, p.13-1 to 13-20.

——— 2006a. Geology of Porter and Vernon townships; Ontario Geological Survey, Preliminary Map P.2845, scale 1:20 000.

——— 2006b. Geological, geochemical and geophysical data from the Porter and Vernon townships area, Southern Province; Ontario Geological Survey, Miscellaneous Release—Data 197.

——— 2006c. Complex folding and faulting history in Huronian Supergroup rocks located north of the Murray fault zone, Southern Province, Ontario; 52nd Institute on Lake Superior Geology, Proceedings, Volume 52, Part 1, p.15-16.

Easton, R.M. and Ford, F.D. 1994. Geology of the Grimsthorpe area; Ontario Geological Survey, Open File Report 5894, 153p.

Easton, R.M., Jobin-Bevans, S.L. and James, R.S. 2004. Geological guidebook to the Paleoproterozoic East Bull Lake intrusive suite plutons at East Bull Lake, Agnew Lake and River Valley, Ontario; Ontario Geological Survey, Open File Report 6135, 84p.

Fox, J.S. 1971. Coexisting chloritoid and staurolite and the staurolite-chlorite isograd from the Agnew Lake area, Ontario, Canada; Geological Magazine, v.108, p.205-219.

Fyon, A.J., Bennett, G.L., Jackson, S., Garland, M.I. and Easton, R.M. 1992. Metallogeny of the Proterozoic Eon; *in* Geology of Ontario, Chapter 23, Ontario Geological Survey, Special Volume 4, Part 2, p.1177-1215.

Jackson, S.L. 2001. On the structural geology of the Southern Province between Sault Ste. Marie and Espanola, Ontario; Ontario Geological Survey, Open File Report 5995, 55p.

Kamo, S. 2006. Report on U-Pb geochronological data from the southern Abitibi Subprovince, Bannockburn–Montrose and Vernon townships, and the Grenville Front region, Thistle–Sisk townships, Ontario; internal U/Pb age report from the Jack Satterly Geochronology Laboratory for the Ontario Geological Survey, Jack Satterly Geochronology Laboratory, Department of Geology, University of Toronto, 22 Russell Street, Toronto, Ontario M5S 3B1, 20p.

Kerrick, D.M. 1990. The Al_2SiO_5 polymorphs; Mineralogical Society of America, Reviews in Mineralogy, v.22, 406p.

Kissin, S. 1993. Five-element (Ni-Co-As-Ag-Bi) veins; *in* Ore deposit models, v.II; Geological Association of Canada, Geoscience Canada Reprint Series, v.6, p.87-98.

Krogh, T.E., Corfu, F., Davis, D.W., Dunning, G.R., Heaman, L.M., Kamo, S.L., Machado, N., Greenough, J.D. and Nakamura, E. 1987. Precise U-Pb isotopic ages of diabase dykes and mafic to ultramafic rocks using trace amounts of baddeleyite and zircon; *in* Mafic dyke swarms, Geological Association of Canada, Special Paper 34, p.147-152.

North American Commission on Stratigraphic Nomenclature (NACSN). 2005. North American Stratigraphic Code; American Association of Petroleum Geologists, v.89, p.1547-1591.

Ontario Geological Survey–Geological Survey of Canada 1978a. Geophysical series (airborne gamma-ray spectrometric), potassium (K), Sudbury, Ontario (41I); Ontario Geological Survey, Preliminary Map P.1611, scale 1:250 000.

——— 1978b. Geophysical series (airborne gamma-ray spectrometric), equivalent uranium (eU), Sudbury, Ontario (41I); Ontario Geological Survey, Preliminary Map P.1612, scale 1:250 000.

——— 1978c. Geophysical series (airborne gamma-ray spectrometric), equivalent thorium (eTh), Sudbury, Ontario (41I); Ontario Geological Survey, Preliminary Map P.1613, scale 1:250 000.

Pearson, W.N., Bretzlaff, R.E. and Carrière, J.J. 1985. Copper deposits and occurrences in the north shore region of Lake Huron, Ontario; Geological Survey of Canada, Paper 83-28, 34p.

Robertson, J.A. 1966. Geology of Salter Township; Ontario Department of Mines, Preliminary Map P.378, scale 1:15 840.

——— 1968. Uranium and thorium deposits of northern Ontario; Ontario Department of Mines, Mineral Resources Circular 9, 106p.

——— 1976. Geology of the Massey area; Ontario Division of Mines, Geoscience Report 136, 130p.

Robertson, J.A., Card, K.D. and Frarey, M.J. 1969. The Federal–Provincial Committee on Huronian Stratigraphy Progress Report; Ontario Department of Mines, Miscellaneous Paper 31, 26p.

Roscoe, S.M. 1969. Huronian rocks and uraniferous conglomerates in the Canadian Shield; Geological Survey of Canada, Paper 68-40, 205p.

Shklanka, R. 1969. Copper, nickel, lead and zinc deposits of Ontario; Ontario Department of Mines, Mineral Resources Circular 12, 394p.

Spear, F.S. 1993. Metamorphic phase equilibria and pressure–temperature–time paths; Mineralogical Society of America, Monograph 1, 799p.

Thomson, J.E. 1952. Geology of Baldwin Township; Ontario Department of Mines, Map 1952-1, scale 1:12 000.

——— 1953. Geology of Baldwin Township; Ontario Department of Mines, Annual Report, 1952, v.61, pt.4, 33p.

——— 1960. Uranium and thorium deposits at the base of the Huronian system in the District of Sudbury; Ontario Department of Mines, Geological Report 1, 40p.

Young, D.A. 1962. Radioactive conglomerates of the Agnew Lake area, District of Sudbury, Ontario; unpublished BSc thesis, Princeton University, Princeton, New Jersey, 89p.

15. Project Unit 04-013. Geology and Mineral Potential of the Western Grimsthorpe Domain, Grenville Province: Insights from Examination of Archived Diamond-Drill Core

R.M. Easton[1]

[1]Precambrian Geoscience Section, Ontario Geological Survey

INTRODUCTION

This project was initiated in 2004 to study the potential of the western Grimsthorpe domain to host gold and diamond mineralization. Preliminary results of the 2004 mapping program were presented in Easton (2004). Subsequent U/Pb geochronological studies established that gold mineralization in the western Grimsthorpe domain occurred at 1282±3 Ma (Easton and Kamo 2005). In 2005, the Ministry of Northern Development and Mines Resident Geologist's Office in Tweed acquired nearly 4 km of diamond-drill core that had been drilled by Lydia Diamond Exploration of Canada Limited[2] (LDEC) during their diamond exploration program in western Grimsthorpe domain. Many of these drill holes were located along the trend of the gold-bearing Moira River fault, in areas of limited outcrop exposure. Thus, they had the potential to provide some valuable information on the geology and mineral potential of the western Grimsthorpe domain. Consequently, 2 weeks of the 2006 field season were devoted to examining, logging and sampling some of this drill core.

Terminology

Lamprophyre is used herein in the sense of Mitchell and Bergman (1991); namely, it is a field term to describe any melanocratic dike rock that contains ferromagnesian phenocrysts (e.g., biotite, hornblende, etc.). The term groups together rocks of diverse character and origin and, in this report, has no petrological implications. Lamproite, as defined geochemically by Mitchell and Bergman (1991), is an ultrapotassic, peralkaline rock with high Ba (>2000 ppm), high TiO_2 (1 to 7 weight %), high Zr (>500 ppm), Sr (>1000 ppm), and high La (>200 ppm). Lydia Diamond Exploration of Canada Limited used a number of informal names to refer to various mafic dikes they encountered during their mapping, including the '250', '107', '112', 'black' and 'Wild Dog' dikes. These names are retained herein so as to facilitate comparison with data found in the assessment files at the Tweed Resident Geologist's Office.

This Study

Between 2000 and 2002, Lydia Diamond Exploration of Canada Limited (LDEC) drilled 113 holes, acquiring approximately 5224 m of mostly NQ core. Drill-hole length varied from 3 to 181 m.

[2] Name changed from Lydia Consolidated Diamond Mines of Canada Limited in May 2001.

Summary of Field Work and Other Activities 2006,
Ontario Geological Survey, Open File Report 6192, p.15-1 to 15-21.

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Approximately 75%, or 3897 m, of this drill core is stored at the Tweed drill core library. As part of this study, approximately 980 m of drill core was examined, representing 25% of the LDEC diamond-drill core stored at Tweed, or approximately 19% of the total amount drilled. Drill logs for most of the drill core are available in the assessment files at the Tweed Office (Lydia Diamond Exploration of Canada Limited 2001a, 2002a-e, 2003a-c).

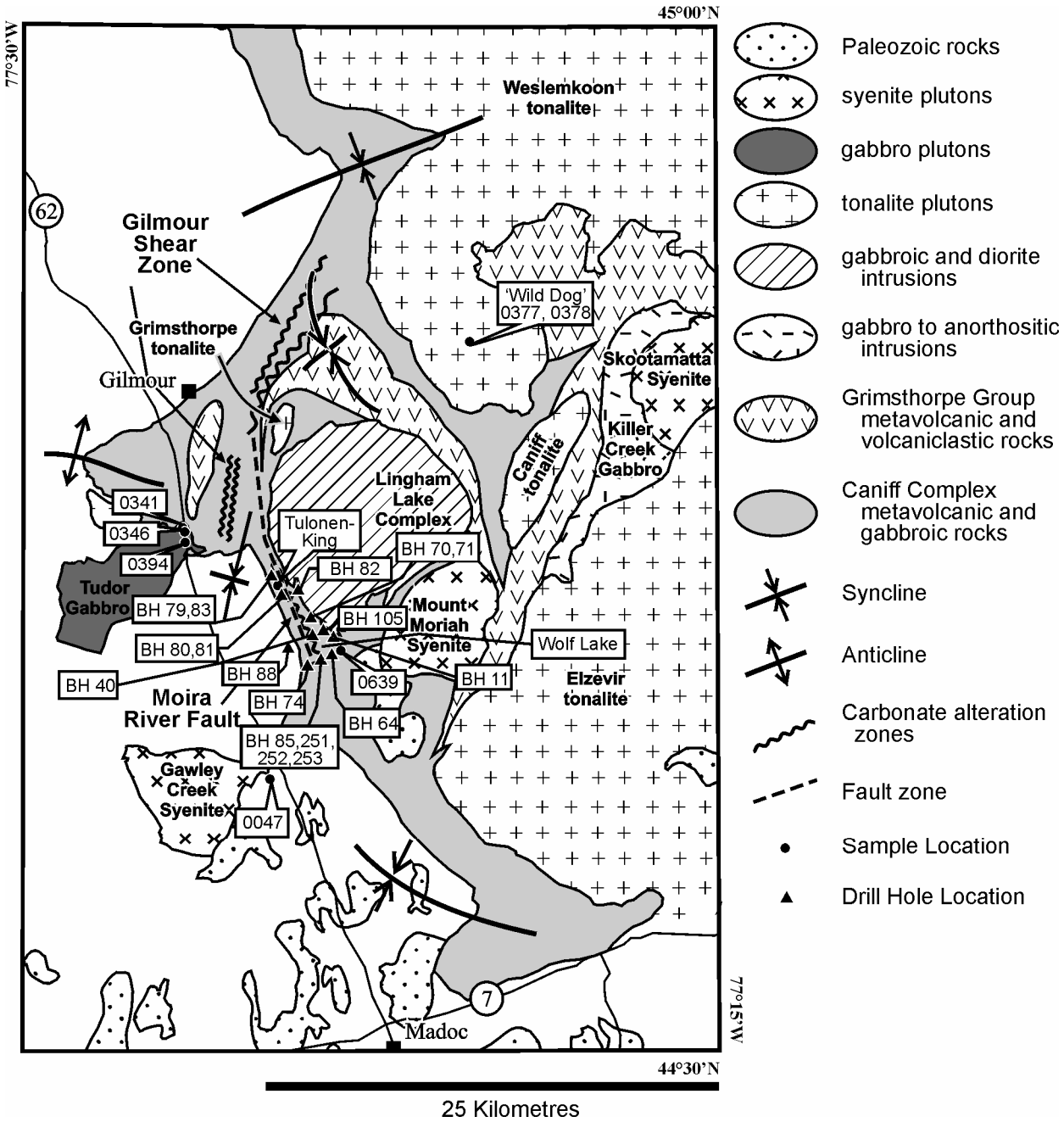

Figure 15.1. Geological sketch map of western Grimsthorpe map area, showing major geological features. Only units from Grimsthorpe domain are shown in detail, rocks of Belmont domain are not ornamented. Location of drill holes examined in this study, as well as the location of selected chemistry samples listed in Tables 15.3 and 15.4 are also shown. Only the last 4 digits of the sample numbers are given; these are preceded by the prefixes 89RME-, 04RME-, or 06RME-.

WESTERN GRIMSTHORPE DOMAIN

Geology

The map area straddles 2 geological domains of the Central Metasedimentary Belt: Belmont and Grimsthorpe, with the study focussing on the Grimsthorpe domain (Figure 15.1). The Belmont domain consists of several discrete packages of bimodal metavolcanic rocks, ranging in age from 1287 to 1250 Ma, as well as siliciclastic and carbonate metasedimentary rocks, all of which are intruded by mafic (Lavant intrusive suite) and granitic (Methuen intrusive suite) plutons at circa 1245 Ma (Easton 1992). Metamorphic grade in the Belmont domain, particularly the southern and eastern parts of the domain ranges from middle greenschist to lower amphibolite facies. Adjacent to the study area, the Belmont domain consists mainly of grey, thin-bedded, calcite marbles with interbedded metasiltstone and locally metasandstone. In contrast, the Grimsthorpe domain is dominated by mafic, metavolcanic and volcaniclastic metasedimentary rocks that are older than 1270 Ma. Carbonate metasedimentary rocks are rare. Plutonic rocks are dominated by tonalite and granodiorite plutons of the Elzevir intrusive suite. Metamorphic grade ranges from lower to middle greenschist facies in the south and east, to amphibolite facies in the north (Easton 1992).

Two major supracrustal packages occur within the Grimsthorpe domain (Easton 1992), as follows, from youngest to oldest:

- *Grimsthorpe Group:* Metasedimentary rocks derived from a mafic volcanic and gabbroic source region and minor metabasalt flows. Main rock types are matrix- and clast-supported metaconglomerate, gabbro cobble metaconglomerate, meta-arenite, metawacke, minor metasiltstone, metapelite, rusty schist. Minor pillowed and massive tholeiitic metabasalt flows.

unconformity?

- *Canniff Complex:* Massive and pillowed tholeiitic metabasalts, spilitic metabasalts; protomylonitic metagabbro and metaperidotite. Ultramafic rocks commonly altered to talc ± anthophyllite ± actinolite rocks.

A U/Pb zircon age of 1279±3 Ma (Heaman et al. 1987) from a felsite within the Grimsthorpe Group in Tudor Township provides a minimum age of deposition for both the Canniff Complex and the Grimsthorpe Group. Both the Grimsthorpe Group and the Canniff Complex are intruded by a variety of younger plutonic rocks (*see* Figure 15.1). These include

1. ultramafic, gabbroic and anorthositic rocks of the Killer Creek intrusive suite (>1270 Ma, Easton 1992)
2. gabbroic and dioritic rocks of the Lingham Lake intrusive complex
3. tonalitic and granodioritic rocks of the Elzevir intrusive suite, dated at ~1270 Ma (Heaman et al. 1987). These include the Grimsthorpe, Canniff, Weslemkoon and Elzevir intrusions.
4. gabbroic rocks of the Lavant intrusive suite, which were emplaced at ~1240 to 1250 Ma (Easton 1992). The Tudor gabbro is the largest body of this suite in the study area.
5. syenitic rocks of the Kensington–Skootamatta suite, which were emplaced at ~1075 to 1090 Ma (Easton 1992). Both the Mount Moriah syenite and the Skootamatta syenite intruded supracrustal rocks of Grimsthorpe domain, whereas the Gawley Creek syenite intruded rocks of Belmont domain.

There are several notable differences between the eastern and western parts of Grimsthorpe domain. The Grimsthorpe Group in the west contains a higher proportion of metavolcanic rocks (Tudor Formation) than in the east, and mafic rocks of both the Canniff Complex and the Grimsthorpe Group in the western Grimsthorpe domain are more extensively altered than they are in the east. In addition, primary volcanic and sedimentary textures are less commonly observed in supracrustal rocks in the western Grimsthorpe domain. There may also be more felsite horizons in the western Grimsthorpe domain. It remains to be determined if these felsites are felsic flows or tuffs intercalated with the mafic volcanic rocks or if they are simply fine-grained, deformed, intrusive rocks. The Canniff Complex in the western Grimsthorpe domain is dominated by metabasaltic rocks, with a minimal amount of metagabbroic or metaperidotitic rocks.

Alteration

Alteration of the mafic metavolcanic rocks of both the Grimsthorpe Group and the Canniff Complex ranges from minor to intense, and is complex. The dominant form of alteration is the introduction of calcite and dolomite, brown to red-brown weathering ankerite, and quartz into the metavolcanic rocks. This occurs in a variety of forms (*see* Easton 2004 for details):

- Along thin (1 to 10 mm wide) carbonate ± quartz veins injected along fractures. Vein spacing may be on the order of tens of centimetres, but typically is on the order of 1 or 2 cm. Veins may be continuous or discontinuous along strike.
- A more pervasive introduction of carbonate, generally accompanied by the development of chlorite, white mica and/or biotite along cleavage surfaces. Rocks become highly schistose, and weathered surfaces may appear pocked, due to recessive weathering of large carbonate grains.
- An almost complete replacement by red-brown carbonate, producing a fairly massive rock that no longer resembles an igneous rock. Associated with these zones are biotite-rich (>15%) horizons. Quartz veins and pods, typically disrupted, are commonly associated with these zones of intense alteration.

The zones of alteration and extensive quartz veining are anastomosing, particularly in the north. On a property scale, this makes it difficult to trace some of the more intense alteration and mineralized zones along strike. As noted by Christie (1990), at least 2 main fabrics are present in the alteration zones, an early, steep fabric with associated quartz veins and azimuths of 250 to 220°, and a younger, steep, fabric oriented 170 to 180° and closely associated with carbonate flooding. The alteration and vein systems resemble lode gold-bearing systems found in Archean greenstone belts.

Alteration of felsite bodies hosting gold mineralization is somewhat different in character to the alteration of the mafic rocks (*see* Easton 2004 for details), in that carbonate alteration is minimal. Instead, alteration consists of disseminated arsenopyrite associated with friable, schistose and chloritic zones in the felsite, as well as zones of discrete, concordant to semi-concordant quartz veins with associated arsenopyrite. Mineralization is associated with the development of a protomylonitic fabric in the felsite.

Shear Zones

Alteration, deformation, quartz veining and mineralization are concentrated along 2 major shear zones in the map area (Easton 2004). These are the older, 250 to 220° trending, Gilmour shear zone (*see* Figure 15.1) and the 170 to 180° trending Moira River fault (*see* Figure 15.1). The Gilmour shear zone is anastomosing, and may contain several splays. It corresponds, in part, to the Moira River shear zone of

Christie (1990). The Gilmour shear zone appears to be truncated at the Belmont–Grimsthorpe domain boundary, as there is no evidence of deformation or alteration of the low-grade Belmont domain marbles directly on strike with the trace of the shear zone. This suggests that the alteration and veining within the Gilmour shear zone occurred before development of the domain boundary (Easton 2004).

The Moira River fault parallels the Moira River along much of its length, and extends from the south end of Wadsworth Lake to south of Queensborough. Locally, the Moira River fault forms the Belmont–Grimsthorpe domain boundary. The fault has locally mylonitized rocks of both the Belmont and Grimsthorpe domains. From approximately 4 to 11 km north of Wolf Lake, the Moira River fault deforms rocks of the Gilmour and associated shear zones, resulting in further deformation and the introduction of late semi-concordant to discordant quartz veins. An alteration zone east of the Moira River, that is part of the Moira River fault, is truncated in places by porphyritic monzodiorite of the Lingham Lake intrusive complex, and locally includes inclusion-breccias containing carbonate-altered metavolcanic fragments. This suggests that alteration and veining was largely complete by the time of intrusion of the Lingham Lake intrusive complex at circa 1282 Ma (Easton and Kamo 2005), although it is possible that some reactivation of the Moira River fault occurred after emplacement of the Lingham Lake intrusive complex.

RESULTS

Core Examination

Table 15.1 lists all the LDEC drill holes, as well as indicating the cores from holes examined as part of this study. All drill holes, except BH88, are located in rocks of the Grimsthorpe domain. Drill hole BH88 is located in the Belmont domain, and is hosted entirely in thin-bedded calcite marbles. The other drill holes are hosted mainly in altered mafic metavolcanic rocks or rocks of the Lingham Lake intrusive complex. More than 70 of the drill holes are located within 1 km of the south and east shores of Wolf Lake, concentrated in 3 locations. Most of the remaining holes are located between the Moira River and the western margin of the Lingham Lake intrusive complex, and these holes were the focus of this study.

Most of the core was not split or sampled by LDEC, with the exception of intervals that contained lamprophyre dikes. Intervals containing dikes had been split, and some sections had been removed by LDEC for sampling. Only a few of the drill cores stored at Tweed contained lamprophyre dikes, and no drill core from the area of the 'Wild Dog' trench in Grimsthorpe Township was available for examination. In addition, based on the drill logs filed for assessment, many of the drill holes that intersected lamprophyre dikes are not present at the Tweed drill core library. Consequently, there was insufficient material available to allow for meaningful sampling of any of the dikes for diamonds, which requires a minimum of 25 kg of material.

Selection criteria used by the author in choosing which drill holes to examine included 1) the location of the hole, especially as to whether the hole was isolated or part of a cluster of drill holes; 2) the orientation and length of the hole; and 3) the rock types listed in the company drill logs. Preference was given to deep vertical holes in areas of poor outcrop, holes located near the trace of major gold-bearing alteration zones, or holes containing lamprophyre dikes or unusual rock descriptions. In addition to detailed logging of the studied holes, 63 samples were collected for whole-rock chemical analyses and 60 samples were collected for assay. Preliminary results from these 123 samples are discussed elsewhere in this report. An additional 78 whole-rock chemical analyses are present in the assessment work filed by LDEC (Lydia Diamond Exploration Company Limited 2003d, 2003e). These analyses were compiled and compared with the data obtained as part of this project. Unfortunately, most of the whole-rock

Table 15.1. List of Lydia Diamond Exploration Company Limited drill core and core examined as part of this study. YL and NL indicates holes containing lamprophyre dikes.

Hole No.	NAD83 Easting (m)	Zone 18 Northing (m)	Azimuth	Dip	Length (m)	Comment	At Tweed	Core Examined
BH-1	299639	4955911		90	75.59		Y	
BH-2	299639	4955911		90	47.85		Y	
BH-3	299626	4955923		90	29.87		Y	
BH-4	300166	4952433	288	45	53.34	test anomaly A	Y	
BH-5	300166	4952428	288	45	50.29	test anomaly A	Y	
BH-6	300166	4952431	288	45	41.70	test anomaly A	Y	
BH-7	300166	4952436	288	45	50.29	test anomaly A	Y	
BH-8	300156	4952423	18	45	39.01	test anomaly A	Y	
BH-9	300156	4952423	333	45	38.71	test anomaly A	Y	
BH-10	300156	4952423	18	70	66.45	test anomaly A	Y	
BH-11	299964	4952423		90	75.49	test anomaly B	YL	**Y**
BH-12	299976	4952223		90	75.28	test anomaly B	YL	
BH-13	299938	4952398		90	75.59	test anomaly B	NL	
BH-14	300011	4952373		90	35.66	test anomaly B	NL	
BH-15	299964	4952398		90	75.59	test anomaly B	NL	
BH-16	299964	4952423	240	45	168.55	test anomaly B	YL	
BH-17	299936	4951298	40	45	37.37	quarry area	Y	
BH-18	299936	4951298	30	45	47.24	quarry area	N	
BH-19	299931	4951308	30	45	52.12	quarry area	N	
BH-20						no log	Y	
BH-21						no log	Y	
BH-22/251	299931	4951303	30	78	84.73	250 dike	Y	
BH-23/251						no log	Y	
BH-24/251	299914	4951283	20	45	22.56	250 dike	YL	**Y**
BH-25/252	299913	4951281	20	79	37.10	250 dike	YL	**Y**
BH-26/253	299916	4951288		90	14.63	250 dike	YL	**Y**
BH-29/713	301576	4956508		90	26.82	test anomaly P71	Y	
BH-30/714	301481	4956518		90	79.25	test anomaly P70	N	
BH-31	301796	4955818		90	63.40	test anomaly P64	N	
BH-32/715	301686	4955778		90	90.83	test anomaly P64	N	
BH-33/716	301686	4955738	360	45	59.44	test anomaly	N	
BH-34	301686	4955738	180	45	77.72	test anomaly	Y	
BH-35	299866	4952713	360	45	33.53	test anomaly	N	
BH-36	299866	4952693	180	45	36.58	test anomaly	N	
BH-37	299866	4952703	180	45	23.16	test anomaly	N	
BH-38	299926	4952713		90	39.01	test anomaly	N	
BH-39	299571	4952723		90	60.35	test anomaly	Y	**Y**
BH-40	299566	4952598		90	29.87	test anomaly	Y	
BH-41						no log	Y	
BH-42						no log	Y	
BH-44						no log	Y	
BH-45	299551	4956148		90	39.62	test anomaly 6/6	Y	
BH-46	299651	4956123	180	45	79.25	test anomaly 6/6	Y	
BH-47	299651	4956123	135	45	108.51	test anomaly 6/6	Y	
BH-48	299686	4955983	100	45	92.35	test anomaly 6/6	Y	
BH-49	299686	4955983	140	45	79.25	test anomaly 6/6	Y	

Table 15.1. continued.

Hole No.	NAD 83 Easting (m)	Zone 18 Northing (m)	Azimuth	Dip	Length (m)	Comment	Core at Tweed	Core Examined
BH-50	299451	4956098	90	45	74.68	test anomaly 6/6	Y	
BH-51	299476	4956173	90	45	72.54	test anomaly 6/6	Y	
BH-52	299051	4951315	215	45	29.26	test anomaly 6/6	NL	
BH-53	299051	4951315	215	65	38.71	dip of B dike	NL	
BH-54	299051	4951315	180	45	29.87	strike of B dike	NL	
BH-55	299032	4951286	17	55	13.72	sample B dike	NL	
BH-56	299032	4951286	17	50	20.12	sample B dike	NL	
BH-57	299032	4951286	17	48.5	13.72	sample B dike	NL	
BH-58	299032	4951286	17	46	12.5	sample B dike	NL	
BH-59	299032	4951286	26	47.5	13.72	sample B dike	NL	
BH-60	299032	4951286	26	47	19.81	sample B dike	NL	
BH-61	299032	4951286	26	49	10.36	sample B dike	NL	
BH-62	299032	4951286	26	47	20.12	sample B dike	NL	
BH-63	299125	4952191	197	45	53.64	extension of B dike	YL	
BH-64	299172	4952229	197	45	78.03	extension of B dike	Y	**Y**
BH-65	299037	4951293		90	7.92	sample black dike	NL	
BH-66	299037	4951285	17	48	7.92	sample black dike	N	
BH-67	299037	4951288	17	50	8.53	sample black dike	NL	
BH-68	299037	4951285	17	48	8.53	sample black dike	N	
BH-69	299037	4951285	17	48	13.41	sample black dike	N	
BH-70	299572	4953811		90	36.27	geophysical target	Y	**Y**
BH-71	299446	4953713		90	45.72	geophysical target	Y	**Y**
BH-72	299616	4953643		90	33.22	geophysical target	Y	
BH-73	299020	4951330	200	45	29.26	strike of black dike	YL	
BH-74	299020	4951330	160	45	29.26	strike of black dike	YL	**Y**
BH-75	299056	4951283	170	70	14.78	strike of black dike	NL	
BH-76	299056	4951283	215	70	14.78	strike of black dike	NL	
BH-77	299860	4952719	130	45	38.4	strike of E dike	NL	
BH-78	299866	4952693	242	45	35.36	strike of E dike	Y	
BH-79	298535	4956033	215	45	47.55	test anomaly P41	Y	**Y**
BH-80	298913	4955533	240	45	41.15	test anomaly D12	Y	**Y**
BH-81	298896	4955523		90	42.37	test anomaly D12	Y	**Y**
BH-82	299226	4955673	270	45	41.45	test anomaly P40	Y	**Y**
BH-83	298501	4956030		90	60.66	test anomaly P41	Y	**Y**
BH-84	299891	4951297	270	90	93.88		Y	
BH-85	299897	4951299		90	159.72		Y	**Y**
BH-86						no log	Y	
BH-87						no log	Y	
BH-88	299028	4952393	42	45	124.36	geophysical target	Y	**Y**
BH-89	299931	4951558		90	4.57		NL	
BH-90	299931	4951558		90	3.05		NL	
BH-91	299931	4951558		90	4.88		NL	
BH-92	299931	4951558		90	5.79		NL	
BH-94						no log	YL	
BH-95	299928	4951576	20	85	35.97	dip calculation	NL	
BH-96	299927	4951574	20	89	56.69	dip calculation	YL	
BH-97	300026	4952810	350	45	71.63	gabbro contact	Y	

Table 15.1. continued.

Hole No.	NAD 83 Easting (m)	Zone 18 Northing (m)	Azimuth	Dip	Length (m)	Comment	Core at Tweed	Core Examined
BH-98	300016	4952823	170	45	71.63	gabbro contact	Y	
BH-99	299296	4955425	80	45	162.76		Y	
BH-100	300718	4955644	270	45	181.05		Y	
BH-101	300546	4955513	277	45	123.44	topographic low	Y	
BH-102	300188	4952624	163	45	25.91	below trench 174		
BH-103	300191	4952610	345	45	13.72			
BH-104	300066	4953135	20	45	77.72	topographic low	YL	
BH-105	300066	4953135	20	60	63.09	Intersect BH104 dikes	YL	**Y**
BH-106	300057	4953135	180	45	68.28	topographic low	Y	
BH-107	300066	4953115	20	45	76+	intersect BH104 dikes	Y	
BH-108	300226	4952653	80	45	49.99	topographic low	Y	
BH-109	300220	4952626		90	63.40	topographic low	Y	
BH-110	300219	4952618	0	45	20.12		Y	
BH-111	300219	4952618	45	45	20.12		Y	
BH-112	300060	4952753	40	45	50.60		Y	
BH-113	308212	4968427	150	45	31.00	BQ core, Wild Dog	N	
BH-114	308212	4968427	330	60	35.00	BQ core, Wild Dog	N	
BH-115	308264	4968484	150	45	38.50	BQ core, Wild Dog	N	
BH-116	298806	4953010	90	45	72.50	BQ core, anomaly P24	N	
BH-117	299742	4951724	246	45	123.00	BQ core, anomaly P9	N	

samples from the assessment files do not contain, loss-on-ignition, H_2O or CO_2 analyses, even though most of these rocks have been subjected to carbonate, potassic and/or chlorite alteration. As a substitute, the chemical index of alteration (CIA) [$(Al_2O_3/Al_2O_3+Na_2O+K_2O+CaO\text{-}CaO \text{ in } CO_2)*100$] (Nesbitt and Young 1982) provides an indication of the degree of alteration of these samples, with values less than 50 or over 100 indicating substantial loss of alkalis and/or addition of elements such as CO_2, magnesium and/or iron. This alteration index indicates that 44 out of the 78 samples compiled from the assessment files are highly altered and, thus, do not represent primary igneous or cumulate compositions. The other 34 samples also show varying degrees of alteration as well, but may retain some of their original chemical character. The abundance of altered samples is not surprising given the abundant field evidence for large scale alteration along the Moira River fault reported by Easton (2004).

METAVOLCANIC ROCKS

Metavolcanic rocks of both the Canniff Complex and the Grimsthorpe Group are the most common rock units observed in studied drill holes. As discussed in "Geochemistry", the 2 types of metavolcanic rocks are geochemically distinctive. Rocks of the Canniff Complex occur in proximity to the Lingham Lake complex, and consist of green to dark green weathering, highly flattened, migmatitic (*sensu lato*) amphibolites. Compositionally, these amphibolites were tholeiitic basalts. In BH80 and BH81, Canniff Complex amphibolites occur in sharp contact with metasedimentary rocks of the Grimsthorpe Group. Although the contact is overturned, possibly during emplacement of the Lingham Lake intrusive complex, the metasedimentary rocks are less deformed and lack the fine-scale leucosome present in the amphibolites. This is consistent with surface observations made by Easton and Ford (1994), who suggested that the Canniff Complex rocks were metamorphosed and deformed prior to Grimsthorpe Group deposition.

In contrast, mafic metavolcanic rocks of the Tudor Formation of the Grimsthorpe Group, are green weathering, massive units that are riddled with from 1 to 20% white to buff weathering, carbonate ± quartz veins. Compositionally, these rocks are also tholeiitic basalts. As discussed in "Alteration", at least 2 generations of veins are present. No volcanic textures were observed in rocks of either the Canniff Complex or the Grimsthorpe Group. Many of the altered mafic metavolcanic rocks have CO_2 contents over 10 weight %, with CIA values either greater than 100 or in the 10 to 40 range, indicating significant degrees of alteration. Silicification is present locally. Potassic alteration is common in many metavolcanic rocks, and is manifested by the presence of dark grey biotite phenocrysts and/or elevated K_2O contents (>1 weight %, compared to <0.30 weight % in fresh rock).

No felsite units comparable to those reported by Lumbers (1969) and Easton (2004) were encountered in drill core. Felsite units located along the Moira River fault are known to host significant gold mineralization (Easton 2004). Some light grey horizons in drill hole BH82 that superficially appeared to be felsites, instead turned out to be compositionally similar to dioritic phases of the Lingham Lake intrusive complex and, thus, represent fine-grained dikes rather than possible felsic flows.

METASEDIMENTARY ROCKS

Metasedimentary rocks were observed in BH79, BH80, BH81, BH82, BH83 and BH85, in zones ranging from approximately 1 to 58 m thick. The presence of metasedimentary rocks was not generally noted in the LDEC drill logs; however, many of these zones were noted indirectly in the logs on the basis of colour change (from green to grey) and/or by the presence of sulphides.

In BH85, 4 main metasedimentary zones are present, ranging from 1 to 19 m in thickness. Also in BH85, metre-scale interlayering of metavolcanic and metasedimentary rocks was observed. Many of the metasedimentary bands are sulphide rich, containing pyrrhotite, pyrite, chalcopyrite and locally, arsenopyrite. The sulphide-bearing horizons are quite extensive, accounting for most of the metasedimentary rock in BH85, and 24 m of the 58 m of metasedimentary rock encountered in BH83. The majority of samples collected for assay as part of this study were collected from these sulphide-rich horizons. The sulphide-rich horizons are commonly hosted in a very thin-bedded, dark grey to grey calcareous mudstone unit. These horizons most likely correspond to the poorly exposed rusty schist horizons common within the Grimsthorpe Group (Lumbers 1969; Easton and Ford 1994). In this instance, the drill cores provided an excellent opportunity to study and sample these generally poorly exposed units.

The next most abundant metasedimentary rock type are greenish weathering wackes, likely containing a significant component of mafic volcanic detritus, based on the low SiO_2 content (<55 weight %) of many of these rocks. This is not unexpected, as Easton and Ford (1994) reported the widespread occurrence of volcanic-dominated metasedimentary rocks in the eastern Grimsthorpe domain.

Some wacke, arenite and mudstone beds with more typical SiO_2 contents are found in several of the drill holes (e.g., BH80, BH85). Several calc-arenite beds were encountered in BH79, in association with sulphide- and non-sulphide-bearing dark grey calcareous mudstones. The abundance of calcareous metasedimentary rocks in several of the holes suggests that carbonate production and sedimentation during Grimsthorpe Group deposition may have been more widespread than previously thought.

None of the volcaniclastic conglomerates typical of the eastern Grimsthorpe Group were observed in the drill cores that were studied. This is not surprising since the author rarely observed these rocks in outcrop in the area between the Moira River and the Lingham Lake intrusive complex.

ALTERATION

Two generations of calcite veins were observed in the drill core. Calcite veins of both generations cut both the metavolcanic and metasedimentary rock units. There is an earlier generation of generally subhorizontal veins (dips of 0 to 40°) with limited alteration of the host rocks and a later generation of subvertical veins (dips of 70 to 90°) with 1 to 7 mm wide chlorite alteration rims, which obliterate any existing rock textures, including evidence of earlier veining. Although it cannot be demonstrated unequivocally, it would appear that the earlier veins correspond to the 250 to 220° vein set identified by Christie (1990), with the subvertical veins corresponding to the 180 to 170° veins.

The subhorizontal veins appear to be absent from dikes of the Lingham Lake intrusive complex in the drill holes. The subvertical veins are rarely observed cutting dikes of the Lingham Lake intrusive complex, although they do occur locally within, and altering, Lingham Lake intrusive complex rocks. The latter observation is consistent with the U/Pb geochronological and field data (Easton and Kamo 2005) that indicate that the Lingham Lake intrusive complex is, for the most part, older than the alteration associated with the shear zones, but that some reactivation occurred along the Moira River fault.

Density of both types of veins varies both between and within drill holes. Drill holes located closer to the Moira River (e.g., BH71, BH85, BH79) generally have a greater vein abundance than drill holes located further away from the river (e.g., BH70, BH80, BH82). In addition, vein density can vary considerably within individual holes.

In addition to carbonate veining, carbonate flooding, resulting in the development of pervasive disseminated red-brown weathering throughout the mafic rocks, is also observed in some of the drill holes. As with the carbonate veining, carbonate flooding of this type is most common in drill holes located closest to the Moira shear zone, for example, in drill hole BH85. Similar carbonate flooding was observed by Easton (2004) from surface exposures at the site of this drill hole; however, regrowth of lichen and other vegetation since 2004 has now obscured these surface exposures.

INTRUSIVE ROCKS

More than 15 drill holes are hosted mainly in rocks of the Lingham Lake intrusive complex, a composite intrusion consisting of a variety of melanocratic to leucocratic gabbroic rocks and a slightly younger biotite diorite phase. Dikes related to the Lingham Lake intrusive complex occur in several of the examined drill holes located near the western margin of the complex.

A variety of lamprophyre and mafic dikes occur in several of the drill holes, generally hosted in altered mafic metavolcanic rocks. Thickness of these dikes is difficult to ascertain and, based on intersections in closely spaced drill holes, dike thickness may be irregular. For the most part, the lamprophyre dikes are thin, ranging in thickness from 25 to 200 cm. In drill hole BH105, the ‘90’ dike is 24 cm thick, and the ‘107’ dike is 33 cm thick. At least 5 dikes are present in drill hole BH75, ranging in thickness from 30 to 100 cm. The ‘250’ dike in drill holes BH251 and BH252 is estimated to be 1.5 to 2 m thick, although thicker intersections are reported in some of the non-vertical holes drilled through this dike. The dikes consist of fine-grained to medium-grained, relatively massive rock, and lack inclusions. Additional information on the character of these dikes is presented in “Geochemistry”.

GEOPHYSICS

Magnetic susceptibility measurements were collected at 10 cm intervals on all drill cores studied in detail. Scintillometer readings were taken on selected sections of the drill core. Scintillometer readings were low, with all samples containing less than 1 ppm U, 3 ppm Th, and less than 1.5 weight % K. Both the metasedimentary rocks and the lamprophyre dikes yielded potassium readings in the 1.0 to 1.5 range (1.2 to 1.8 weight % K_2O). Most of the metavolcanic rocks gave potassium readings less than 0.5 weight %. The scintillometer did not detect the high potassium contents (3 to 8 weight % K_2O) reported chemically from the lamprophyre dikes. It is possible that, in the case of all the drill core samples, the scintillometer registered artificially low values for potassium due to the small volume of rock being tested.

Magnetic susceptibility readings on mafic metavolcanic rocks, metasedimentary rocks and rocks of the Lingham Lake intrusive complex were all low, generally less than 0.5×10^{-3} SI. Sulphide-bearing metasedimentary rocks commonly gave values in the 1 to 3×10^{-3} SI range. No magnetic-rich alteration zones, such as those found on surface (Easton 2004), were observed in any of the studied drill holes.

Lamprophyre dikes gave varied magnetic susceptibility results. Type 1 lamprophyre dikes yielded low values less than 0.8×10^{-3} SI; however, the type 2 'black' dike was highly magnetic, giving values of 25 to 80×10^{-3} SI (*see* "Geochemistry" for an explanation of dike types). Type 3 mafic dikes yielded low values (0.5×10^{-3} SI), similar to those recorded from the mafic metavolcanic rocks.

Geochemistry

METAVOLCANIC ROCKS

The geochemical characteristics of the 2 main metavolcanic units in the western Grimsthorpe domain are compared in Table 15.2, and is based on the least altered samples collected from drill core. Amphibolites of the Canniff Complex, are high-magnesium to high-iron, tholeiitic basalts with affinities to modern mid-ocean ridge basalts. In contrast, mafic metavolcanic rocks of the Tudor Formation, Grimsthorpe Group, are high-iron tholeiites, commonly with high TiO_2 (>2 weight %), with affinities to modern ocean island basalts and andesites.

The chemical effects of widespread carbonate alteration of the mafic metavolcanic and mafic intrusive rocks in the study area includes lowering of silica content (Figure 15.2), increasing of iron and magnesium content (*see* Figure 15.2) due to the introduction of ankerite and dolomite, and the development of biotite porphyroblasts in rocks that have undergone potassium enrichment. Texturally, this produces a fine-grained, carbonatized mafic rock with biotite phenocrysts has low silica and moderate to high magnesium contents. With only cursory examination, the resulting rock could be mistaken for a lamprophyre. However, in the study area, it is possible in both outcrop and drill core to see the transition from relatively unaltered mafic metavolcanic rocks into intensely altered rocks, and the shear zones along which this alteration occurs are now relatively well delineated. Careful examination of the geochemistry on these altered rocks and the use of alteration indices, also makes it possible to distinguish the altered rocks from primary lamprophyres.

Table 15.2. Inferred tectonic settings for 10 relatively unaltered mafic metavolcanic rocks from western Grimsthorpe domain, based on 11 trace and major element discrimination diagrams.

Plotted Elements (source in brackets)	Canniff Complex Amphibolite	Tudor Formation, Grimsthorpe Group
Trace Element Diagrams		
Zr/4–Nb*2–Y (Meschede 1986)	Within-plate tholeiite, volcanic arc basalt (C field)	Within-plate alkalic basalt or within-plate tholeiite (AII field)
Zr–Ti (Pearce and Cann 1973)	Ocean floor basalt (D field)	Ocean floor basalt (mainly in D field, some in B field)
Zr–Ti/100–Y*3 (Pearce and Cann 1973)	Within-plate basalt (D field)	Within-plate basalt (D field)
Zr–Ti/100–Sr*2 (Pearce and Cann 1973)	Ocean floor basalt	Ocean floor basalt
Zr–Zr/Y (Pearce and Norry 1979)	Within-plate basalt	Ocean floor basalt
Nb/Y–Zr/TiO_2 (Winchester and Floyd 1977)	Subalkalic basalt	Mostly subalkalic basalt, but includes some alkalic basalt
Zr/TiO_2–SiO_2 (Winchester and Floyd 1977)	Subalkalic basalt	Subalkalic or alkalic basalts
Major Element Diagrams		
SiO_2–Alkali (Irvine and Baragar 1971)	Samples plot in tholeiite field	Samples plot in tholeiite field
Alkali–FeO*–MgO (Irvine and Baragar 1971)	Samples plot in tholeiite field	Samples plot in tholeiite field
Al_2O_3–FeO*+TiO_2–MgO (Jensen 1976)	Most samples straddle the join between the high-iron tholeiite and high-magnesium tholeiite fields	Samples plot in high-iron tholeiite field
MnO–TiO_2/10–P_2O_5 (Mullen 1983)	Samples plot in the mid-ocean ridge basalt field	Samples plot in the ocean-island tholeiite and ocean-island andesite fields

Abbreviations: E-MORB = enriched mid-ocean ridge basalt; N-MORB = normal mid-ocean ridge basalt; P-MORB = primitive mid-ocean ridge basalt.

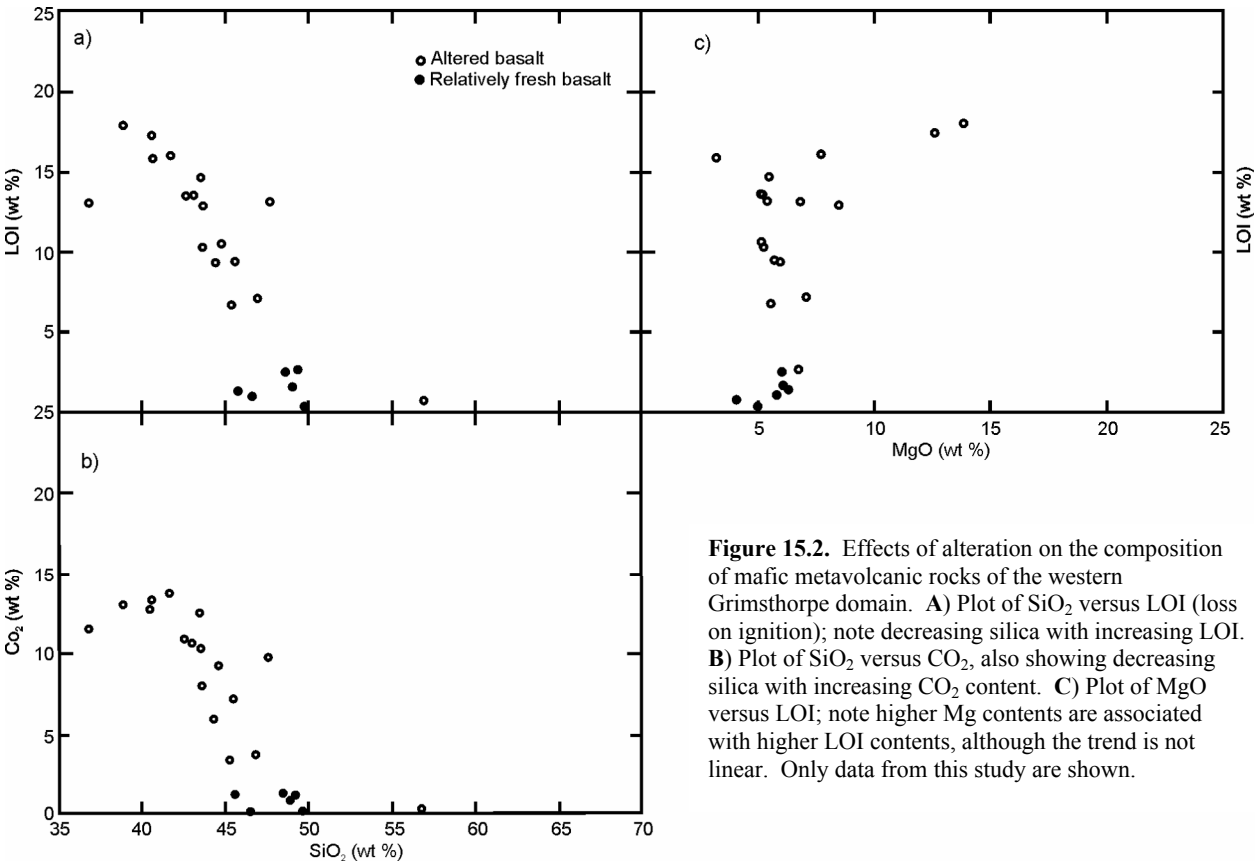

Figure 15.2. Effects of alteration on the composition of mafic metavolcanic rocks of the western Grimsthorpe domain. **A**) Plot of SiO_2 versus LOI (loss on ignition); note decreasing silica with increasing LOI. **B**) Plot of SiO_2 versus CO_2, also showing decreasing silica with increasing CO_2 content. **C**) Plot of MgO versus LOI; note higher Mg contents are associated with higher LOI contents, although the trend is not linear. Only data from this study are shown.

Table 15.3. Geochemical data for lamprophyre and related dikes (types 1 and 2) from western Grimsthorpe domain.

Sample Number	**89RME-0047**	**06RME-1055**	**06RME-1056**	**06RME-1061**	**06RME-1062**	**BH75-25**	**50**	**1006**
Dike Type	lamprophyre	1	1	1	1	1	diorite	lamprophyre
Unit	Gawley Creek	'250' dike	'250' dike	'black' BH74	'black' BH11		Kensington pluton	Kensington pluton
Source	1	1	1	1	1	4	3	3
SiO_2 (wt %)	42.90	45.42	46.35	45.10	46.17	41.60	41.03	43.16
TiO_2	3.05	1.96	1.99	3.01	3.22	2.75	2.30	2.13
Al_2O_3	15.50	15.52	15.95	12.19	12.26	12.82	16.03	15.86
Fe_2O_3	12.60	10.13	11.20	9.67	9.72	14.11	13.06	13.19
MnO	0.10	0.13	0.08	0.11	0.10	0.05	0.15	0.13
MgO	5.07	5.18	5.67	6.08	5.38	9.28	7.34	6.45
CaO	7.56	8.08	5.60	8.26	9.00	10.05	9.30	7.95
Na_2O	3.06	4.03	4.28	3.25	3.20	2.45	2.09	2.49
K_2O	3.27	3.41	3.75	2.39	3.41	3.58	3.67	4.51
P_2O_5	1.87	1.74	1.72	2.16	2.39	2.85	2.01	2.00
CO_2	0.80	2.82	2.38	5.24	3.81	NR	NR	NR
LOI	1.00	3.40	2.28	7.04	4.85	NR	2.01	1.28
Ba (ppm)	3930	3086	1757	>5000	2846	NR	6800	5310
Sr	2804	2431	571	1076	1297	310	6136	5215
Zr	35	406	404	493	498	440	444	422
Nb	<5	10	10	149	157	90	11	13
Mg Number	44.4	50.3	50.1	55.5	52.3	56.6	52.7	49.2
CIA	54.2	55.0	58.6	58.5	51.0	45.0	51.6	51.5
K_2O/ Na_2O	1.1	0.8	0.9	0.7	1.1	1.5	1.8	1.8
Total alkalis	6.33	7.44	8.03	5.64	6.61	6.03	5.76	7.00

Abbreviations: CIA = chemical index of alteration, NR = not reported.
Sources: 1 = this study; 2 = Barnett et al. (1984); 3 = Corriveau and Gorton (1993); 4 = Lydia Diamond Exploration Company Limited (2003d).

LAMPROPHYRE AND RELATED MAFIC DIKES

Geochemical data for these rocks are summarized in Tables 15.3 and 15.4. The mafic dike rocks fall into 3 main chemical groupings.

Type 1 dikes are high TiO_2 (>2 weight %), high P_2O_5 (>1.7 weight %), high alkali (>6.5 weight %), metaluminous rocks, with high Ba (>2000 ppm), Zr (>400 ppm), and Sr (>1000 ppm) (*see* Table 15.3). These rocks exhibit some of the geochemical characteristics of olivine lamproites, but since they are not peralkaline or ultrapotassic (Na_2O/K_2O ratios ≅1), they are not lamproites. In most of these samples, K_2O is generally greater than 3.0 weight %, which, in conjunction with the high alkali content, excludes virtually all kimberlites (Foley et al. 1987). Rocks of this group include the '250' dike, the 'black dike' in drill holes BH74 and BH11, the lamprophyre dikes at 7.6, 9.1 and 10.4 m in drill hole BH75, and sample 89RME-0047 from the Gawley Creek syenite. Sample 04RME-0639 is transitional between type 1 and 2. Petrographically, some samples of this group are not lamprophyres *sensu stricto*, for example, the '250' dike is a fine- to medium-grained, subophitic textured, plagioclase-amphibole rock, with small biotite phenocrysts, that is best described as a fine-grained diorite.

Table 15.3. continued.

Sample Number	04RME-0639	06RME-1072	06RME-1073	19A2, trench 174	MM63	BH75-11	Picton	Varty Lake
Dike Type	1 to 2	2	2	2	1 to 2	2	kimberlite	kimberlite
Unit	Trench	'107' dike	'90' dike					
Source	1	1	1	4	4	4	2	2
SiO_2 (wt %)	40.56	37.60	36.33	46.81	41.82	43.82	26.00	29.80
TiO_2	3.06	2.01	3.37	1.75	2.38	2.60	1.52	3.34
Al_2O_3	11.60	15.66	15.79	16.40	11.12	11.76	2.94	4.55
Fe_2O_3	9.32	17.76	18.90	11.71	23.29	12.87	10.08	15.15
MnO	0.07	0.07	0.15	0.06	0.22	0.05	0.15	0.22
MgO	7.13	15.41	13.97	11.95	8.40	7.20	23.40	23.80
CaO	10.13	0.37	0.67	0.89	5.66	9.82	14.50	8.80
Na_2O	0.16	0.20	0.28	0.21	0.37	0.19	0.02	0.04
K_2O	6.47	8.55	8.04	4.31	3.92	7.33	0.34	1.14
P_2O_5	3.16	0.25	0.46	0.23	1.59	3.73	0.65	1.24
CO_2	4.75	0.09	0.06	NR	NR	NR	11.20	3.20
LOI	6.53	1.94	1.87	NR	NR	NR	19.70	10.90
Ba (ppm)	4600	1332	1558	NR	NR	2740	2078	2055
Sr	1120	13	18	20	50	700	2642	1323
Zr	521	242	280	160	490	470	172	303
Nb	157	23	31	20	NR	70	170	334
Mg Number	60.2	63.2	59.4	66.9	41.7	52.6	82.1	75.7
CIA	49.1	63.4	63.9	102	54.4	41.2	44.5	40.2
K_2O/Na_2O	40.4	42.8	28.7	20.5	10.6	38.6	17.0	28.5
Total alkalis	6.63	8.75	8.32	4.52	4.29	7.52	0.36	1.18

Abbreviations: CIA = chemical index of alteration, NR = not reported.
Sources: 1 = this study; 2 = Barnett et al. (1984); 3 = Corriveau and Gorton (1993); 4 = Lydia Diamond Exploration Company Limited (2003d).

Type 2 dikes are ultrapotassic rocks, with K_2O greater than 8.0 weight %, MgO greater than 3.0 weight %, and very low Na_2O (<0.25 weight %), as well as more moderate La, Zr, Sr, Ba, and Rb contents compared to type 1 dikes (*see* Table 15.3). Two subsets might be present, with one characterized by higher P_2O_5 and lower Al_2O_3 contents which may be transitional to type 1 dikes. Again, the high K_2O content excludes these rocks as kimberlites (Foley et al. 1987), in addition to high Al_2O_3. Rocks of this group are the '107' and '90' dikes from drill hole BH105, the '11' dike from drill hole BH75, a dike from LDEC trench 174, and LDEC sample MM63. Samples of these dikes are extremely fine-grained, black weathering, micaceous rocks, generally with small biotite phenocrysts.

Type 3 dikes are probably altered ultramafic rocks, based on their high Cr, Ni and MgO contents, and are represented by the 'Wild Dog' dike (*see* Table 15.4). These rocks are hosted within the core of the Weslemkoon tonalite to granodiorite pluton, and may be dikes. It is also possible that they may be a large raft of undigested country rock incorporated into the intrusion. As seen in Table 15.4, MgO, Cr and Ni content appear to be coupled in these samples. These 3 elements are probably a reasonable proxy for olivine content. Samples containing the highest Cr and Ni and, thus, the most olivine, generally are the most highly weathered and altered samples.

Table 15.4. Comparison of type 3 mafic dikes ('Wild Dog' trench) with melanocratic phases of the Tudor gabbro.

Sample Number	**04RME-0341**	**04RME-0346**	**04RME-0394**	**04RME-0377**	**BH115 @11m**	**04RME-0378**	**BH115 @8.1m**	**WD-ART-1**
Unit	Tudor gabbro	Tudor gabbro	Tudor gabbro	Wild Dog dike	Wild Dog dike	Wild Dog dike	Wild Dog dike	Wild Dog dike
Source	1	1	1	1	2	1	2	2
SiO_2 (wt %)	49.29	44.40	46.44	46.84	44.85	38.69	44.30	49.16
TiO_2	0.64	2.44	1.91	0.83	0.92	0.57	0.54	1.12
Al_2O_3	5.18	16.42	10.79	10.08	12.53	8.77	7.88	12.49
Fe_2O_3	15.80	16.77	14.88	12.73	11.37	11.23	11.62	15.82
MnO	0.27	0.15	0.19	0.21	0.13	0.22	0.15	0.14
MgO	16.42	6.42	9.08	16.38	29.54	22.64	26.46	11.30
CaO	9.89	10.88	14.14	9.02	4.51	7.16	5.85	6.20
Na_2O	0.98	2.82	2.02	0.80	0.67	0.28	0.35	1.35
K_2O	0.20	0.14	0.20	2.58	1.64	0.15	0.14	1.73
P_2O_5	0.06	0.03	0.04	0.10	0.12	0.06	0.10	0.41
CO_2	0.74	0.74	0.94	0.16	NR	4.51	NR	NR
LOI	0.79	0.80	0.73	1.44	NR	8.81	NR	NR
Cr (ppm)	533	34	133	1280	880	2400	1620	850
Ni	293	116	138	441	270	686	970	320
Mg Number	67.3	43.1	54.7	71.8	69.3	80.0	81.9	58.6
CIA	33.4	55.6	41.2	45.2	50.2	74.0	67.3	58.0
Na_2O/K_2O	0.2	0.0	0.1	3.2	0.4	0.5	2.5	0.8
Total alkalis	1.18	2.96	2.22	3.38	2.31	0.43	0.24	3.08
Comment				Alkalis added	Alkalis and Mg added, Ca lost?			Alkalis added, Ca lost?

Abbreviations: CIA = chemical index of alteration, NR = not reported.
Sources: 1 = this study, 2 = Lydia Diamond Exploration Company Limited (2003d).

DISCUSSION

Type 1 dikes are most likely related to the Kensington–Skootamatta intrusive suite (Easton 1992; Corriveau and Gorton 1993), which was emplaced into the Central Metasedimentary Belt between 1090 to 1075 Ma. In the study area, plutons of this suite include the Mount Moriah syenite, located 5 km east of Wolf Lake, and the Gawley Creek syenite, located 6 km southwest of Wolf Lake. Corriveau and Gorton (1993) recognized 2 chemical groupings within the Kensington–Skootamatta intrusive suite: a mostly felsic, silica-saturated, shoshonitic group and a felsic to ultramafic, silica-undersaturated, potassic to ultrapotassic group (Figure 15.3). In Table 15.3, type 1 dikes are compared with a diorite and a lamprophyre dike from the Kensington pluton in Quebec, which were presented in Corriveau and Gorton (1993), as well as a lamprophyre dike from the Gawley Creek syenite collected by the author in 1989. All of these samples show the same chemical characteristics as the felsic to ultramafic, silica-undersaturated, potassic to ultrapotassic group (*see* Figure 15.3). This is not surprising given the proximity (~5 km) of Wolf Lake to 2 large intrusions of the Kensington–Skootamatta intrusive suite. Corriveau and Gorton (1993) classified rocks of the Kensington–Skootamatta intrusive suite as Group III ultrapotassic rocks (Foley et al. 1987), which generally form in arc environments; in this case, probably a continental arc. An arc-related intrusive suite, even one emplaced into a continental margin, is not likely to be a favourable host for diamonds.

Type 2 dikes may be related also to the Kensington–Skootamatta intrusive suite; however, these rocks are more ultrapotassic than any rocks previously reported from the suite (*see* Figure 15.3). Two of these dikes (samples 06RME-1071 and 06RME-1072) also gave higher magnetic susceptibility readings than any other rock unit in the study area, suggesting that these rocks were not affected by regional metamorphism, which is consistent with magnetic susceptibility data for intrusions of the Kensington–Skootamatta intrusive suite, and with previous observations that rocks of the Kensington–Skootamatta intrusive suite were emplaced syn- to post-regional metamorphism. The difference in magnetic susceptibility between the type 1 dikes (<0.8 $\times 10^{-3}$ SI) and the Type 2 dikes (25 to 80 $\times 10^{-3}$ SI) could indicate that the type 1 dikes are slightly older, and were emplaced during the waning phases of regional metamorphism.

Type 3 dikes may be related to the Tudor gabbro and some of the melanocratic mafic phases of the Lingham Lake intrusive complex, as illustrated in Figure 15.4 and Table 15.4. The compositional range of 2 samples from the 'Wild Dog' trench lie within the range of samples collected from the Tudor gabbro along Highway 62 (*see* Figure 15.4). Furthermore, independent petrographic study of the 'Wild Dog' samples indicated that they represented melatroctolites or komatiites that had been moderately to intensely altered (Lydia Diamond Exploration Company 2003e), consistent with the geochemical data presented herein.

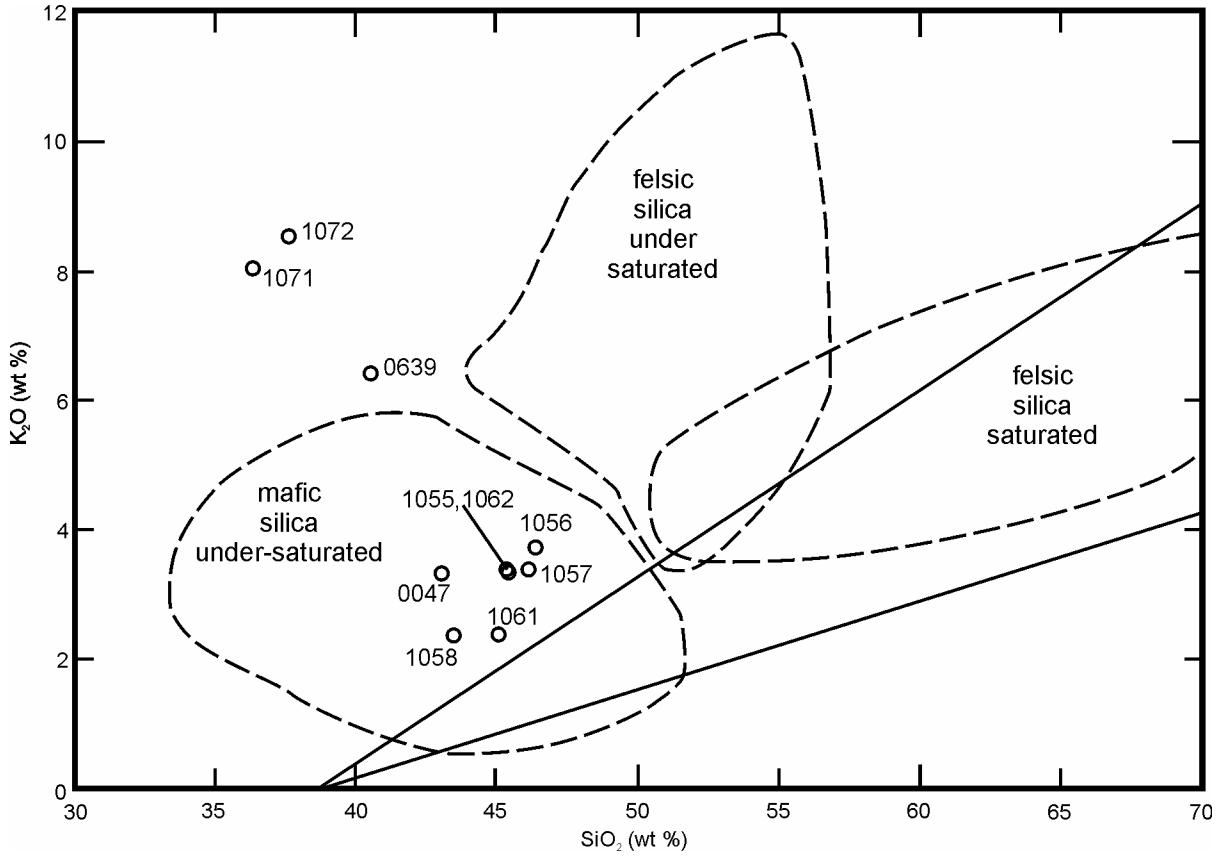

Figure 15.3. Plot of SiO_2 versus K_2O for type 1 and type 2 lamprophyre dikes from this study. Fields of Kensington–Skootamatta intrusive suite rocks are from Corriveau and Gorton (1993). Type 1 dikes fall in the field of mafic silica-undersaturated rocks of the Kensington–Skootamatta intrusive suite. Type 2 dikes are more potassic than previously reported members of the Kensington–Skootamatta intrusive suite. All samples shown are listed in Table 15.3, but only the last 4 digits of the sample number are shown in the diagram.

RECOMMENDATIONS FOR EXPLORATION

Base Metals

Surface sampling of rusty schists in western Grimsthorpe domain have yielded spotty results, with local anomalous concentrations of copper, lead and zinc (e.g., Lumbers 1969; Easton and Ford 1994; Easton 2004), but with limited continuity or size of the mineralized zones. Assay data from this study show a similar pattern, at least for lead.

An exception is drill hole BH83, which contains over 24 m of sulphide-rich metasedimentary rock. This drill hole lies only 600 m north (location: UTM 298501E 4956030N, NAD83, Zone 18) of the Tulonen-King occurrence (location: UTM 298400E 4955400N, NAD83, Zone 18), which has reported values of up to 14 925 ppm Zn and between 110 and 930 ppm Cu (Tulonen and King 1999), from a rusty schist belt. This schist belt lies immediately east of the Moira River fault and the Belmont–Grimsthorpe domain boundary. Complete assay results from 10 samples collected from this drill hole were not available at the time of writing; however, sample 06RME-2040 (15.46–15.56 m depth) assayed 664 ppm Pb. In addition, a sulphide vein at 10.06 to 10.16 m depth (sample 06RME-2036) contained 1520 ppm As. Gold in the Moira River fault is commonly associated with arsenopyrite. These were the highest lead or arsenic contents reported from the 60 assay samples collected from this study. These assay results suggest that BH83 might be located on an extension of the Tulonen–King zone, and further exploration of this rusty schist belt is warranted.

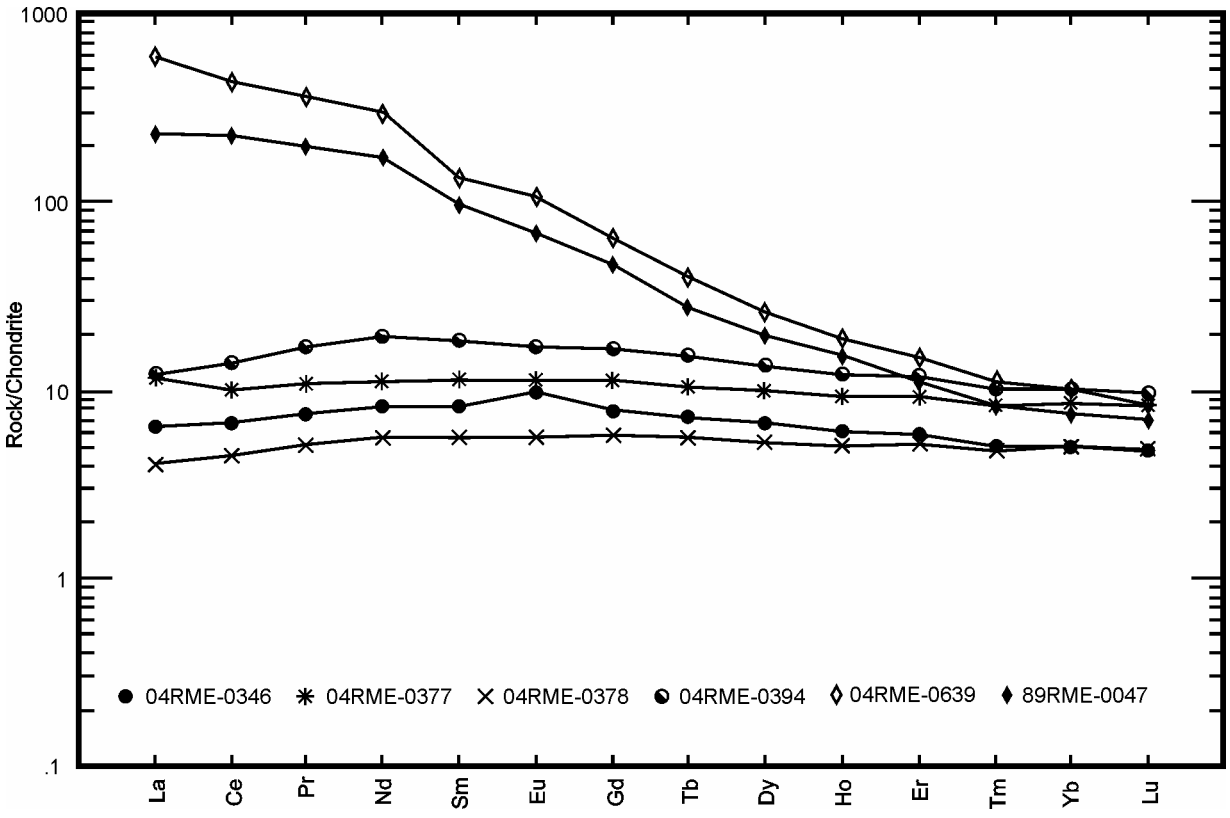

Figure 15.4. Chondrite-normalized rare earth element plot for samples of the Tudor gabbro (04RME-0346 and 04RME-0394), the 'Wild Dog' dike (samples 04RME-0377 and 04RME-0378) and lamprophyre dikes related to the Kensington–Skootamatta intrusive suite (89RME-0047 and 04RME-0639). Note similarity between the Tudor gabbro and 'Wild Dog' samples.

Gold

This study has reinforced the observations made by Easton (2004) with respect to gold mineralization in western Grimsthorpe domain. The style of shear-zone hosted gold mineralization has many similarities to Archean greenstone belt gold-bearing shear zones, and exploration techniques utilized in areas such as the Abitibi greenstone belt should be fruitful in the western Grimsthorpe domain. Primary exploration targets are the intersection of the Gilmour shear zone and the Moira River fault, and the area along the Moira River (Moira River fault) from approximately 6 km north of Wolf Lake south to Wolf Lake. Exploration in the latter area has been limited because the ground had been staked by LDEC for diamond exploration.

Many of the exploration trenches dug by LDEC, east and northeast of Wolf Lake, expose schistose, carbonatized, and veined metabasaltic rocks. The most intense alteration and veining being present in the vicinity of the quarry on the Wolf Lake access road, which is also observed in LDEC drill hole BH85 located near the quarry. The metavolcanic belt east and northeast of Wolf Lake is a promising exploration target should this ground become available for staking.

Exploration techniques for gold that have proven successful in the area include soil geochemical surveys (Christie 1990) and heavy mineral sampling of stream gravels (Dillman 2003). Heavy mineral sampling of tills has not been successful in identifying gold exploration targets (Dillman 2003).

As noted in Easton (2004), only low-grade gold and arsenopyrite mineralization has been reported from vein systems located within the Lingham Lake intrusive complex (e.g., Lumbers 1969). If the combination of carbonate alteration within the Gilmour shear zone and subsequent deformation and quartz veining along the Moira River fault is needed to produce significant gold enrichment, then the Lingham Lake intrusive complex is not a prime exploration target for gold.

Diamonds

The rationale for diamond exploration in southeastern Ontario is, in part, based on the fact that it has been noted that a significant number of kimberlite clusters and other rocks (i.e., lamprophyres) thought to have potential to host diamonds lie within a broad regional trend that extends from near Attawapiskat in the far north of Ontario, south to the Belleville area and beyond (Sage 1999). This regional trend, oriented at 325°, is not defined by a specific geological or geophysical feature; however, along much of its length, it is marked by several major structural features (e.g., the Lake Timiskaming Structural Zone, Ottawa–Bonnechere graben). Kimberlite clusters occur along this regional trend at Attawapiskat, Coral Rapids, Matheson, Kirkland Lake, Temiskaming, Cobalt, Picton and Syracuse in New York State (Sage 1999). The kimberlites tend to be located where faults and lineaments or major lithologic boundaries intersect the regional trend.

West-trending lineaments found in the region northeast of Tweed are interpreted as a system of faults related and parallel to the Ottawa–Bonnechere graben system. This feature is known as one of the region's principal fault zones, is likely rooted in the lower crust or upper mantle, and has been active in the Neoproterozoic to Early Cambrian and in the Jurassic. Theoretically, such a structure could provide a conduit for mantle-derived kimberlite, lamproite and lamprophyre magmas that are known to transport diamonds to higher crustal levels. On the other hand, the absence of a thick lithospheric root, or substantial amounts of Archean crust in the lower crust between the Central Metasedimentary Belt of the Grenville Province (White et al. 2000), as well as asthenospheric upwelling during the early history of the Ottawa–Bonnechere graben, are all negative indicators with respect to the development of diamondiferous kimberlites in the area.

A modern alluvium survey conducted by the Ontario Geological Survey, which included the western Grimsthorpe domain, did not find any indicator minerals diagnostic of the presence of kimberlites, such as G9 or G10 garnets (Felix, Reid and Easton 2006), although some less diagnostic minerals, such as Cr-diopside were found. More detailed surveys in the Wolf Lake area conducted by LDEC and submitted for assessment (Lydia Diamond Exploration of Canada Limited 2001b, 2002f) gave similar results.

Of the lamprophyre and other mafic dikes for which geochemical data are available (type 1 and type 2, *see* Table 15.3), they appear to be geochemically related to the Kensington–Skootamatta intrusive suite. This is not surprising given the proximity of the Wolf Lake area to 2 large Kensington–Skootamatta intrusive suite plutons. Furthermore, the Kensington–Skootamatta intrusive suite has an arc-related chemical affinity and, thus, is unlikely to be a favourable host rock for diamonds. The 1090 to 1075 Ma age range for emplacement of rocks of the Kensington–Skootamatta intrusive suite is significantly older than known Jurassic kimberlite dikes, such as the Picton and Varty Lake dikes, present in southeastern Ontario. As shown in Table 15.3, the Picton and Varty Lake dikes are geochemically distinct from the lamprophyres present in the Wolf Lake area.

It should be noted that all of the dikes found so far from the Wolf Lake area are small, with a maximum thickness of 2 m, but generally on the order of 30 to 50 cm thick. No dikes containing heterolithic breccia zones have been reported. No large continuous dike has been reported, nor has any larger mass of lamprophyre or kimberlite material been found.

Type 3 mafic dikes from the study area, represented by the 'Wild Dog' dike, appear to be a variably altered ultramafic rock similar to phases of the Tudor gabbro, and are neither a lamprophyre nor a kimberlite. Therefore, it is not surprising that a bulk sample of this rock collected by LDEC and submitted to SGS Lakefield Research for caustic dissolution did not yield any diamonds (von Anhalt and von Anhalt 2003).

In summary, the existing data, such as the absence of kimberlitic indicator minerals in the area, the geochemical affinities of the known lamprophyre dikes, and the absence of a thick lithospheric root suggest a low potential for diamond mineralization. In order to better distinguish between favourable and unfavourable exploration targets, any further studies in the Wolf Lake area need to account for the presence of widespread carbonate alteration of mafic rocks in the area, as well as the presence of lamprophyre dikes related to the Kensington–Skootamatta intrusive suite.

REFERENCES

Barnett, R.L., Arima, M., Blackwell, J.D., Winder, C.G., Palmer, H.C. and Hayatsu, A. 1984. The Picton and Varty Lake ultramafic dikes: Jurassic magmatism in the St. Lawrence Platform near Belleville, Ontario; Canadian Journal of Earth Sciences, v.21, p.1460-1472.

Christie, B.J. 1990. Soil survey assessment report, Gilmour Property; Tweed Resident Geologist's office, Grimsthorpe Township, assessment file Grimsthorpe 24, 12p.

Corriveau, L. and Gorton, M.P. 1993. Coexisting K-rich alkaline and shoshonitic magmatism of arc affinities in the Proterozoic: a reassessment of syenitic stocks in the southwestern Grenville Province; Contributions to Mineralogy and Petrology, v.113, p.262-279.

Dillman, R.J. 2003. Report on heavy mineral sampling on the Black River Property, Ontario; Tweed Resident Geologist's office, Grimsthorpe Township, assessment file Grimsthorpe 77, 16p.

Easton, R.M. 1992. The Grenville Province; *in* Geology of Ontario, Chapter 19, Ontario Geological Survey, Special Volume 4, Part 2, p.713-904.

——— 2004. Geology, tectonic history and controls on gold mineralization in western Grimsthorpe domain, Central Metasedimentary Belt, Grenville Province; *in* Summary of Field Work and Other Activities, 2004, Ontario Geological Survey, Open File Report 6145, p.14-1 to 14-21.

Easton, R.M. and Ford, F.D. 1994. Geology of the Grimsthorpe area; Ontario Geological Survey, Open File Report 5894, 153p.

Easton, R.M. and Kamo, S.L. 2005. Timing of gold mineralization in western Grimsthorpe domain, Central Metasedimentary Belt, Grenville Province; *in* Summary of Field Work and Other Activities, 2005, Ontario Geological Survey, Open File Report 6172, p.15-1 to 15-10.

Felix, V.E., Reid, J.L. and Easton, R.M. 2006. Regional modern alluvium and till sampling of the Tweed area, southeastern Ontario; Ontario Geological Survey, Open File Report 6178, 134p.

Foley, S.F., Venturelli, G., Green, D.H. and Toscani, L. 1987. The ultrapotassic rocks: characteristics, classification, and constraints for petrogenetic models; Earth Science Reviews, v.24, p.81-134.

Heaman, L.M., Davis, D.W., Krogh, T.E. and Lumbers, S.B. 1987. Geological evolution of the Central Metasedimentary Belt (CMB), Ontario: a U-Pb perspective; Geological Association of Canada–Mineralogical Association of Canada, Program with Abstracts, v.12, p.A-54.

Irvine, T.N. and Baragar, W.R.A. 1971. A guide to chemical classification of the common volcanic rocks; Canadian Journal of Earth Sciences, v.8, p.523-548.

Jensen, L.S. 1976. A new cation plot for classifying subalkalic volcanic rocks; Ontario Division of Mines, Miscellaneous Paper 66, 22p.

Lumbers, S.B. 1969. Geology of Limerick and Tudor townships; Ontario Department of Mines, Geological Report 67, 110p.

Lydia Diamond Exploration of Canada Limited 2001a. Report on diamond drilling program, Tudor Township by Lydia Diamond Exploration of Canada, Ltd. (contains logs for holes BH5 to BH10); Tweed Resident Geologist's Office, Tudor Township, assessment file Tudor 99, AFRO# 2.21476, 40p.

——— 2001b. Report on soil sampling and processing, Tudor Township, Ontario by Saxongate Ltd.; Tweed Resident Geologist's Office, Tudor and Grimsthorpe townships, assessment file Tudor 101, Grimsthorpe 74, AFRO# 2.21987, 34p.

——— 2002a. Report on diamond drilling program, Tudor Township by Lydia Diamond Exploration of Canada, Ltd. (contains logs for holes BH78 to BH83); Tweed Resident Geologist's Office, Tudor Township, assessment file Tudor 102, AFRO# 2.23019, 27p.

——— 2002b. Report on diamond drilling program, Tudor Township by Lydia Diamond Exploration of Canada, Ltd. (contains logs for holes BH45 to BH77); Tweed Resident Geologist's Office, Tudor Township, assessment file Tudor 103, AFRO# 2.22968, 108p.

——— 2002c. Report on diamond drilling program, Tudor Township by Lydia Diamond Exploration of Canada, Ltd. (contains logs for holes BH11 to BH16); Tweed Resident Geologist's Office, Tudor Township, assessment file Tudor 104, AFRO# 2.23235, 35p.

——— 2002d. Report on diamond drilling program, Tudor Township by Lydia Diamond Exploration of Canada, Ltd. (contains logs for holes BH1 to BH3); Tweed Resident Geologist's Office, Tudor Township, assessment file Tudor 105, AFRO# 2.22988, 21p.

——— 2002e. Report on diamond drilling program, Tudor Township by Lydia Diamond Exploration of Canada, Ltd. (contains logs for holes BH17 to BH19); Tweed Resident Geologist's Office, Tudor Township, assessment file Tudor 107, AFRO# 2.23613, 25p.

——— 2002f. Report on soil sampling and processing, Tudor Township, Ontario by Consorminex Inc.; Tweed Resident Geologist's Office, Tudor Township, assessment file Tudor 108, AFRO# 2.24321, 103p.

——— 2003a. Report on diamond drilling program, Tudor and Grimsthorpe townships by Lydia Diamond Exploration of Canada, Ltd. (contains logs for holes BH96 to BH116); Tweed Resident Geologist's Office, Tudor and Grimsthorpe townships, assessment file Tudor 109, Grimsthorpe 76, AFRO# 2.24321, 80p.

——— 2003b. Report on diamond drilling program, Tudor Township by Lydia Diamond Exploration of Canada, Ltd. (contains logs for holes BH84 to BH92, BH117, BH251 to BH253); Tweed Resident Geologist's Office, Tudor Township, assessment file Tudor 111, AFRIO#2.26490, 38p.

——— 2003c. Report on diamond drilling program, Tudor Township by Lydia Diamond Exploration of Canada, Ltd. (contains logs for holes BH25 to BH40); Tweed Resident Geologist's Office, Tudor Township, assessment file Tudor 112, AFRO# 2.26745, 49p.

——— 2003d. Report on XRF analyses of samples, Grimsthorpe and Tudor Township, Ontario, for Lydia Diamond Exploration of Canada, Ltd., by M.P. Gorton; Tweed Resident Geologist's Office, Tudor and Grimsthorpe townships, assessment file Tudor 114, Grimsthorpe 81, AFRO# 2.26551, 177p.

——— 2003e. Report on petrographic studies of samples, Grimsthorpe and Tudor Townships, Ontario, for Lydia Diamond Exploration Company Ltd., by I. Kjarsgaard and R. Mitchell; Tweed Resident Geologist's Office, Tudor and Grimsthorpe townships, assessment file Tudor 117, Grimsthorpe 84, AFRO# 2.26685, 110p.

Meschede, M. 1986. A method of discriminating between different types of mid-ocean ridge basalts and continental tholeiites with the Nb–Zr–Y diagram; Chemical Geology, v.56, p.207-218.

Mitchell, R.H. and Bergman, S.C. 1991. Petrology of lamproites; Plenum Press, New York, 447p.

Mullen, E.D. 1983. $MnO/TiO_2/P_2O_5$: a minor element discriminant for basaltic rocks of oceanic environments and its implications for petrogenesis; Earth and Planetary Science Letters, v.62, p.53-62.

Nesbitt, H.W. and Young, G.M. 1982. Early Proterozoic climates and plate motions inferred from major element chemistry of lutites; Nature, v.299, p.715-717.

Pearce, J.A. and Cann, J.R. 1973. Tectonic setting of basic volcanic rocks determined using trace element analyses; Earth Planetary Science Letters, v.19, p.290-300.

Pearce, J.A. and Norry, M.J. 1979. Petrogenetic implications of Ti, Zr, Y, and Nb variations in volcanic rocks; Contributions to Mineralogy and Petrology, v.69, p.33-47.

Sage, R.P. 1999. Structural patterns and kimberlite emplacement; *in* Summary of Field Work and Other Activities, 1998, Ontario Geological Survey, Miscellaneous Paper 169, p.224-229.

Tulonen, P.V.G. and King, B.R. 1999. 1999 OPAP Technical Summary Report, Wolfe Lake exploration project, lots 8 and 9, concession VI, Tudor Township; Tweed Resident Geologist's office, Tudor Township, assessment file Tudor #96, not paginated.

Von Anhalt, Princess Emilia and von Anhalt, Prince Jurgen 2003. Report on caustic fusion for microdiamond recovery, Grimsthorpe Township, Ontario for Lydia Diamond Exploration Company Ltd.; Tweed Resident Geologist's Office, Grimsthorpe Township, assessment file Grimsthorpe 82, AFRO# 2.26742, 27p.

White, D., Forsyth, D.A., Asudeh, I., Carr, S.D., Wu, H., Easton, R.M. and Mereu, R.F. 2000. A seismic-based cross-section of the Grenville Orogen in Ontario and western Quebec; Canadian Journal of Earth Sciences, v.37, p.183-192.

Winchester, J.A. and Floyd, P.A. 1977. Geochemical discrimination of different magma series and their differentiation products using immobile elements; Chemical Geology, v.20, p.325-343.

16. Keweenawan Felsites of the Mamainse Point Formation and Implications for Mineralization

A. Pace[1]

[1]Resident Geologist Program, Sault Ste. Marie District, Ontario Geological Survey

INTRODUCTION

The Mamainse Point area is located approximately 80 km northwest of Sault Ste. Marie along the shore of Lake Superior (Figure 16.1). Rocks of the Mamainse Point Formation were deposited during the inception of the Midcontinent Rift and have been of economic interest due to the widespread presence of copper mineralization. This led to the development of mining operations as far back as the middle 1800s, to most recently at the Coppercorp and Tribag Mines, which were in production from 1965 to 1972. Recently, new logging roads have provided greater access to outcrop exposures of lower division Mamainse Point Felsite rocks. In recent years, iron oxide-copper-gold (IOCG) deposits of Olympic-Dam type have been the primary exploration target within the Mamainse Point area.

This project was designed to study Keweenawan-age (circa 1.1 Ga) felsic rocks that make up a part of the Mamainse Point Formation. The purpose of the study was to determine the composition and tectonic setting of these felsic rocks and their implications with respect to mineralization. The 3 main primary textures noted in felsite rock samples collected during the summer of 2005 include quartz

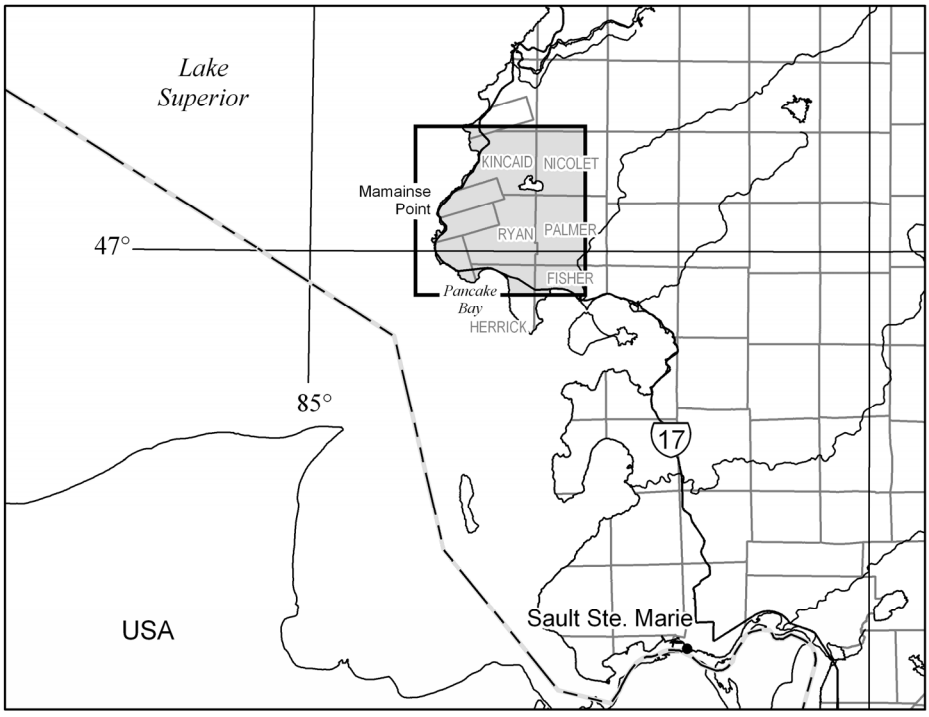

Figure 16.1. Location of the Mamainse Point study area.

Summary of Field Work and Other Activities 2006,
Ontario Geological Survey, Open File Report 6192, p.16-1 to 16-7.

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porphyry, massive felsite (likely representing hypabyssal intrusions) and flow-banded rhyolite. The Mamainse Point Formation rocks have been previously mapped and described by Giblin (1969a-d) and Annells (1973). Twenty-five samples of felsic rocks have been identified as being dominantly intrusive or subvolcanic in nature (Figure 16.2).

RESULTS

Whole-rock geochemistry and thin section descriptions provide information on the composition, texture and setting of these felsite rocks. All geochemical analyses reported herein were preformed by the Geoscience Laboratories, Ontario Geological Survey, Sudbury. Major element geochemistry was used to chemically classify the felsic rocks using the silica versus total alkali diagram (after LeBas et al. 1986)

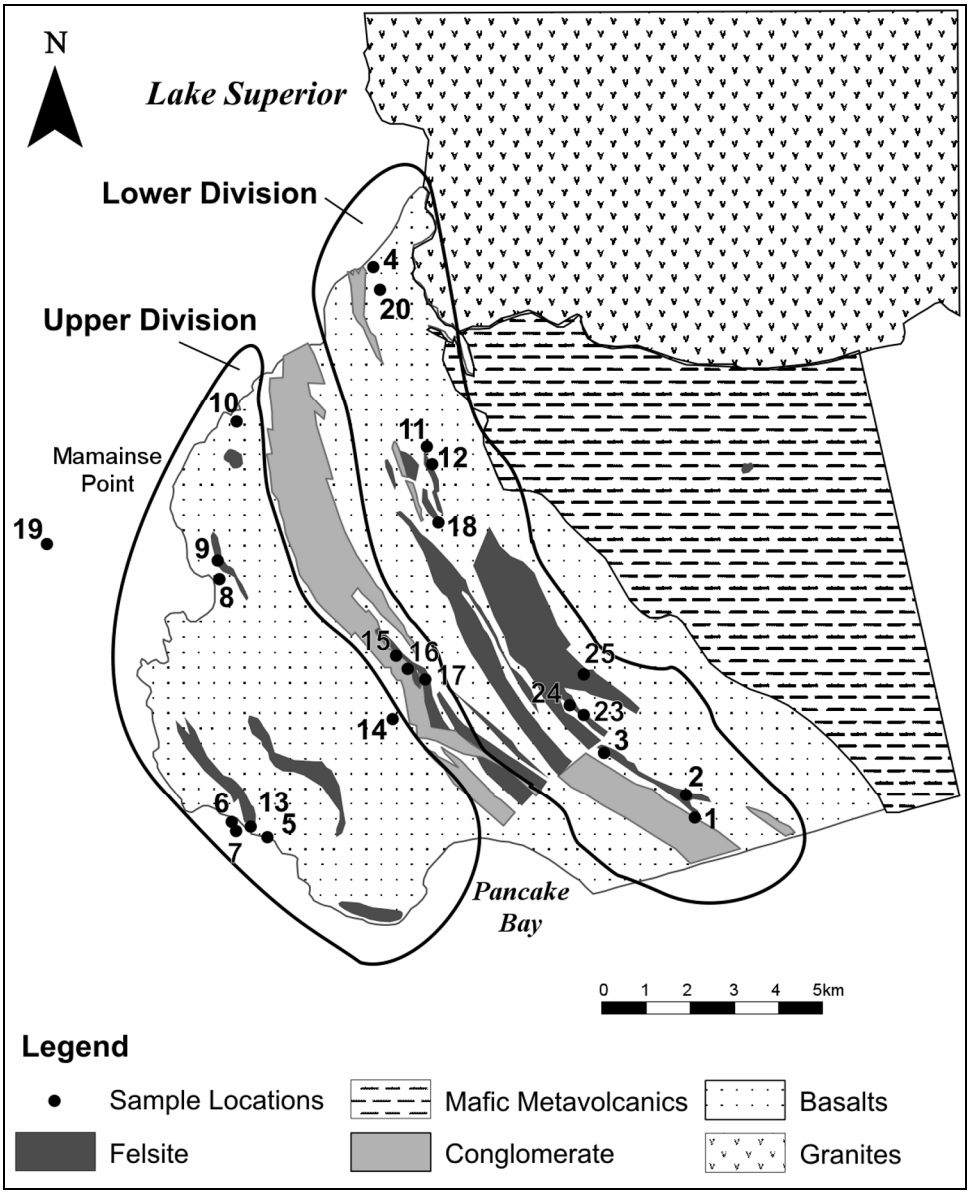

Figure 16.2. Locations of sample sites in the Mamainse Point Formation (*after* Giblin and Armburst 1973; Richards 1985).

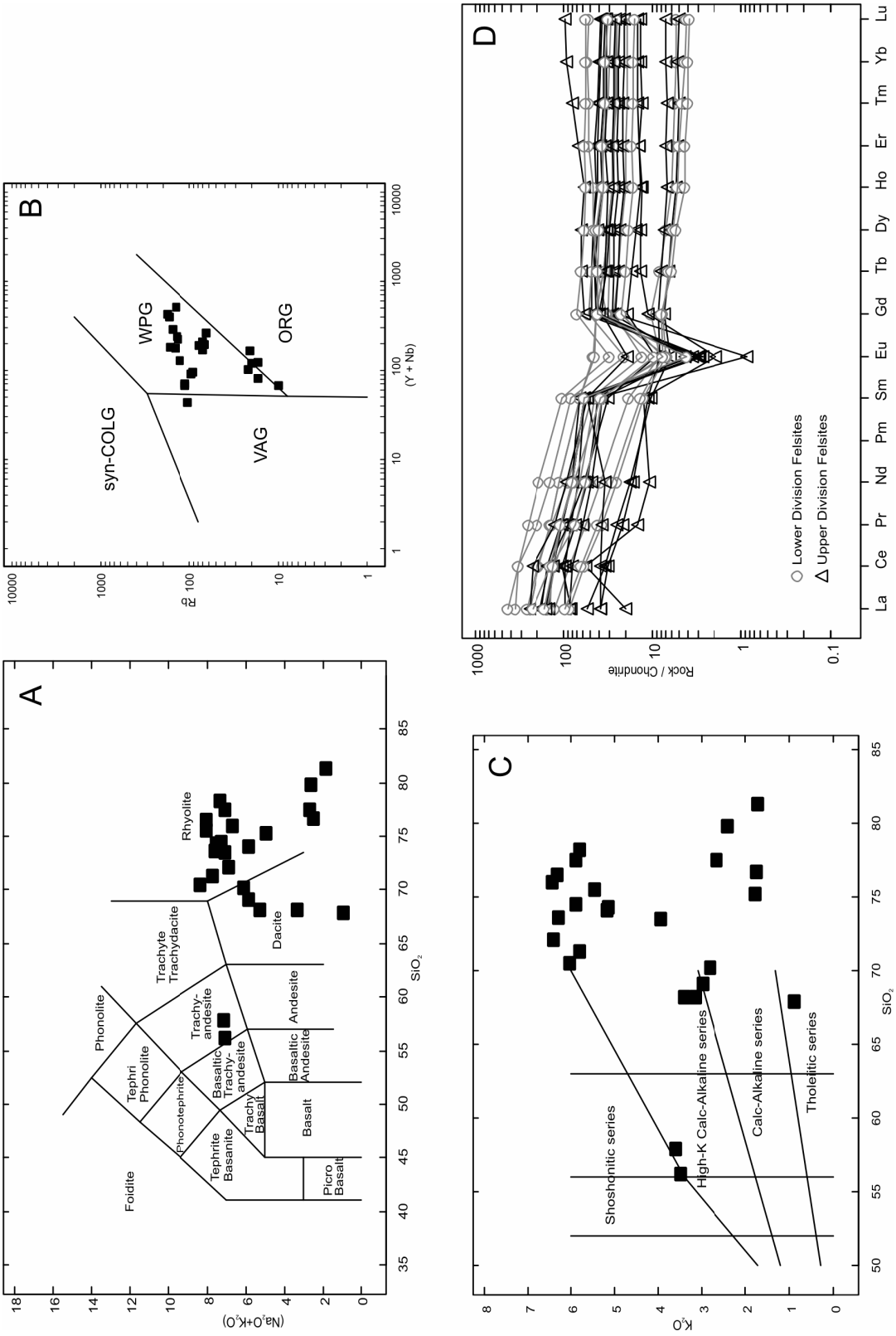

Figure 16.3. a) Silica versus total alkalis diagram for the 25 felsite samples collected as part of this study. Note that the majority of samples classify as high-silica rhyolites. b) Y+Nb versus Rb diagram (*after* Pearce, Harris and Tindle 1984) indicating a within-plate tectonic setting for most of the felsite samples. Only samples classified as rhyolites in Figure 16.3a are shown. Abbreviations: ORG = ocean ridge granitoids; syn-COLG = syn-collisional granitoids; VAG = volcanic-arc granitoids; WPG=within plate granitoids. c) SiO_2 versus K_2O diagram (*after* Peccerillo and Taylor 1976) for the felsite samples. d) Chondrite-normalized rare earth element diagram for samples from both the upper and lower division felsites. Normalizing factors of Sun and McDonough (1989) were used.

(Figure 16.3a). The felsite rocks are classified as mainly rhyolites, with some dacite and with two samples classed as andesites. In thin section, quartz and alkali feldspar (albite and sanidine) are the dominant minerals present, and indicate a quartz latite (*sensu lato*) composition. It should be noted that these results are preliminary and ongoing work on the felsites will help to further elucidate their significance.

Felsite rocks of the upper division located closest to the Lake Superior shore, are fine grained, reddish brown, and vary from massive to quartz porphyritic and exhibit flow-banding toward the margins. Massive sections contain light brown to beige lenses and patches. Giblin (1974) reported that this change was a result of hematite alteration and extensive development of kaolinite. In thin section, "Felsite 7" and "Felsite 19", in particular, are clay rich, appearing as mosaic-like masses of crystals. Giblin (1974) suggested that these irregular felsite bodies in the upper division of the sequence may represent shallow rhyolitic domes, indicating a high level of emplacement.

Thin sections of rhyolites in the upper division contain high levels of mica, especially, sericite. The sericite appears interstitial in a fine-grained groundmass along with some crystals scattered throughout the matrix that appear to be phenocrysts. The large sericite component appears to be the result of alteration of potassium feldspar. Many plagioclase grains maintain their lath-like form, but the carlsbad twinning has disappeared, leaving crystal surfaces filled with interstitial sericite. Some samples also show patches of chlorite crystals developed as an alteration product of biotite and/or sericite alteration.

Felsite rocks of the lower division appear less altered and are more porphyritic in texture. This is easily seen in thin section, where varied proportions of quartz and alkali feldspar exist in a medium- to coarse-grained felsic matrix. Sericite is present both as phenocrysts and as a product of potassium feldspar alteration. A large percentage of the plagioclase crystals have preserved their twinning, unlike the plagioclase found in the upper division rocks.

The rocks of the Mamainse Point Formation, in particular the mafic lava flows, have undergone low-grade hydrothermal metamorphism. A large amount of information discussing the metamorphism of the lava flows has been documented previously (e.g., Annells 1973; Massey 1980; Richards 1985). The effect of metamorphism on the felsic rocks has not been documented.

Felsite rocks of the upper division appear to have undergone a greater degree of hydrothermal alteration compared to felsite rocks of the lower division. In thin section, upper division felsites show the replacement of alkali feldspar with sericite and with an abundance of coarse intercalated quartz crystals. Sericite is the dominant crystal filling within relict feldspar crystals and may represent secondary mineral development due to hydrothermal alteration. The intense hydrothermal alteration within upper division felsites is reflected by the presence of kaolinite within the rocks, along with other clay minerals. Many felsite samples from the lower division display porphyritic textures visible only in thin sections where quartz and alkali feldspar are present. The matrix is fine grained and siliceous with sericite and small amounts of biotite. Sericite appears as isolated phenocrysts and interstitially within feldspar crystals. Sericite appears to be more abundant in the samples collected from felsites of the upper division. Felsites located farther away from the upper division contain sericite crystals in smaller amounts. A felsite in the lower division, "Felsite 25", shows spherulitic devitrification structures, suggesting an original glassy protolith, which would be highly susceptible to reaction with hydrothermal fluids (Richards 1985, p.26-29). The fact that these structures are unaltered indicates that hydrothermal overprint in the vicinity of "Felsite 25" was minimal.

Thickness, number, and size of felsite units in each division may account for differences in the degree of alteration. The upper division consists of a smaller number of thinner sheets compared to the lower division, where there are a greater proportion of felsites, in much thicker sheets. The thinner felsic

units may have been more easily affected by alteration due to their proximity to the mafic volcanic flows, which may have provided a more permeable environment for meteoric waters to move through and alter the adjacent, thin felsite sheets.

Samples of felsites collected from the Mamainse Point Formation were plotted on a Rb versus Y+Nb diagram (Figure 16.3b), and most indicate a within-plate tectonic setting. Five samples suggest an oceanic ridge granitoid setting, but loss of Rb in these samples related to alteration might account for the position of these samples on the diagram. Many of the felsites are high silica rhyolites (>75 weight % SiO_2), and most classify as high-potassium calc-alkalic rocks (Figure 16.3c). This is consistent with Figure 16.3a, where the dacite and rhyolite samples show subalkalic affinities. Samples with lower K_2O contents are also characterized by low Rb contents, and may have been altered. The rare earth element patterns of the samples are illustrated in Figure 16.3d. The patterns are typical of rhyolites formed in continental environments, and are similar to those of FIII rhyolites (Lesher et al. 1986). Samples from both divisions overlap, and there is no indication of a separate source region for felsites within each division based on the rare earth element data. This is consistent with Figures 16.3a, 16.3b, and 16.3c, as most of the felsites plot as a tight cluster, despite the fact that these diagrams utilize a variety of mobile elements.

The geochemical data, in particular the rare earth element contents, are consistent with the felsites being derived by partial melting of pre-existing sialic crust under high heat flow conditions, generated by rifting and mafic volcanism (Massey 1980, p.41-43). The proximity of the Mamainse Point Formation rocks to a large terrane of Archean granites and gneisses is also consistent with derivation of the felsic rocks through crustal melting.

ECONOMIC IMPLICATIONS

A small Keweenawan stock, called the Jogran porphyry, intruded Archean volcanic rocks to the east of the basalt exposures at Mamainse Point. The mineralized Tribag breccias are located approximately 6 km to the east-northeast of the Jogran porphyry. Blecha (1965, 1969) described the Jogran porphyry as a fine-grained rock with abundant phenocrysts of quartz and feldspar, along with pyrite, chalcopyrite and minor molybdenite mineralization disseminated throughout the porphyry. The Jogran porphyry has a Rb/Sr isochron age of 1048±50 Ma (Van Schmus 1971, age converted to current decay constants), comparable to the K/Ar age of 1055±35 Ma from muscovite within the cement of the Tribag (Breton) breccias (Wanless et al. 1966). Both these porphyries may be genetically related to the same source as the felsites of the Mamainse Point Formation.

Based on fluid inclusion and stable isotope work, Richards (1985) identified the Jogran porphyry as a possible source for mineralizing fluids for the Coppercorp deposit, within the Mamainse Point Formation. The mineralization formed as a result of interaction between hot magmatic fluids and lower temperature meteoric fluids, possibly hydrothermal-metamorphic fluids (Richards 1985, p.26-29).

It has been documented that the breccias were formed as a result of a collapse of rocks caused by the withdrawal of a deep-seated pulsating magma of felsic composition (Blecha 1974). Evidence for this style of intrusion is provided by the high proportion of felsitic fragments within each of the breccia pipes, along with subsequent diamond drilling that encountered a highly altered feldspar porphyry intrusion under the breccias (Blecha 1969, 1974).

More recently, an iron oxide-copper-gold deposit model has been used as an exploration model in the Mamainse Point area, in part due to the intracontinental rift setting of the area, as well as the presence of copper-bearing breccia intrusions such as Tribag and Coppercorp (e.g., Tortosa and Moss 2004). How the felsites fit into this model is one of the questions posed in this study.

Table 16.1. Comparison between the tectonic setting of ron oxide-copper-gold deposits and the Mamainse Point area.

Typical Tectonic Settings for Iron oxide-Copper-Gold Deposits	Mamainse Point Formation
Intracontinental rift setting	Midcontinent Rift (intracontinental) setting
Alkalic to subakalic, calc-alkalic, high-potassium to shoshonitic series	Calc-alkalic, high-potassium calc-alkalic
Derived from partial melting of older igneous rocks in the middle to lower crust with varied mantle input	Close proximity of Archean granites and gneisses suggests that the felsites were derived by fusion of pre-existing sialic crust generated by rifting and mafic volcanism
Proterozoic in age	Proterozoic in age

The majority of iron oxide-copper-gold deposits are Proterozoic in age and typically form in intracontinental tectonic settings (Pollard 2000). Iron oxide-copper-gold deposits are typically related to I-type granitoids formed by partial melting of older igneous material in the middle to lower crust with varying amounts of mantle input (Ramo and Haapola 1995; Creaser 1996; Pollard, Mark and Mitchell 1998). Many of the intrusive rocks associated with this type of mineralization range from alkalic to subalkalic (as defined by Irvine and Baragar 1971) and are calc-alkalic, high-potassium to shoshonitic in character (Pollard, Mark and Mitchell 1998).

REFERENCES

Annells, R.N. 1973. Proterozoic flood basalts of eastern Lake Superior: the Keweenawan volcanic rocks of the Mamainse Point area, Ontario; Geological Survey of Canada, Paper 72-10, 51p.

Blecha, M. 1965. Geology of the Tribag Mine; Canadian Institute of Mining and Metallurgy, Bulletin, v.58, no.642, p.1077-1082. [sometimes cited as Canadian Institute of Mining and Metallurgy, Transactions, v.68, p.321-326.]

——— 1969. The origin of the Breton breccia, Batchawana area, Ontario; unpublished PhD thesis, McGill University, Montreal, Quebec, 148p.

——— Batchawana area—a possible Precambrian porphyry copper district; Canadian Institute of Mining and Metallurgy, Bulletin, v.67, no.748, p.71-76.

Creaser, R.A., 1996. Petrogenesis of a Mesoproterozoic quartz latite-granitoid suite from the Roxby Downs area, South Australia; Precambrian Research, v.79, p.371-394.

Giblin, P.E. 1969a. Mamainse Point area, District of Algoma; Ontario Department of Mines, Preliminary Map P.554, scale 1:15 840.

——— 1969b. Ryan Township, District of Algoma; Ontario Department of Mines, Preliminary Map P.555, scale 1:15 840.

———. 1969c. Herrick Township, District of Algoma; Ontario Department of Mines, Preliminary Map P.556, scale 1:15 840.

——— 1969d. Fisher Township, District of Algoma; Ontario Department of Mines, Preliminary Map P.557, scale 1:15 840.

——— 1974. Middle Keweenawan rocks of the Batchawana–Mamainse Point area; *in* Field Guides for the 20th Annual Institute on Lake Superior Geology, May 1974, Sault Ste. Marie, Ontario, p.39-67.

Giblin, P. and Armburst, G.A. 1973. Batchawana, Algoma District; Ontario Department of Mines, Map 2251, scale 1:63 360.

Irvine, T.N. and Baragar, W.R.A., 1971. A guide to the chemical classification of the common volcanic rocks; Canadian Journal of Earth Sciences, v.8, p.523-548.

Le Bas, M.J., LeMaitre, R.W., Streckeisen, A. and Zanettin, B. 1986. A chemical classification of volcanic rocks based on the total alkali-silica diagram; Journal of Petrology, v.27, p.745-750.

Lesher, C.M., Goodwin, A.M., Campbell, I.H. and Gorton, M.P. 1986. Trace-element geochemistry of ore-associated and barren, felsic metavolcanic rocks in the Superior Province, Canada; Canadian Journal of Earth Sciences, v.23, p.222-237.

Massey, N.W.D. 1980. The geochemistry of some Keweenawan metabasites from Mamainse Point, Ontario; unpublished PhD thesis, McMaster University, Hamilton, Ontario, 353p.

Pearce, J.A., Harris, N.B.W. and Tindle, A.G. 1984. Trace element discrimination diagrams for the tectonic interpretation of granitic rocks; Journal of Petrology, v.25, p.956-983.

Peccerillo, A. and Taylor, S.R. 1976. Geochemistry of Eocene calc-alkaline volcanic rocks for the Kastamonu area, northern Turkey; Contributions to Mineralogy and Petrology, v.58, p.63-81.

Pollard, J.P. 2000. Evidence of magmatic fluid and metal source for Fe-oxide Cu-Au mineralization; *in* Hydrothermal iron oxide copper-gold and related deposits: a global perspective, v.1. Australian Mineral Foundation, p.27-41.

Pollard, P.J., Mark, G. and Mitchell, L.C. 1998. Geochemistry of post-1540 Ma granites in the Cloncurry district, northwest Queensland; Economic Geology, v.93, p.1330-1344.

Richards, J.P. 1985. A fluid inclusion and stable isotope study of Keweenawan fissure-vein hosted copper sulphide mineralization, Mamainse Point, Ontario; unpublished MSc thesis, University of Toronto, Toronto, Ontario, 290p.

Ramo, O.T. and Haapola, I. 1995. One hundred years of rapakivi granite; Mineralogy and Petrology, v.52, p.129-185.

Tortosa, D. and Moss, R. 2004. Geology and exploration of the Coppercorp property, Sault Ste. Marie Mining Division, Ontario, technical report for Nikos Exploration Ltd.; Sault Ste. Marie District Geologist's Office, assessment file SSMP-Ryan-15, not paginated.

Sun, S-s. and McDonough, W.F. 1989. Chemical and isotopic systematics of oceanic basalts: implications for mantle compositions and processes; *in* Magmatism in ocean basins: Geological Society of London, Special Publication No.42, p.313-345.

Van Schmus, W.R. 1971. Rb-Sr Age of middle Keweenawan rocks, Mamainse Point and vicinity, Ontario, Canada; Geological Society of America Bulletin, v.82, p.3221-3226.

Wanless, R.K., Stevens, R.D., Lachance, G.R. and Rimsaite, J.Y.H. 1966. Age determinations and geological studies, K-Ar isotopic ages, report 6; Geological Survey of Canada, Paper 65-17, p.58.

17. Project Unit 00-101. Summary of Geophysical Projects and Activities

D.R.B. Rainsford[1] and T.L. Muir[1]

[1]Precambrian Geoscience Section, Ontario Geological Survey

INTRODUCTION

Support of the bedrock mapping program in the Precambrian Geoscience Section (PGS) of the Ontario Geological Survey (OGS), through the integration of geology and geophysics, has continued to be the focus of our efforts this year. Support has also been provided to both the Sedimentary Geoscience Section and the Resident Geologist Program. Ongoing commitments include assisting with enquiries from the public, providing information on the availability of geophysical data, advising on the use of the data and putting clients in touch with geophysical service providers.

Geophysical projects and activities for 2006 covered the following areas:

1. support for the bedrock mapping program
2. Far North Geological Mapping Initiative
3. Lake Nipigon inversion modelling
4. Abitibi gravity compilation

SUPPORT FOR THE BEDROCK MAPPING PROGRAM

This year has seen expanded support for bedrock mapping projects as a result of a greater number of field projects. Prior to the start of the field season, georeferenced digital images, vector layers and paper maps of geophysical data for areas of interest were prepared. The digital products were plotted and imaged using Oasis Montaj™ software and assembled in an ESRI® ArcMap™ geographic information system (GIS) platform. The geophysical data are drawn from published archive data sets held by the Ministry of Northern Development and Mines (MNDM), the Geological Survey of Canada (GSC) and from other sources. Each project has specific requirements for the images, including formatting for use with GIS software.

The geophysical data are discussed with geologists before field work begins, when possible, and specific problems requiring further investigation are identified. Modelling of specific features is undertaken using three-dimensional (3D) inversion or other software. Collaborative interpretation workshops, where geological, geophysical and other geoscience data are concurrently interpreted with the field geologists, were held as required.

Summary of Field Work and Other Activities 2006,
Ontario Geological Survey, Open File Report 6192, p.17-1 to 17-5.

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Geophysical support was provided for the following PGS projects during 2006:

- Abitibi Greenstone Belt (Burntbush–Detour Area) (Project 95-024)
- Sachigo Subprovince (Project 98-005)
- James Bay Lowland (Project 98-006)
- Hudson Bay Lowland (Project 98-007)
- Kidd–Munro Area (Project 06-001)
- Bartlett Dome Area (Project 06-002)
- Shebandowan Greenstone Belt (Project 06-003)
- Baldwin Township (Project 06-005)
- Frame Lake Area (Project 06-010)
- McInnes Lake Area (Project 06-011)
- Fry Lake (West End) (Project 06-012)
- Fry Lake (East End) (Project 06-013)

FAR NORTH GEOLOGICAL MAPPING INITIATIVE

Geophysical support for the Far North Geological Mapping Initiative (FNGMI) has included the creation of geophysical image layers for the Lang, Fry, Frame and McInnes lakes areas in northwestern Ontario. The images were compiled primarily from published data sets, but also included scanned maps submitted for assessment credits and proprietary data on loan from company sources. A pre-field season interpretation workshop was held to interpret and integrate the compiled geological, geophysical and other information for the Lang and Fry lakes areas.

Airborne magnetic, electromagnetic (EM) and ground gravity data have been compiled, imaged and basic interpretation layers created for the Pickle Lake and Fort Hope greenstone belts. These products will be used to assist in the 1:250 000 scale geological compilation of the region (Madon and Puumala, this volume; Puumala and Madon, this volume).

A contract has been awarded to Fugro Airborne Surveys Corp. to fly a GEOTEM® II airborne EM and magnetic survey in the North Spirit Lake area of northwestern Ontario (Figure 17.1). The survey will cover an area of approximately 1760 km^2 and require approximately 10 200 line-kilometres of flying. The work is scheduled to begin in October 2006.

Paterson Grant and Watson Ltd. have been retained to provide quality assurance and quality control services for airborne surveys flown as part of the FNGMI. The services will include monitoring and approval of data acquisition, data processing and generation of publication-ready deliverable products.

LAKE NIPIGON AREA MODELLING

The results of smooth model, inversion modelling of aeromagnetic and ground gravity data (Ontario Geological Survey 2004a, 2004c), acquired as part of the Lake Nipigon Region Geoscience Initiative (LNRGI), were published as MRD 193 (Reed and Rainsford 2006). Magnetic models were developed in 23 areas and gravity models in 15 areas. The work was done to gain a better understanding of specific features (i.e., particular gravity and magnetic anomalies) and to obtain insights into regional structure.

The work incorporates models covering relatively large areas as well as smaller, more detailed areas. Where the model areas overlap, it was noted that the smaller study areas tended to yield simpler body shapes than the more complex results obtained from the larger areas. Also, 2 approaches were used in the creation of gravity models. The first method involved the filtering of the gridded Bouguer gravity data, prior to running the inversions, to remove the long wavelength component that generally results from deep sources. The second approach used the residual Bouguer gravity data obtained from a regional-residual separation performed during the processing of the newly acquired gravity data. A comparison of the results showed that the filtered data tended to yield more confined sources than the residual data, which developed broader bodies.

Drilling in the Lake Nipigon area is relatively sparse, but, in 3 locations (Geikie Lake, Grand Bay and Seagull areas), the modelling could be assessed against drill results and the correspondence, particularly of the magnetic models, was found to be good. In the Seagull area, detailed gravity data were provided courtesy of Platinum Group Metals Inc. As a result, it was possible to develop much more detailed inversion gravity models than elsewhere in the Lake Nipigon region.

The results of some of the Nipigon inversion modelling were presented at the Ontario Exploration and Geoscience Symposium in December 2005.

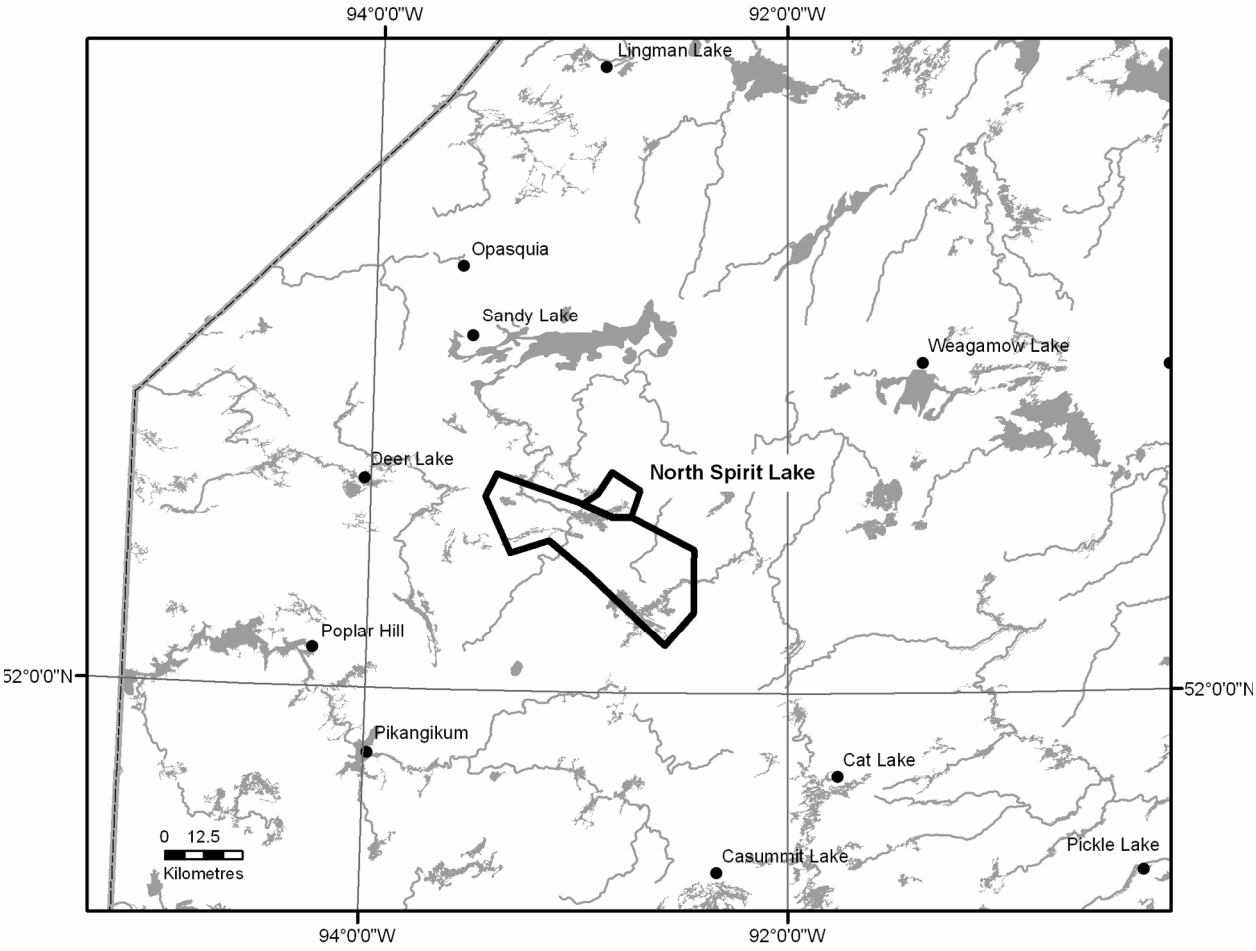

Figure 17.1. North Sprit Lake airborne magnetic and EM survey location map.

ABITIBI GRAVITY COMPILATION

The results of airborne gravity surveys flown for the Discover Abitibi Initiative (Ontario Geological Survey 2004b) were integrated with ground gravity data and published as part of a 1:250 0000 scale map series comprising geology, airborne magnetics and gravity compilations (Ayer et al. 2005; Rainsford 2005a, 2005b, 2006). The airborne data were acquired at a flight height of 200 m on lines spaced at 500 m or 1000 m intervals. The ground data had been obtained at irregular station spacings ranging from 1 to 15 km. In order to achieve a seamless integration of the ground and airborne data sets, the following process was used:

1. the ground Bouguer gravity was gridded and upward continued by 200 m to correspond with the airborne gravity survey flight height
2. the upward-continued Bouguer gravity value for each ground gravity station was obtained by sampling the upward-continued grid
3. ground gravity data points lying within the airborne survey area were then removed by masking (because the airborne data provide more uniform coverage)
4. the upward-continued and masked ground Bouguer gravity were then merged with the airborne data into a single database and gridded using a 200 m cell size
5. a 2.5 km Butterworth filter was applied to the resulting grid in order to remove high frequency noise

The final grid does not exhibit any appreciable discontinuities between the data sets. Considerably higher resolution of features is offered by the airborne coverage in areas of sparse ground data.

GEOPHYSICAL ATLAS

The Web-based Geophysical Atlas, which shows the disposition of public domain geophysical data in Ontario, has continued to be maintained as new data sets are released. The Geophysical Atlas may be accessed at http://www.mndm.gov.on.ca/mndm/mines/ogs/gpxatlas/Default_e.asp. We recommend visiting this site to gather information about surveys that are available in general, or surveys of particular interest.

Geophysical data sets, along with all other OGS publications, can now be downloaded from the recently launched "Geology Ontario" Web site: http://www.geologyontario.mndm.gov.on.ca/ (*see also* Berdusco and Madon, this volume). Gridded data, anomaly database, Keating coefficient databases, vector files and survey reports are all available from this site. Owing to the large size of many the of the airborne geophysical data sets, users requiring the profile databases still need to order the CDs containing these data from Publication Sales (tel: 1-888-415-9845).

REFERENCES

Ayer, J.A., Berger, B.R., Hall, L.A.F., Houlé, M.G., Johns, G.W., Josey, S., Madon, Z., Rainsford, D., Trowell, N.F. and Vaillancourt, C. 2005. Geological compilation of the central Abitibi greenstone belt: Kapuskasing Structural Zone to the Quebéc border; Ontario Geological Survey, Preliminary Map P.3565, scale 1:250 000.

Ontario Geological Survey 2004a. Ontario airborne geophysical surveys, magnetic and gamma-ray spectrometer data, grid and profile data (ASCII and Geosoft® formats) and vector data, Lake Nipigon Embayment Area; Ontario Geological Survey, Geophysical Data Set 1047.

——— 2004b. Ontario airborne geophysical surveys, gravity data, grid and profile data (ASCII and Geosoft® formats) and vector data, northeast, northwest and south Timmins areas; Ontario Geological Survey, Geophysical Data Set 1051.

——— 2004c. Ontario geophysical surveys, gravity data, grid and point data (ASCII and Geosoft® formats) and vector data, Lake Nipigon Embayment survey; Ontario Geological Survey, Geophysical Data Set 1052.

Rainsford, D. 2005a. Airborne magnetic survey, residual magnetic field, Abitibi greenstone belt compilation; Ontario Geological Survey, Map 81 952, scale 1:250 000.

——— 2005b. Airborne magnetic survey, shaded magnetic relief, Abitibi greenstone belt compilation; Ontario Geological Survey, Map 81 953, scale 1:250 000.

——— 2006. Ground and airborne gravity survey, Bouguer gravity, Abitibi greenstone belt compilation; Ontario Geological Survey, Map 81 959, scale 1:250 000.

Reed, L.E. and Rainsford, D.R.B. 2006. Gravity and magnetic three-dimensional (3D) modelling: Lake Nipigon Region Geoscience Initiative; Ontario Geological Survey, Miscellaneous Release—Data 193.

18. Far North Geological Mapping Initiative

J.A. Fyon[1]

[1]Director, Ontario Geological Survey

INTRODUCTION

In spring 2005, the Ontario Government announced the allocation of funding to conduct geoscience in the Far North. In August 2005, in Sioux Lookout, MNDM described the conceptual and policy framework for the Far North Geological Mapping Initiative (FNGMI). Each year, for three years, $5 million would be allocated to the FNGMI. There is a geoscience and an aboriginal community engagement component of FNGMI. Where there is a geoscience project anticipated or planned, a collaborative communication or technical project has been/will be developed with the associated aboriginal community.

TECHNICAL SCOPE

FNGMI will focus primarily on mapping the bedrock geology and assessing mineral resource potential. The secondary focus is on the Quaternary geology and non-renewable energy potential. Only selected, small geographic areas will be surveyed during the 2006–2007 fiscal year.

The geographic area of interest is approximately north of the 51st parallel.

GOALS AND OBJECTIVES

The objective of the geoscience projects is to collect new, modern geoscience over areas of the Far North where modern geoscience does not exist. This objective modern geoscience will be used to:

- support land-use planning decisions related to Government policy initiatives, such as Northern Boreal Initiative;
- identify areas having mineral resource and non-renewable energy potential;
- influence physical infrastructure development (e.g., winter road realignment, all season roads, electricity corridors);
- support the Crown's and aboriginal's natural resource stewardship responsibility and interests.

The objective of the aboriginal community engagement is to collaboratively build relationships, exchange relevant information, and build technical and knowledge capacity within the aboriginal community. The goal is to enhance mutual understanding about aboriginal and Ontario Government interests and to help ensure the community has options to pursue should they choose to seek community-level benefits from the public geoscience and mineral and energy resource development activity that may result.

Summary of Field Work and Other Activities 2006,
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FOCUS OF EFFORT

During the 2005–2006 fiscal year, MNDM undertook a series of information meetings in communities and with aboriginal leaders to raise the awareness and understanding of FNGMI. Concurrently, 2 technical, geoscience gap analysis meetings were held: one in Red Lake and one in Thunder Bay. Aboriginal and non-aboriginal mineral sector practitioners and advisors participated in the gap analysis meetings.

Collaborative communication and engagement projects and collaborative planning for geoscience projects were initiated with aboriginal communities whose traditional use areas warranted geoscience inventory. Major geoscience projects are being carried out in proximity to North Spirit Lake First Nation, Slate Falls First Nation, and Pikangikum First Nation (*see* Parker, this volume, Article 19). MNDM is in dialogue with several other remote First Nations as planning proceeds for fiscal year 2006–2007.

CAPACITY-BUILDING PARTNERSHIPS

To help address community-level, technical capacity-building, MNDM is working in partnership with Confederation College, the Ministry of Community and Social Services (MCSS) and private sector to support the design and delivery of a Basic Line Cutting Course. The 5-week course yields certified graduates who have received health and safety training and in-field practical line cutting training. To date, the course has been delivered in Thunder Bay and area, although there are plans to deliver a series of courses in aboriginal communities to meet community needs and requirements.

NEXT STEPS

Planning for fiscal 2007–2008 continues. It is anticipated that there will be an expanded emphasis on non-renewable energy geoscience to help assess the energy potential of the Hudson Platform and to help assess the potential for gas-hydrates in the Hudson Bay Lowland.

19. The Far North Geological Mapping Initiative: Update on Geoscience Activities

J.R. Parker[1]

[1]Precambrian Geoscience Section, Ontario Geological Survey

GOAL OF THE FAR NORTH GEOLOGICAL MAPPING INITIATIVE

Recognizing the economic impact of global demand for Ontario's mineral resources and the potential for jobs and investment in new discoveries the Ontario government announced $15M over 3 years for geological mapping in the Far North in the 2005 Ontario Budget. This Far North initiative is also part of the Ministry of Northern Development and Mine's Northern Prosperity Plan.

The Far North Geological Mapping Initiative (FNGMI) is a a science-based, geological mapping or inventory initiative to better understand the geological history of the Far North and its mineral resources.

The geographic area covered by the Initiative is depicted in Figure 19.1. The general Far North region (north of 51° latitude) includes the Ministry of Natural Resource's Northern Boreal Initiative (NBI) area.

Using state-of-the-art technologies, the FNGMI will provide independent and credible geoscience data for

- community-based land-use planning;
- private sector mineral exploration;
- policy support;
- infrastructure and other development.

The FNGMI will also engage First Nation communities to continue to enhance communication and mutual understanding, build relationships, transfer technical knowledge, build capacity and facilitate First Nations–mineral industry–Government business and other collaborations.

GEOSCIENCE ACTIVITIES IN 2006–2007

The following is a summary of various geoscience activities conducted in 2006 by the Precambrian Geoscience Section and the Resident Geologist Program of the Ontario Geological Survey as part of the FNGMI.

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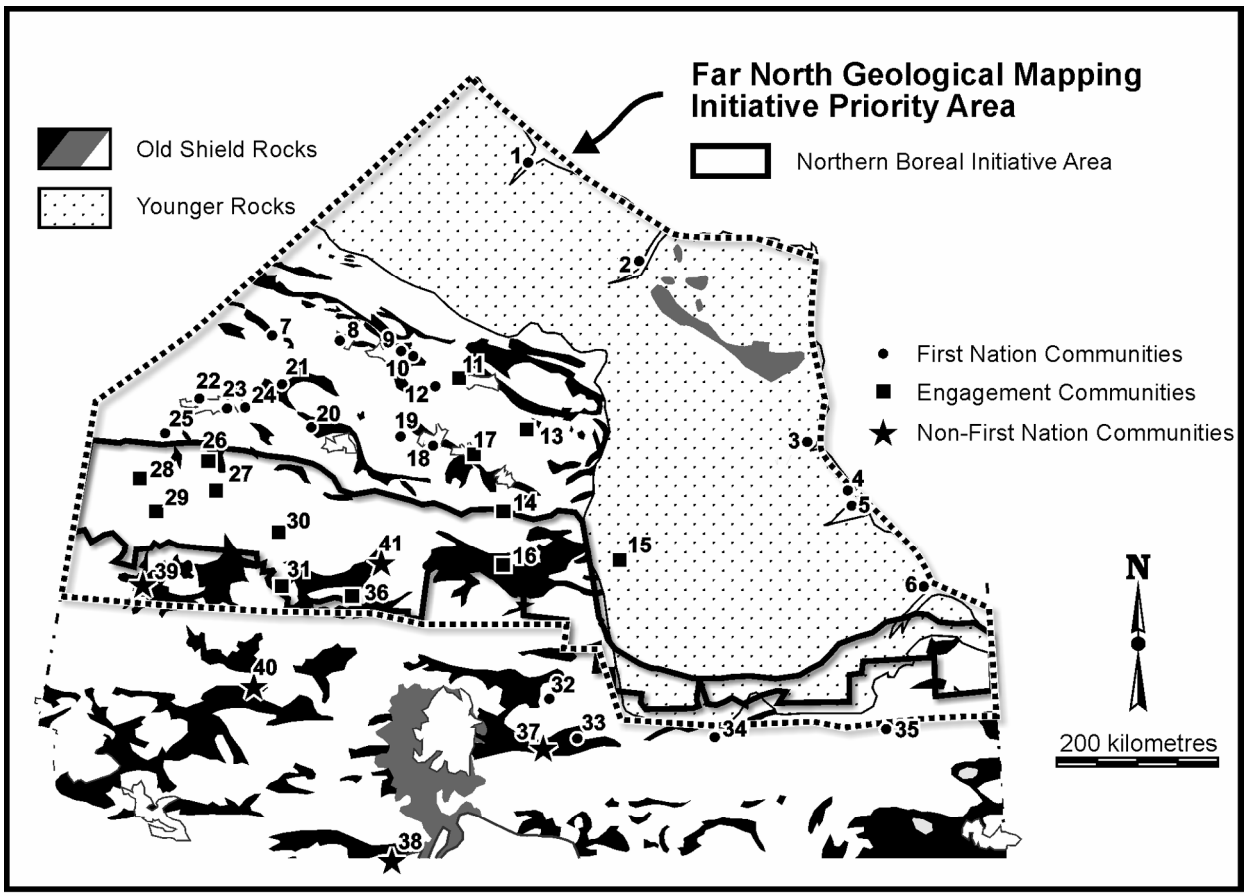
Bedrock Mapping Projects

One of the key components of the three-year FNGMI is geoscience data collection and analysis. During 2006, 4 Precambrian Geoscience Section bedrock mapping field crews, collected and analyzed geoscience data to create new geological maps, reports and data sets for targeted areas in the Far North. These mapping projects were developed based on results from 2 Geoscience Gap Analysis client meetings conducted in 2005 (Parker et al. 2005) and in collaboration, and with the support of, First Nation communities.

The following bedrock mapping activities were conducted during the summer of 2006:

1. 1:20 000-scale bedrock mapping of the Bamaji–Fry lakes area was conducted by N. Pettigrew and E. Dinel in collaboration with the Slate Falls First Nation. Parts of this area were last mapped in the mid-1970s and 1930s. More details on the preliminary results of this work are described by Dinel, Pettigrew and Gagnon (this volume).



First Nation Communites:1-Fort Severn, 2-Weenusk (Peawanuck), 3-Attawapiskat, 4- Kashechewan, 5-Fort Albany, 6-Moose Factory, 7-Sachigo Lake, 8-Bearskin Lake, 9- Big Trout Lake, 10-Wapekeka, 11-Kasabonika, 12-Wawakapewin, 13-Webequie, 14-Neskantaga, 15-Marten Falls, 16-Eabametoong, 17-Nibinamik, 18-Wunnumin, 19-Kingfisher, 20-North Caribou Lake, 21-Muskrat Dam, 22-Sandy Lake, 23-Keewaywin, 24- Koocheching, 25-Deer Lake, 26-North Spirit, 27-McDowell Lake, 28-Poplar Hill, 29-Pikangikum, 30-Cat Lake, 31-Slate Falls, 32-Aroland, 33-Long Lake #58, 34-Constance Lake, 35 New Post, 36-Mishkeegogamang. **Non-First Nation Communities** 37- Geraldton, 38-Thunder Bay, 39-Red Lake, 40-Sioux Lookout 41-Pickle Lake

Figure 19.1. Location of the general Far North region that is the focus of the Far North Geological Mapping Initiative.

2. 1:20 000-scale bedrock mapping of the McInnes Lake greenstone belt was completed by S. Préfontaine (this volume). This area had previously been mapped at reconnaissance scales and was never detail mapped by the Ontario Geological Survey (OGS). The mapping was conducted in collaboration with the Pikangikum First Nation.
3. 1:20 000-scale bedrock mapping of the Frame Lake intrusion and the greenstone slivers north of the Red Lake greenstone belt was conducted by S. Buse (this volume, Articles 21 and 22, respectively). Again, these areas had been previously mapped at reconnaissance scales by the OGS. This mapping was conducted in collaboration with the Pikangikum and North Spirit Lake First Nation communities.

Airborne Geophysical Data Acquisition

In March 2006, the Ontario Geological Survey retained S. Reford with Paterson, Grant & Watson Limited to provide project management and quality assurance-quality control services for the airborne geophysics component of the FNGMI.

A Request for Proposal (RFP) for a time-domain electromagnetic (TDEM) and magnetic survey over the North Spirit Lake greenstone belt was issued in July 2006. As a result, Fugro Airborne Surveys Corp. was retained to conduct the survey during the fall and winter of 2006. This survey was designed and planned in collaboration with the North Spirit Lake First Nation and will consist of approximately 10 200 line-kilometres of new geophysical data.

The OGS issued a Request for Data (RFD) in late 2005 in an attempt to purchase existing proprietary airborne geophysical survey data from industry in order to complement the existing and new government coverage. Unfortunately, data were not purchased; therefore, another Request for Data will be issued in the winter of 2006.

Compilation Projects

Another key component of the FNGMI is to revise and up-date several 1:250 000-scale bedrock compilation maps. This project is described by Madon and Puumala (this volume). The first 2 maps in this series will be released in April 2007.

The Mineral Deposit Inventory (MDI) database for the Far North region is also being revised and updated under the Resident Geologist Program (Puumala and Madon, this volume) and based out of the Thunder Bay Resident Geologist's office. The updated MDI data will be integrated into the bedrock compilation maps and will include a revised symbology that will represent regional metallogenic patterns in the Far North.

REFERENCES

Parker, J.R., Baker, C.L., Newsome, J. and Fyon, J.A. 2005. The Far North Geological Mapping Initiative—enhancing northern prosperity; *in* Summary of Field Work and Other Activities 2005, Ontario Geological Survey, Open File Report 6172, p.2-1 to 2-3.

20. Project Units 06-012 and 06-013. New Insights from Archean Bedrock Mapping in the Fry Lake Area, Meen–Dempster Greenstone Belt, Northwestern Ontario

E. Dinel[1], N. Pettigrew[1] and M. Gagnon[2]

[1]Precambrian Geoscience Section, Ontario Geological Survey, Sudbury, Ontario
[2]Department of Earth Sciences, University of Ottawa, Ottawa, Ontario

INTRODUCTION

This study is part of the Far North Geological Mapping Initiative. The study area is located in the Uchi Subprovince in northwestern Ontario, approximately 130 km northeast of Sioux Lookout and 15 km east of the community of Slate Falls. The project consists of 1:20 000 scale bedrock mapping in the southwest portion of the Meen–Dempster greenstone belt and covers a 15 by 40 km corridor centred on Fry Lake (Figure 20.1).

The age of rocks in the Fry Lake area range from 2699 to 2816 Ma, based on 2 samples collected by Stott and Wilson (1986) and Corfu and Stott (1993b), and represent a volcano-sedimentary stratigraphy of folded mafic to felsic metavolcanic and chemical to clastic metasedimentary rocks, which are interpreted to be part of the Kaminiskag and Billet Lake assemblages, respectively (Young 2003; Stott and Corfu 1991). They are intruded by subvolcanic mafic sills, dikes and stocks and pretectonic to syntectonic mafic to felsic intrusive rocks. The purpose of the project is to revise and improve upon the knowledge of these lithologies and their relationships, as well as the structural evolution of the area with the aid of detailed mapping, the collection of new geochemical and age data, and compilation from historical exploration data and regional geophysical surveys. A total of 400 samples will be submitted for geochemical analyses (major oxides, trace elements) and thin sections, 50 samples for assay (Au, Ag, Cu, Zn, Pb, Ni, PGE, U, Mo), and 14 samples for U/Pb zircon analysis.

Previous geological work, as well as past exploration projects, are summarized by Sage et al. (1973), Wallace (1983, 1985), Sage and Breaks (1982), Stott and Wallace (1984), Stott and Corfu (1991), the Ontario Geological Survey (1992), and Corfu and Stott (1993a, 1993b, 1996). Additional geological and geophysical data are also available from assessment files located in the Resident Geologist Office, Ministry of Northern Development and Mines, in Thunder Bay.

REGIONAL SETTING

Archean metavolcanic rocks of various compositions and metasedimentary rocks, predominantly sandstone and siltstone, cover most of the area. The volcano-sedimentary stratigraphy is intruded by synvolcanic and syntectonic mafic to ultramafic intrusive rocks, and pretectonic to syntectonic felsic meta-intrusive rocks. The map area is bounded by 6 kilometre-scale plutons. The map area is largely bounded to the north by the granodioritic Obaskaka pluton, to the northwest by the Scanes pluton, to

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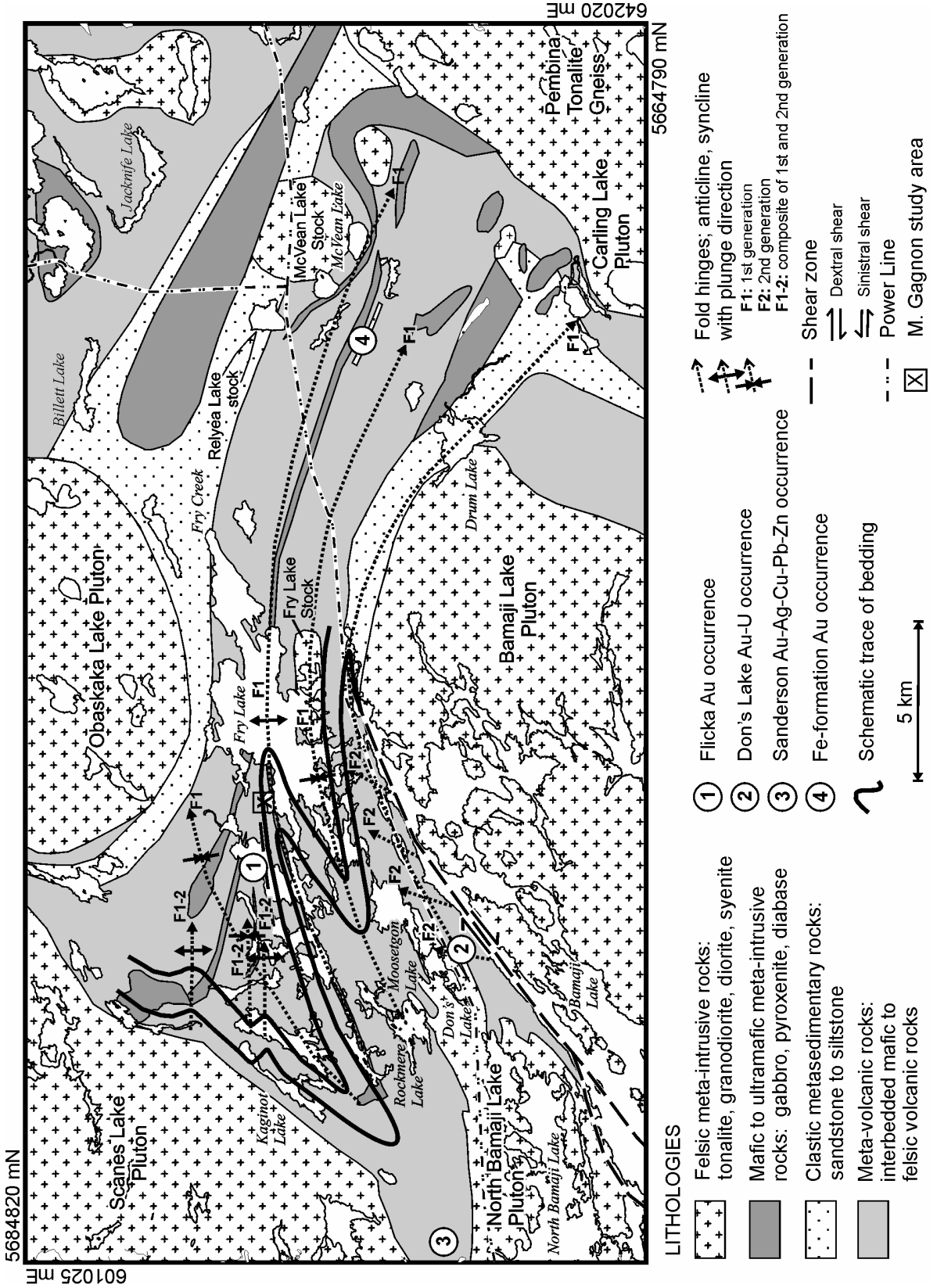

Figure 20.1. Generalized bedrock geology map of the Fry Lake area based on the summer 2006 mapping season.

the west by the North Bamaji pluton (2806 Ma: Scharer 1989), to the south by the Bamaji pluton and to the east by the younger Carling pluton and by the older Pembina tonalite gneiss (2887±3Ma: Corfu and Stott 1993a). The Bamaji pluton postdates the North Bamaji pluton and appears to stope into the greenstone belt possessing a complex, highly strained, contact zone. The contact relationships of these plutons with the greenstone belt are typically poorly exposed, due to a thick overburden, and have been inferred from historical exploration data and regional geophysical surveys.

Mafic Metavolcanic Rocks

The bulk of the mafic metavolcanic rocks are located in the southern portion of the area, between the centre of Fry and Bamaji lakes and extend westward toward the Carling Lake pluton (*see* Figure 20.1). The unit is characteristically aphanitic to medium grained and dark green to pale green, with predominant massive to pillowed flow facies with local flow breccias and pillow breccias.

Felsic to Intermediate Metavolcanic Rocks

Felsic to intermediate metavolcanic rocks are recognized primarily by their tuffaceous facies. They are mostly composed of lapilli tuff to tuff breccias, debris flows, ash tuff and possible thinly bedded fine-grained surge deposits. A detailed description and interpretation of the unit is the subject of a BSc thesis by M. Gagnon at the University of Ottawa for which data was gathered during this project.

A well-preserved (~18 by 5 m) volcaniclastic outcrop (Figure 20.2) is situated on the north shore of Fry Lake on the south limb of a synclinal fold (*see* Figure 20.1). The outcrop is composed of beds of lapilli tuff breccias, lapilli tuff and ash tuff and is cut by a quartz feldspar porphyry intrusion.

The dominant feature in the lapilli tuff breccias beds are tabular clasts (Photo 20.1A) that appear to have a bimodal distribution in size of about 4 cm and 50 to 70 cm in length, and are aligned in an eastward trend. The clasts have a white exterior and brownish-white interior and are composed mostly of millimetre-scale feldspar crystals and 1 to 10 mm quartz crystals and what appear to be ribbons of sericite

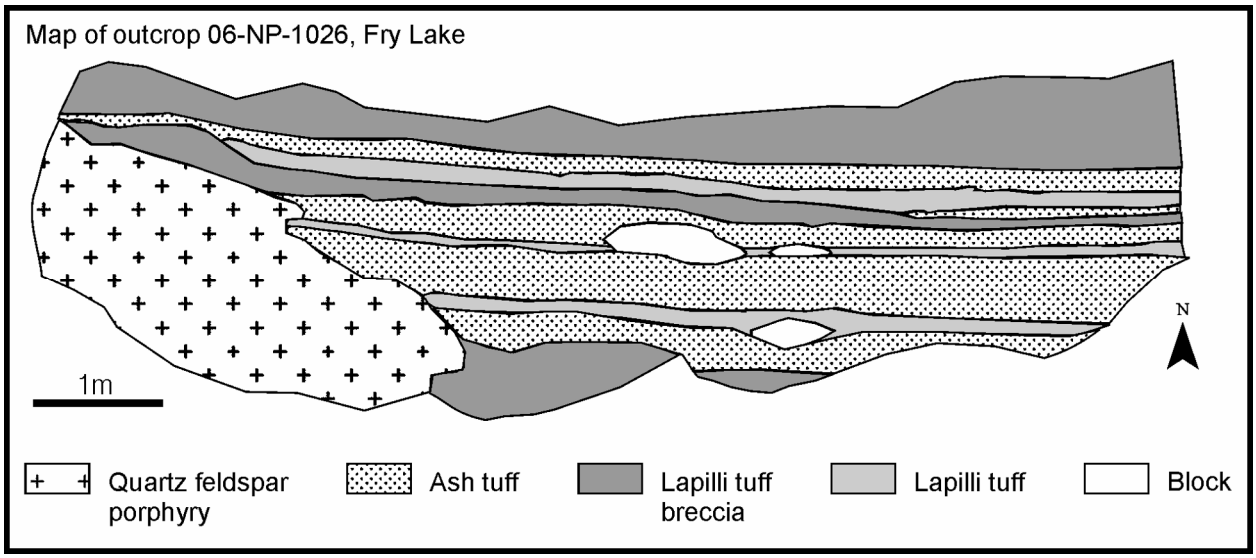

Figure 20.2. Detail outcrop map of the felsic metavolcanic unit in the Fry Lake area.

developed along crystals along the east-striking fabric. The matrix of the lapilli tuff breccias is reddish-white on weathered surfaces with green fresh surfaces, and it contains lapilli composed mostly of feldspar crystals. The northernmost bed of lapilli tuff breccias mapped has an abundance of clasts that are irregular in shape, whereas elsewhere the clasts are lens shaped.

The beds of lapilli tuff (approximately 15 to 20 cm in thickness) are homogeneous and similar throughout the outcrop. They are composed of millimetre-size feldspar crystals in an aphanitic greenish matrix.

Ash tuff layers composed of fine to very fine particles, some of which are feldspar crystals, were also observed throughout the outcrop. The beds vary in thickness from 1 to 15 cm, some with well defined laminations, and others with either normal or reverse grading. The northernmost bed of the unit contains possible scours (Photo 20.1C) with lamination of the fine-grained material contouring the underlying planar lapilli tuff bed indicating a top to the north. Blocks that are interpreted to be bombs are found within the ash tuff. Characteristically, these have a drape of ash at the edge (Photo 20.1B).

The porphyry intrusion (*see* Figure 20.2) is massive looking, but has a weak foliation trending eastward. The rock is composed of about 5 to 10%, 1 to 5 mm sized subhedral quartz crystals. The feldspars (likely albite, but undetermined at time of writing) are subhedral and range in size from 0.5 to 6 mm, some of which are zoned. The fabric is defined by a dull-grey platy mineral, possibly sericite,

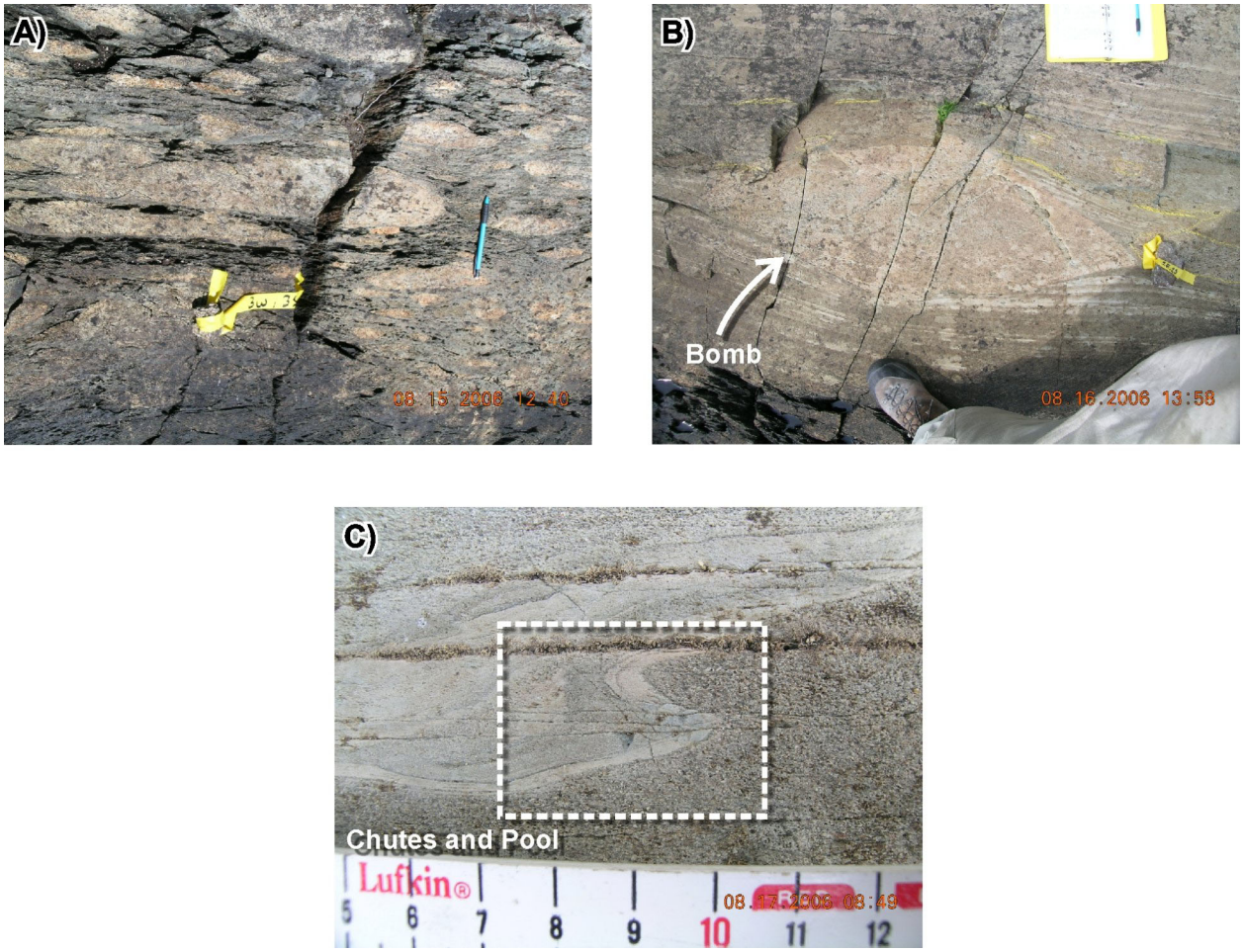

Photo 20.1. a) Photo of the southernmost lapilli tuff breccias; b) photo showing draping around the block in the ash tuff; and c) photo of the scouring into the lapilli tuff by the ash tuff.

which is deflected by the quartz and feldspar. Fresh surfaces react with acid and have pyrite euhedral crystals of about 5 mm in size. The unit contains some white quartz veins about 5 to 10 cm. The contact with the volcaniclastic rocks is sharp and crosscuts the pyroclastic beds demonstrating the intrusion is younger.

The presence of bombs and scoured beds of fine-grained material, which may be the result of surges, suggest that these rocks are pyroclastic deposits. The alternative is that they are resedimented volcanic detritus. Samples of the different beds have been taken for thin section and geochemistry, to determine the origin of this volcanic sequence.

Mafic to Ultramafic Meta-Intrusive Rocks (Subvolcanic Sills)

Widespread gabbro sills and plugs are the most prominent feature of the map area (*see* Figure 20.1). These rocks are interpreted to have intruded very early in the sequence, having recorded the same deformational and metamorphic history as adjacent metavolcanic rocks. They most likely represent a large-scale subvolcanic sill and are possible feeders to the mafic volcanic pile. The sills are typically medium grained, although they vary from fine to coarse grained and locally appear gradational with adjacent mafic metavolcanic rocks. Some larger sills also contain coarse, subhedral feldspar phenocrysts, producing very distinctive porphyritic gabbros. Possible crude magmatic layering defined by variations in abundance of these phenocrysts was locally observed; however, overall no definitive igneous layering was found. The rocks also typically contain very low sulphide mineral content, most are barren and if present are typically in the form of trace disseminated pyrite; however, trace disseminated pyrrhotite and even rarer trace chalcopyrite were locally observed.

The gabbroic rocks, with the exceptions of the larger plugs, are also characterized by very low magnetic susceptibilities. The larger gabbroic plugs are more complex, and may be younger than the sills since they intrude clastic metasedimentary rocks. They possess a handful of phases (locally olivine and orthopyroxene bearing) and are locally moderately to strongly magnetic.

Metasedimentary Rocks

CHEMICAL METASEDIMENTARY ROCK

Chemical metasedimentary rocks consist primarily of bedded argillite and chert with rare oxide-facies iron formation and are typically associated with the clastic metasedimentary rocks. Very thin, centimetre-scale, interflow oxide-facies iron formation also occurs throughout the tuffaceous felsic metavolcanic rocks.

CLASTIC METASEDIMENTARY ROCK

These consist primarily of well to poorly bedded, laminar siltstone, silty sandstone and fine-grained sandstone. They are spatially associated with the felsic metavolcanic rock and often appear gradational with reworked felsic volcanic tuff. It is currently unknown if all the clastic metasedimentary rocks corresponds to the Billet assemblage (2699 to ≤2740 Ma) (Stott and Wilson 1986).

Felsic Meta-intrusive Rocks

OBASKAKA PLUTON

The Obaskaka pluton, located in the northern part of the map area (*see* Figure 20.1), has a general subcircular shape with a diameter of approximately 15 km. Best described by Sage and Breaks (1982) and Wallace (1985), it consists of multiphase massive porphyritic to equigranular leucocratic biotite and hornblende biotite quartz monzonite, with quartz content decreases toward the margins.

McVEAN PLUTON

The McVean pluton, located in the eastern part of the map area (*see* Figure 20.1), is extensively covered by thick overburden and is only exposed in one area where it consists of a medium- to coarse-grained multiphase granite-granodiorite with abundant clastic sedimentary xenoliths and centimetre-scale aplitic dikes. The surrounding sediments are also cut by abundant decimetre- to metre-scale granodioritic dikes and/or sills parallel to the S_1 fabric. Both the Obaskaka pluton and McVean pluton intrude the clastic metasedimentary rocks of the Billet assemblage and may be from the same intrusive suite.

RELYEA LAKE PORPHYRY

The distinctive quartz porphyry is located to the east southeast of Relyea Lake in the eastern part of the map area (*see* Figure 20.1) and differs significantly from other felsic meta-intrusive rocks in the area. It is apparently stratigraphy parallel, approximately 1 by 4 km, and consists of an aphanitic, quartz porphyry intrusion hosted by clastic metasedimentary rocks.

FRY LAKE STOCK

The Fry Lake stock is located along the southern shore in the central part of Fry Lake (*see* Figure 20.1). The stock is distinct from other felsic meta-intrusive rocks in the map area. It consists of a very homogeneous, aphanitic to fine-grained matrix with abundant subhedral to euhedral, locally zoned 2 to 4 mm feldspar phenocrysts. The stock is old, recording both D_1 and D_2 deformation and the western portion has also undergone significant alteration. Another strongly deformed, possibly similar stock occurs along the south shore of the eastern part of Fry Lake.

NORTH BAMAJI PLUTON

The North Bamaji pluton (2806 Ma), centred on North Bamaji Lake, and associated interfingering quartz-feldspar porphyry dikes or sills located in the western part of the map area (*see* Figure 20.1), intruded during or very soon after deposition of the volcanic pile. The quartz-feldspar porphyry dikes and, to a lesser extent, the pluton itself, consist of anhedral quartz and feldspar phenocrysts in a fine-grained equigranular quartz-feldspar matrix. This is a synvolcanic intrusion with complex interfingering of highly porphyritic dikes and sills in the country rock and a less porphyritic to massive core with Mo-Cu-Au-Ag mineralization (e.g., the Loon Lake showing: Sage and Breaks 1982) within the intrusion and more distal gold showings on the outlying porphyritic dikes and sills (e.g., Don's Lake area Au-U-Th showings).

Several quartz-feldspar porphyry intrusions of small to moderate size (tens to hundreds of metres long) occur throughout the eastern portion of the map area (*see* Figure 20.1). These intrusions are most likely dikes and/or sills, although some of the larger ones may be small plugs or stocks. The intrusions appear to be affected by both D_1 and D_2 deformation and are generally only moderately porphyritic with a fine-grained, rather equigranular quartz-feldspar matrix. These intrusions most closely resemble the quartz-feldspar porphyry dikes and sills related to the North Bamaji pluton, although they are rather distal.

FELDSPAR PORPHYRY DIKES

A less abundant group of feldspar porphyry dikes occur in the centre of the Fry Lake area. These dikes are very feldspar phenocryst rich, but do contain minor to trace quartz phenocrysts as well. In addition to the abundance of feldspar and, to a lesser extent, quartz phenocrysts, this suite of dikes differs from those related to the North Bamaji pluton in that they possess an aphanitic quartz-rich matrix and the feldspar phenocrysts are subhedral to euhedral. The dikes appear to be very old having recorded D_1 deformation and have only been observed cutting the felsic volcanic pile, hence they may represent feeders to these volcanic rocks.

REGIONAL METAMORPHISM

The metamorphic grade observed in the rocks of the Fry Lake area is within the lower to upper greenschist facies, with a chlorite-albite-muscovite-carbonate-hornblende mineral assemblage. Locally, lower to upper amphibolite facies has been mapped in the northwest part of the belt, between the Obaskaka and Scanes plutons (*see* Figure 20.1) and, in the south, near the contact with Bamaji pluton and North Bamaji Lake pluton (*see* Figure 20.1). In these areas, the mineral assemblage consists of amphibole to biotite and local garnet. This higher metamorphic grade is mostly observed in the proximity of large intrusions. In the southeast of the map area, the rocks underwent upper amphibolite-facies metamorphism forming a migmatitic complex composed of gabbros, clastic metasedimentary rock and granodiorite.

REGIONAL STRUCTURES

Two deformation events are recorded in the volcano-sedimentary stratigraphy. Regional mapping and geophysical interpretations identified isoclinal F_1 folds with 10 to 20 km amplitudes (*see* Figure 20.1), which are associated with a penetrative S_1 cleavage parallel to bedding (Figures 20.3A and 20.3B). In general, S_1 is steeply dipping and oriented in an eastward trend in the central portion of the area. Towards the west, the S_1 cleavage rotates slightly to a 60 to 70° orientation and, in the east portion, it is rotated to a 100 to 120° orientation (*see* Figure 20.3B). A preliminary interpretation for the curvature in the S_1 cleavage is interpreted to be the result of the surrounding tonalite-granodiorite plutons squeezing the volcanic-sedimentary rock of the Fry Lake area. In the western portion of the belt, in the Kaginot Lake area, the S_1 cleavage and bedding are shallowly dipping to the southeast (20 to 60°) and the uplift is interpreted to be the results of the Scanes Lake pluton.

The S_1 cleavage intensity is heterogeneous throughout the area, and can be highly localized, such as the bands of higher strain (deformation zones) surrounding the Flicka showing and the Bamaji shear zone located along the north shore of Bamaji Lake. The Flicka shear zones range in size from 5 to 50 m wide corridors of deformation that are continuous over at least 2 km strike length and display an anastamosing pattern (*see* Figure 20.1).

F_1 folds have been recognized in numerous outcrops (Photo 20.2A). In the central portion of the map area, the F_1 hinge plunges approximately 45° to the east, subparallel to the stretching lineation (*see* Figure 20.3B). In the Kaginot Lake area, the F_1 fold hinge plunges approximately 40° to the northeast. In addition, some $F_{1\text{-}2}$ folds have been preserved, possessing an eastward plunge of approximately 45°; these are interpreted to be a composite of F_1 and F_2 folds, formed by rotation of F_2 folds into F_1 fold orientations.

The stretching lineation (L^e_1) (*see* Figure 20.3B) observed in the S_1 plane shows the approximate direction of maximum displacement during D_1. The stretching ratio of clasts and crystals are in the order of up to 20:1, in zones of intense deformation (e.g., Flicka shear zone), thus possibly controlling the orientation of mineralized bodies.

The second deformation event, D_2, is recognized in the field as a local centimetre-spaced crenulation cleavage, S_2, axial planar to asymmetric folds (Photo 20.2B; *see* Figure 20.3C). The asymmetric folds generally possess Z-shape geometry (90% of cases) and are interpreted to be drag folds, indicating a general dextral sense of shear along the S_1 cleavage. In the western portion of the mapping area, the S_2 fabric occurs as a conjugate set that strike approximately eastward and a second set northeastward. This conjugate set of cleavages is only visible in the Kaginot Lake area.

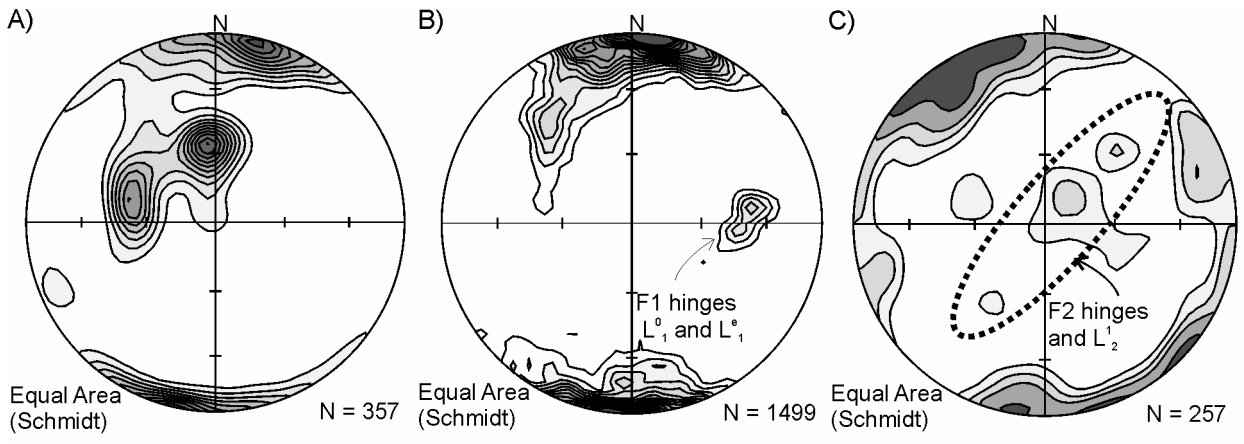

Figure 20.3. A) Density distribution of S_0 poles. B) Density distributions of S_1poles, the F_1 hinges, S_0-S_1 intersection lineation (L^0_1) and stretching lineation (L^e_1) are concentrated in an area with similar direction and plunges. C) Density distribution of S_2 poles; F_2 hinges and S_1–S_2 intersection lineation (L^1_2) plots in an area which would form an average northeast F_2 axial plane.

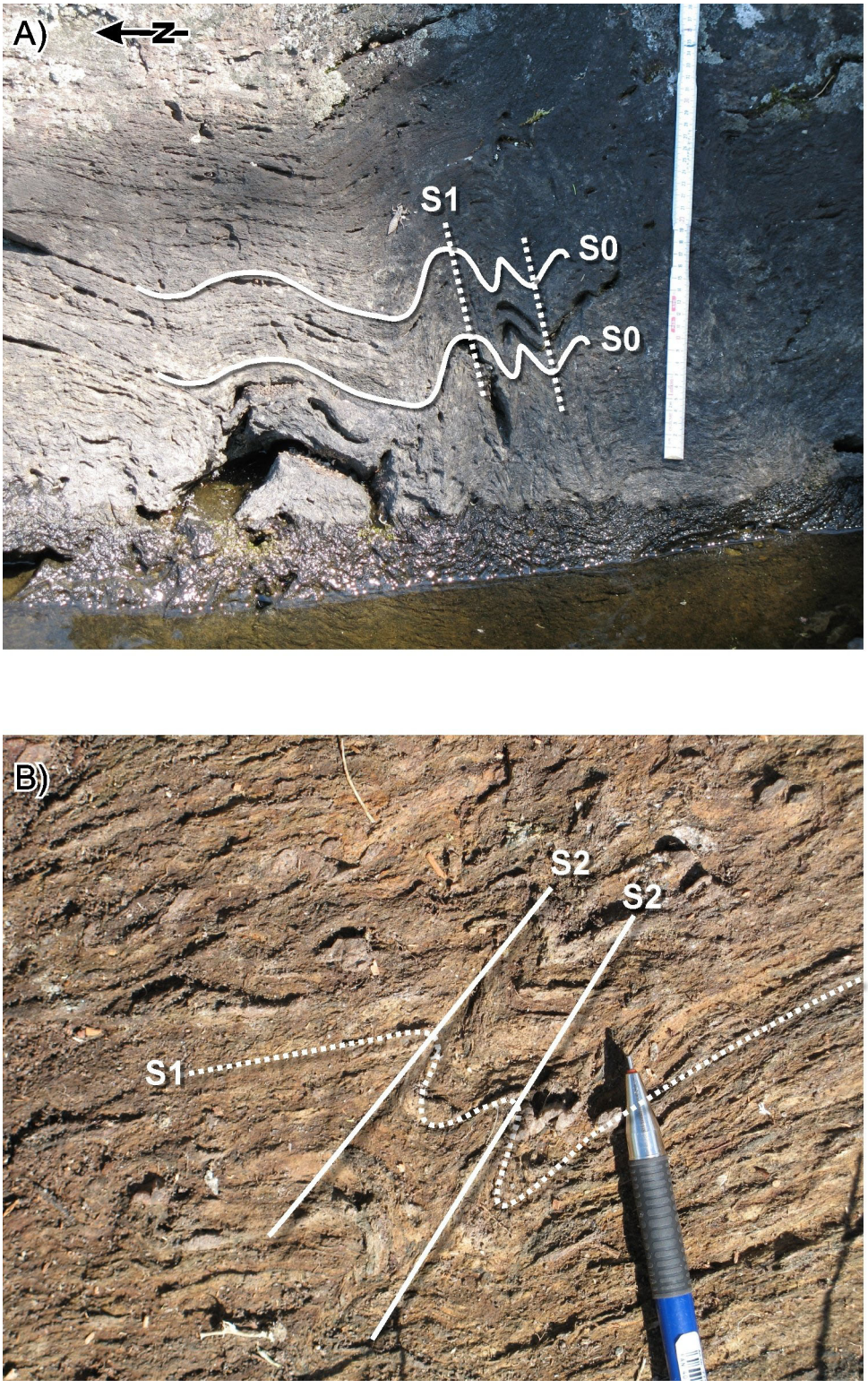

Photo 20.2. A) Photograph showing F_1 fold hinge in felsic to intermediate volcanic tuff, S_0 indicating the folded bedding surface and S_1 cleavage axial planar to second- and/or third-order parasitic F_1 folds; picture looking east. B) Photograph showing S_2 crenulation cleavage folding S_1 penetrative cleavage defining Z-shape asymmetry; pen is pointing north.

ECONOMIC GEOLOGY

The economic potential of the map area resides primarily in lode and disseminated gold mineralization. This section highlights 2 previously unrecognized areas of gold potential as well as suggestions for future exploration in 4 historical areas (*see* Figure 20.1) with differing styles of mineralization.

New Areas of Gold Potential

THE FRY LAKE STOCK

The western portion of the feldspar porphyritic Fry Lake stock (*see* Figure 20.1) exhibits strong, pervasive sericite-carbonate alteration ± fine-grained disseminated pyrite and minor tourmaline as well as locally strong, fracture-controlled iron carbonate (with minor quartz and pyrite) alteration and/or veining (Photo 20.3). Rare, narrow (1 to 5 cm) quartz-tourmaline veins also occur locally. The fractures hosting the iron carbonate alteration are subparallel to S_1, and deformed by both D_1 and D_2 indicating that the alteration is most likely synchronous with D_1 (*see* Photo 20.3). Rare, centimetre to metre-scale zones of silicification also occur. This area contains the highest concentration of iron carbonate alteration observed in the map area and represents excellent ground preparation alteration for later higher grade quartz-pyrite lode vein-style mineralization. The pervasive alteration of the stock is also promising for disseminated-style lower grade, bulk tonnage type mineralization. Outcrop exposure in the western portion of the stock is poor and no historical drilling has targeted this alteration.

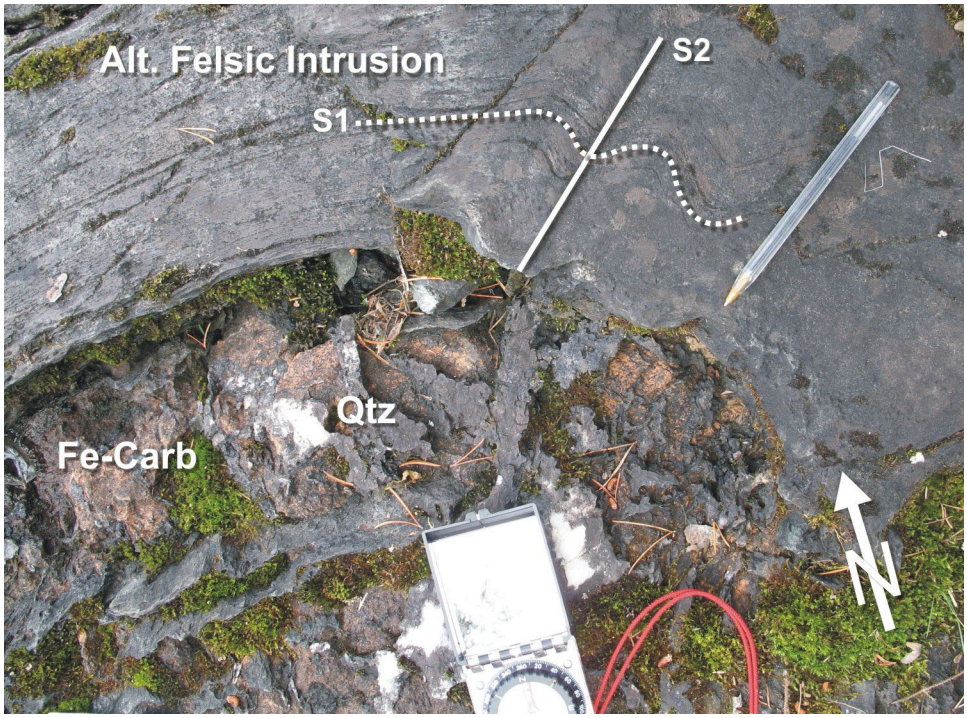

Photo 20.3. Photograph showing a fracture- and/or fault-fill iron carbonate (Fe-carb)–quartz (qtz) vein hosted by the Fry Lake Stock in a D_1 structure crenulated by D_2.

THE RELYEA LAKE PORPHYRY

This apparently strata-parallel, aphanitic, quartz porphyry intrusion, hosted in clastic metasedimentary rocks is unique among the felsic intrusive rocks in the map area, by its reminiscent of the quartz and quartz-feldspar porphyry "syenitic" intrusive rock found in the Kirkland Lake area of the Abitibi Subprovince. Local metre-scale zones of moderate silicification and the presence of local 1 to 20 cm wide greasy, translucent, bluish quartz veins suggest potential for gold mineralization. Outcrop exposure in the area is poor and no historical drilling has been conducted on the porphyry.

Recommendations for Select Historical Showings

THE FLICKA AREA LODE GOLD OCCURRENCES

The area surrounding the Flicka occurrence is structurally complex, consisting of several east-northeast-trending shear zones cutting a package of mafic to felsic metavolcanic rocks, chemical metasedimentary rocks and gabbro intrusion. The Flicka occurrence proper consists of 3 gold-bearing structures of limited extent hosted by gabbroic rocks which strike perpendicular to the main shear zones in the area and dip 55 to 65° to the east. Assays as high as 11.182 g/t Au over 1.47 m, have been intersected in diamond drilling (Dowhaluk 1984). Approximately 300 m to the south of the Flicka occurrence is the Fry Lake #9 zone, which is hosted in a large (up to 50 m wide) east-northeast-trending iron carbonate-rich shear zone. This zone was tested by 6 diamond drill holes in 1945, the best of which returned 0.70 ounce gold per ton over 0.23 m (Wallace 1985). Much of the past exploration work has focussed on the relatively small structures hosting the Flicka occurrence and it is recommended that the larger east-northeast-trending shear zones (such as the Fry Lake #9 zone) should be investigated more closely, specifically for high-angle splay faults as well as subhorizontal north-trending oriented extensional fractures hosted within the shear zones themselves in areas of increased quartz veining and/or sulphide mineralization.

THE DON'S LAKE AREA SUITE OF SHEAR ZONE HOSTED GOLD-URANIUM-THORIUM OCCURRENCES

The area surrounding these showings has been the focus of the most intense exploration in the map area with values of up to 0.51 ounce gold per ton over 1.1 m in diamond drilling (Umex Inc. 1988). These showings are hosted by intensely sericite-quartz-calcsilicate-disseminated pyrite altered shear zones at the contact of quartz-feldspar porphyry dikes and mafic volcanic rocks as well as wholly within the porphyry dike intrusive rocks. The felsic intrusive rocks are related to the North Bamaji pluton, indicating that exploration should not be limited to areas with abundant mafic volcanic rocks. These shear zones are also S_1 parallel and have been folded by D_2; any future work must take into account this folding event. For example, the valley between Don's Lake and the North Bamaji, which possesses gold showings on both sides of the valley, is an F_2 anticline; therefore, these 2 apparently separate showings may be the same fold-repeated horizon.

THE SANDERSON SUITE OF LODE GOLD-SILVER-COPPER-LEAD-ZINC OCCURRENCES

These quartz vein-hosted occurrences have historically produced some high-grade values, up to 25.12 ounces gold per ton over 0.21 m in diamond drilling (Cochenour Exploration Ltd. 1966). The veins are hosted by discrete centimetre- to metre-scale biotite-chlorite-calcite, east-striking shear zones apparently parallel and related to D_2 as the shear zones cut the S_1 fabric. These structures cut both the mafic volcanic rocks and the North Bamaji pluton; hence, exploration for this style of mineralization should not be restricted to the volcanic rocks. Future exploration should trace these structures further east into the Rockmere Lake area.

IRON FORMATION HOSTED GOLD OCCURRENCE

This occurrence, located approximately 3 km east of McVean Lake was discovered by diamond drilling in 1991. Values up to 24.07 g/t Au over 0.5 m (Mullen 1992) were returned from an anomalous gold-bearing iron formation within a strongly deformed zone of intercalated quartz-feldspar porphyry dikes and chemical sediments. This occurrence is in an area of poor outcrop exposure with only limited drilling. Further investigation is recommended as this style of mineralization may have similarities to the iron formation hosted gold deposits in the nearby Pickle Lake greenstone belt.

ACKNOWLEDGMENTS

We thank the Slate Falls First Nation community for advice concerning access to specific mapping areas as well as Bamaji Air for providing excellent service and logistical support. We also thank geoscientists Desmond Rainsford and Greg Stott for assistance in geophysical and structural interpretations. Finally, we thank geological assistants Jillian Martin, Tamara Moss, Melanie Mercier, Yves Moussallam, Avery Henderson, Victoria Stinson, Kristy Lea Beal, Toby Hagen, Courtney Crane, Misty Bunting, Julius Bunting and Gordon Wesley for their hard work during the field season mapping.

REFERENCES

Cochenour Exploration Ltd. 1966. Diamond drill logs, Sanderson option; Thunder Bay Resident Geologist's office, NTS 52 O/4, assessment file AFRI# 52O04NE9642, 49p.

Corfu, F. and Stott, G.M. 1993a. Age and petrogenesis of two Late Archean magmatic suites, northwestern Superior Province, Canada: zircon U-Pb and Lu-Hf isotopic relations; Journal of Petrology, v.34, p.817-838.

——— 1993b. U-Pb geochronology of the central Uchi Subprovince, Superior Province; Canadian Journal of Earth Sciences, v.30, p.1179-1196.

——— 1996. Hf isotopic composition and age constraints on the evolution of the Archean central Uchi Subprovince, Ontario, Canada; Precambrian Research, v.78, p.53-63.

Dowhaluk, H. 1984. Report on the Fry Lake property, Rockmere Lake Explorations Limited, Thunder Bay Resident Geologist's office, NTS 52 O/3, assessment file AFRI# 52O03NW9035, 47p.

Mullen, D.V. 1992. Diamond drill report, Major General Resources Ltd., McVean Lake Project; Thunder Bay Resident Geologist's office, NTS 52 O/3, assessment file AFRI# 52O03NE9359, 150p.

Ontario Geological Survey 1992. Tectonic assemblages of Ontario, west-central sheet; Ontario Geological Survey, Map 2576, scale 1:1 000 000.

Sage, R.P. and Breaks, F.W. 1982. Geology of the Cat Lake–Pickle Lake area districts of Kenora and Thunder Bay; Ontario Geological Report, Miscellaneous Report 207, 238p.

Sage, R.P., Breaks, F.W., Troup, W.R. and Jordan, G.W. 1973. Operation Pickle Lake, Bamaji Lake–Lake St-Joseph sheet, District of Kenora (Patricia Portion); Ontario Division of Mines, Preliminary Map P.808, scale 1:126 720.

Scharer, U. 1989. Age, origin and metamorphic overprint of volcanic and plutonic rocks in the central Uchi Subprovince, Superior Province, Canada; Geological Association of Canada–Mineralogical Association of Canada, Annual Meeting, Program with Abstracts, v.10, p.A62.

Stott, G.M. and Corfu, F. 1991. Uchi Subprovince; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.145-238.

Stott, G.M. and Wallace, H. 1984. Regional stratigraphy and structure of the central Uchi Subprovince: Meen Lake–Kasagiminnis Lake and Pashkokogan Lake sections; *in* Summary of Field Work 1984, Ontario Geological Survey, Miscellaneous Paper 119, p.7-13.

Stott, G.M. and Wilson, A.C. 1986. Precambrian geology of the Muskegsagagen–Bancroft lakes area; Ontario Geological Survey, Preliminary Map P.3049, scale 1:50 000.

Umex Inc.1988. Diamond drill logs; Thunder Bay Resident Geologist's office, NTS 52 O/3, assessment file AFRI# 52O03NW0015, 53p.

Wallace, H. 1983. Moosetegon Lake; Ontario Geological Survey, Map 2482, scale 1:31 680.

——— 1985. Geology of the Slate Falls area, District of Kenora (Patricia Portion); Ontario Geological Survey, Miscellaneous Report 232, 85p.

Young, M.D. 2003. New structural, geochronological, and geochemical constraints on the tectonic assembly of the Pickle Lake greenstone belt, Uchi Subprovince, western Superior Province; unpublished MSc thesis, Queen's University, Kingston, Ontario, 192p.

21. Project Unit 06-010. Geology of the Frame Lake Pluton: A Young Intrusion in the Berens River Subprovince, Northwestern Ontario

S. Buse[1]

[1]Precambrian Geoscience Section, Ontario Geological Survey

INTRODUCTION

The Frame Lake pluton (FLP) is located within the Berens River Subprovince in northwestern Ontario approximately 125 km north of Red Lake (Figure 21.1). It is an oval-shaped pluton surrounded by older granitoids. The first map produced of the FLP was by Ayres et al. (1973) who described it as a diorite to granodiorite hornblende-bearing pluton. The most recent map of the pluton is a 1:50 000 scale map produced by Stone, Crawford and Lange (1994a, 1994b) who defined 3 units within the pluton, which are roughly concentrically zoned. Due to its shape and nature, the pluton has been interpreted to be one of the youngest intrusions in the Berens River Subprovince.

Mapping was conducted during the 2006 field season as part of the Far North Geological Mapping Initiative at 1:20 000 scale in order to better understand the lithologies of the pluton as well as its economic potential.

REGIONAL GEOLOGY

The FLP is located within the Berens River Subprovince, a Mesoarchean to Neoarchean dominantly granitic region between the Uchi Subprovince to the south and the Sachigo Subprovince to the north. This subprovince within the Superior craton includes northward-trending greenstone belts, in contrast to the eastward-trending belts of the Uchi (Thurston, Osmani and Stone 1991). Plutonism within the Berens Subprovince is estimated to have occurred between 2750 and 2690 Ma with intrusion of the FLP at 2696 Ma (Corfu and Ayres 1984) occurring as the last pulse of magmatism in the area (Stone 1998). In contrast, the volcanic sequences that form the McInnes Lake greenstone belt were extruded during the Mesoarchean with ages of 2974 Ma, 2969 Ma and 2928 Ma, which are correlative to the ages within the Red Lake greenstone belt of the Balmer and Ball assemblages (Corfu et al. 1998).

The FLP is bounded to the northwest by the Hornby Lake greenstone belt and, to the west, by a long sliver of metasedimentary rocks extending south from the Hornby Lake belt. To the north and northeast of the pluton are older tonalite to granodiorite intrusions with biotite and/or hornblende, and to the south and southeast of the pluton are granite to granodiorite bodies ranging in texture from megacrystic to equigranular (Stone, Crawford and Lange 1994a, 1994b). Owing to its shape and lack of deformational history relative to the surrounding rocks, the FLP has been determined to be a young intrusion. Previous studies by Stone (1998) and Lange (1993) concluded that the FLP is a sanukitoid intrusion based on its whole rock geochemistry and its petrographic and structural similarities to other sanukitoid intrusions within the Superior craton. Plutons such as the FLP are rare in this subprovince and it is distinctive from other plutonic rocks by its oval shape, its composition and its high aeromagnetic signature.

Summary of Field Work and Other Activities 2006,
Ontario Geological Survey, Open File Report 6192, p.21-1 to 21-6.

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LITHOLOGIC UNITS

Previous maps separate the FLP into 3 lithologic groups based on their geochemistry and where they lie in the quartz-plagioclase-alkali feldspar diagram of Streckeisen (1976). These units are roughly made up of a tonalite-quartz diorite-diorite unit, a monzodiorite, quartz diorite, granodiorite unit and a monzonite, quartz monzonite, syenite, quartz syenite, granite unit (Stone, Crawford and Lange 1994a, 1994b). This classification for the pluton is reasonable, but it neglects factors such as textures that are distinctive within the different units, as well as the presence of a granitic core surrounded by potassium feldspar porphyritic granite. All the suites, except the 2 suites that form the core of the pluton, are hornblende bearing and all contain magnetite.

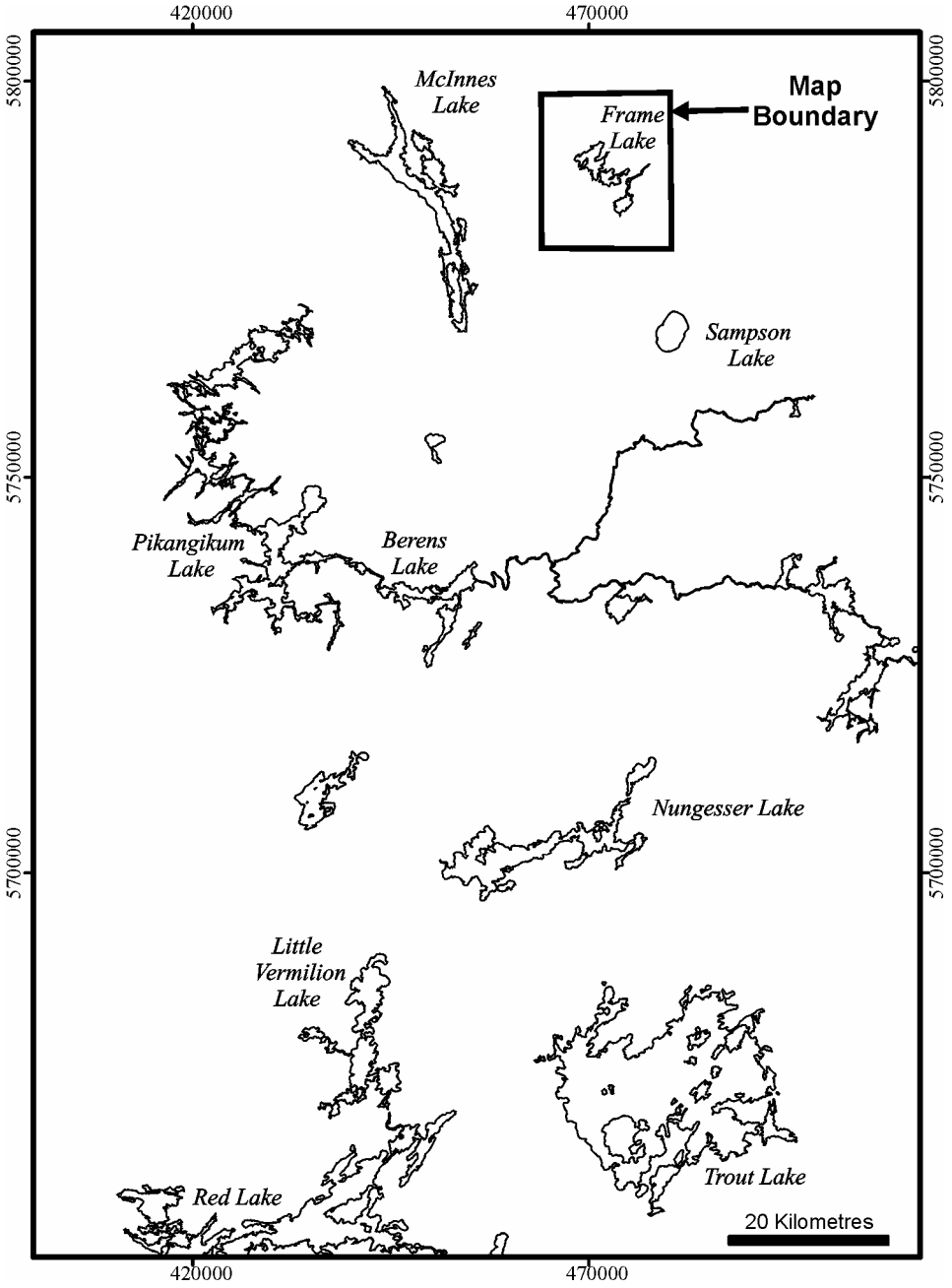

Figure 21.1. Location of 1:20 000 scale mapping project.

The youngest of the rocks within the pluton is a biotite-magnetite granite phase, the Mag Granite, that forms the core of the pluton. It is medium grained, equigranular and generally massive with a local weak foliation. This phase is locally monzonitic to quartz monzonitic in composition. Surrounding this is a potassium feldspar porphyritic granite phase that is biotite-magnetite bearing, medium grained, with phenocrysts up to 3 to 4 cm long. Magnetite in this suite is often intergrown with biotite, and hornblende occurs locally.

The hornblende granodiorite to granite phase is medium grained, generally inequigranular and contains plagioclase, quartz and variable amounts of potassium feldspar bearing. Other phases of the rock include biotite, hornblende and magnetite where the hornblende is often intergrown with biotite. This phase is widespread throughout the pluton.

Two syenitic compositions are distinguished, but textures within them are highly varied. The first is a hornblende-biotite-magnetite syenite to quartz syenite. This suite is a medium grained, weakly foliated and generally very pink in colour. The second composition is a biotite syenite to quartz syenite. This phase ranges from potassium feldspar porphyritic to equigranular medium grained to equigranular fine grained. Monzodiorite to quartz monzodiorite rocks are medium grained with a distinctive texture. These rocks are hornblende, biotite and magnetite bearing. They are often quite coarse grained with a moderate foliation.

The diorite and quartz diorite are interpreted to be the oldest of the phases in the FLP and are generally found associated with each other. The quartz diorite is very consistent in its nature, generally equigranular with plagioclase, quartz, hornblende, biotite and finer grained magnetite. It exhibits a moderate foliation and a characteristic black and white colour. Diorite ranges in texture from fine-grained salt and pepper, to medium-grained, well-formed crystals of hornblende, plagioclase and biotite. This phase also has abundant magnetite.

Rare ultramafic rocks occur as pods within the FLP, such as on the northwestern side of the pluton. These rocks are pyroxene bearing and are interpreted to be the lower crustal source rock for the pluton (Lange 1993).

Crosscutting all of these units are aplitic dikes and intrusions. The aplites are very fine grained with less than 5% biotite. They occur as decimetre- and metre-wide dikes to large outcrop-wide scale intrusions and are highly distinctive by their colour, grain size and texture.

MAGNETITE

Despite the complex lithologies within the FLP, there is one common feature across the pluton that has been ignored by previous studies. This is the abundant amount of magnetite in all of the rock suites. Magnetite makes up to 5% of the bulk composition of the magmatic phases and ranges from less than 1 mm to 4 mm in width and can often be seen without a hand lens.

The pluton forms a distinctive magnetic anomaly in the aeromagnetic geophysical data (Ontario Geological Survey 1999). The amount of magnetite within the rocks is likely the source for the anomaly. This contrasts with the surrounding granitoids, which are only biotite or biotite-hornblende bearing with no magnetite. and with the supracrustal rocks to the west. which are upper amphibolite-grade migmatites, also with no magnetite.

Table 21.1. Average magnetic susceptibility values for plutonic suites.

Plutonic Suite	Average Magnetic Susceptibility
Aplites	23.3
Mag granite	32.1
Potassium feldspar porphyritic granite	36.8
Hornblende granodiorite to granite	42.2
Biotite syenite to quartz syenite	47.3
Hornblende syenite to quartz syenite	49.8
Monzodiorite to quartz monzodiorite	57.1
Diorite to quartz diorite	63.7

The amount of magnetite in the rocks also reflects the state of the magma from which the FLP crystallized. Previous workers (e.g., Stone 1998; Lange 1993) concluded that the FLP is a sanukitoid intrusion based on its whole rock geochemical features (e.g., Stern, Hanson and Shirey 1989), but there is little mention of the high amounts of magnetite. Without any other chemical data, this would indicates that the magma was likely very oxidized, and the amount of magnetite in a plutonic rock is related to the oxidation state of the source magma.

The amount of magnetite present in different lithologies also becomes evident through the magnetic susceptibility data. The overall magnetic susceptibility of the pluton is very high relative to the surrounding greenstone belts and granitoids. Average readings range from 32.1 for the granitic core of the pluton to 63.7 for the dioritic rocks of the outer pluton (Table 21.1). The average magnetic susceptibility of the rocks generally increases from the more felsic phases, such as the Mag granite and the potassium feldspar porphyritic granite to the monzonites, granodiorites, syenites, monzodiorites and diorites. This may mean that the magma became less oxidized as it became more crustally evolved or there was more than one magmatic source.

STRUCTURE OF THE PLUTON

The FLP is a roughly oval pluton with asymmetrical lithologic zoning. The core of the pluton is made up of the most crustally evolved plutonic phases, the Mag granite and the potassium feldspar porphyritic granite. The pluton forms zones towards the core as the phases progressively become more felsic in composition with diorites and quartz diorites near the rim.

Weak foliations are observed within the various plutonic phases, but the general planar fabric seems to conform to the contact of the pluton. This is likely a magmatic fabric formed by the younger core pushing against the older dioritic phases, flattening them and creating a foliation parallel to the margin of the pluton. The pluton was emplaced too late to be affected by deformational and metamorphic events that affected the surrounding greenstone belts.

SURROUNDING ROCKS

To the west of the FLP are supracrustal rocks extending southward from the Hornby Lake supracrustal belt. These rocks are dominantly migmatized metasediments at upper amphibolite grade. They have coarse-grained quartz-plagioclase leucosomes and abundant metamorphic minerals such as sillimanite and garnet. Also associated with this unit is a two-mica S-type granite that exhibits sedimentary xenoliths and schlieren. This granite is medium grained, inequigranular and bears plagioclase, quartz, biotite, muscovite and local occurrences of garnet and sillimanite. These rocks extend the full length of the pluton and directly flank the pluton in most places, which is different than previous maps.

To the south of the pluton is an equigranular, fine- to medium-grained granite with a low percentage of biotite (typically 5 to 7%). This suite is very similar to the YPG suite found intruding the greenstone slivers between Red Lake and the McInnes Lake greenstone belts (Buse, this volume, Article 22). The YPG suite extends north halfway along the pluton before the contact between it and a biotite tonalite. This biotite tonalite is medium grained with typically less than 15% mafic minerals and extends northward encompassing the rest of the eastern and northern portions of the pluton.

ECONOMIC POTENTIAL

The FLP was targeted due to its mineral potential for platinum group elements (PGEs) and with the discovery of mineralization at the Entwine Lake intrusion (Stone 2000), another sanukitoid pluton with similarities to the FLP, further exploration was initiated. Rocks of the Entwine Lake intrusion show mineralization within diorite composition rocks and include sulphide minerals such as pyrite, chalcopyrite, pyrrhotite, pentlandite with assay results yielding platinum, palladium and gold (Stone 2000). Significant mineralization within the Entwine Lake intrusion is always related to alteration zones of actinolite, chlorite and epidote.

Within the FLP, only minor mineralization was observed. Disseminated pyrite is found commonly within the diorite and quartz diorite units and locally within other suites. At one locality within the Mag granite, at the core of the pluton, there is a small 10 m wide alteration zone with knots of pyrite up to 5 mm wide. This alteration zone is not pervasive and does not show any of the same characteristics or mineral assemblages as the alteration zone at the Entwine Lake intrusion. Any mineralization present at the FLP was sampled for assay.

SUMMARY

The FLP, with an age of 2696 Ma (Corfu and Ayres 1984) is an oval-shaped, roughly concentric lithologically zoned sanukitoid pluton. It has a core of granite that is the most crustally evolved, and a rim of quartz diorite and diorite, interpreted to be the oldest rocks. The pluton evaded all deformation due to its late emplacement, but shows weak intrusive fabrics. Only minor disseminated sulphide mineralization have been observed. Further geochemical analyses will help characterize the different intrusive phases within the FLP and evaluate the platinum group element potential of the more mafic outer phases.

ACKNOWLEDGMENTS

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REFERENCES

Ayres, L.D., Raudsepp, M., Averill, S.A. and Edwards, G.R. 1973. Favourable Lake–Berens Lake, geological compilation series, Kenora District; Ontario Department of Mines, Map 2262, scale 1:253 440.

Corfu, F. and Ayres, L.D. 1984. U-Pb age and genetic significance of heterogeneous zircon populations in rocks from the Favourable Lake area, northwestern Ontario; Contributions to Mineralogy and Petrology, v.88, p.86-101.

Corfu, F., Davis, D.W., Stone, D. and Moore, M.L. 1998. Chrono-stratigraphic constraints in the genesis of Archean greenstone belts, northwestern Superior Province, Ontario, Canada; Precambrian Research, v.92, p.277-295.

Lange, M. 1993. Geologie und Petrographie der Frame Lake-Intrusion in der Berens River-Subprovinz in Nordwest-Ontario, Kanada; unpublished MSc thesis, Universität Münster, Münster, Federal Republic of Germany, 101p.

Ontario Geological Survey 1999. Single master gravity and aeromagnetic data for Ontario; Ontario Geological Survey, ERLIS Data Set 1036.

Stern, R.A., Hanson, G.N. and Shirey, S.B. 1989. Petrogenesis of mantle-derived, LILE-enriched Archean monzodiorites and trachyandesites (sanukitoids) in southwestern Superior Province; Canadian Journal of Earth Sciences, v.26, p.1688-1712.

Stone, D. 1998. Precambrian geology of the Berens River area, northwest Ontario; Ontario Geological Survey, Open File Report 5963, 116p.

——— 2000. Geology, mineral chemistry and thermobarometry of the Entwine stock, northwestern Ontario: base metal, platinum group element and gold mineralization; Ontario Geological Survey, Open File Report 6021, p.1-8.

Stone, D., Crawford, J. and Lange, M. 1994a. Precambrian geology, Margot Lake area; Ontario Geological Survey, Preliminary Map P.3283, scale 1:50 000.

——— 1994b. Precambrian geology, Sampson Lake area; Ontario Geological Survey, Preliminary Map P.3294, scale 1:50 000.

Streckeisen, A. 1976. To each plutonic rock its proper name; Earth Science Reviews, v.12, p.1-33.

Thurston, P.C., Osmani, I.A. and Stone, D. 1991. Northwestern Superior Province: review and terrane analysis; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.81-144.

22. Project Unit 06-010. Geology of Supracrustal Remnants in the Berens River Subprovince, Northwestern Ontario

S. Buse[1]

[1]Precambrian Geoscience Section, Ontario Geological Survey

INTRODUCTION

In northwestern Ontario, several thin supracrustal belts extend approximately 50 km between Red Lake and McInnes Lake greenstone belts. These remnants were originally mapped by Ayres et al. (1973), who defined these slivers as a series of mafic, intermediate and sedimentary units encompassed within unsubdivided granites. Stone and Good (1990) and Stone and Crawford (1993) also mapped them as part of a regional mapping project targeted at defining the extensive granitoid bodies. These maps better defined the greenstone slivers by distinguishing between the mafic and intermediate rocks within specific belts, but, due to better accessibility and smaller scale mapping, the map changed significantly with the 1:20 000 scale mapping during the 2006 field season as part of the Far North Geological Mapping Initiative (Figure 22.1).

The greenstone belts are separated into 4 separate slivers, a north, central and south sliver as well as a long belt to the east of the north sliver. Each of the slivers is only 2 to 3 km wide, but together they stretch approximately 50 km in a northward direction (Figure 22.2). All 4 slivers show similar structural features and are extensively intruded by felsic plutons.

REGIONAL GEOLOGY

The Berens River Subprovince is an east-trending subprovince located between the Uchi Subprovince to the south and the Sachigo Subprovince to the north. The greenstone slivers and remnants lie within the Berens Subprovince as part of the dominantly granitic terrain (Thurston, Osmani and Stone 1991). Unique to this subprovince is the orientation of the greenstone belts. To the south, in the Uchi Subprovince, the greenstone belts trend roughly eastward, whereas the greenstone belts of the Berens River Subprovince trend northward. These belts include the greenstone slivers as well as the Hornby and McInnes Lake greenstone belts. Ages within the McInnes Lake belt are 2974 Ma, 2969 Ma, 2928 Ma (Corfu et al. 1998) and are comparable to the Balmer and the Ball assemblages in the Red Lake greenstone belt (Corfu et al. 1998). Surrounding the greenstone belts are voluminous Neoarchean granitoids that make up approximately 90% of the Berens Subprovince and range in composition from tonalite to granite. Also present are rare sanukitoid plutons such as the Frame Lake pluton (Stone 1998), which has an age of 2696 Ma (Corfu and Ayres 1984). The granitoids range in age from 2750 to 2690 Ma (Corfu and Stone 1998) and represent a shift from hornblende-bearing tonalite suites to more evolved granitoids such biotite granites (Stone 1998).

Summary of Field Work and Other Activities 2006,
Ontario Geological Survey, Open File Report 6192, p.22-1 to 22-8.

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LITHOLOGY

Northern and Eastern Greenstone Slivers

The northernmost greenstone sliver, compared to other slivers, is at the lowest metamorphic grade, ranging from upper greenschist in the north end of the belt to lower and mid-amphibolite grade at the south end. The belt is only about 2 km wide at the thickest and approximately 12 km long extending in a northwest direction. Mafic metavolcanic rocks dominate the northern portion of the greenstone belt and

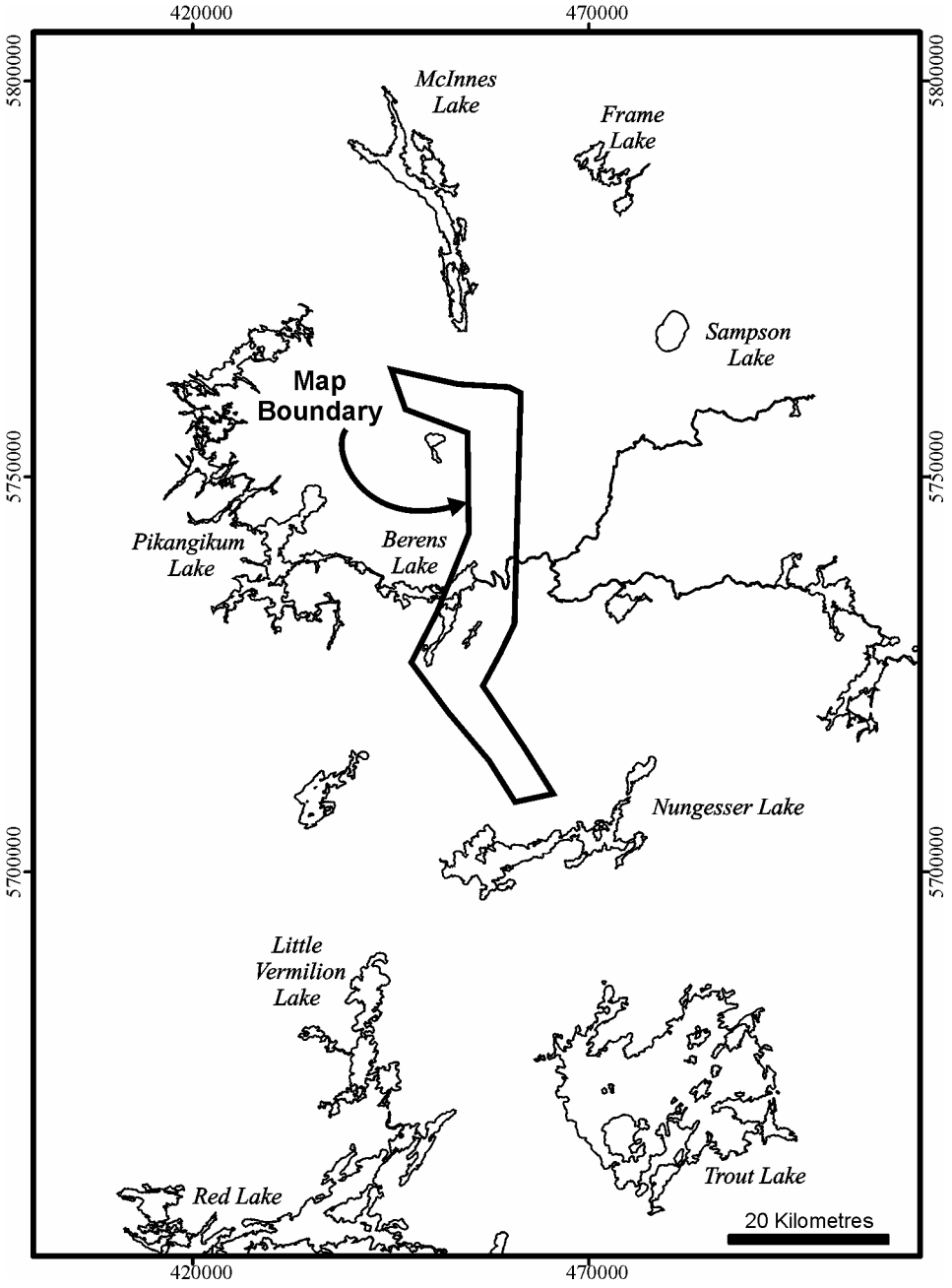

Figure 22.1. Location of map area.

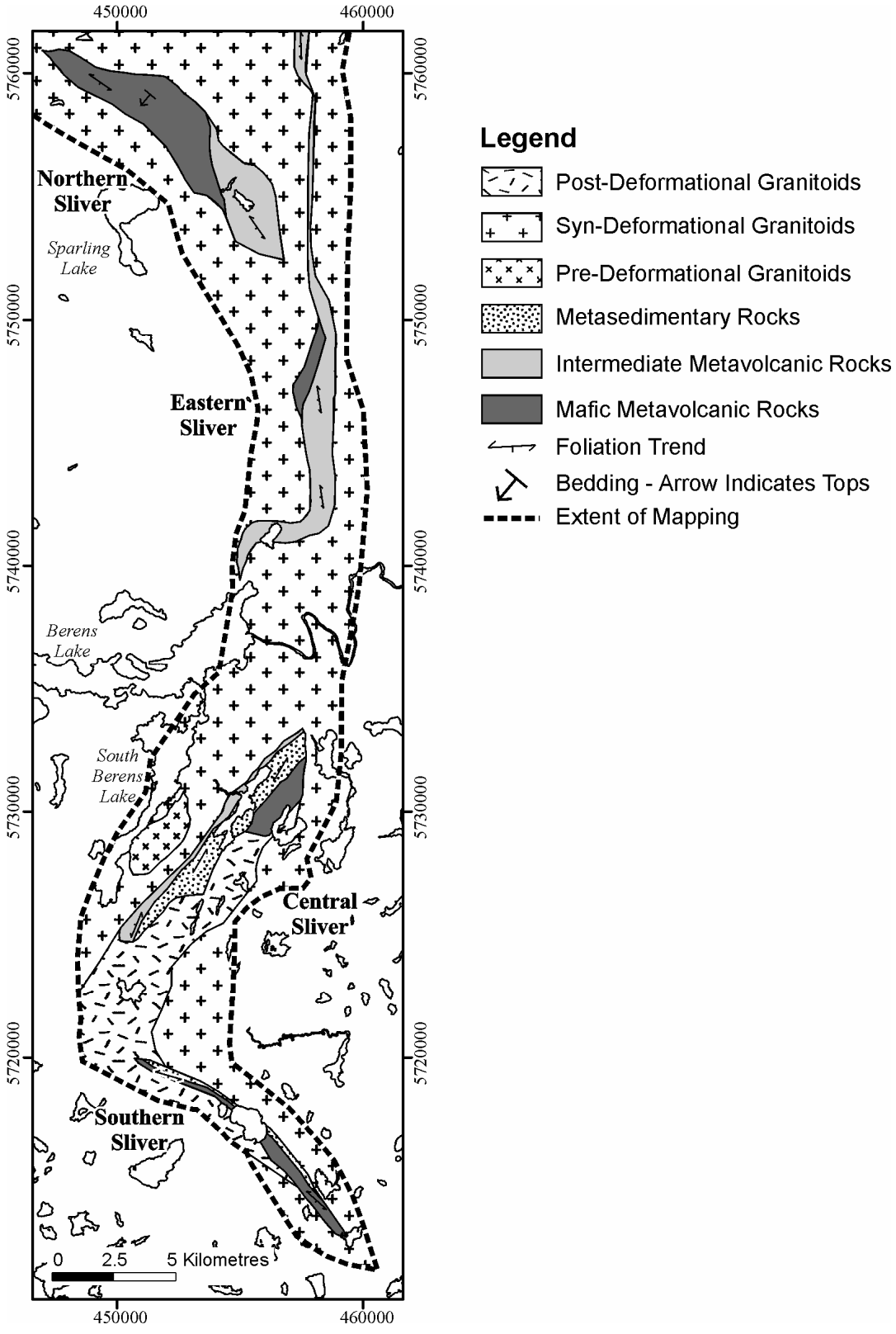

Figure 22.2. Simplified geologic map of the greenstone slivers.

range from pillowed flows with associated flow-top breccias to variolitic pillowed flows to massive variolitic flows to massive flows. Pillowed flows are rare, but, when present, they show topping directions in a southwesterly direction. The intermediate composition rocks are andesitic to rhyolitic in composition and range from well-preserved lapilli tuffs to gneissic dacitic rocks that have no recognizable primary features. Within the mafic metavolcanic rocks in the northern portion of the belt, only slivers of intermediate composition rocks are preserved, whereas the entire southern portion of the belt is composed of intermediate gneisses. Only small sections, no more that 100 m in width, of sedimentary rocks are preserved in the northern sliver. At the northernmost portion of the belt, there are garnet-bearing metasedimentary rocks that are extensively intruded by tonalites.

To the east of this sliver is an elongate strip of greenstone rocks that extend from just north of the central belt to the south end of the McInnes Lake greenstone belt (Préfontaine, this volume). This strip extends approximately 20 km northward and has a unique structural trend that differs from the northern sliver. It varies in width between 200 m and 1 km, which is likely the result of the extensive plutonism. The eastern sliver is composed of intermediate composition gneisses with plagioclase, quartz and biotite with local hornblende. There is also a small occurrence of massive basalt along the west side of the belt that is at anomalously low grade relative to the surrounding intermediate rocks.

Central Greenstone Sliver

The central greenstone sliver is composed of consistently higher grade rocks than the northern sliver, ranging from lower to upper amphibolite grade. The centre of the belt is dominated by wacke metasedimentary rocks that are migmatitic with a leucosome melt fraction ranging from 10 to 30%. The metasedimentary rocks are composed of plagioclase, quartz and biotite with rare occurrences of garnet and sillimanite. The leucosome of the sediments is often folded into Z and S patterns with axial planes parallel to the dominant foliation. The leucosome itself is medium grained and composed of plagioclase and quartz with rare potassium feldspar and hornblende. When hornblende is present, it is coarse grained and is found near the margins of the leucosome–paleosome contact. Garnet is found within aluminum-rich beds in the sediments and rare sillimanite is observed in upper amphibolite-grade sediments that are migmatized. At 2 localities, a quartzite was observed along the eastern margin of the sedimentary rocks.

Surrounding the metasedimentary rocks are amphibolite and dacite sequences. On the east side of the belt, amphibolites range from totally recrystallized foliated amphibolites to partially recrystallized, finer grained basalts that often exhibit epidote alteration. The dacitic rocks occur on the west side of the belt and range from gneisses to tuffs. The tuffs range from tuff to lapilli tuff where the lapilli are dominantly feldspar and quartz. The tuffs show evidence for resedimentation in one locality indicating that they may be volcaniclastic. There is also one location where mafic tuffs are present within dacitic units; a BSc thesis by Rod Dammeier at the University of Ottawa will be conducted in this area to study the genetic relationships between these units. Associated with these dacitic and amphibolite units are older trondhjemitic units as well as tonalite gneisses. These units are often less than 1 m thick and are highly sheared and boudinaged.

As the slivers extend southward, the greenstone rocks occur as xenoliths within the younger tonalite and granite suites. The xenoliths range from schlieric layering to large metre-scale blocks. Also, the eastward width of the central sliver was likely much larger prior to intrusion of the granitoids.

Southern Greenstone Sliver

The southernmost greenstone sliver is only 200 to 300 m wide and, similar to its northern counterparts, it is highly intruded by granitoids. Very few outcrops are found in the area as it is dominated by esker, but the same 3 basic lithologies that are seen in the central sliver can be traced. On the southwest side of the belt, there are mafic metavolcanic rocks that are highly sheared. The metavolcanic rocks are massive basalts with no other volcanic features preserved, likely due to the high degree of sheering in that location. At the southern portion of the belt is one outcrop of dacitic tuff composed of plagioclase, biotite, quartz and hornblende with layering on the millimetre scale. On the eastern side of the belt, there are wacke metasedimentary rocks that occur as large metre-scale blocks intruded by a non-foliated granite.

FELSIC PLUTONIC ROCKS

Surrounding the greenstone slivers, voluminous plutonism occurred during predeformational, syndeformational, and postdeformational stages. The predeformational granitoids are found within the greenstone belts, most commonly within the central sliver. These are largely composed of tonalite and trondhjemite gneisses. They occur only as thin 2 to 10 m wide units with the same structural trends as the surrounding greenstone rocks. Other predeformational to syndeformational gneisses occur surrounding the greenstone slivers. A gneissic tonalite succession crops out along the arm between Berens Lake and South Berens Lake as well as along the top of South Berens Lake, which is likely related to the greenstone belt. Also, there is a granodiorite gneiss between the central greenstone sliver and the foliated tonalite around South Berens Lake that resembles the wacke metasedimentary rocks within the greenstone sliver. It may be a paragneiss formed during metamorphism of the greenstone belt.

Syndeformational granitoids show moderate to strong foliations and surround the greenstone slivers. Three of the most common granitoids include a foliated biotite tonalite, a hornblende tonalite, a granodiorite and a potassium feldspar megacrystic granite. The foliated biotite tonalite occurs dominantly on the west side of the central and southern greenstone belt. It is medium grained, well foliated to gneissic and contains abundant amphibolite enclaves. The hornblende tonalite suite occurs as a wedge between the northern and eastern slivers as well as south of the central greenstone sliver. This unit is also medium grained and foliated with less than 15% mafic minerals. The granodiorite occurs to the west and south of the northern sliver, is weakly foliated, has less than 10% biotite, and has small 2 to 3 mm wide plagioclase phenocrysts. Lastly, the potassium feldspar megacrystic granite, known as the UCG suite, occurs along the eastern side of almost the entire map area. It has 3 to 7 cm long megacrysts as well as contains hornblende and biotite. It shows a moderate to strong foliation and the proportion of megacrysts varies from 0 to 30% within the rocks.

There are only 2 true postdeformational bodies within the map area. The first is a diorite suite at the southeastern end of the central greenstone sliver. It is well foliated with variable amounts of hornblende, but the foliation differs from the tectonic foliation of the main belt and is likely the result of a younger, posttectonic igneous fabric. The second granite is a pink, medium- to fine-grained, massive to weakly foliated, equigranular granite known as the YPG suite. It intrudes the central greenstone sliver as subvertical sheets and as dikes in other units in the map area. Late pegmatite and aplite dikes are also common.

STRUCTURE

Within all 3 belts, similar structural features can be seen. With the exception of the northernmost belt, the slivers exhibit one dominant foliation that trends parallel to the trend of the slivers. This common foliation typically dips steeply to the southwest and, from a regional perspective, it defines a broad open Z fold (*see* Figure 22.2) visible by the shape of the slivers. Few stratigraphic tops were noted, owing to the high degree of deformation and metamorphism, which, in most places, destroyed any primary features. An exception is pillow basalts observed in the northern sliver where the pillows top to the southwest. Other folding can be seen, especially in the central sliver, where Z, S and M folds are very common in leucosomes and granitoid veins. These folds are always axial planar to the penetrative foliation and are only found at the centimetre to decimetre scale. The dominant fabric within all of the slivers was likely caused by a regional flattening of the greenstone belts, accentuating their northward trend. Boundinage, found in many of the predeformational granitoids and some of the volcanic sequences, appears to have developed during this deformation. Stretching and mineral lineations within the greenstone belts and granitoids, as well as all of the fold hinges, plunge in a southward direction that is regionally characteristic in the Berens River Subprovince. Both the Hornby Lake and McInnes Lake greenstone belts exhibit this feature and it is likely related to the large scale Z-fold pattern in the area (Stott et al., this volume).

Late intrusive bodies cause the arcuate shapes of the belts adjacent to younger, circular or crescent-shaped intrusions. This plutonism likely occurred after the prevalent flattening foliation in the slivers. This deflection is illustrated in the northern volcanic sliver where the Sparling Lake pluton (defined by Stone and Good 1990) pushes the belt from the southwest causing the rounded shape of the sliver and, in the central belt, where the UCG suite intrudes from the east producing a convex shape towards the west.

Intense shearing is preserved within all the greenstone slivers, but is seen best in the sedimentary rocks as well as pervasively in the granitoid rocks. It always occurs always in a dextral sense. This is recorded at the McInnes Lake greenstone belt (Préfontaine, this volume) as well as at other belts in the northern Berens Subprovince (Stott et al., this volume) indicating that it is likely the result of a regional sheer over a large area.

The greenstone slivers as presented in Figure 22.2 are likely only remnants of larger greenstone packages that may be preserved at depth. Geophysical data suggest that the slivers are much wider and more continuous (Ontario Geological Survey 1999) than what the surficial geology presents. Much of the greenstone belts as mapped by Stone and Good (1990) and Stone and Crawford (1993) are actually only decimetre- to metre-scale xenoliths. These xenoliths are lithologies that can be traced back to the greenstone slivers and are thus likely part of the greenstone sequence, but are so heavily intruded by granitoids that they are no longer a consistent unit. This is specifically relevant in the southern portions of the north and central slivers where they were previously mapped as much larger units.

The last deformational event in the area is recorded as small brittle faults, oriented in a southwest direction, almost always with sinistral displacement. These are observed as centimetre to decimetre offsets of veins and dikes.

METAMORPHISM

The metamorphism of the 3 slivers ranges from upper greenschist to upper amphibolite grade. The lowest grade rocks are found in the northern sliver where pillow structures and amygdules are still preserved in the basaltic composition rocks. As the sliver continues southward and the dominant lithology becomes intermediate gneisses, the grade becomes higher.

The metamorphism of these slivers is likely the result of contact with the surrounding plutons. Grading within the metamorphism generally occurs in the belt towards the younger plutons. For example, in the northern belt, a young granite intrudes along the southern margin and forms amphibolites along the contact between the granitoid and the greenstone belt. To the north of the contact, the amphibolites are observed as massive to pillowed flows. Examples of this are also seen in the south and central slivers.

Folding of the leucosomes within the metasedimentary rocks indicates that folding occurred during or after the main metamorphic event. This event would be a low pressure–high temperature event resulting in melting and recrystallization. Aluminum in the rocks proves to be very low due to the lack of metamorphic minerals such as cordierite, andalusite, sillimanite and garnet, which are only present locally even though the metamorphic conditions were high enough to produce them.

ECONOMIC POTENTIAL

Only local mineralization was recorded within all the greenstone slivers. Pyrite occurs as disseminated mineralization ranging from less than 1 to 6% within the metasedimentary rocks, mafic volcanic rocks and some of the granitoid rocks. Also, within the central greenstone sliver, there is one occurrence of pyrrhotite and pyrite. This may mean that the metamorphic conditions within the belts were too high to preserve any significant mineralization. Alteration zones within the supracrustal rocks are also limited. The only prevalent alteration is epidote within the mafic metavolcanic rocks, including amphibolites, but with no associated mineralization. No shear zone-related hydrothermal alteration suitable for lode gold mineralization was observed, or synvolcanic alteration, apart from the locally epidotized mafic volcanic rocks. Any mineralization observed was sampled for assay.

CONCLUSIONS

The 4 greenstone slivers between McInnes Lake and Red Lake are likely remnants of larger greenstone belts, but, due to extensive plutonism, only remnants are preserved. This plutonism was responsible for the metamorphism of the area to upper amphibolite grade as well as for modifying the shape of the greenstone slivers. Although ages have not been determined, the greenstone slivers are on strike with, and may be correlated to, the Balmer assemblage in the Red Lake and McInnes Lake greenstone belts, which show similar ages. Further research in this area includes extensive geochemistry and geochronology that will help to answer some of the questions within the Berens River Subprovince.

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Appreciation is extended to GoldCorp for providing the use of their geophysical data for mapping and interpretation. Also thanks to Alexia Greschner, Rod Dammeier, Jonathan Munn and Leanne Smar for their excellent assistance during the 2006 field season. Acknowledgment goes to the Far North Team, Sonia Préfontaine, Neil Pettigrew, and Etienne Dinel for discussion, as well as Greg Stott for his insight and discussion. Lastly, great appreciation goes to the pilots of Green Airways for flying during the project as well as Ministry of Natural Resources helicopter staff for their aerial support.

REFERENCES

Ayres, L.D., Raudsepp, M., Averill, S.A. and Edwards, G.R. 1973. Favourable Lake–Berens Lake, geological compilation series, Kenora District; Ontario Department of Mines, Map 2262, scale 1:253 440.

Corfu, F. and Ayres, L.D. 1984. U-Pb age and genetic significance of heterogeneous zircon populations in rocks from the Favourable Lake area, northwestern Ontario; Contributions to Mineralogy and Petrology, v.88, p.86-101.

Corfu, F., Davis, D.W., Stone, D. and Moore, M.L. 1998. Chrono-stratigraphic constraints in the genesis of Archean greenstone belts, northwestern Superior Province, Ontario, Canada; Precambrian Research, v. 92, p. 277-295.

Corfu, F. and Stone, D. 1998. Age structure and orogenic significance of the Berens River composite batholiths, western Superior Province; Canadian Journal of Earth Sciences, v.35, p.1089-1109.

Ontario Geological Survey 1999. Single master gravity and aeromagnetic data for Ontario; Ontario Geological Survey, ERLIS Data Set 1036.

Stone, D. 1998. Precambrian geology of the Berens River area, northwest Ontario; Ontario Geological Survey, Open File Report 5963, 116p.

Stone, D. and Crawford, J. 1993. Precambrian geology, Berens Lake area; Ontario Geological Survey, Preliminary Map P.3218, scale 1:50 000.

Stone, D. and Good, D. 1990. Precambrian geology, Kirkness Lake; Ontario Geological Survey, Preliminary Map P.3174, scale 1:50 000.

Thurston, P.C., Osmani, I.A. and Stone, D. 1991. Northwestern Superior Province: review and terrane analysis; *in* Geology of Ontario, Ontario Geological Survey; Special Volume 4, Part 1, p.81-144.

23. Project Unit 06-011. Geology of the McInnes Lake Supracrustal Belt, Northwestern Ontario

S. Préfontaine[1]

[1]Precambrian Geoscience Section, Ontario Geological Survey

INTRODUCTION

The McInnes Lake supracrustal belt was mapped at 1:20 000 scale as part of the Far North Geological Mapping Initiative. The McInnes Lake area is located approximately 137 km north of Red Lake (Figure 23.1). Access is by float-equipped plane only. The rock exposure is generally good along the lakeshore; however, some areas surrounding the lake are covered by very thick pine forest and other areas have been affected by fire. Previous exploration work in the area was completed by several companies, such as Phelps Dodge Corporation of Canada Limited (1962), which drilled 9 holes. Later, this area was mapped by Averill and Ayres (1968) and then incorporated in a compilation map of the Berens River block (Ayres et al. 1973). Cominco Limited, in the late 1970s, performed detailed geophysical surveys on 12 grids around the lake and also drilled 5 holes (Cominco Limited 1977–1979). Geophysical surveys were also completed by Placer Dome (1989–1991) covering the southern part of the lake. Cortis mapped the lakeshore (A.L. Cortis, OGS, unpublished map, 1988; Cortis et al. 1988) and Stone mapped the area at 1:50 000 scale (Stone and Crawford 1993; Stone et al. 1993), which was later incorporated into an Open File Report on the Berens River Area (Stone 1998).

GENERAL GEOLOGY

McInnes Lake supracrustal belt is situated in the Berens River Subprovince and trends northward, which is in contrast to most of the supracrustal belts in the Sachigo, Uchi and Berens River subprovinces. This belt is composed of a series of Mesoarchean volcanic units ranging from ultramafic to felsic with interlayered clastic and chemical metasediments. This belt was subdivided into 3 cycles (Cortis et al. 1998) based on lithologies and marker units (Figure 23.2). The overall facing direction is east, which is in agreement with the geochronology previously completed in this belt (Corfu et al. 1998). The general metamorphic grade is higher than in the other greenstone belts in northwestern Ontario. Three younger intrusions surround this belt: an older tonalite to the west, a granodiorite to granite to the east, and a younger granite to granodiorite to the west. Also the belt is crosscut by several dikes, sills and small stocks of different composition.

Summary of Field Work and Other Activities 2006,
Ontario Geological Survey, Open File Report 6192, p.23-1 to 23-8.

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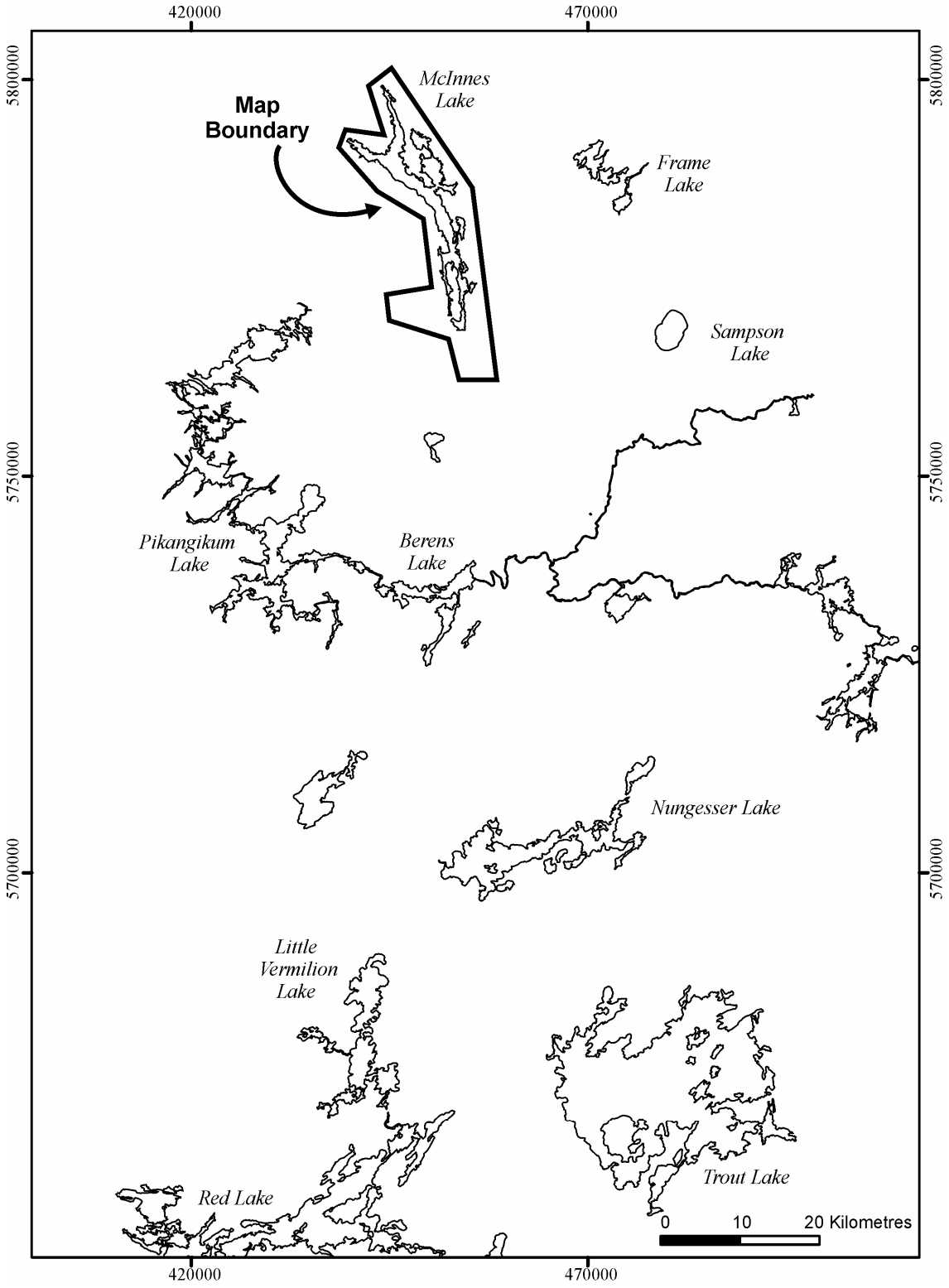

Figure 23.1. General location map of the study area.

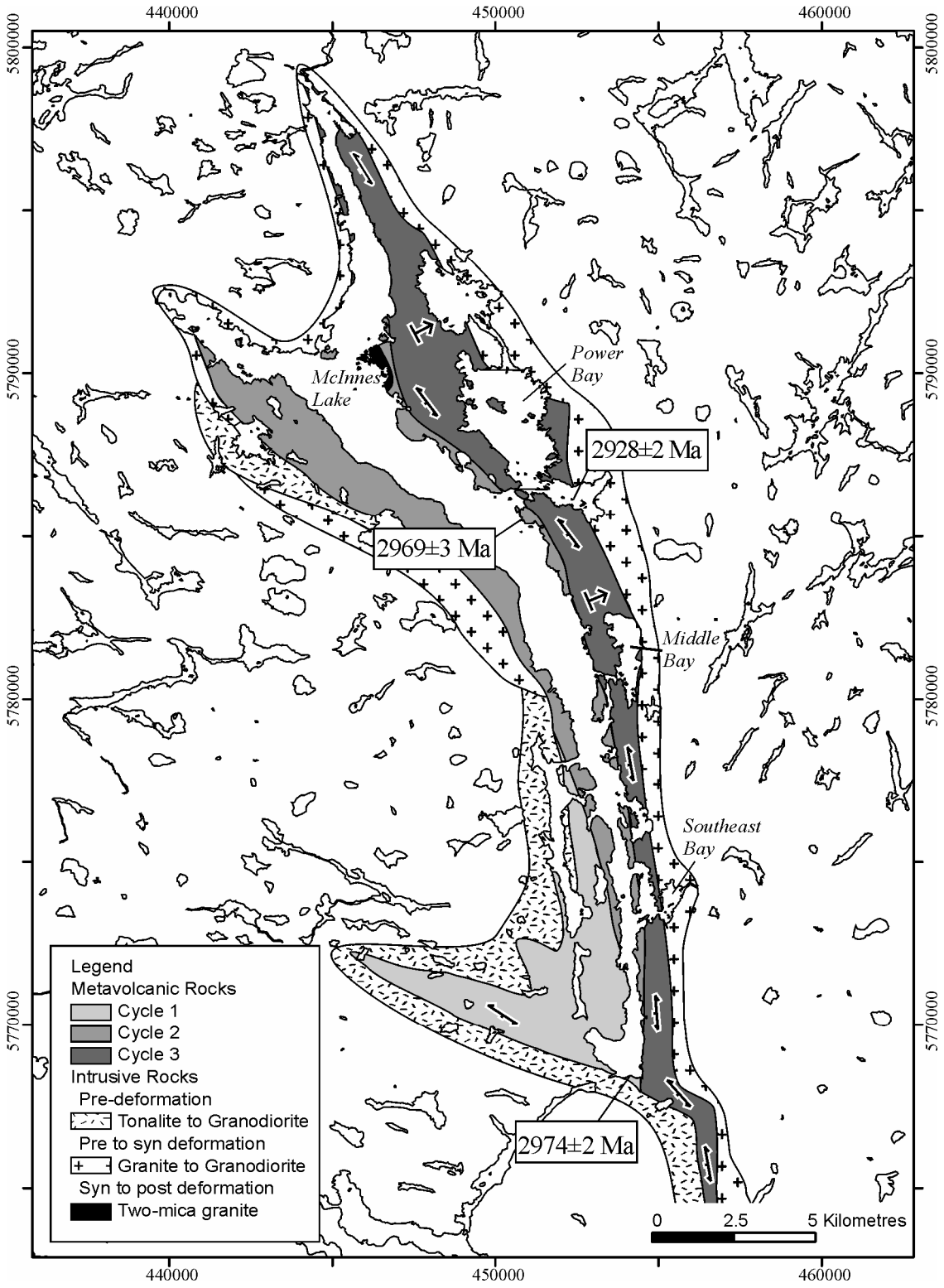

Figure 23.2. Volcanic cycles of the McInnes greenstone belt and surrounding intrusions.

MESOARCHEAN ROCKS

Cycle 1

In the southwestern part of the belt, a sequence of mafic to intermediate metavolcanic rocks is tentatively labelled Cycle 1 (*see* Figure 23.2). The mafic flows and tuffs are interlayered with intermediate pyroclastic rocks. The thickness of these mafic and intermediate units can be measured in tens to hundreds of metres. They appear to be continuous in this cycle. Only one example of primary bedding (grading) was observed in this volcanic cycle. This cycle is the oldest cycle in this belt, 2974±2 Ma (Stone 1998). This age is correlative with the Balmer assemblage, 2964–2992 Ma (Stott and Corfu 1991) in the Red Lake greenstone belt or on the western margin of the Confederation belt (Rogers 2002).

Cycle 2

Cycle 2 covers the whole northwestern part of the belt and is continuous to the south where it pinches out (*see* Figure 23.2). The base of cycle 2 is composed of mafic metavolcanic rocks that have a maximum thickness of 300 m and is discontinuous and generally absent in the southern part of the belt. All the primary fabrics have been overprinted due to the proximity of the granite–greenstone contact.

The intermediate metavolcanic rocks, which compose the larger section of this belt, are mostly made up of pyroclastic rocks. Tuffs, lapilli tuffs and lapilli tuff breccias, as well as possible volcaniclastic sediments, are found in the Power Bay area suggesting a more proximal environment to the edifice. These are thickly bedded over several metres and are laterally extensive over hundreds of metres. To the south, this pyroclastic sequence is mainly tuffaceous, thinly bedded to laminated and appears to represent a more distal facies. The northern section of Power Bay is composed of flows and tuff beds. The tuffs are laminated to finely bedded, which correspond as well to a more distal environment. This unit has previously had an age of 2969±3 Ma (Stone 1998) determined, which again can be correlated to the Balmer assemblage (2964–2992 Ma) of the Red Lake greenstone belt (Stott and Corfu 1991), or the Narrow Lake assemblage (<2975 Ma, >2880 Ma) in the Confederation greenstone belt (Rogers 2002).

There is a set of ultramafic sills that is unique to cycle 2. Although they may not all be related, they seem to intrude in the same intermediate metavolcanic stratigraphic layer at the top of this cycle. These sills are generally parallel to the strata even though some variation in strike has been seen up to 15° from the bedding direction. They are massive, homogeneous, coarse grained, poorly foliated, and generally altered to actinolite, talc with rare serpentine.

The upper unit of this cycle is dominated by beds of clastic and chemical metasediments. The clastic metasediments are discontinuous and composed of wackes and argillites, which are probably volcanic derived. This unit is no more than 50 m thick and is overlain by an iron formation that is no more than 100 m thick. This iron formation is more oxide rich, chert-magnetite, between Power Bay and Middle Bay, and becomes more siliceous with garnet-actinolite-chlorite-biotite and chert mixed with wackes and mudstone in the south. Rare sulphide mineral-bearing beds composed mainly of pyrite were observed. This unit is cut locally by the overlying mafic metavolcanic rocks of cycle 3. There may be another iron formation that is poorly exposed in the upper part of the intermediate pyroclastic rocks of this lake; however, it is only observed in the northern section of the belt. Magnetic deflections affecting the compass suggest that it may continue in the southern area of the lake.

Cycle 3

Cycle 3 has been found to be larger than previously mapped (Cortis et al. 1988). It covers the northeastern part of the belt and is continuous to the south where it thins to form part of the volcanic slivers that trend south towards the Red Lake greenstone belt (Buse, this volume, Article 22) (*see* Figure 23.2). It is composed of a suite of mafic and intermediate to felsic metavolcanic rocks. The basal unit is composed of mafic massive to pillowed flows with associated breccias and can be as thick as 1.5 km. The massive flow units may be as thick as 100 m and are generally homogeneous and well foliated. The massive flows are distributed along the length of the greenstone belt. Small intermediate metavolcanic slivers occur within this unit. The pillows are, for the most part, situated just west of Power Bay and continue to the south of Middle Bay. These can be as large as 1.5 m and are amygdaloidal and variolitic in places. In the Middle Bay area, a repeated series of mafic pillows and interflow metasedimentary rocks indicate the different flows. The pillows show alteration containing garnet, biotite, possibly sillimanite and plagioclase. The metasedimentary rocks are composed of argillaceous beds and quartzite sandstones. The argillite beds are also completely replaced by the same metamorphic mineral assemblage as the mafic pillows.

The intermediate to felsic unit overlying the mafic metavolcanic rocks is composed mostly of lapilli tuff and lapilli tuff breccias, which grade into more felsic tuffs to the northeast. The lapilli tuff can be up to several metres thick, although they are typically tens of centimetres thick. Some top indicators such as grading were found in these units suggesting a constant northeast facing. This upper unit is at its largest in the Power Bay area and pinches out to the south near Middle Bay. Rare mafic metavolcanic lenses are found at the top of this unit. An age of 2928±2 Ma has been previously obtained for this unit (Stone 1998), which corresponds to the Ball assemblage at 2940–2925 Ma (Stott and Corfu 1991) in the Red Lake greenstone belt or the Narrow Lake assemblage in the Confederation belt (Rogers 2002).

In Middle Bay, 2 outcrops of komatiite flows overlie the metasedimentary rocks. They appear to have a peridotite composition. Flow-top breccia is composed of clasts up to 7 cm and is the same composition as the matrix. The breccia is approximately 30 cm in thickness and is followed by massive flow. This unit is foliated and the initial mineralogy is completely replaced by actinolite and serpentine. No other primary fabrics, such as spinifex, were observed.

INTRUSIONS

The plutons surrounding the belt are considered to be of similar composition and fabrics than Neoarchean rocks of the Berens River Subprovince for which ages have been determined (Corfu and Stone 1998). The northern and eastern sections of the greenstone belt are bounded by a deformed granodiorite to granite (*see* Figure 23.2) intrusion. In places, this intrusion contains megacrystic potassic feldspar. The contact between the greenstone and the granitoid is typically a lit-par-lit injection of the granitoid in a more gneissic greenstone rock. Several dextral shear sense indicators were found in this unit including sigmoidal, z-drag fold and back rotation of boudins.

A coarse-grained two-mica, garnetiferous granite occurs as small stocks and sheets throughout the belt. The major intrusion is at the southern end of the northeastern arm of the lake (*see* Figure 23.2). It is typically undeformed with weak foliation and lineation. It is composed primarily of quartz, potassic feldspar and plagioclase containing secondary minerals such as muscovite, biotite and garnet.

To the west of the supracrustal belt, a well-foliated hornblende tonalite surrounds the younger granite to granodiorite (*see* Figure 23.2). This younger granitoid affected the belt by causing an easterly concave bowing of the belt, steepening the lineation and rotating the foliation. It is only weakly deformed and contains potassic feldspar megacrysts.

Near the southeast bay, there is a coarse-grained to pegmatitic granite with graphic texture and secondary minerals such as tourmaline, muscovite and garnet. It is undeformed and thought to be posttectonic.

On the eastern shore of McInnes Lake, a series of north-trending mafic dikes crosscut cycles 2 and 3. These dikes are generally massive to weakly foliated. Poikilitic mafic dikes contain feldspar oikocrysts as large as 8 cm locally. The dikes might be correlated to the Proterozoic gabbroic intrusions mentioned by Stone (1998).

METAMORPHISM

This belt, on average, expresses a higher metamorphic grade than similar greenstone belts in northwestern Ontario. It is generally in the range of lower to middle amphibolite with assemblages in the intermediate and mafic metavolcanic rocks of hornblende-plagioclase-garnet. The metasedimentary rocks generally exhibit garnet-biotite-sillimanite-chlorite. However, especially in the mafic metavolcanic rocks, chlorite and actinolite seem to be locally preserved indicating upper greenschist metamorphism. This metamorphism is probably related to the emplacement of the granitoid intrusions surrounding the greenstone belt.

STRUCTURAL GEOLOGY

The map area is complexly deformed. A north-striking S_1 penetrative foliation is apparent throughout the supracrustal rocks dipping west. Intrusion of the pluton west of McInnes Lake resulted in rotation and steepening of the S_1 foliation as the supracrustal rocks were wrapped around the pluton. Lineation generally plunges to the south with local variation in the southwest plunging easterly. East of McInnes Lake, low-angle dips on foliation planes and down-dip lineations indicate the supracrustal rocks are thrust over the granitic plutons. Several top indicators were found in the northeastern part of the belt. They generally indicate an eastward-facing stratigraphy with local westward facing in the tuff and sediments. The top indicators coupled with the continuous, tabular stratigraphy and the available geochronology indicate that the strata predominantly youngs to the east.

The most intense deformation event resulted in a transpression deformation (Stott et al., this volume) creating Z-folds having a south-trending axial plane with axes plunging south, accompanied by dextral shear sense indicators throughout the belt. This deformation probably increased the curvature of the belt first imposed by the emplacement of the younger pluton. This deformation is more visible in the sediments in the Middle Bay area. The deformation is younger than the surrounding Neoarchean granitoid, and as young as 2712±2 Ma (Stone 1998), but does not seem to affect the nearby Frame Lake pluton (Buse, this volume, Article 21), which has an age of 2696±2 Ma (Corfu and Ayres 1984).

At a larger scale, the belt lithologies seem to undulate asymmetrically, which could be interpreted as large Z folds. This would explain the local rotation in the foliation. The northwestern arm seems to be the dominantly deformed by open east to southeast trending.

Sigmoidal, Z-drag folds, back rotation of boudinaged dikes, dextral shear bands and sinistral kinking indicate a dextral sense of movement in the belt. Locally, small-scale sinistral brittle deformation zones are found and have been interpreted to be part of a late readjustment.

MINERALIZATION AND ALTERATION

The mineralization in the McInnes Lake belt is generally north trending and possibly related to shear zones trending in the same direction. It mostly consists of disseminated and small veins of pyrite; however, chalcopyrite and rare pyrrhotite has been observed. Most of the mineralization is found in intermediate metavolcanic tuff and fine-grained flows of cycle 2. One showing of molybdenite occurs in ultramafic rocks on the east shore near Middle Bay.

Very little alteration was observed. The dominant alteration is veining composed of actinolite-plagioclase-quartz and generally found in the intermediate metavolcanic rocks; however, some veining is also found in the mafic metavolcanic rocks. These veins are no wider than 10 cm and are generally boudinaged. Locally, epidote and garnet were observed, which implies high temperature. In the mafic metavolcanic rocks, weak disseminated calcite is present.

Reports of alteration described in the assessment files are very limited. Our observations also indicate that the belt contains limited alteration. Major shearing associated with Z folding occurs along the length of the belt, but there is very little quartz veining and alteration associated with this deformation.

ACKNOWLEGMENTS

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REFERENCES

Averill, S.A. and Ayres, L.D.1968. Favourable Lake–Poplar Hill area, District of Kenora (Patricia Portion); *in* Summary of Field Work 1968, Ontario Department of Mines, Miscellaneous Paper 22, p.6-10.

Ayres, L.D., Raudsepp, M., Averill, S.A. and Edward, G.R. 1973. Favourable Lake–Berens Lake, Geological compilation series, Kenora District; Ontario Division of Mines, Map 2262, scale 1:253 440.

Cominco Ltd. 1977–1979. Drill logs, electromagnetic survey and airborne magnetic survey; assessment files AFRI# 53C04NE0001, 53C04NE0002, 53C04NE5000, 53C04NE5001, 53C04NE50002, 53C05SW0001, 67p.

Corfu, F. and Ayres, L.D. 1984. U-Pb age and genetic significance of heterogeneous zircon population in rocks from the Favourable Lake area, northwestern Ontario; Contributions to Mineralogy and Petrology, v.88, p.86-101.

Corfu, F., Davis, D.W., Stone, D. and Moore, M.L. 1998. Chrono-stratigraphy constraints on the genesis of Archean greenstone belts, northwestern Superior Province, Ontario, Canada; Precambrian Research, v.92, p.277-295.

Corfu, F. and Stone, D. 1998. Age structure and orogenic significance of the Berens River composite batholiths, western Superior Province; Canadian Journal of Earth Sciences, v.35, p.1089-1109.

Cortis, A.L., Stott, G.M., Osmani, I.A., Atkinson, B. and Thurston, P.C. 1988. A geological re-evaluation of northwestern greenstone belts; *in* Summary of Field Work and Other Activities 1988; Ontario Geological Survey, Miscellaneous Paper 141, p.25-52.

Phelps Dodge Corporation of Canada Limited. 1962. Drill logs; assessment files 53C04NE0005, 53C04NE0009, 53C04NE8143, 31p.

Placer Dome, Inc. 1989–1991. Geophysical surveys; assessment files 53C04NE0004, 53C04NE0008, 137p.

Rogers, N. 2002. Geology, Confederation Lake, Ontario; Geological Survey of Canada, Open File 4265, scale 1:50 000.

Stone, D. 1998. Precambrian geology of the Berens River area, northwest Ontario; Ontario Geological Survey, Open File Report 5963, 116p.

Stone, D., Atkinson, B., Crawford, J. and Halstead, J. 1993. Precambrian geology, Critchell Lake area; Ontario Geological Survey, Preliminary Map P.3219, scale 1:50 000.

Stone, D. and Crawford, J. 1993. Precambrian geology, McInnes Lake area; Ontario Geological Survey, Preliminary Map P.3217, scale 1:50 000.

Stott, G.M. and Corfu, F. 1991. Uchi Subprovince; *in* Geology of Ontario, Ontario Geological Survey; Special Volume 4, Part 1, p.81-144.

24. Project Unit 06-006. Bedrock Geology Map Compilation: Far North Geological Mapping Initiative

Z.B. Madon[1] and M.A. Puumala[2]

[1]Precambrian Geoscience Section, Ontario Geological Survey
[2]Resident Geologist Program, Ontario Geological Survey

INTRODUCTION

A 1:250 000 bedrock geological compilation is being completed for select portions of northern Ontario as part of the Far North Geological Mapping Initiative (FNGMI). The objective of the project is to research and assemble the most recent geoscience information for these areas so that new exploration targets can be generated for the mining community and a reliable and current bedrock geology theme can be produced for land use planning purposes. The new compilation maps will illustrate our most recent interpretation of the regional geology and include an updated reference to all the mineral deposits in the area.

These maps will incorporate existing 1:250 000 (Ontario Geological Survey 2003) and 1:1 000 000 (Ontario Geological Survey 1991a, 1991b) scale geological compilations with recent published bedrock maps and tectonic interpretations as well as all current geological compilations from mineral assessment files. The new interpretations will make use of the latest airborne geophysical surveys in the area to confirm the known geological interpretation and extend it into unmapped areas or with extensive overburden cover. Available satellite imagery and the digital elevation model for the area will be used in conjunction with the geology and geophysics to delineate all major structural features.

SELECTION OF MAP AREAS

The following areas were chosen for compilation during the FNGMI (Figure 24.1). They include

Planned Release	NTS Sheet	Area	Greenstone Belts
2007	42M	Fort Hope	Miminiska–Fort Hope
2007	52P	Miminiska Lake	Miminiska–Fort Hope; Pickle Lake; Lake St. Joseph
2008	52O	Lake St. Joseph	Pickle Lake; Meen–Dempster; Lake St. Joseph; Lang Lake
2008	53C	North Spirit Lake	North Spirit Lake; Favourable Lake; McInnes Lake; Hornby Lake; Sandy Lake
2008	43E	Winiskisis Channel	Kasabonika; Asheweig River
2008	53H	Asheweig River	Kasabonika; Asheweig River; Big Trout Lake–Swan Lake

Summary of Field Work and Other Activities 2006,
Ontario Geological Survey, Open File Report 6192, p.24-1 to 24-9.

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The map tiles planned for year 2 might be subject to some modification.

Some of the criteria for choosing these areas include

1. the areas should have high mineral potential (multiple commodities) and be a frontier area
2. the areas must be of current exploration interest
3. the areas should have readily available, relevant and recent geoscience data
4. the areas should be within the boundaries of the Northern Boreal Initiative (NBI) and/or should encompass areas where new data will be collected under the FNGMI
5. the areas do not encompass any major parks

Gap analysis workshops, organized by the Ontario Geological Survey (OGS), were held in the fall of 2005 in both Red Lake and Thunder Bay. The goal was to identify and prioritize the geoscience gaps and needs for the Far North. Industry representatives were encouraged to attend the meetings, or failing that, were encouraged to write or email the OGS with their geoscience priorities.

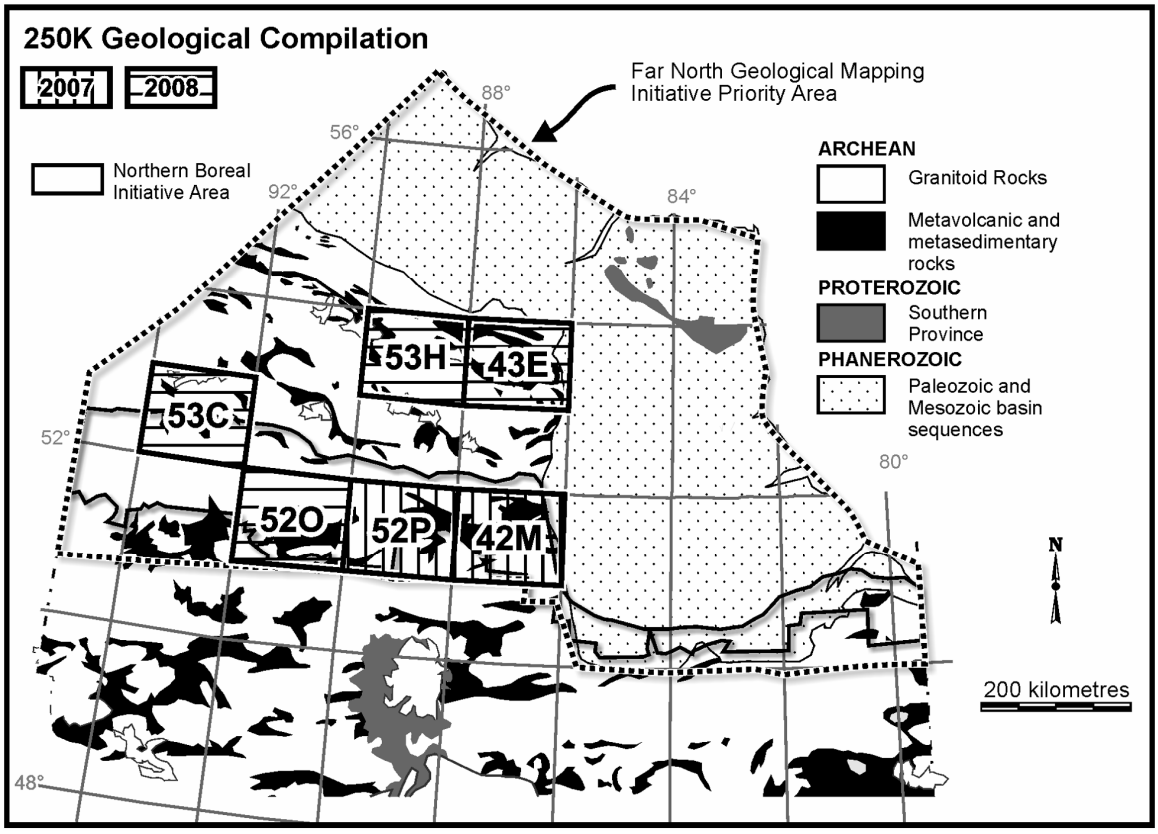

Figure 24.1. Location of the planned 1:250 000 geological compilation tiles for the Far North Geological Mapping Initiative (FNGMI).

MAP COMPILATION PROCESS

The map compilation process borrows heavily from previous OGS compilation products of similar scale, including the Operation Treasure Hunt (OTH) bedrock map compilation series (Santaguida 2000; Johns, McIlraith and Muir 2003), the Abitibi bedrock map compilation series (Ayer et al. 2005), the Northwest Superior area (Stone 2005) as well as earlier 1 inch to 4 mile geological compilation maps (2000 series), published between the mid-1960s and the mid-1970s. Similar scale maps from other geological surveys were also examined for comparison purposes.

A schematic summary of the entire process, modified after the OTH compilation project (Santaguida 2000), is illustrated in Figure 24.2. The one major difference between the FNGMI compilation and previous bedrock compilations is that these new maps will be released in both paper and digital format. Moreover, an attempt will be made to complete the entire process in a digital environment, including on-screen digitization of all geological contacts, faults and folds as well as the generation of lithological polygons. Nonetheless, paper proofs will still need to be plotted for review, cartographic and editing purposes.

Because of the extensive preparation and consultation that went into the design of the OTH map compilation series, the FNGMI used that map template as a starting point (Figure 24.3). An example of the OTH maps was distributed to all Resident Geologist offices and comments were solicited from our clients regarding the map design and content. Feedback from our clients indicated that very little needed to be changed with respect to map design. As such, the FNGMI bedrock geology compilation series will be essentially identical to the OTH map design.

The map tiles will be published at a 1:250 000 scale and will be defined by existing National Topographic System (NTS) boundaries (1 degree latitude by 2 degree longitude quadrangles). The map projection will be Universal Transverse Mercator (UTM), using the North American 1983 Datum (NAD83). This is in line with the current transition of both federal and provincial geomatics services to the more accurate representation of the Earth's surface using the NAD83 datum as opposed to the earlier NAD27 datum. Digital base data for the FNGMI areas is derived primarily from the federal government's 1:50 000 planimetric series for the Precambrian Shield area and 1:250 000 planimetric series for the James Bay Lowland area. The provincial government's 1:20 000 Ontario Digital Topographic Database planimetric series does not generally extend into the FNGMI area of interest.

In order to produce a common lithological legend for all FNGMI bedrock maps, an extensive review of all previous bedrock compilations was completed. All legends were correlated to the Geology of Ontario 1:1 000 000 master legend. Any disparities with Geology of Ontario were highlighted by the author and reviewed and resolved with the scientific lead for the FNGMI. In general, it was determined that the Geology of Ontario legend (Ontario Geological Survey 1991b) was detailed enough to use as the common lithological legend for all FNGMI bedrock compilation maps. Using the Geology of Ontario legend also provides some level of consistency with previous geological compilations.

The map compilation process is being greatly facilitated by the recent development of the Geology Ontario Web portal (www.ontario.ca/geology: Berdusco and Madon, this volume), designed to allow for the discovery and delivery over the Internet of the entire MNDM publication archive, including digital data releases as well as all the archived mineral assessment files (AFRI). Both publication and assessment archives were converted to PDF files, a popular portable document format developed by Adobe Systems®. Published maps and pertinent assessment files for the map area were quickly tabulated using the Geology Ontario search tools and efficiently downloaded from the Web portal. These digital image files were then georeferenced to the master planimetric base in preparation for the geological interpretation process. Any recent maps not yet archived into AFRI were scanned using the OGS map scanner and then georeferenced to the master planimetric base.

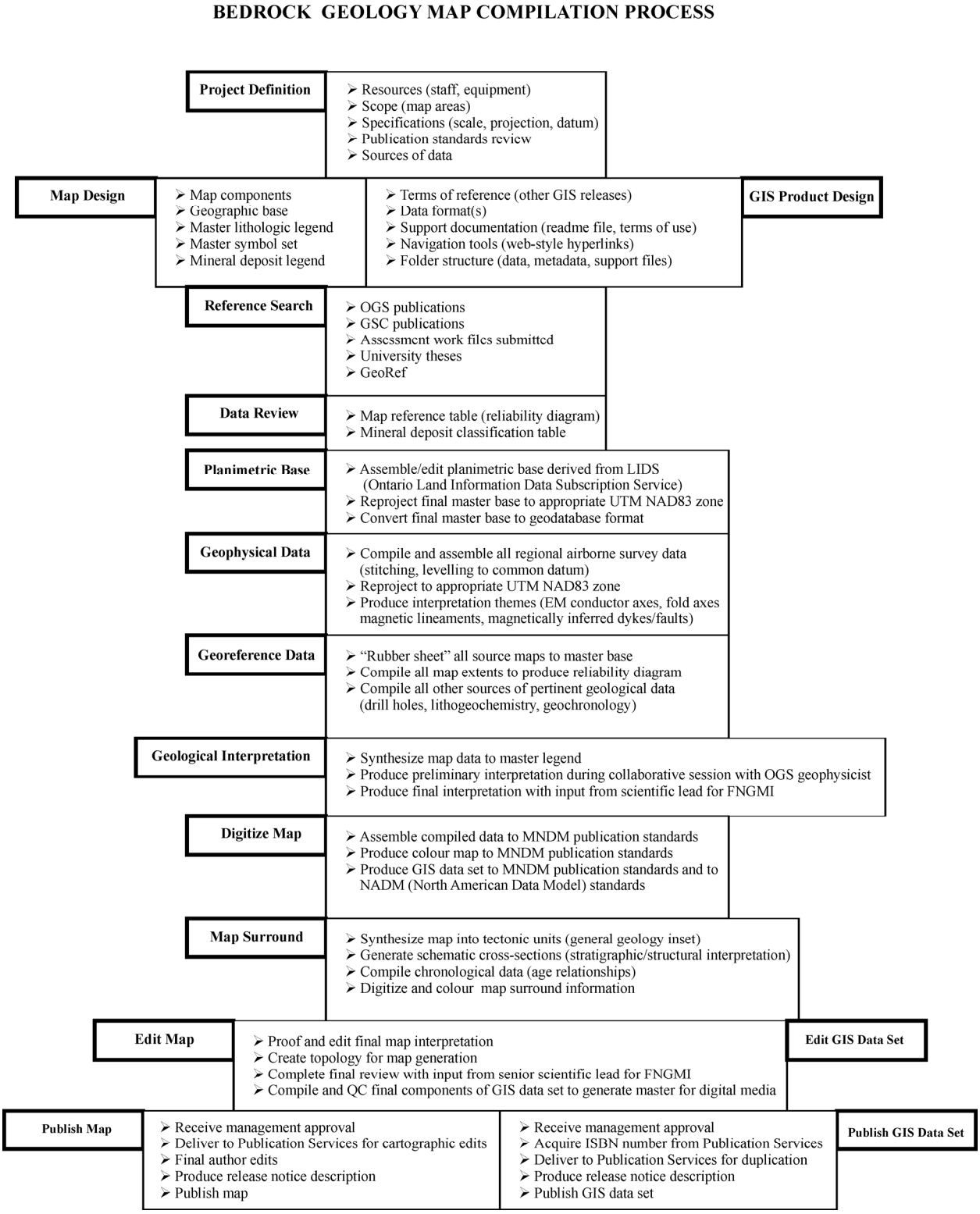

Figure 24.2. Schematic workflow of the FNGMI map compilation process.

MAP COMPILATION PRODUCTS

Paper Maps

Figure 24.3 illustrates a typical outline for one of the geological compilation sheets published during the Operation Treasure Hunt initiative, between 2001 and 2003. The FNGMI geological compilation will, for the most part, follow the same design layout. Each sheet will contain the following components: 1) a map face, 2) legend and symbols, 3) mineral deposits, 4) reliability map, 5) references, 6) aeromagnetic image, 7) stratigraphy, and 8) regional geology. Where necessary, cross-sections and more detailed inset maps will be included.

The map face will portray lithology, regional structures, stratigraphic interpretation if known (younging direction), and the distribution of mineral deposits. The planimetric base will illustrate selected geographic information such as drainage, roads and trails, townships or areas, park boundaries and Indian reserves as well as a UTM grid and appropriate annotation for all major lakes, rivers and place names. Each map sheet is published individually, although adjacent map sheets will have seamless joins resulting from the use of a common lithological legend.

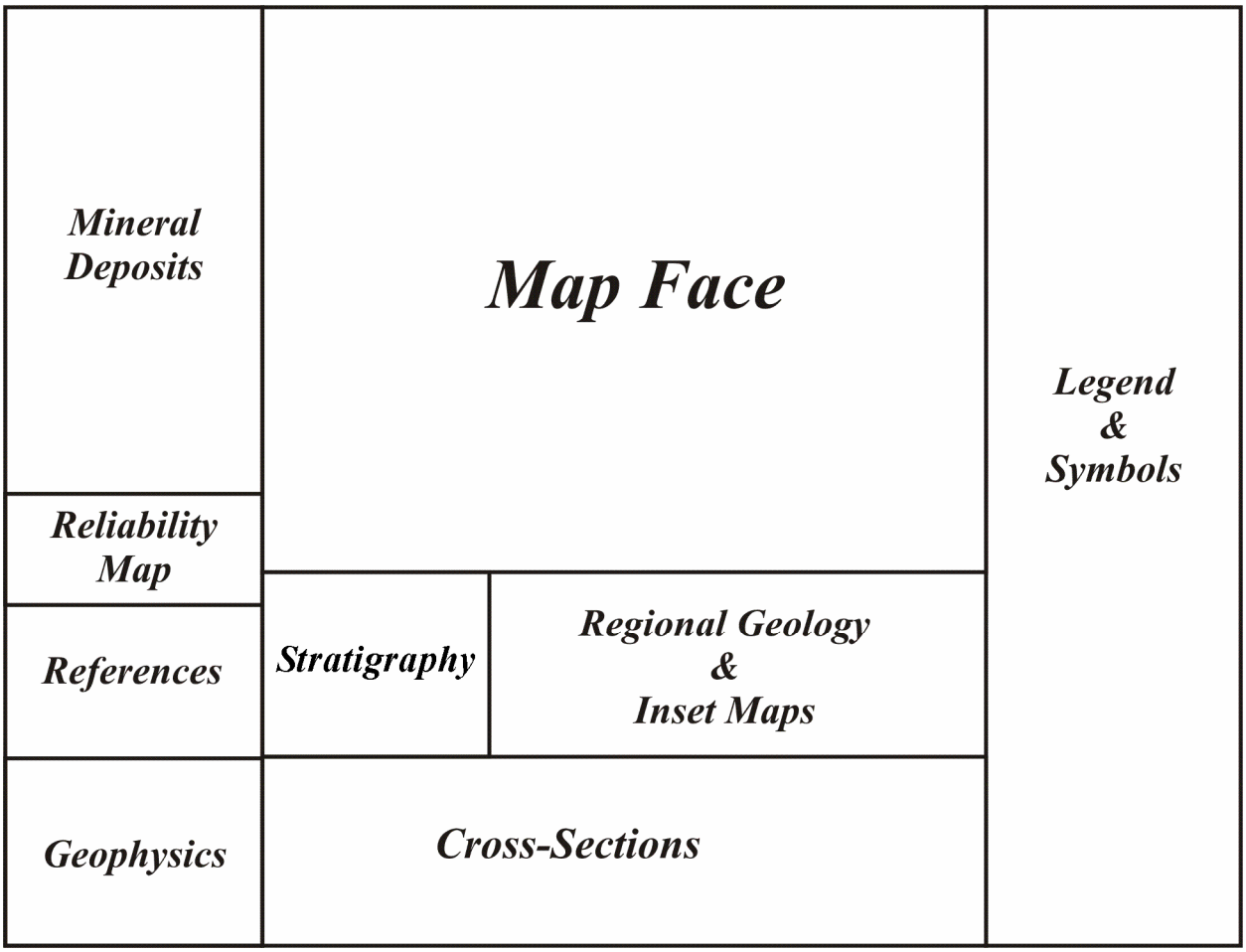

Figure 24.3. Template of the planned paper map layout.

The legend is organized in the standard OGS format with lithological units represented as numbers. As much as possible, the numbers will correlate with the Geology of Ontario legend numbers so that gaps in the numbering system may appear on an individual map sheet. Although it is a lithological legend, the Geology of Ontario numbering system generally follows a stratigraphic younging with increasing value. Within the Archean though, increasing numbers correspond to the evolution of volcanic sequences from primitive to evolved metavolcanic rocks to sedimentary sequences and finally to plutonic rocks, many of which are synvolcanic intrusions. Where possible, age ranges for a particular rock unit are given in the legend. The symbols used for geologic boundaries, structure and stratigraphy follow existing OGS standards (Jackson, Muir and Romkey 1995; Muir, Watkins and Berdusco 2000).

Mineral deposit information is derived initially from the Ontario Mineral Deposit Inventory (MDI2 – October 2004 Release) database and supplemented with recent occurrences from Resident Geologist *Report of Activities* and current assessment file submissions (Puumala and Madon, this volume). The status of each mineral occurrence is ranked in order of importance, from "producing mine" down to "discretionary occurrence". Other information related to each occurrence, such as location, commodities, deposit type, host geology, mineralization, alteration and structure tends to decrease in volume and quality with decreasing rank. As such, information for discretionary occurrences will be included only if they can be adequately verified by the compilation geologist. All significant occurrences represented on the maps will follow a metallogenic classification scheme that has been successfully used in recent OGS bedrock compilations (Ayer, Berger and Trowell 1998; Ayer and Trowell 1999) as well as a national mineral deposit synthesis (Sinclair 1994). The classification scheme is relatively simple and easily accommodates most deposits, with the exception of industrial minerals and building stone. Where sufficient information is available, deposits will also be classified according to morphology. Morphological classification systems are currently employed in a number of jurisdictions, including Quebec, South Africa and Finland, and provide information regarding the relationship of deposits to regional stratigraphic and/or structural features. The proposed morphological classification system will differentiate between stratiform/vein, stockwork and disseminated/irregular deposits.

The reliability map will simply outline the location, extent and scale of the source geological maps used in this compilation. It gives the reader a clear indication of where the geology is based on solid bedrock information and where it is based on interpretation. Similarly, references will give readers access to all the source documentation used in the compilation. For the digital geographic information system (GIS) data set, all these source maps will be provided as georeferenced image files that can be brought up and easily compared to the final interpretation.

The aeromagnetic map will contain the main geological contacts from the map face, illustrating the geophysical signature of the major contacts and rock types as well as their continuity in areas of thick overburden. The geophysical image is derived from regional and detailed OGS and Geological Survey of Canada (GSC) airborne surveys. Most of the compilation areas contain recently flown or acquired high quality airborne surveys (Fort Hope, Pickle Lake, Vickers, Bamaji–Fry lakes, Birch–Confederation lakes, North Spirit Lake, Attawapiskat), which will provide valuable information in producing a new geological interpretation.

A regional geology overview map will illustrate the main subprovince boundaries for the map area. Inset maps, stratigraphic correlations and cross-sections will be provided where the information is available in the literature and where they can provide an interpretation of known mineralization to guide new exploration. Each schematic will be located on the main map face. Age relationships between greenstone belts will also be shown where geochronological data are available.

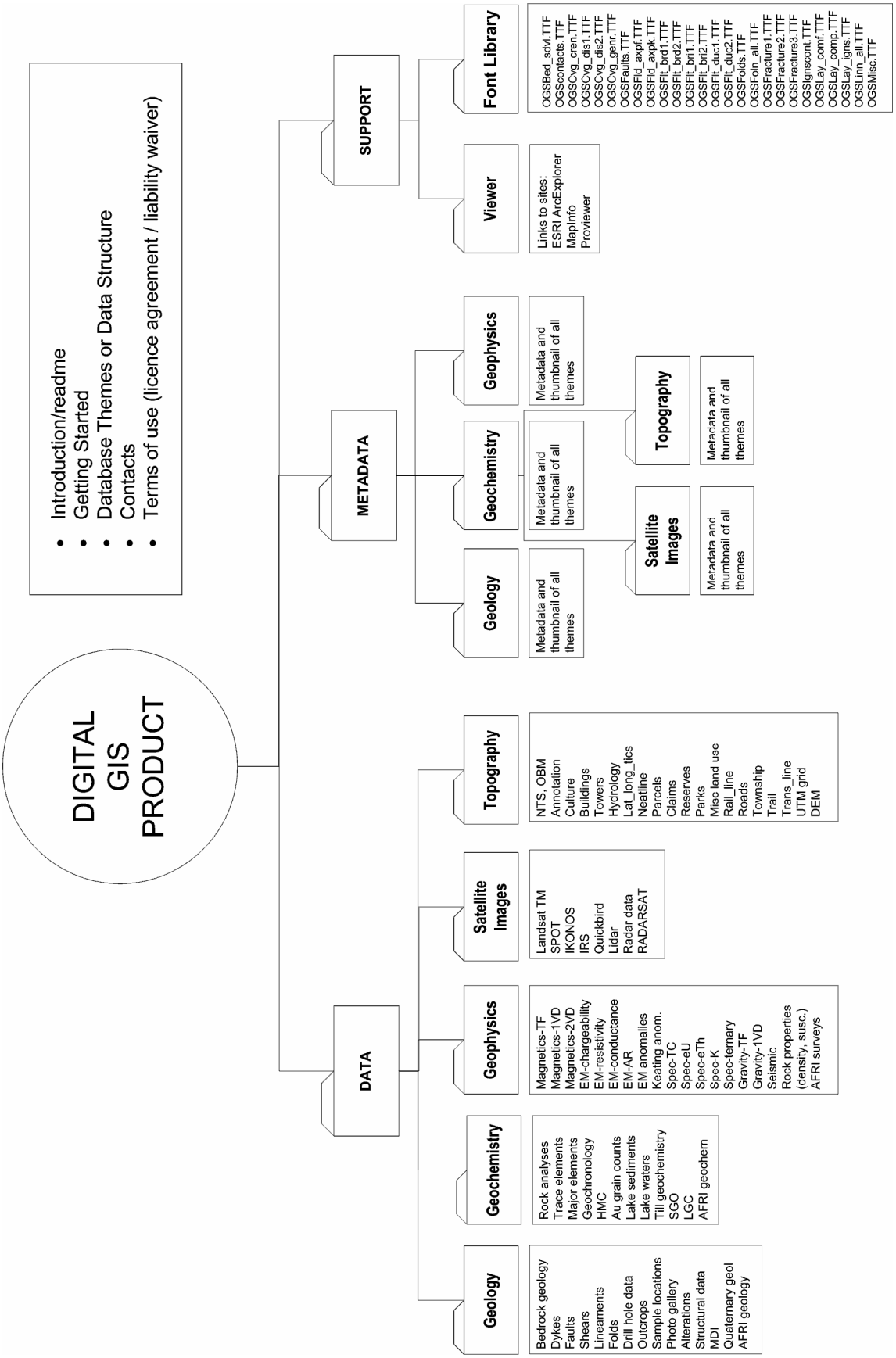

Figure 24.4. Schematic illustration of the GIS data set structure.

Geographic Information System Data Set

Because the publication standards for the release of digital GIS data sets are not yet rigorously established within the OGS, a sampling of previously released GIS data sets from various federal and provincial geological surveys was examined, including GIS data sets published by the OGS (Ayer et al. 2003; Lemkow et al. 2005; Panagapko et al. 2000, 2002). In general, the information contained within these data sets is similar. The greatest variability occurs with data formats used and how the data is structured. The FNGMI data are being compiled using ESRI® software and will be distributed in that format – a format that is one of the most widely used by geological surveys around the world and that is the GIS standard for the Ontario government.

Figure 24.4 is a schematic illustration of how the FNGMI data will be structured. The root directory will contain a hypertext markup language (html)-based startup file, similar to Web pages with hyperlinks, which can be used to help clients understand the data structure and to navigate through the various geological themes provided. The root directory will also have the necessary documentation related to the GIS data release, including an introduction or "readme" file with brief instructions on how to view and use the data, contact information, citations, and the standard Terms of Use agreement (i.e., licence and liability waiver).

The "DATA" folder will contain all the pertinent geoscientific information accumulated in producing the geological map. It will be subdivided into the following subfolders: Geology, Geochemistry, Geophysics, Satellite Images and Topography. Examples of the type of information stored in each subfolder are listed in Figure 24.4, though not all of these will be necessarily available for each publication release. Attribution of the geological map will be structured according to the North American Data Model (NADM), a concerted effort between federal, state and provincial surveys to produce a well-structured, interoperable spatial database (North American Geologic Map Data Model Steering Committee 2004).

The "METADATA" folder will contain information about the data. Metadata is defined as structured, encoded data describing the characteristics of information-bearing entities so that an individual could identify, discover, assess and manage that information. As with the "DATA" folder, the "METADATA" folder will be similarly subdivided in subfolders as illustrated. Metadata will be populated using the ESRI® metadata tool and will provide clients with the following information about each data theme: thumbnail preview of all spatial data sets, general description (i.e., keywords, abstract, purpose, status, time period, publication information, data storage and access), spatial information (co-ordinate system, bounding co-ordinates, lineage, geoprocessing history) and attribute information (object type, number of records, number of fields, field descriptions including alias, data type and field width).

Finally, the "SUPPORT" folder will contain all the necessary files for properly viewing and querying the data. This would include at least the following subfolders: a "Viewer" subfolder with free viewing software or links to download these free viewers from the software vendors and a "Font Library" folder containing all the OGS-developed font files (in TrueType® font (*.ttf*) format) for displaying structural point features (bedding, foliations, lineations, etc.) and OGS style files for displaying line features (contacts, folds, faults, etc.).

REFERENCES

Ayer, J.A., Berger, B.R., Hall, L.A.F., Houlé, M.G., Johns, G.W., Josey, S., Madon, Z., Rainsford, D., Trowell, N.F. and Vaillancourt, C. 2005. Geological compilation of the central Abitibi greenstone belt: Kapuskasing structural zone to the Québec border; Ontario Geological Survey, Preliminary Map P.3565, scale 1:250 000.

Ayer, J.A., Berger, B.R. and Trowell, N.F. 1998. Geological compilation of the Lake Abitibi area, Abitibi greenstone belt: Ontario Geological Survey, Preliminary Map P.3398, scale 1:100 000.

Ayer, J.A. and Trowell, N.F. 1999. Geological compilation of the Timmins area, Abitibi greenstone belt; Ontario Geological Survey, Preliminary Map P.3379, scale 1:100 000.

Ayer, J.A., Trowell, N.F., Josey, S., Nevills, M., Valade, L., and Madon, Z., 2003. Geological compilation of the Matachewan area, Abitibi greenstone belt; Ontario Geological Survey, Miscellaneous Release—Data 94.

Jackson, S.L., Muir, T.L. and Romkey, S.W. 1995. A library of digital bedrock mapping symbols. Part 1: digital files, figures and descriptions; Ontario Geological Survey, Open File Report 5909, 56p.

Johns, G.W., McIlraith, S.J. and Muir, T.L. 2003. Bedrock geology compilation map—Sault Ste. Marie–Blind River sheet; Ontario Geological Survey, Map 2670, scale 1:250 000.

Lemkow, D.R., Sanborn-Barrie, M., Stott, G.M., Percival, J.A., Stone, D., Tomlinson, K.Y., Skulski, T., McNicoll, V., Davis, D.W., Whalen, J.B. and Hollings, P. 2005. GIS compilation of the geology and tectonostratigraphic assemblages, Wabigoon–Winnipeg River–Marmion transect, western Superior Province, Ontario; Geological Survey of Canada, Open File 4971; Ontario Geological Survey Miscellaneous Release—Data 187, scale 1:250 000. 1 CD-ROM.

Muir, T., Watkins, T.W. and Berdusco, B.J. 2000. A library of digital line standards; Ontario Geological Survey, Open File Report 6026, 208p.

North American Geologic Map Data Model Steering Committee, 2004. NADM Conceptual Model 1.0: a conceptual model for geological map information; Geological Survey of Canada, Open File 4737, 1 CD-ROM. *also* United States Geological Survey, Open-file Report 2004-1334, 58p.

Ontario Geological Survey 1991a. Geology of Ontario; Ontario Geological Survey, Special Volume 4, Map and Charts, scale 1:1 000 000.

——— 1991b. Bedrock geology of Ontario, explanatory notes and legend; Ontario Geological Survey, Map 2545.

——— 2003. 1:250 000-scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126.

——— 2004. Mineral Deposit Inventory Version 2 (MDI2), October 2004 Release; Ontario Geological Survey.

Panagapko, D.A., Harris, J.R., Valade, L. and Ayer, J.A. 2002. Regional GIS database for the Abitibi greenstone belt, Ontario; Ontario Geological Survey, Miscellaneous Release—Data 99.

Panagapko, D.A., Valade, L., Harris, J.R. and Brown, N. 2000. Preliminary release of geoscience data: Red Lake greenstone belt, northwestern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 62.

Santaguida, F. 2000. Bedrock map compilation, northwestern Ontario: Operation Treasure Hunt; *in* Summary of Field Work and Other Activities 2000, Ontario Geological Survey, Open File Report 6032, p.42-1 to 4-12.

Sinclair, W.D. 1994. Mineral deposits of Canada; Geological Survey of Canada, Open File 2874, scale 1:6 000 000.

Stone, D. 2005. Precambrian geology, northern Superior area; Ontario Geological Survey, Preliminary Map P.3545, scale 1:250 000.

25. Project Unit 06-006. A Progress Report on the Far North Mineral Deposit Compilation

M.A. Puumala[1] and Z.B. Madon[2]

[1]Resident Geologist Program, Ontario Geological Survey
[2]Precambrian Geoscience Section, Ontario Geological Survey

INTRODUCTION

One of the goals of the Far North Geological Mapping Initiative (FNGMI) is to obtain a better understanding of the geology and mineral resource potential of the Far North. The Far North Mineral Deposit Compilation project, which started in June 2006, is a key component of this initiative. The mineral deposit information that is collected through this project, when integrated with new FNGMI mapping and surveys (Madon and Puumala, this volume) is expected to provide valuable information to assist mineral resource development and land use planning in the Far North.

The region covered by this project is generally located north of 51° latitude, encompasses portions of the Red Lake, Thunder Bay North and Timmins Resident Geologist districts, and includes the entire area covered by the Ministry of Natural Resources' Northern Boreal Initiative (Figure 25.1). The project involves the compilation of all relevant, publicly available, geological information regarding mineral occurrences in the FNGMI area. Sources of information include

- assessment files
- the Mineral Deposit Inventory (MDI) database
- government geological reports/maps
- scientific papers
- unpublished university theses; and
- unpublished data in the files of the Resident Geologists' Offices (i.e., mineral deposit files).

The archived information will be supplemented by data collected in the field by the author and other Ontario Geological Survey (OGS) staff.

This compiled and collected information will be used to classify mineral deposits and occurrences according to metallogeny, morphology and size. Metallogenic classifications will be based upon those used on recent OGS compilation maps (e.g., Ayer, Berger and Trowell 1999), while deposit or occurrence size will continue to be based upon the existing MDI classification system (i.e., occurrences, prospects, mines). Discretionary occurrences listed in MDI will only be included in the compilation where data can be verified and the information is of significant value for geological interpretation. Where sufficient information is available, deposits will also be classified according to morphology. Morphological classification systems are currently employed in a number of jurisdictions, including Quebec, South Africa and Finland, and provide information regarding the relationship of deposits to regional stratigraphic and/or structural features (e.g., stratiform/vein, stockwork and disseminated/irregular deposits).

Summary of Field Work and Other Activities 2006,
Ontario Geological Survey, Open File Report 6192, p.25-1 to 25-8.

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Current mineral deposit compilation activities are being concentrated on the 1:250 000 scale compilation map areas of Madon and Puumala (this volume). Future work areas will be prioritized based on the scheduling of geological compilation and bedrock map releases, in consultation with Resident Geologist Program field staff.

Upon completion of the project, an Open File Report will be published. This report will include geological data summaries for individual deposits or occurrences, and will provide interpretation of the observed metallogenic patterns relative to the regional tectonic framework.

PRELIMINARY RESULTS – NTS 42M AND 52P MAP AREAS

To date, compilation efforts have been focussed on the NTS 42M and 52P 1:250 000 scale geological compilation areas of Madon and Puumala (this volume). These map areas are underlain by Archean rocks of the Uchi and English River subprovinces. The main area of interest for economic mineral deposits is the Miminiska–Fort Hope greenstone belt. Portions of these map areas have been mapped by Prest (1939, 1944a, 1944b), Thurston and Carter (1970), Wallace (1978, 1981a, 1981b) and Hall (2005). The Miminiska–Fort Hope greenstone belt was also included in the mineral deposit compilation of Mason and White (1995).

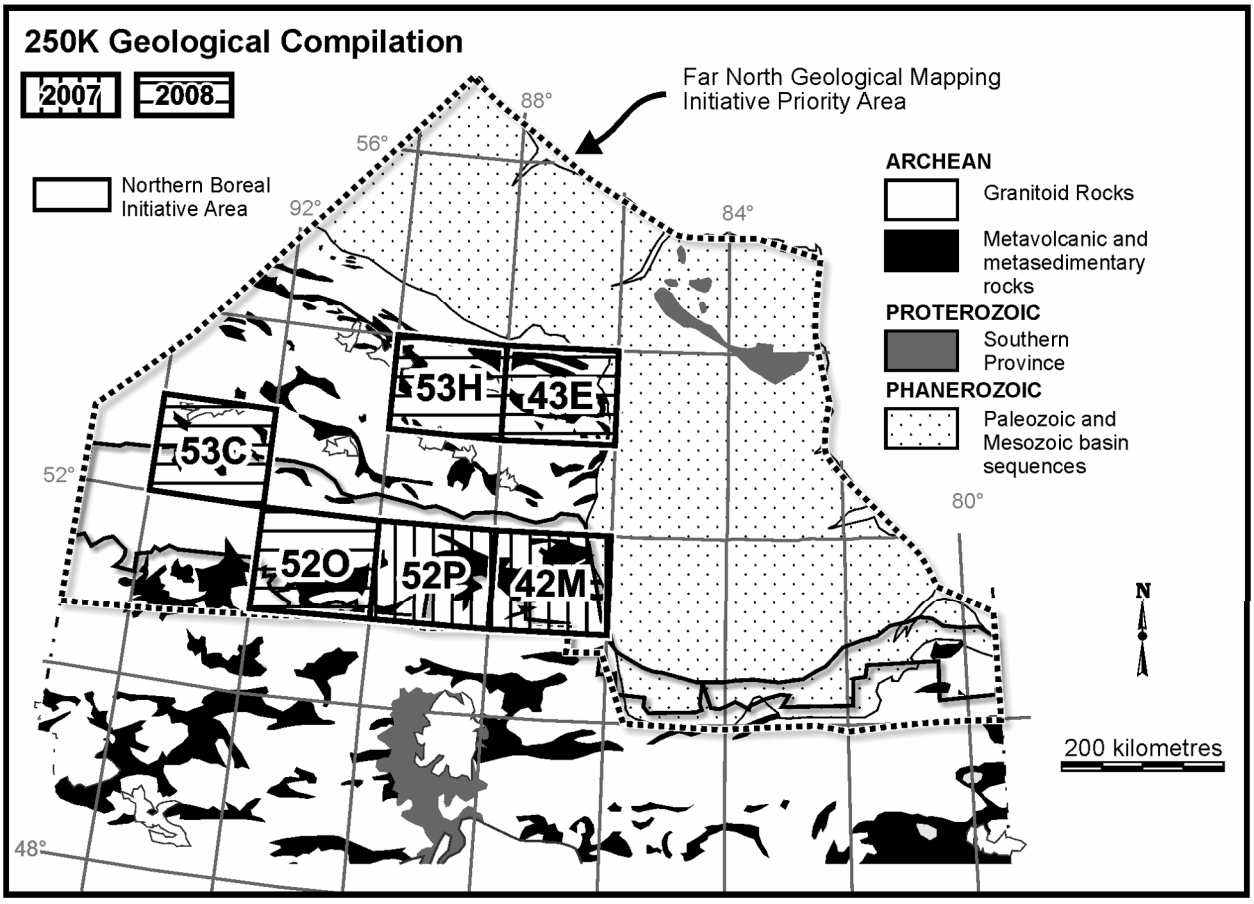

Figure 25.1. Location of the FNGMI area. Priority areas for the completion of mineral deposit compilations correspond with the 2007 and 2008 1:250 000 compilation map areas of Madon and Puumala (this volume).

Table 25.1. List of mineral occurrences and prospects not previously tecorded in MDI.

Occurrence Name	UTM (NAD83, Zone 16)		Status	Principal Commodities
	Easting (m)	Northing (m)		
Asarco Sample No. 6	483125	5692760	Occurrence	Copper
Baroque-Felmont	382225	5719500	Occurrence	Gold
Baroque Grid 12B	383600	5720275	Prospect	Gold
GSC Map 56-1963	461300	5676240	Occurrence	Copper
Lilypad Lakes F-anomaly	412328	5722475	Occurrence	Tantalum, cesium, lithium, rubidium
Lilypad Lakes JJ Dikes	410200	5721475	Occurrence	Tantalum, cesium, lithium, rubidium
Lilypad Lakes Pollucite Dike	411620	5722775	Prospect	Tantalum, cesium, lithium, rubidium
Lilypad Lakes Rubellite Dike	414100	5722605	Prospect	Tantalum, cesium, lithium, rubidium
Lilypad Lakes South Dike	413220	5721590	Prospect	Tantalum, cesium, lithium, rubidium
Luella Lake	375600	5673800	Occurrence	Copper, nickel
M-6	385400	5714900	Occurrence	Gold
MC79-10	378815	5717095	Occurrence	Gold
Miminiska Lake Au	394910	5715720	Prospect	Gold
Miminiska Lake Fe East	390750	5718350	Occurrence	Iron
Miminiska Lake Fe West	394500	5716650	Occurrence	Iron
MW80-13	388900	5722250	Occurrence	Gold
OL-87-17	422600	5719275	Occurrence	Gold
OL-87-18	423800	5719675	Occurrence	Gold
Rond Lake	429100	5718975	Occurrence	Gold
S04-01	383224	5720653	Occurrence	Gold
S04-08	398860	5735015	Occurrence	Gold
S04-09	399050	5735560	Occurrence	Gold
S04-12	395680	5737022	Occurrence	Gold
Sim Lake	416900	5659700	Occurrence	Copper, nickel
SL87-04	402500	5719100	Occurrence	Gold
WSaspy1	403820	5718160	Occurrence	Gold
Zone 41	428050	5719325	Prospect	Gold
Zone 41 Extension	428425	5719225	Occurrence	Gold

Prior to commencement of this project, a total of 70 MDI mineral occurrences and prospects had been recorded in these NTS blocks. The area has no history of economic mineral production. The relatively small number of economic mineral occurrences recorded in these areas is considered to be related to the lack of road access and the relative scarcity of outcrops, especially in the eastern portions of the NTS 42M area, which is located at the western edge of the James Bay Lowland. The principal commodities reported for the MDI occurrences and/or prospects include gold (40 occurrences), copper (17), iron (9), antimony (1), cobalt (1), lithium (1), and sulphur (1). Mineral deposit compilation activities carried out since June 2006 have documented an additional 28 occurrences and/or prospects in the NTS 42M and 52P map areas that were not previously recorded in MDI. As listed in Table 25.1, the principal reported commodities for these occurrences include gold (17), iron (2), copper (3), tantalum (5) and nickel (1).

A wide range of mineralization types have been identified in this area, including vein or replacement gold, mafic to ultramafic intrusion-hosted copper-nickel-platinum group elements (PGE), rare-element-bearing pegmatites, volcanogenic massive sulphide copper-zinc, and Algoma-type banded iron formation. Some gold and copper occurrences also appear to have characteristics consistent with alkalic or calc-alkalic porphyry-type mineralization.

Table 25.2. Summary of mineral occurrences and prospects referenced in this document.

Occurrence Name	UTM (NAD83, Zone 16)		Status	Principal Commodities
	Easting (m)	Northing (m)		
Boylen	413100	5697475	Occurrence	Copper, zinc
Gould Lake	367708	5672540	Occurrence	Copper, nickel
KL-12	398690	5736330	Prospect	Gold
KL-27	401290	5738140	Prospect	Gold
KL-31	397305	5738750	Occurrence	Gold
KL-35	394855	5735670	Occurrence	Gold
Leitch	364250	5671085	Occurrence	Copper, nickel
Lilypad Lakes	411620	5722775	Prospect	Tantalum, cesium, lithium, rubidium
Luella Lake	375600	5673800	Occurrence	Copper, nickel
Miminiska Lake	394910	5715720	Prospect	Gold
NBK	394125	5737570	Occurrence	Gold
Norton Lake	470912	5750083	Prospect	Nickel, copper
OL-12	427600	5719275	Prospect	Gold
OL-29	426900	5719375	Prospect	Gold
Reserve Creek	448950	5714305	Prospect	Gold, tungsten, copper
S04-12	395680	5737022	Occurrence	Gold
Sim Lake	416900	5659700	Occurrence	Copper, nickel
Weese Lake	385525	5683390	Occurrence	Copper, nickel
Zulapa	444645	5712843	Prospect	Gold, copper, zinc, lead

Preliminary evaluation of the stratigraphic and structural information in the mineral deposit compilation data may provide some ideas regarding the metallogeny of the Miminiska–Fort Hope greenstone belt. Characteristics of specific deposits (Table 25.2) that may provide guidance for future base metal and gold exploration efforts are discussed below.

Copper-Nickel-Platinum Group Element Mineralization

The Norton Lake prospect is a mafic to ultramafic intrusion-hosted copper-nickel-PGE deposit located in a mafic metavolcanic rock-dominated supracrustal assemblage interpreted by Stott and Corfu (1991) to be stratigraphically equivalent to the Northern Pickle assemblage of the Pickle Lake greenstone belt. A measured and indicated Mineral Resource of 2 258 654 tonnes grading 0.67% Ni, 0.61% Cu, 0.03% Co and 0.46 g/t Pd has been reported at Norton Lake by East West Resource Corporation in their 2006 Annual Report. Johnson (2005) has noted similarities in the mineralization histories and geological settings of the Norton Lake and Thierry deposits and suggests that the host rocks for both deposits are geochemically and stratigraphically similar. Copper-nickel-PGE mineralization at both locations is also hypothesized to have occurred as the result of sulphur saturation of ultramafic magma following assimilation of previously existing iron formation.

The existence of several banded iron formation units within mafic metavolcanic rock-dominated sequences throughout the Miminiska–Fort Hope greenstone belt, suggests that the potential exists for the discovery of other copper-nickel-PGE deposits similar to those at Norton Lake and Thierry. Notably, a diamond-drill hole log (Oja 1961) in the assessment files for the Lelievre iron occurrence reported the occurrence of gabbro containing assimilated iron formation.

Numerous occurrences of mafic intrusion-hosted copper-nickel-PGE mineralization have also been documented at a number of locations near the southern margins of the Miminiska–Fort Hope greenstone belt. These include a number of anorthosite-hosted occurrences between Shabuskwia and Weese Lakes (e.g., Luella Lake, Gould Lake, Leitch and Weese Lake) along the margins of the Shabuskwia Lake Batholith, and at Sim Lake. These occurrences are distinct from the Norton Lake deposit, in that they are situated within the transition zone between the Uchi and English River subprovinces, and are likely to be hosted by late-tectonic intrusions (i.e., the Norton Lake deposit is hosted by an older synvolcanic intrusion). Similar mineralization has been noted in mafic intrusions located along the margins of batholiths in the Quetico Subprovince (Rogers et al. 1995). Therefore, mafic intrusions that occur within the transition zone between the Uchi and English River subprovinces are considered to have the potential to host copper-nickel-PGE mineralization.

Volcanogenic Massive Sulphide Mineralization

Occurrences of volcanogenic massive sulphide (VMS) copper-zinc mineralization (e.g., Boylen occurrence) in the Miminiska–Fort Hope greenstone belt are confined to a relatively narrow belt of metavolcanic rocks between Auger and Kawitos lakes that is bounded to the north, south and east by felsic intrusions. The VMS mineralization is associated with felsic fragmental rock units.

The rocks that host the Boylen occurrence have been classified by Stott and Corfu (1991) as being part of the St. Joseph assemblage, which is considerably younger than 2750 Ma. Since all known economic VMS deposits in the Superior Province are younger than 2750 Ma, it is possible that a significant deposit of VMS mineralization could be found within the St. Joseph assemblage.

Gold Mineralization

The majority of mineral occurrences in the Miminiska–Fort Hope greenstone belt are gold occurrences. They largely occur in a number of "clusters," with the most significant located in the following areas:

- near Keezhik Lake
- between Miminiska and Goss Lakes
- southeast of Opikeigen Lake
- near the eastern boundary of the Eabametoong First Nation Reserve
- in the vicinity of Howells Lake

Available information suggests that the majority of the gold occurrences can be classified as hydrothermal lode gold-type deposits within or in proximity to brittle and/or ductile deformation zones (Rogers et al. 1995). However, the gold occurrences located near the eastern boundary of the Eabametoong First Nation Reserve (Zulapa and Reserve Creek) exhibit characteristics that suggest a possible genetic relationship to porphyry intrusions. Characteristics of these occurrences consistent with the alkalic porphyry deposit type described by Rogers et al. (1995) include the following:

- Local gold mineralization is reported to be associated with chalcopyrite, scheelite, magnetite, pyrite, pyrrhotite, as well as biotite alteration.
- Molybdenite has been reported in the area south of Reserve Creek.
- The occurrences are located in close proximity to, or are hosted within, felsic intrusions.

Although there are a variety of styles of mineralization and host rocks (i.e., metavolcanic rocks, intrusive rocks, banded iron formation and clastic metasediments) at the various occurrences, it is interesting to note that, with the exception of the occurrences in the Keezhik Lake area, all are located in close proximity to northeast-striking faults mapped by Hall (2005), Wallace (1981b) and Thurston and Carter (1970). It is possible that these faults played a significant role in the gold mineralization event(s), especially in areas where they crosscut older, belt-parallel shear zones. Examples of locations where such a setting may exist include the Miminiska Lake prospect and the OL-12 and OL-29 prospects southeast of Opikeigen Lake.

At the Miminiska Lake prospect, where gold is hosted in sheared and altered iron formation, Needham and Sale (2004) note the presence of a northeast-striking fault that crosscuts the east-striking, gold mineralized, deformation zone in an area of magnetite destruction (i.e., where magnetite is converted to iron sulphide minerals). Lemaitre (1997) has interpreted gold mineralization in the vicinity of the metavolcanic rock-hosted OL-12 and OL-29 prospects, as being related to east-northeast- and east-striking shear zones. Both of these occurrences are located within 250 m of an east-northeast-trending fault mapped by Hall (2005).

Although northeast-trending faults have not previously been noted in the Keezhik Lake area, it is noteworthy that one of the most significant prospects (KL-12) described by Mason and White (1995) is hosted within a north-northeast-striking shear zone in quartz-feldspar porphyry. Another interesting observation made during the compilation of gold occurrences in the Keezhik Lake area is that many (i.e., KL-27, KL-31, KL-35, NBK and S04-12) are found in the vicinity of contacts between lithologic units that are likely to have a significant competency contrast (i.e., metavolcanic rocks and iron formation or metavolcanic rocks and porphyry intrusions). This observation is consistent with the potential existence of gold-mineralized splays from the nearby North Caribou Lake–Totogan Lake shear zone that follow competent lithological formations such as banded iron formation or porphyry intrusions as hypothesized by Osmani and Stott (1988).

Rare-Element-Bearing Pegmatites

Rare-element-bearing pegmatites mineralized with significant tantalum, lithium, cesium and rubidium occur near Lilypad Lakes. The Kawitos Lake batholith, which has been mapped 400 m to the south of the mineralized pegmatite field, has been suggested by Breaks and Tindle (2004) as the fertile parental granite.

CONCLUSIONS

Since June 2006, the Far North Mineral Deposit Compilation has collected information regarding the metallogeny of a number of mineral deposits in the Miminiska–Fort Hope greenstone belt area. Available information indicates the presence of a variety of types of economic mineralization, including hydrothermal lode gold, mafic to ultramafic intrusion-hosted copper-nickel-PGE, VMS, and rare-element-bearing pegmatite.

Hydrothermal lode gold mineralization in the Miminiska–Fort Hope greenstone belt is associated with brittle and/or ductile deformation zones of varying orientation. However, many of these gold occurrences also appear to have a close spatial association with late northeast-striking faults. Therefore, locations where earlier belt-parallel structures intersect the northeast-striking faults are considered to be favourable locations for gold exploration. In addition, gold mineralization in the Keezhik Lake area has

characteristics that suggest a possible relationship to splays from the North Caribou Lake–Totogan Lake shear zone. This structure is a regional transcurrent shear that is associated with gold mineralization at the Musselwhite Mine, and is considered to be a favourable gold exploration target. Although the Miminiska–Fort Hope greenstone belt does not have a history of gold production, it is worth noting that numerous current and past-producing gold mines are located elsewhere in the Uchi Subprovince (i.e., in the Red Lake, Meen–Dempster and Pickle Lake greenstone belts).

Two types of mafic to ultramafic intrusion-hosted copper-nickel-PGE deposit have been interpreted to be present in the vicinity of the Miminiska–Fort Hope greenstone belt. The Norton Lake prospect is interpreted to be an example of a synvolcanic intrusion-hosted deposit in a mafic metavolcanic rock-dominated assemblage. The potential exists for the occurrence of similar mineralization in the extensive mafic metavolcanic-rock dominated sequences that have been mapped in the Miminiska–Fort Hope greenstone belt. A number of copper-nickel-PGE occurrences associated with late-tectonic anorthosite intrusions have also been documented in the transition zone between the Uchi and English River subprovinces. Therefore, other mafic intrusions in this area may have copper-nickel-PGE mineralization potential.

Rare-metal-bearing pegmatite in the Lilypad Lakes area is likely to be related to the Kawitos Lake batholith. Therefore, the area surrounding this intrusion has the potential for additional rare-metal mineralization.

In the upcoming year, the Far North Mineral Deposit Compilation project will continue to compile metallogenic information from mineral deposits located in the 1:250 000 scale compilation areas of Madon and Puumala (this volume).

REFERENCES

Ayer, J.A., Berger, B.R. and Trowell, N.F. 1999. Geological compilation of the Lake Abitibi area, Abitibi greenstone belt; Ontario Geological Survey, Preliminary Map P.3398, scale 1:100 000.

Breaks, F.W. and Tindle, A.G. 2004. Rare-element granitic pegmatites of the Fort Hope field, north-central Ontario; *in* Summary of Field Work and Other Activities 2004, Ontario Geological Survey, Open File Report 6145, p.11-1 to 11-9.

Hall, L.A.F. 2005. Precambrian geology, Opikeigen Lake area; Ontario Geological Survey, Preliminary Map P.3269, scale 1:20 000.

Johnson, J.R. 2005. Mineralization and tectonic setting of the Norton Lake region, Uchi Subprovince; unpublished MSc thesis, Lakehead University, Thunder Bay, Ontario, 171p.

Lemaitre, R. 1997. Opikeigen Lake project assessment report, 1997 Exploration Program; unpublished report, Thunder Bay North Resident Geologist's office, assessment file AFRI# 52P09NE2001, 36p.

Mason, J.K. and White, G.D. 1995. Mineral occurrences and prospects in the Fort Hope–Winisk area; Ontario Geological Survey, Open File Report 5926, 212p.

Needham, R.B. and Sale, M. 2004. 2003/2004 Diamond drill report, Miminiska project for Landore Resources Inc.; unpublished report, Thunder Bay North Resident Geologist's office, assessment file AFRO# 2.30410, 85p.

Oja, R.V. 1961. Diamond drill hole log; Thunder Bay Resident Geologist's office, NTS 42 M/11, assessment file AFRI# 42M11NE0003, 2p.

Osmani, I.A. and Stott, G.M. 1988. Regional-scale shear zones in Sachigo Subprovince and their economic significance; *in* Summary of Field Work and Other Activities 1988, Ontario Geological Survey, Miscellaneous Paper 141, p.53-67.

Prest, V.K. 1939. Geology of the Keezhik–Miminiska lakes area; Ontario Department of Mines, Annual Report, 1939, v.48, pt.6, 21p.

——— 1944a. Geology of the Fort Hope area; Ontario Department of Mines, Annual Report, 1942, v.51, pt.3, p.1-28.

——— 1944b. Geology of the eastern extension of the Fort Hope area; Ontario Department of Mines, Annual Report, 1942, v.51, pt.3, p.29-42.

Rogers, M.C., Thurston, P.C, Fyon, J.A., Kelly, R.I. and Breaks, F.W. 1995. Descriptive mineral deposit models of metallic and industrial deposit types and related mineral potential assessment criteria; Ontario Geological Survey, Open File Report 5916, 241p.

Stott, G.M. and Corfu, F. 1991. Uchi Subprovince; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.145-236.

Thurston, P.C. and Carter, M.W. 1970. Operation Fort Hope; Ontario Department of Mines and Northern Affairs, Miscellaneous Paper 42, 64p.

Wallace, H. 1978. Geology of the Opikeigen Lake area, District of Kenora (Patricia Portion); Ontario Geological Survey, Report 185, 58p.

——— 1981a. Geology of the Attwood Lake area, District of Thunder Bay; Ontario Geological Survey, Report 203, 49p.

——— 1981b. Geology of the Miminiska Lake area, districts of Kenora (Patricia Portion) and Thunder Bay; Ontario Geological Survey, Report 214, 96p.

Sedimentary Geoscience Section

26. Project Unit 05-019. Till Sampling and Mapping in Aid of Mineral Exploration: Pickle Lake, Wawa and Armstrong Areas, Northwestern Ontario

P.J. Barnett[1]

[1]Sedimentary Geoscience Section, Ontario Geological Survey

INTRODUCTION

Field work involving till sampling and surficial geology mapping was undertaken in the Pickle Lake, Wawa and Armstrong areas of northwestern Ontario this past summer (Figure 26.1). The field work done: in Pickle Lake was to evaluate the response of "carbonate till" to changes in local bedrock lithology; in Wawa, to determine glacial dispersion from the "Engagement zone" lamprophyre; and at Armstrong, to create regional Quaternary geology maps and collect till samples for heavy mineral indicator and geochemical analysis over a part of the Caribou Lake greenstone belt located north of Lake Nipigon. The Pickle Lake and Wawa studies are aimed at trying to determine the usefulness of till as a mineral exploration tool in these particular unique geological environments. The Armstrong area study will provide guidance in the interpretation of results from overburden sampling programs and regional information on the mineral potential of this part of the Caribou Lake greenstone belt (Barnett 2005; MacDonald, this volume). The Caribou Lake greenstone belt area lies within an area that experienced a complex interplay between fluctuating glacial margins.

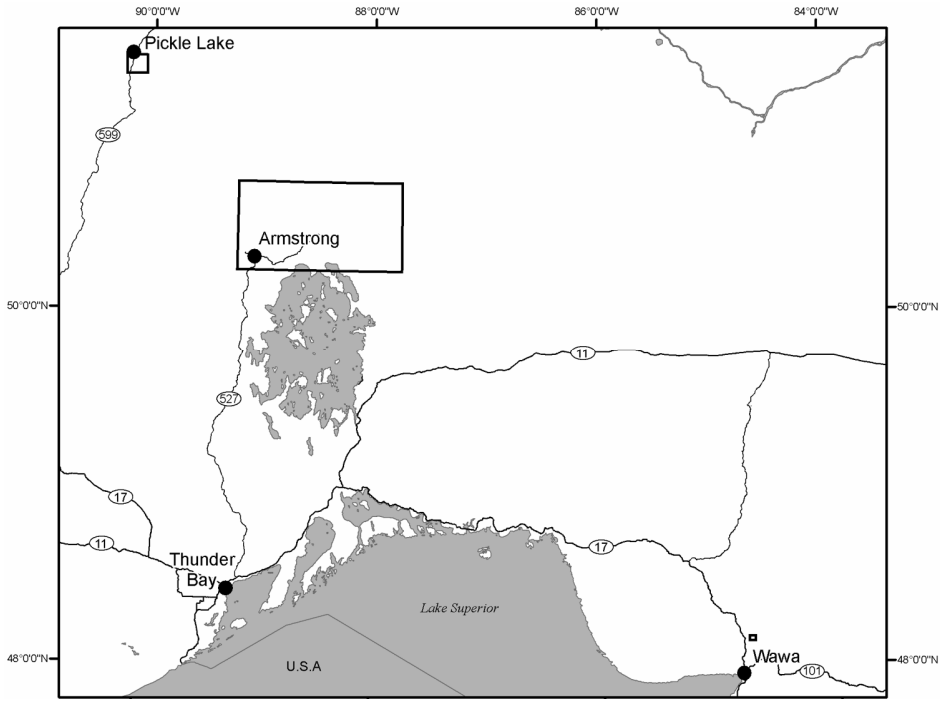

Figure 26.1. Location map of the study areas.

Summary of Field Work and Other Activities 2006,
Ontario Geological Survey, Open File Report 6192, p.26-1 to 26-7.

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PICKLE LAKE STUDY

The Pickle Lake study was undertaken to determine the response of "carbonate till" to changes in local bedrock lithology. The study area is located in the vicinity of the Dona Lake Mine, 9 km southeast of the community of Pickle Lake, Ontario (Figure 26.2). Extensive areas of carbonate till, or exotic till, occur in a broad area extending from Hudson Bay to Pickle Lake, Geraldton, Hemlo and Wawa in northwestern Ontario and the Chapleau moraine in northeastern Ontario (Geddes 1984; Karrow and Geddes 1987; Hicock 1988; Dredge and Cowan 1989; Hicock, Kristjansson and Sharpe 1989; Thorleifson and Kristjansson 1990, 1993). Several workers suggest that this till should be avoided in drift exploration programs using till, particularly where the till is thick (Geddes 1984; Hicock and Kristjansson 1989; Thorleifson and Kristjansson 1990, 1993). The carbonate in the till is derived from the Hudson Bay lowland and is a far-travelled or exotic component in this till where it overlies Precambrian Shield rocks. The carbonate dilutes the geochemical signature derived from the local bedrock in till matrix samples. However, the heavy mineral component of the till matrix is not so affected due to the minimal contribution from the lowland carbonate rocks to the heavy mineral fraction. This study will look at the heavy mineral component of the till (14 sites) in the Dona Lake Mine area; its mineralogy and chemistry; and to see how quickly the till responds to local changes in bedrock lithology.

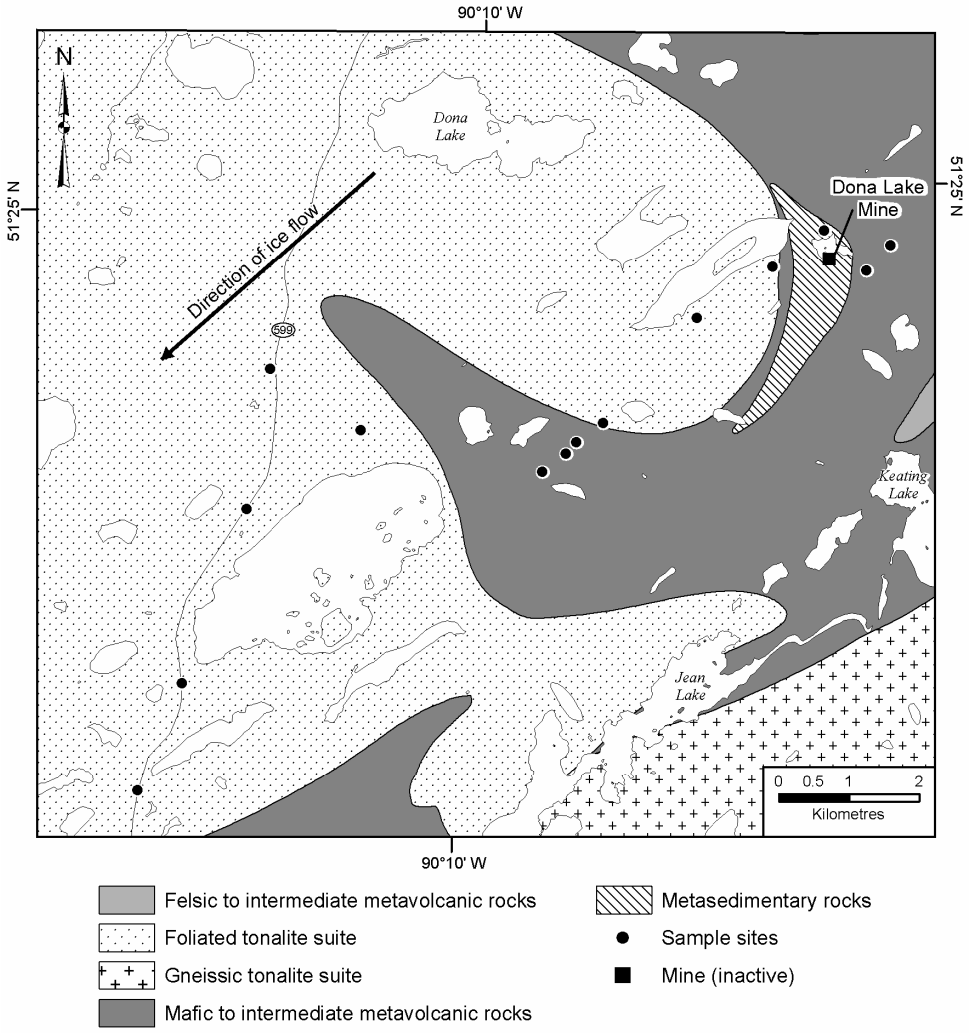

Figure 26.2. Bedrock geology (Ontario Geological Survey 2003) and sample locations, Pickle Lake study area.

WAWA STUDY

The Wawa study was undertaken to determine if till sampling and analysis could be used for the exploration of diamond-bearing lamprophyre dikes. The area of the BandOre Resources Ltd. Engagement zone occurrence was selected for study (Figure 26.3). This particular occurrence was selected, in part, because the dike is diamond bearing (Cavey 2004), its mineralogy studied (Stone and Semenyna 2004), it is easily accessible and there is a thick cover of till in and around the occurrence to sample (Morris 2001). The direction of ice flow associated with the till in the area was toward the south (175 to 185°). Till samples were taken for heavy mineral concentrate analysis, till matrix geochemistry and pebble lithology studies at 11 sites.

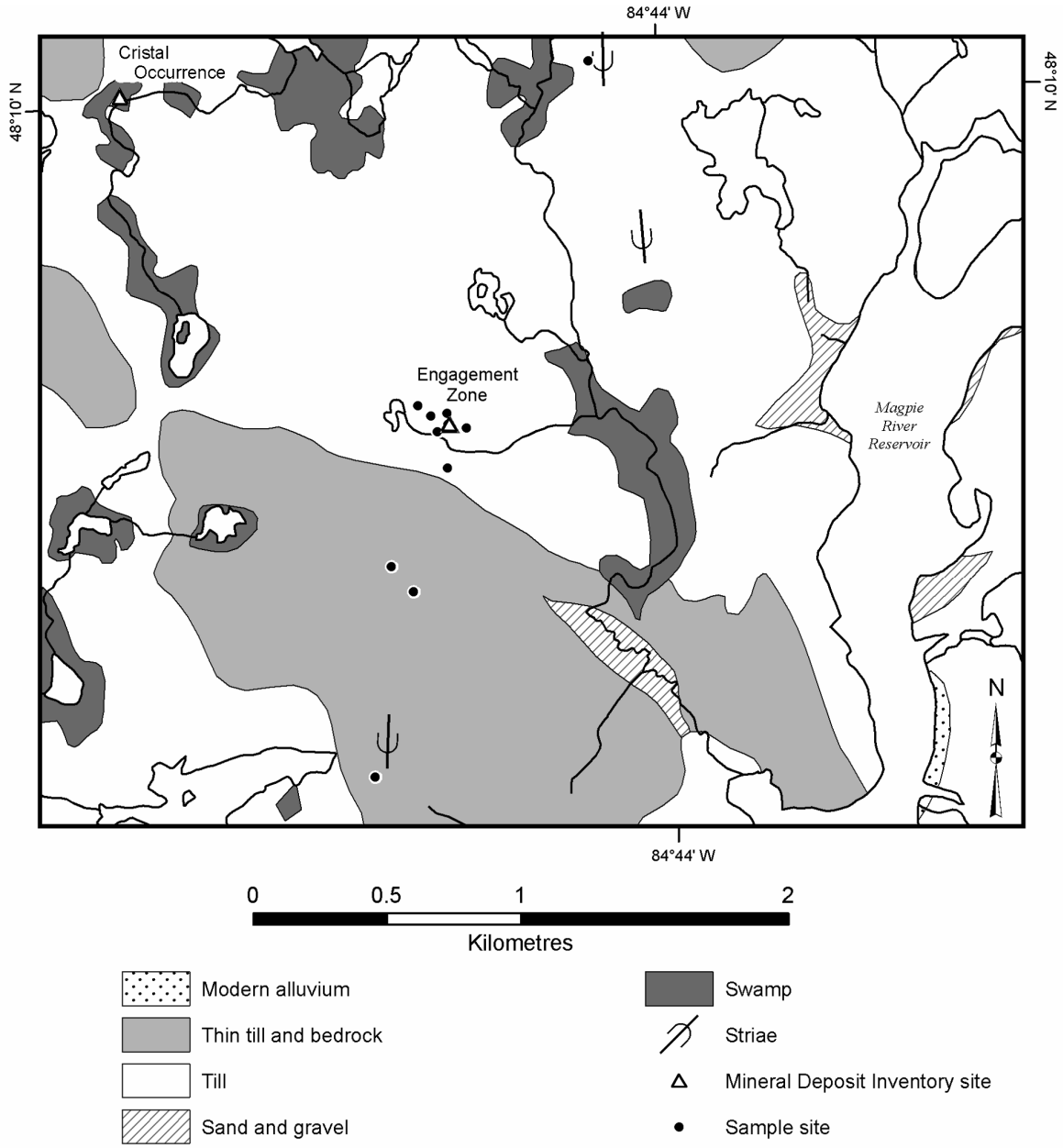

Figure 26.3. Location of samples collected for the Wawa study. Surficial sediment distribution *after* Morris (2001) and mineral showings from the Mineral Deposit Inventory (MDI) and current to 2004 (Ontario Geological Survey 2004).

Glacial dispersion from several other lamprophyre dikes, including the Sandor property located to the northwest of the Engagement zone, has been studied by Thomas and Gleeson (2000). Their findings (Thomas and Gleeson 2000) indicate that the dikes do not contain 2 of the commonly used kimberlite indicator minerals: pyrope garnet and chrome diopside. However, the till heavy-mineral concentrate (HMC) analyses contain low magnesium, high chromium, zinc-rich chromite and ilmenites of varied composition that could be used, along with the mineral actinolite that occurs in the methylene iodide (sg = 3.2) lights, to find additional lamprophyre dikes. Till samples collected by Thomas and Gleeson (2000) down-ice flow of lamprophyre dikes contained elevated concentrations of nickel and chromium in the <0.177 mm fraction of the till matrix.

ARMSTRONG AREA STUDY

During August 2006, work continued on a reconnaissance-level evaluation to determine the potential for using drift (till) prospecting to aid in mineral exploration of the Armstrong area and to determine directions of glacial transport (Barnett 2005). Pye (1968, p.40) wrote, "Because of the general scarcity of outcrops throughout much of the map-area, conventional prospecting is difficult." Till, however, is generally well distributed in the study area and is commonly thick enough to obtain C-horizon samples. There are, however, a few areas of thick glaciofluvial and glaciolacustrine sediments within the study area that hinder the collection of till samples. However, these are commonly located over the area of granitic and granodioritic rocks located south of the Caribou Lake greenstone belt. The overall pattern of ice advance as recorded by glacial striae is displayed in Figure 26.4. Multiple directions of ice flow (striae) were recorded at only a few localities; commonly located near (up-ice flow) of former ice marginal positions such as the Nipigon moraine.

During the 2005 field season (Barnett 2005), till was sampled for HMC analysis at 42 sites and samples sent to Overburden Drilling Management Ltd., Nepean, Ontario, for processing. C-horizon till matrix samples were collected at 80 sites for geochemical analysis by the Geoscience Laboratories, Ministry of Northern Development and Mines. Pebbles were also collected at the till matrix sample sites for lithology identification to provide information on distance of glacial transport. An additional 50 samples were collected for HMC, matrix geochemistry and pebble lithology analysis in 2006 (*see* Figure 26.4). During both field seasons sampling was extended eastward and westward from the study area along and beyond the Caribou Lake greenstone belt because of the availability of recently constructed forest access roads. Additional information was collected to refine the record of ice movement and field mapping observations on the distribution of surficial sediments to better understand the behaviour of the Laurentide Ice Sheet as it relates to glacial dispersal of mineralized bedrock.

Several float boulders were sent in for assay by Mark Smyk of the Resident Geologist Office in Thunder Bay (the following locations are provided as UTM co-ordinates in Zone 16 using North American Datum 1983 (NAD83)). Two banded iron formation boulders, 05MLL-01 (UTM location: 433613E 5582025N) and 05MLL-02 (UTM location: 432408E 5584286N) returned values of 204 ppm Cu and 132 ppm Zn, and 459 ppm Cu and >3000 ppm Zn, respectively. A float boulder, a sulphidic metavolcanic, collected this past summer (06MSL-01, UTM location: 442357E 5582702N) returned 0.29 oz/ton Au, 429 ppm Cu and 122 ppm Zn, but no detectible silver.

FUTURE WORK

Field work for all 3 projects is completed and samples have been submitted to various laboratories for analysis. Research, data organization and airphoto interpretation is ongoing and it is anticipated that maps and reports for these 3 studies will be available before the beginning of the 2007 field season.

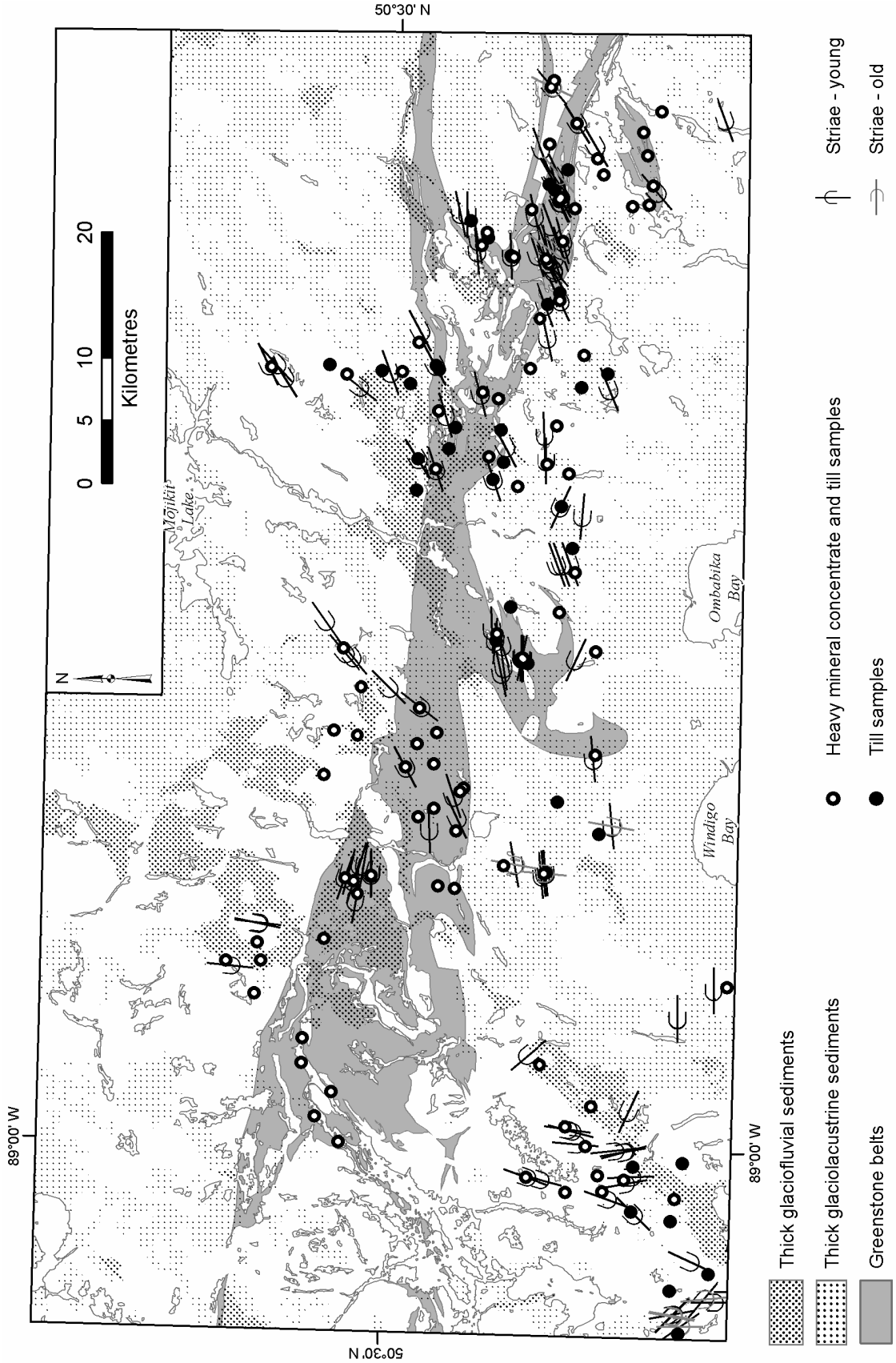

Figure 26.4. Location of till samples collected for HMC and geochemical analysis and areas of extensive cover of non-till sediments (*modified from* Ontario Geological Survey, Ministry of Northern Development and Mines, and Northeast Science and Information Section, Ministry of Natural Resources 2005). Location of greenstone belts *modified from* Percival et al. (2002) and Stott et al. (2002).

ACKNOWLEDGMENTS

The writer is thankful for the co-operation of the Whitesands First Nation and the various mining companies who hold leases and claims in the study areas. A. Ryan provided valuable field assistance.

REFERENCES

Barnett, P.J. 2005. Reconnaissance till sampling in the Caribou Lake greenstone belt area, northwestern Ontario; *in* Summary of Field Work and Other Activities, Ontario Geological Survey, Open File Report 6172, p.20-1 to 20-5.

Cavey, G. 2004. Summary geological report on the GQ property for Band-Ore Resources Ltd., Sault Ste. Marie Mining Division, Ontario: Technical Report under NI-43-101F1; filed December 17, 2004, with SEDAR®, *see* Sedar Home Page, 39p.

Dredge, L.A. and Cowan, R.W. 1989. Quaternary geology of the southwestern Canadian Shield; *in* Chapter 3 of Quaternary geology of Canada and Greenland, Geological Survey of Canada, Geology of Canada, no.1. p.214-249.

Geddes, R.S. 1984. An exotic till in the Hemlo area, northern Ontario; Geological Association of Canada–Mineralogical Association of Canada, Annual Meeting, London, Ontario, Program and Abstracts, v.9, p.66.

Hicock, S.R. 1988. Calcareous till facies north of Lake Superior, Ontario: implications for Laurentide ice streaming; Géographie physique et Quaternaire, v.42, p.120-135.

Hicock, S.R. and Kristjansson, F.J. 1989. Gold exploration using tills of the Beardmore–Geraldton area, northern Ontario; Canadian Institute of Mining and Metallurgy, Bulletin, v.82, no.992, p.50-54.

Hicock, S.R., Kristjansson, F.J. and Sharpe, D.R. 1989. Carbonate till as a soft bed for Pleistocene ice streams on the Canadian Shield north of Lake Superior; Canadian Journal of Earth Sciences, v.26, p.2249-2254.

Karrow, P.F. and Geddes, R.S. 1987. Drift carbonate on the Canadian Shield; Canadian Journal of Earth Sciences, v.24, p.150-155.

Morris, T.F. 2001. Quaternary geology of the Wawa area, northeastern Ontario; Ontario Geological Survey, Open File Report 6055, 67p.

Ontario Geological Survey 2003. 1:250 000 scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126.

——— 2004. Mineral Deposit Inventory Version 2 (MDI2), October 2004 Release; Ontario Geological Survey.

Ontario Geological Survey, Ministry of Northern Development and Mines, and Northeast Science and Information Section, Ministry of Natural Resources 2005. Digital Northern Ontario Engineering Terrain Study (NOEGTS); Ontario Geological Survey, Miscellaneous Release—Data 160.

Percival, J.A., Whalen, J.B., Tomlinson, K.Y., McNicoll, V. and Stott, G.M., 2002. Geology and tectonostratigraphic assemblages, north-central Wabigoon Subprovince, Ontario; Ontario Geological Survey, Preliminary Map P.3447, or Geological Survey of Canada, Open File 4270, scale 1:250 000.

Pye, E.G. 1968. Geology of the Crescent Lake area, District of Thunder Bay; Ontario Department of Mines, Geological Report 55, 72p.

Stone, D. and Semenyna, L. 2004. Petrography, chemistry and diamond characteristics of heterolithic diamond-bearing breccias and lamprophyre dikes at Wawa, Ontario; Ontario Geological Survey, Open File Report 6134, 39p.

Stott, G.M., Davis, D.W., Parker, J.R., Straub, K.J. and Tomlinson, K.Y. 2002. Geology and tectonostratigraphic assemblages, eastern Wabigoon Subprovince, Ontario; Ontario Geological Survey, Preliminary Map P.3449, or Geological Survey of Canada, Open File 4285, scale 1:250 000.

Thomas, R.D. and Gleeson, C.F. 2000. Use of till geochemistry and mineralogy to outline areas underlain by diamondiferous spessartite dikes near Wawa, Ontario; Exploration Mining Geology, v.9, p.215-231.

Thorleifson, L.H. and Kristjansson, F.J. 1990. Geochemical, mineralogical, and lithological analyses of glacial sediments for gold, base metal and kimberlite exploration, Beardmore–Geraldton area, District of Thunder Bay, northern Ontario; Geological Survey of Canada, Open File 2266, 418p.

——— 1993. Quaternary geology and drift prospecting, Beardmore–Geraldton area, Ontario; Geological Survey of Canada, Memoir 435, 146p.

27. Project Unit 06-022. North Swayze Area High-Density Regional Lake Sediment and Water Survey, Northeastern Ontario

V.E. Felix[1]

[1]Sedimentary Geoscience Section, Ontario Geological Survey

INTRODUCTION

Field work for a high-density lake sediment and water geochemical survey of the northern portion of the Swayze greenstone belt of northeastern Ontario was carried out by staff of the Ontario Geological Survey (OGS) from July 11 to 22, 2006. The survey area is located approximately 200 km northwest of Sudbury, Ontario (Figure 27.1) and is represented on National Topographic System (NTS) 1:50 000 scale map sheets 42 B/1 (Foleyet) and 42 A/4 (Kenogaming Lake). This survey covers approximately 2100 km^2 over the north Swayze greenstone belt and the Kenogamissi batholith and is bounded by Ivanhoe Lake to the west and Kenogamissi Lake to the east. Lake sediment and/or water samples were collected at 800 sites for an average density of 1 sample per 2.6 km^2. This lake water and sediment survey completes the final year of a 3-year project to generate geochemical data for the Swayze greenstone belt. The south Swayze area was surveyed in 2002 (Takats and Jackson 2005) and the central Swayze in 2003 (Takats 2005) (*see* Figure 27.1). The Swayze greenstone belt was selected for this type of geochemical survey because of its high potential for base and precious metal mineralization and because lake sediment and water geochemistry sampling is an effective and expeditious method to assess the regional mineral potential of an area.

REGIONAL GEOLOGIC SETTING

Bedrock Geology

The Swayze greenstone belt is located in the western Abitibi Subprovince of the Superior Province. The Swayze greenstone belt (SGB) is bounded to the north by the Nat River granitoid complex, to the west by the Kapuskasing structural zone, to the south by the Ramsey–Algoma granitoid complex and to the east by the Kenogamissi granitoid complex (Figure 27.2). The SGB is connected to the Abitibi greenstone belt by a narrow band of metasedimentary and metavolcanic rocks that wrap around the northern and southern margins of the Kenogamissi granitoid complex (Heather 1993; Heather, Shore and van Breemen 1995). Although largely separated from rocks of the Abitibi greenstone belt by the Kenogamissi batholith, the 2 greenstone belts are considered to be roughly equivalent in age. New mapping and geochronological evidence shows that the SGB contains many of the structures and stratigraphic ages typical of the Abitibi belt in the Timmins–Kirkland Lake area and is now interpreted to represent a deeper erosional level of a once-continuous Abitibi greenstone belt (Heather, Shore and van Breemen 1995).

Summary of Field Work and Other Activities 2006,
Ontario Geological Survey, Open File Report 6192, p.27-1 to 27-6.

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Bedrock in the study area is Archean in age with the exception of Proterozoic diabase dikes in the eastern portion of the survey area (Ayer and Trowell 2002). Massive peridotite, pyroxenite and dunite intrusions are common within the SGB. These ultramafic rocks are also spatially related to polysutured and spinifex-textured komatiite volcanic flows (Heather 2001). Mafic to intermediate metavolcanic and synvolcanic intrusive rocks are widely dispersed throughout the belt. These include iron-tholeiitic basalt, magnesium-tholeiitic basalt, calc-alkalic basalt and gabbro and/or diorite sills and dikes. The metavolcanic rocks consist of massive, pillowed, pillow breccia, variolitic and amygdaloidal flows. Several large sequences of felsic to intermediate metavolcanic rocks also occur within the SGB and consist of massive to pillowed flows and associated pyroclastic rocks. Chemical metasedimentary rocks consisting of sulphide- and carbonate-facies iron formations occur within most of the metavolcanic rocks within the SGB (Heather 1993). Older sequences of clastic metasedimentary rocks in the SGB contain a close temporal and tectonic relationship to the metavolcanic rocks in the belt. Younger sequences of clastic metasedimentary rocks in the SGB unconformably overlie the older supracrustal sequences and are correlated with the Timiskaming assemblage rocks in the Abitibi greenstone belt. In general, rock units and structural features within the supracrustal sequences trend easterly with steep dips. Supracrustal rocks have been metamorphosed to greenschist facies, with the exception of areas in close proximity to the granitic intrusions which are of amphibolite facies (Ayer 1995).

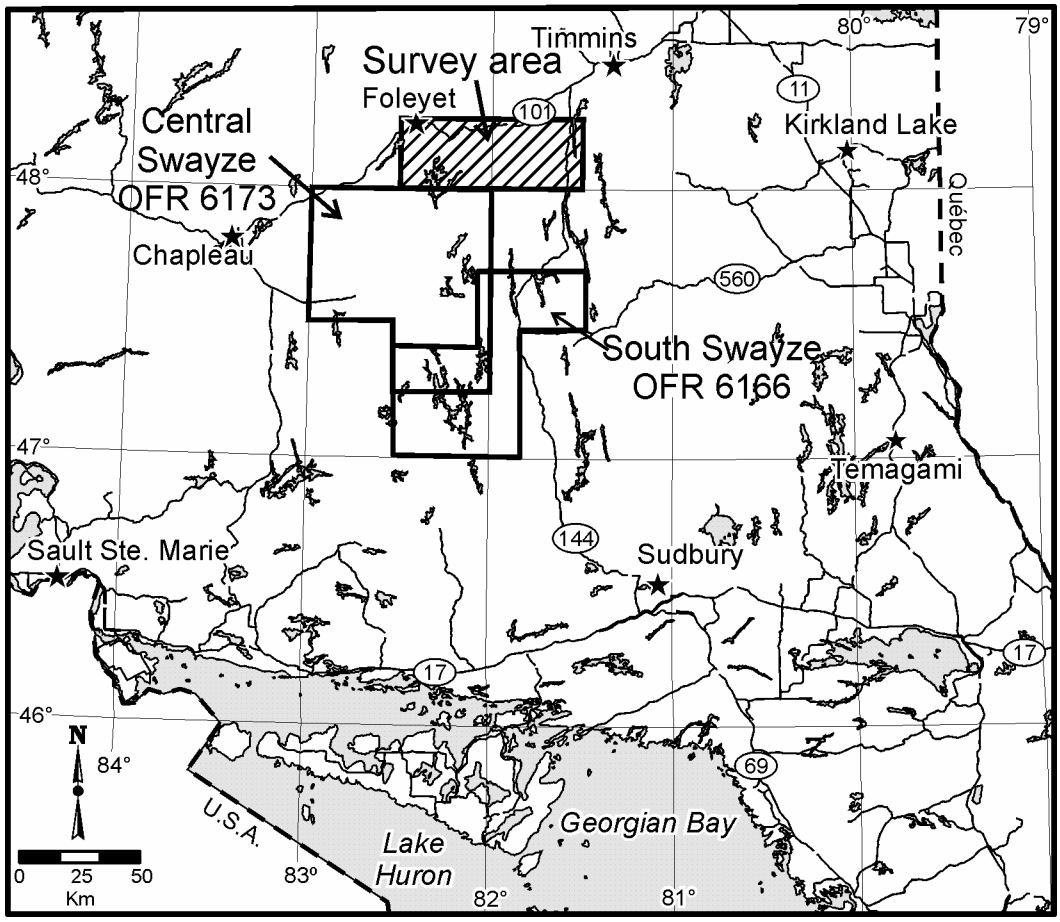

Figure 27.1. Location of the 2006 survey area in relation to the previous south and central Swayze survey areas.

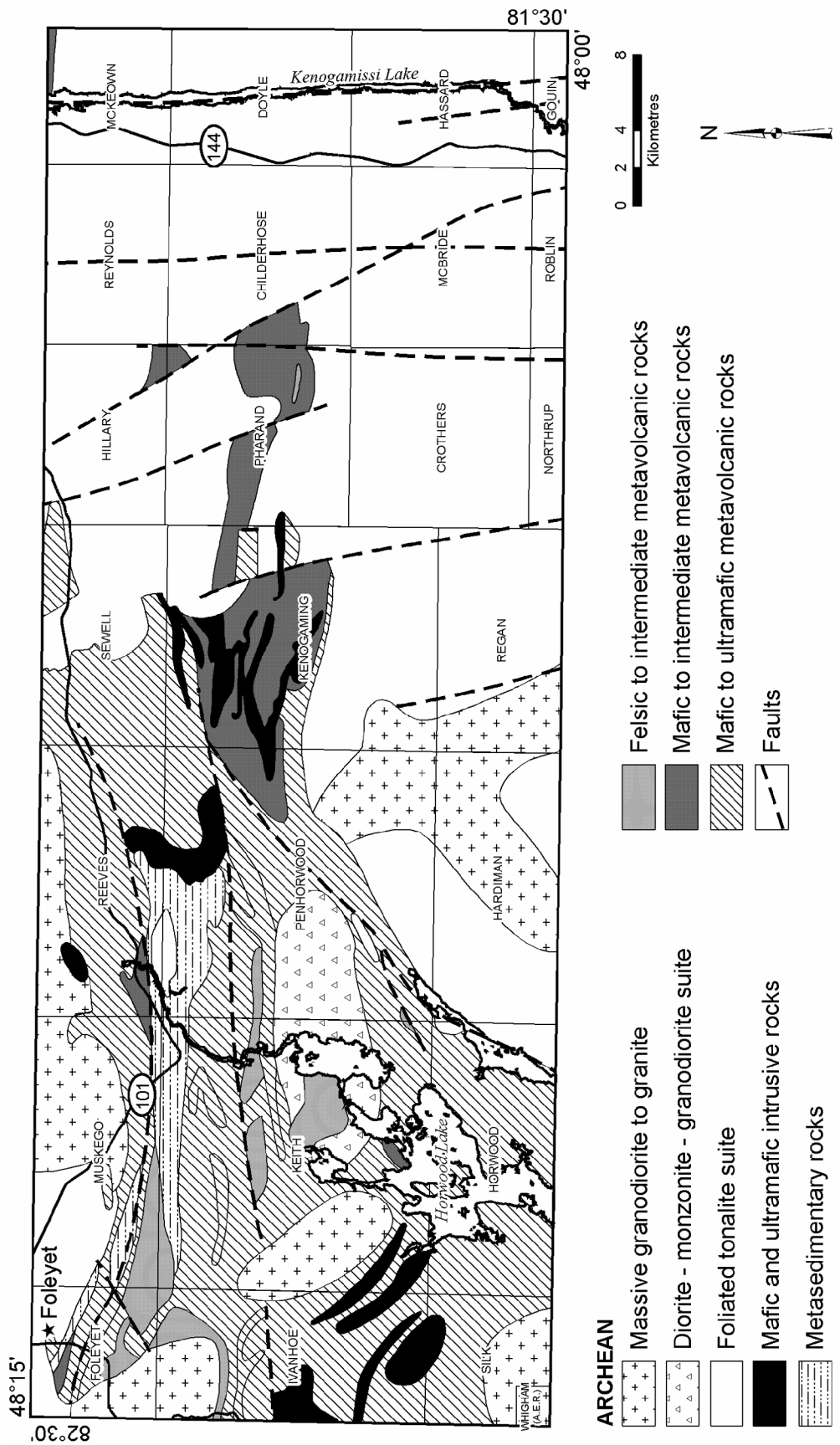

Figure 27.2. Generalized bedrock geology of the survey area (*from* Ontario Geological Survey 1991).

Supracrustal rocks of the north SGB are subdivided into 3 assemblages: the Muskego–Reeves assemblage, the Horwood assemblage and the Hanrahan assemblage (Jackson and Fyon 1991). The Muskego–Reeves assemblage, located in the northern part of the belt, is composed of tholeiitic mafic volcanic rocks with lesser components of komatiitic volcanic rocks, calc-alkalic intermediate and felsic volcanic units, and clastic and chemical sedimentary units (Ayer 1995). The Horwood assemblage is located south of the Muskego–Reeves assemblage and these 2 terranes are separated by the Muskego River fault, a broad east-trending deformation zone. The Horwood assemblage consists predominantly of tholeiitic mafic volcanic rocks. The Hanrahan assemblage is confined to the southeast part of the north SGB and consists predominantly of calc-alkalic intermediate and felsic volcanic rocks that have been intruded by extensive ultramafic and gabbroic sills (Ayer 1995).

The SGB has a high potential for mesothermal gold as indicated by the number of significant gold occurrences and past-producing gold mines. In the north SGB, gold potential may exist in association with east-trending carbonatized shear zones such as the Muskego River fault (Ayer 1993). Gold mineralization occurs in a wide variety of rock types, but is most commonly associated with rusty weathering and schistose, iron carbonatized and/or sericitized, mafic volcanic rocks. The mineralization is closely associated with quartz-carbonate veining, commonly with disseminated iron sulphides, and locally with arsenopyrite, stibnite and base metal sulphides (Ayer 1995).

Copper-zinc mineralization is found in association with sulphide-facies iron formation and with metavolcanic sequences. The Muskego–Reeves assemblage is considered to have the greatest potential for economic concentrations of copper and zinc sulphides in this area (Ayer 1995). In addition, the potential exists for nickel-copper and/or platinum group element mineralization in mafic to ultramafic rocks and komatiitic rocks (Heather 1993; Ayer et al. 2002).

A recent compilation map of the entire Swayze greenstone belt was completed at a scale of 1:100 000 by the Ontario Geological Survey (Ayer and Trowell 2002).

Physiography and Surficial Geology

The survey area lies within with Abitibi Uplands physiographic region (Bostock 1970). These uplands are underlain by crystalline Archean rocks and characterized by broad rolling surfaces that rise gently from the Hudson Bay Lowland in the north, reaching about 500 m asl near their southwest and southern extent. Most of the uplands lie between 300 and 400 m asl in elevation. These uplands form a rocky landscape, scattered with lakes and large areas that are mantled by a variety of glacial deposits (Thurston 1991).

The survey area is drained northward by the Ivanhoe, Groundhog, Kamiskotia and Tatachikapika rivers and their tributaries. Engineering geology terrain maps have been produced for the Foleyet area at a scale of 1:100 000 (Lee and Scott 1980). Local relief is described as slight with smoothly rolling ridges interspersed with flat swampy areas. Exceptions to the smooth rolling topography are high steep, sinuous esker ridges that trend southwest. In the vicinity of these eskers, local relief ranges up to 65 m. Materials associated with these large esker systems are varied, but commonly comprise well-sorted cobble gravel (Kaszycki 1992).

The survey area is also characterized by extensive till cover. In these areas, thick deposits of till and associated debris flow sediments mask underlying bedrock topography forming fluted till plains or till plateaux. Till composition is varied, but is commonly composed of a sandy silty matrix with a high clast content (Kaszycki 1992).

SAMPLING METHODS

Sampling of organic lake sediments was performed using a float-equipped Bell 206B helicopter. An overall average of 21 lakes were sampled for each hour of helicopter time. The samples were collected using an OGS-designed gravity corer, which was lowered from the helicopter float and then pulled to surface. Samples were taken from depths greater than 20 cm below the sediment–water interface (SWI) in order to minimize or avoid anthropogenic influences and SWI effects. These deeper sediments more accurately reflect geochemical effects that may be attributed to the local geology. The samples were extruded from the collection tube into breathable fabric bags and then placed in a sealable plastic bag until the end of the sampling run. If a site contained no organic component (e.g., sand and/or clay), only a water sample was taken.

Lake water samples were taken upon landing at a sample site, prior to the collection of sediment samples. On lakes less than 2 m deep, samples were collected at 0.5 m below the water surface; on lakes deeper than 2 m, samples were collected at a depth of 2 m. A semi-automated water sampling apparatus, developed by the OGS and consisting of a pump, a YSI multiparameter water-quality analyzer (for measurement of parameters such as pH, temperature and conductivity), a sample bottle tray and a variety of hoses and valves, was used for sample collection. Lake water is pumped through the system in order to purge it prior to the collection of a sample and the recording of water-quality data. The water samples were kept cool immediately following collection and were processed (filtered and acidified) within 24 hours of collection.

Sample site locations were recorded using a global positioning system (GPS) receiver mounted in the cockpit of the helicopter. In addition, a GPS receiver connected to a tablet computer was utilized to provide "heads up" real-time navigation between lake sites. Sediment sample information and descriptions were recorded on standardized forms and later entered into a Microsoft® Access database. Water quality data were recorded using a hand-held data logger and transferred to a computer at the end of each sampling run. The GPS co-ordinates of each sample site location, as well as flight tracks, were also downloaded to a computer at the end of each field day.

SAMPLE PREPARATION AND ANALYTICAL METHODS

Lake sediment samples were partially air dried in porous collection bags while in the field. Upon return from the field, samples were dried, partially pulverized in a ceramic ring mill and sieved to obtain the –80 mesh (<177 μm) size fraction. Samples will be submitted for a variety of laboratory analyses. Samples will be subjected to nitric–aqua regia digestion followed by inductively coupled plasma mass spectrometry (ICP–MS) and inductively coupled plasma optical emission spectrometry (ICP–OES) to determine approximately 50 trace and major elements. Nitric–aqua regia digestion attacks all sample matrix constituents except for silicate minerals and, therefore, is considered a non-selective, relatively strong partial extractant. Approximately 15 g of sample pulp will be pressed into briquettes prior to analysis by instrumental neutron activation analysis (INAA) for gold and 27 other elements. Loss on ignition (LOI) is determined at 500°C using an automated gravimetric technique. Quality control for all analyses is monitored through the use of certified reference materials placed regularly through the sample sequence and randomly taken sample pulp duplicates.

Water samples were passed through 0.45 μm syringe filters and acidified to ~1% ultrapure nitric acid in the field. Analysis of water will be completed by direct aspiration ICP–MS to determine approximately 50 elements. Quality of the analyses will be monitored through the use of blanks, National Research Council certified reference standard SLRS-4 and random sample duplicates.

REFERENCES

Ayer, J.A. 1993. Geology of Foleyet and Ivanhoe townships; Ontario Geological Survey, Open File Report 5851, 42p.

——— 1995. Precambrian geology, northern Swayze greenstone belt; Ontario Geological Survey, Report 297, 57p.

Ayer, J.A. and Trowell, N.F. 2002. Geological compilation of the Swayze area, Abitibi greenstone belt; Ontario Geological Survey, Preliminary Map P.3511, scale 1:100 000.

Ayer, J.A., Trowell, N.F., Valade, L., Nevills, M. and Madon, Z. 2002. Geological compilation of the Swayze area, Abitibi greenstone belt; Ontario Geological Survey, Miscellaneous Release—Data 93.

Bostock, H.S. 1970. Physiographic subdivisions of Canada; *in* Geology and economic minerals of Canada, Geological Survey of Canada, Economic Report No. 1, p.10-30.

Heather, K.B. 1993. Regional geology, structure and mineral deposits of the Archean Swayze greenstone belt, southern Superior Province, Ontario; *in* Current Research, Part C; Geological Survey of Canada, Paper 93-1C, p.295-305.

——— 2001. The geological evolution of the Archean Swayze greenstone belt, Superior Province, Canada; unpublished PhD thesis, Keele University, Staffordshire, England, United Kingdom, 370p.

Heather, K.B., Shore, G.T. and van Breemen, O. 1995. The convoluted "layer-cake": an old recipe with new ingredients for the Swayze greenstone belt, southern Superior Province, Ontario; *in* Current Research 1995-C, Geological Survey of Canada, p.1-10.

Jackson, S.L. and Fyon, J.A. 1991. The western Abitibi Subprovince in Ontario; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.405-482.

Kaszycki, C.A. 1992. Quaternary geology of the Foleyet area, northern Ontario; *in* Summary of Field Work and Other Activities, 1992, Ontario Geological Survey, Miscellaneous Paper 160, p.203-206.

Lee, H.A. and Scott, S.A. 1980. Foleyet area (NTS 42B/SE), districts of Algoma, Cochrane and Sudbury; Ontario Geological Survey, Northern Ontario Engineering Geology Terrain Study 75, 17p. Accompanied by Map 5102, scale 1:100 000.

Ontario Geological Survey 1991. Bedrock geology of Ontario, east-central sheet; Ontario Geological Survey, Map 2543, scale 1:1 000 000.

Takats, P.A. 2005. Central Swayze area high-density regional lake sediment and water geochemical survey, northeastern Ontario; Ontario Geological Survey, Open File Report 6173, 132p.

Takats, P.A. and Jackson, J.E. 2005. South Swayze area high-density regional lake sediment and water geochemical survey, northeastern Ontario; Ontario Geological Survey, Open File Report 6166, 121p.

Thurston, P.C. 1991. Geology of Ontario: Introduction; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.3-25.

28. Project Unit 06-023. Nipigon–Beardmore Area Lake Sediment and Water Geochemical Survey

R.D. Dyer[1]

[1]Sedimentary Geoscience Section, Ontario Geological Survey

INTRODUCTION

Field work for a high-density lake sediment and water geochemical survey of the Nipigon to Beardmore area was carried out between June 5 and June 30, 2006. The survey area is located approximately 100 km northeast of Thunder Bay (Figure 28.1). The survey completely covered the area defined by National Topographic System (NTS) 1:50 000 scale map sheets 42 E/4, 42 E/5, 42 E/12, 52 H/1 and partially covered the area outlined by map sheets 52 H/8 and 52 H/9. The study area covers areas of high mineral potential (e.g., the western portion of the Beardmore–Geraldton greenstone belt) as well as areas traditionally considered to have low or unknown mineral potential (e.g., Quetico Subprovince metasedimentary rocks and granitoids).

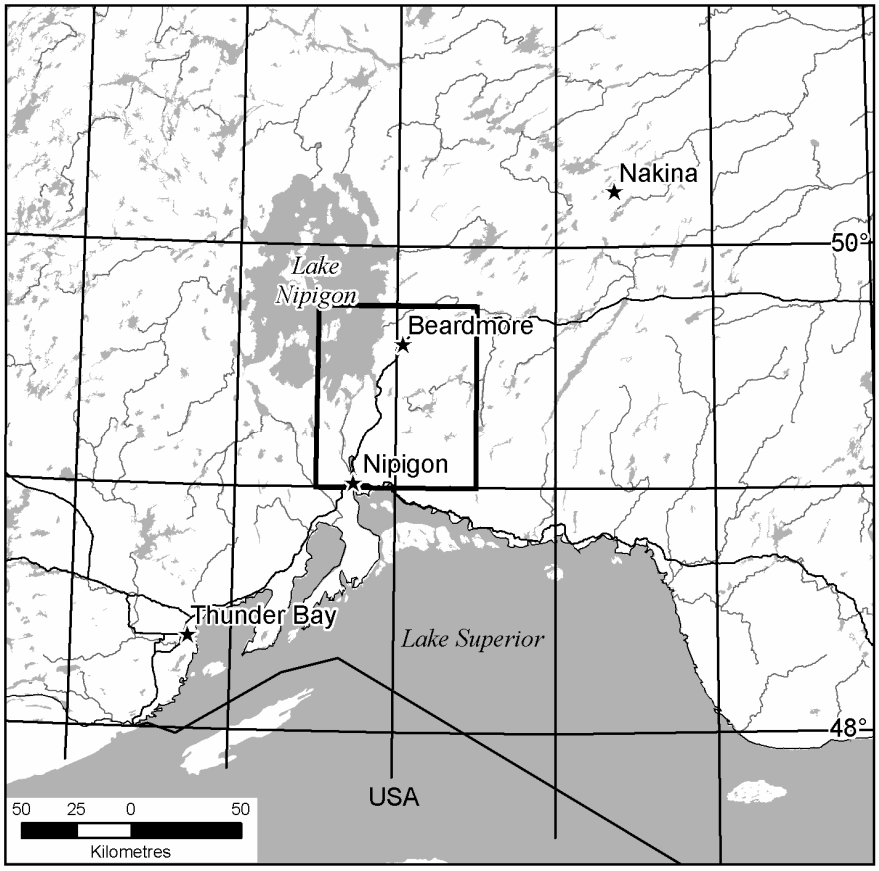

Figure 28.1. Location of Nipigon–Beardmore survey area.

Summary of Field Work and Other Activities 2006,
Ontario Geological Survey, Open File Report 6192, p.28-1 to 28-4.

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Lake sediment and water samples were collected at 2209 sites over an area of approximately 4400 km^2 for an average density of 1 sample per 2 km^2. This survey is the first high-density regional lake sediment geochemistry coverage to be completed over the region. This study area was previously sampled at a much lower density during the National Geochemical Reconnaissance (NGR) lake sediment program carried out jointly by the Geological Survey of Canada and the Ontario Geological Survey (OGS) during the late 1970s and early 1980s (Hornbrook, Coker and Lynch 1978a, 1978b; Hornbrook et al. 1990; Friske et al. 1990).

REGIONAL SETTING

The study area contains Mesoarchean Wabigoon Subprovince (Blackburn et al. 1991) and Quetico Subprovince (Williams 1991) rocks of the Superior Craton and younger Proterozoic Sibley Group and Nipigon Diabase sill (Sutcliffe 1991) rocks of the Southern Province. The majority of the survey area is underlain by monotonous metasediments, paragneisses, migmatites and granites that dominate the rocks of the Quetico Subprovince. Exceptions include the most northerly portion of the survey area, which is underlain by the western extent of the Beardmore–Geraldton greenstone belt. Diabase sills of the Nipigon Embayment underlie much of the west-central portion of the survey area and are also prominent along the south-central survey boundary, an area known as the Kama Hills. Relatively minor amounts of Sibley Group sedimentary rocks are present in the southwestern portion of the study area. The most recent bedrock mapping of the area (Hart, ter Meer and Jolette 2002) focussed on the western portion of the Beardmore greenstone belt and the adjacent Nipigon Embayment along the coast of Lake Nipigon.

Systematic, detailed Quaternary geological mapping has not been conducted over most of the study area. The most recent Quaternary mapping and till sampling was undertaken by Thorleifson and Kristjansson (1993) over the Beardmore–Geraldton greenstone belt, located along the most northern portion of the survey area. Reconnaissance Quaternary mapping of the entire area, at a scale of 1:506 880, was completed by Zoltai (1965). Engineering geology terrain maps, at a scale of 1:100 000, were produced for the region by Gartner (1979a, 1979b) and Mollard and Mollard (1981a, 1981b). A more recent regional compilation of the Quaternary geology of the area has been completed by Barnett, Henry and Babuin (1991). These sources indicate that surficial materials within the study area are mostly sparse, consisting predominantly of a thin, discontinuous veneer of drift (till) over bedrock. Two significant exceptions are 1) the townships of Booth, Ledger and Purdom in the southwestern portion of the survey area, where thick accumulations of glaciolacustrine and glaciofluvial deposits occur; and 2) the area north of Lake Jean and Parks Lake, in the east-central portion of the survey area, where thick units of till and lesser glaciofluvial outwash deposits have been mapped.

In the eastern and northeastern portions of the area, the topography is rolling and relatively flat; relief rarely exceeds 60 m between widely scattered points. This contrasts with areas underlain by Nipigon sill rocks (western and southern portions of the survey area) where the incidence of cliffs and dramatic topographic changes is most significant.

SAMPLING METHODS

Organic-rich lake sediment samples were collected from a helicopter float using the OGS-designed gravity corer. In order to avoid anthropogenic influences and water–sediment interface effects (i.e., increased manganese due to anoxic conditions that result in secondary accumulation of base metals), only deep sediment (>20 cm below the sediment surface) was collected. This sediment better reflects the effects of natural geochemical inputs that may be traced to local geology.

Lake water samples were collected from a depth of 1.0 m using a weighted intake hose and pump. Water quality parameters, including pH and conductivity, were measured at each lake site using a flow cell attached to a multi-parameter probe. Lake water was pumped from each lake and allowed to purge the sampling system prior to the collection of a water sample and the recording of water quality parameters. Water samples were kept cool after collection and processed (filtered and acidified) within 6 hours of collection.

A global positioning system (GPS) receiver was utilized to record accurate sample site positions and to record each flight track. In addition, a GPS receiver mated to a tablet computer was utilized to provide "heads up" real-time navigation between lake sites. In comparison to the OGS lake sediment project completed in 2005, this navigation system was the most significant factor in increasing overall sampling efficiency by more than 30%.

SAMPLE PREPARATION AND ANALYTICAL METHODS

Lake sediment samples were placed in breathable fabric bags and allowed to partially air dry prior to shipment to the laboratory. The samples were then air dried, partially pulverized in a ceramic ring and puck pulverizer and sieved to obtain the –80 mesh (<177 μm) size fraction. Laboratory analysis will include nitric acid–aqua regia digestion followed by inductively coupled plasma mass spectrometry (ICP–MS) to determine approximately 50 trace elements. Nitric acid–aqua regia digestion attacks all sample matrix constituents, except for silicate minerals and, therefore, is considered a nonselective, relatively strong partial extractant.

Approximately 10 g of sample pulp are pressed into briquettes prior to analysis by instrumental neutron activation analysis (INAA) for Au, As and a suite of approximately 30 other elements. Quality control will be monitored through the use of sample pulp duplicates and certified reference materials. Loss-on-ignition (LOI) is determined at 500°C, using an automated gravimetric technique.

Water samples were passed through 0.45 μm syringe filters and acidified to 1% ultrapure nitric acid within 6 hours of collection. Analysis of water will include direct aspiration ICP–MS to determine approximately 50 elements. Quality of the analyses is monitored through the use of sample duplicates, CANMET certified reference standard SLRS-4 and distilled water blanks.

REFERENCES

Barnett, P.J., Henry, A.P. and Babuin, D. 1991. Quaternary geology of Ontario, west-central sheet; Ontario Geologic Survey, Map 2554, scale 1:1 000 000.

Blackburn, C.E., Johns, G.W., Ayer, J.A. and Davis, D.W. 1991. Wabigoon Subprovince; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.303-382.

Friske, P.W.B., Hornbrook, E.H.W., Lynch, J.J., McCurdy, M.W., Gross, H., Galletta, A.C. and Durham, C.C. 1990. National geochemical reconnaissance lake sediment and water data, Thunder Bay region, northwestern Ontario (NTS 52A and 52H south); Geological Survey of Canada, Open File 2179.

Gartner, J.F. 1979a. Jellicoe area (NTS 42E/NW), District of Thunder Bay; Ontario Geological Survey, Northern Ontario Engineering Geology Terrain Study 27, 16p. Accompanied by Map 5077, scale 1:100 000.

——— 1979b. Roslyn Lake area (NTS 42E/SW), District of Thunder Bay; Ontario Geological Survey, Northern Ontario Engineering Geology Terrain Study 43, 12p. Accompanied by Map 5079, scale 1:100 000.

Hart, T.R., ter Meer, M. and Jolette, C. 2002. Precambrian geology of Kitto, Eva, Summers, Dorothea and Sandra townships, northwestern Ontario: Phoenix Bedrock Mapping Project; Ontario Geological Survey, Open File Report 6095, 206p.

Hornbrook, E.H.W., Coker, W.B. and Lynch, J.J. 1978a. National geochemical reconnaissance release NGR 18-1977, regional lake sediment and water geochemical reconnaissance data, Ontario–north shore Lake Superior; Geological Survey of Canada, Open File 507.

——— 1978b. National geochemical reconnaissance release NGR 17-1977, regional lake sediment and water geochemical reconnaissance data, Ontario–north shore Lake Superior; Geological Survey of Canada, Open File 506, 275p.

Hornbrook, E.H.W., Friske, P.W.B., Lynch, J.J., McCurdy, M.W., Gross, H., Galletta, A.C. and Durham, C.C. 1990. National geochemical reconnaissance lake sediment and water data, central northern Ontario (parts of NTS 42E, 42L and 52H); Geological Survey of Canada, Open File 2177.

Mollard, D.G. and Mollard, J.D. 1981a. Frazer Lake area (NTS 52H/SE), District of Thunder Bay; Ontario Geological Survey, Northern Ontario Engineering Geology Terrain Study 42, 30p. Accompanied by Map 5052, scale 1:100 000.

——— 1981b. Mount Royal area (NTS 52H/NE), District of Thunder Bay; Ontario Geological Survey, Northern Ontario Engineering Geology Terrain Study 26, 18p. Accompanied by Map 5050, scale 1:100 000.

Sutcliffe, R.H. 1991. Proterozoic geology of the Lake Superior area; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.627-661.

Thorleifson, L. H. and Kristjansson, F.J. 1993. Quaternary geology and drift prospecting, Beardmore–Geraldton area, Ontario; Geological Survey of Canada, Memoir 435, 146p.

Williams, H.R. 1991. Quetico Subprovince; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.383-405.

Zoltai, S.C. 1965. Surficial geology, Thunder Bay; Ontario Department of Lands and Forests, Map S265 Scale 1:506 880.

29. Project Unit 05-018. Gold Dispersion Case Studies, Northeastern Ontario

R.D. Dyer[1]

[1]Sedimentary Geoscience Section, Ontario Geological Survey

INTRODUCTION

A project focussing on the dispersion of gold from point source bedrock mineral occurrences and from associated glacial dispersion plumes was initiated in northeastern Ontario (Figure 29.1) in 2005 (Dyer 2005). Sampling at 2 additional case study areas was completed during the 2006 field season, one located within the Swayze greenstone belt, the other located near the Galer Lake fault east of Matachewan. Samples of till, lake sediment and stream sediment were collected near (and where appropriate in the down-ice and up-ice direction) existing bedrock gold occurrences, lake sediment anomalies and till anomalies (containing anomalous levels of gold grains). One of the additional case study areas is centred on the old Kenty gold mine area located in townships Swayze and Dore (Figure 29.2). The other area is located in Holmes Township centred on Galer Lake (Figure 29.3). These new

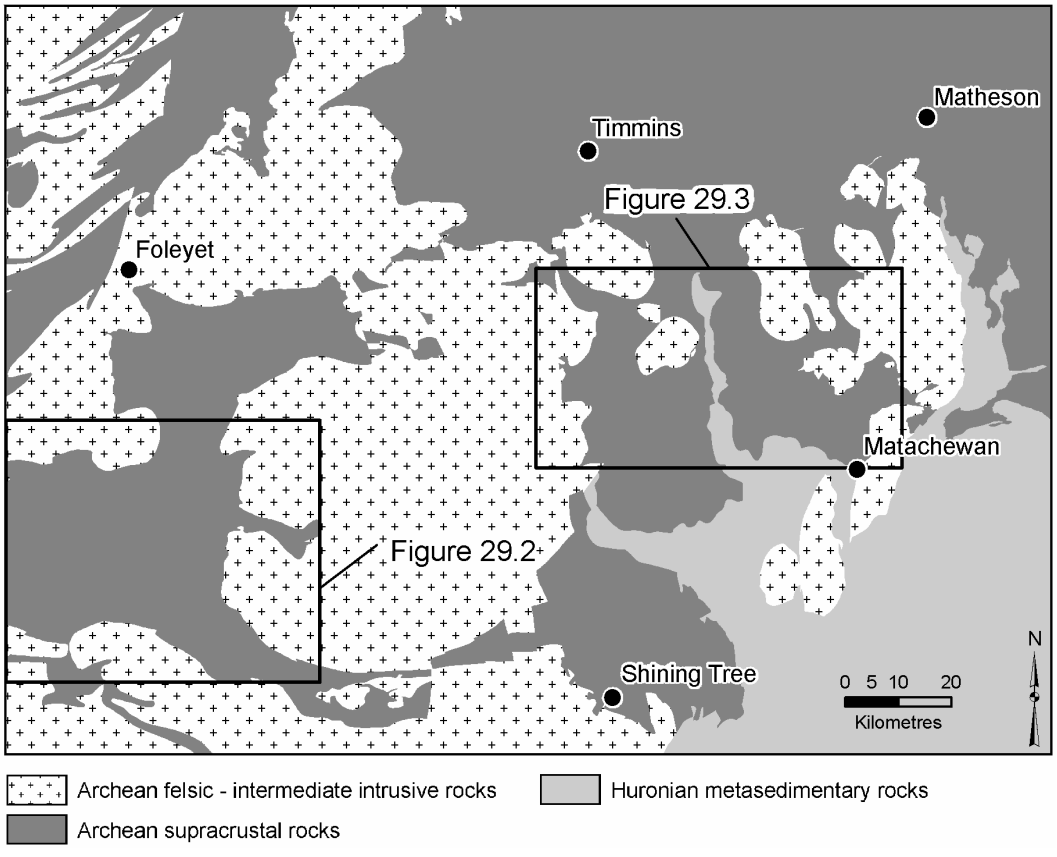

Figure 29.1. Location of case study areas, southern Abitibi greenstone belt.

Summary of Field Work and Other Activities 2006,
Ontario Geological Survey, Open File Report 6192, p.29-1 to 29-7.

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case study areas complement the existing study areas in providing a range of gold enrichment and deposit size (in particular surface exposure) of undisturbed gold occurrences, and size of gold dispersal plumes in till. In part, this will help determine, at least qualitatively, to what degree the intensity of surficial (in particular lake sediment) gold anomalies reflect the surface extent and grade of the source.

FIELD WORK

Suitable gold dispersion study areas to build case histories were guided by the presence of at least 3 characteristics: the presence of an existing gold bedrock showing; an associated gold anomaly in surficial media (till or lake sediment); and a nearby lake within the drainage watershed of the bedrock gold occurrence. A portion of the Abitibi greenstone belt, south of Timmins between Matachewan and Peterlong Lake, was chosen for this project due to the abundance of gold showings (*see* Figure 29.3) and

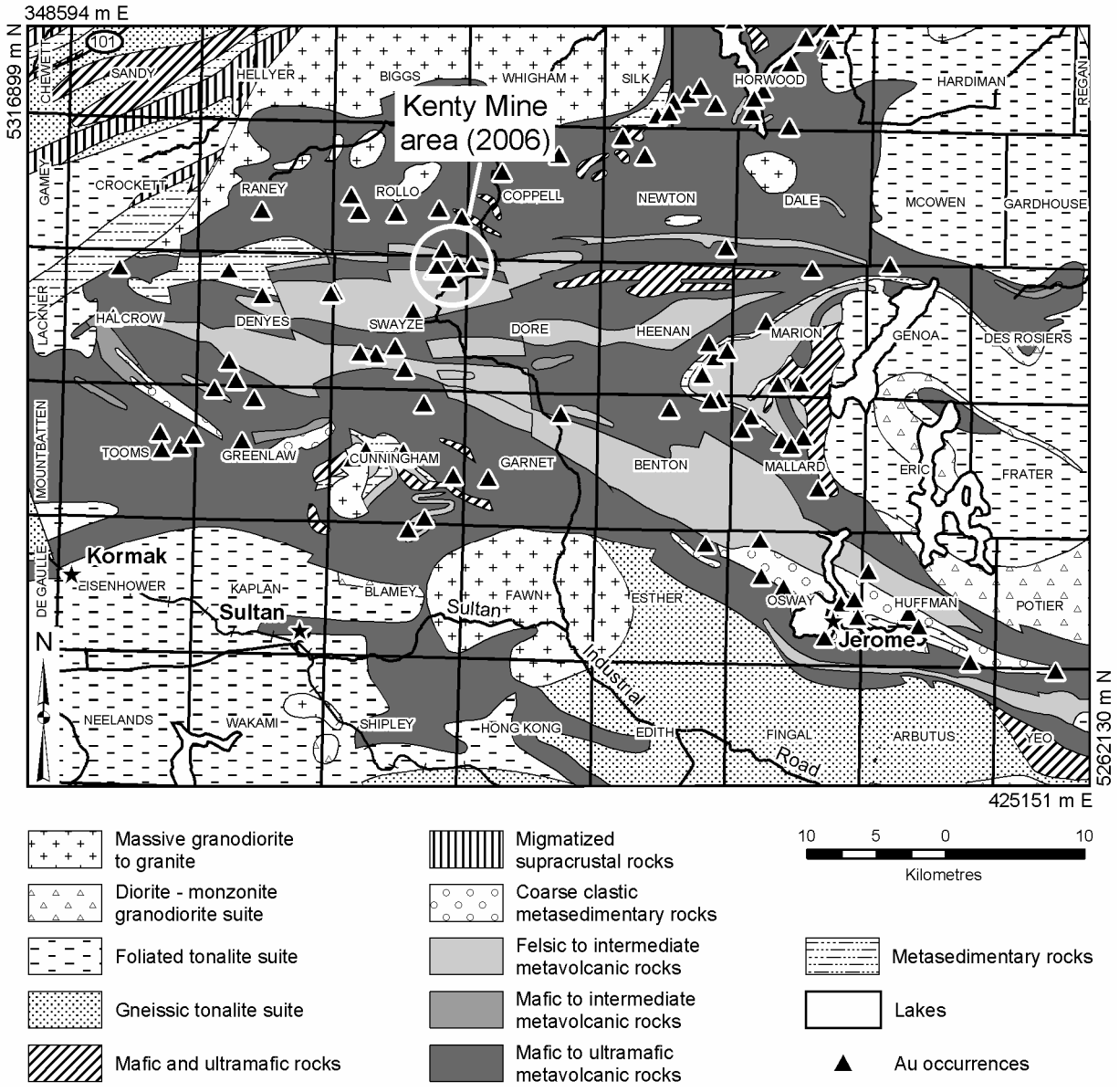

Figure 29.2. Location of the Kenty Mine case study area, central Swayze greenstone belt.

the wealth of recent data for the area including Quaternary mapping (Bajc and Paterson 2000a, 2000b), till geochemistry and indicator mineral sampling (Bajc 1996; Bajc et al. 1996; Bajc 1997; Bajc and Crabtree 2001), bedrock mapping (Ayer et al. 2003; Berger 2004; Berger and Préfontaine 2005; Préfontaine and Berger 2005) and lake sediment geochemistry (Bajc et al. 1996; Ontario Geological Survey 2001). In 2006, the area of interest was broadened to include the central Swayze greenstone belt, as it also features an abundance of gold showings and a large volume of geoscientific data. This data includes bedrock mapping and compilations (Heather and Shore 1999; Ayer and Trowell 2002), Quaternary mapping and till sampling (Bernier 1994, 1998; Bernier et al. 1995; Bernier and Kaszycki 1995), and lake sediment geochemistry (Takats 2005).

The Kenty Mine area is underlain by mafic and felsic metavolcanic rocks, the latter intercalated with sandstone and conglomerate metasedimentary rocks and intruded locally by discrete quartz-feldspar porphyritic bodies (Heather and Shore 1999). Both fine- and coarse-grained free gold is associated with quartz veins and stringer networks within highly iron-carbonate (ankerite) altered and silicified, east-trending shear zones that dissect the metavolcanic rocks. The fracture or alteration zones average 1.5 m in width, but may be up to 5 m wide, with heavily silicified, ankeritized and pyritized wall rock (Rickaby 1935). The author observed similar shearing and alteration within new trenches, approximately 1.5 km to the southeast of the Kenty Mine shafts, within conglomerate metasedimentary rocks.

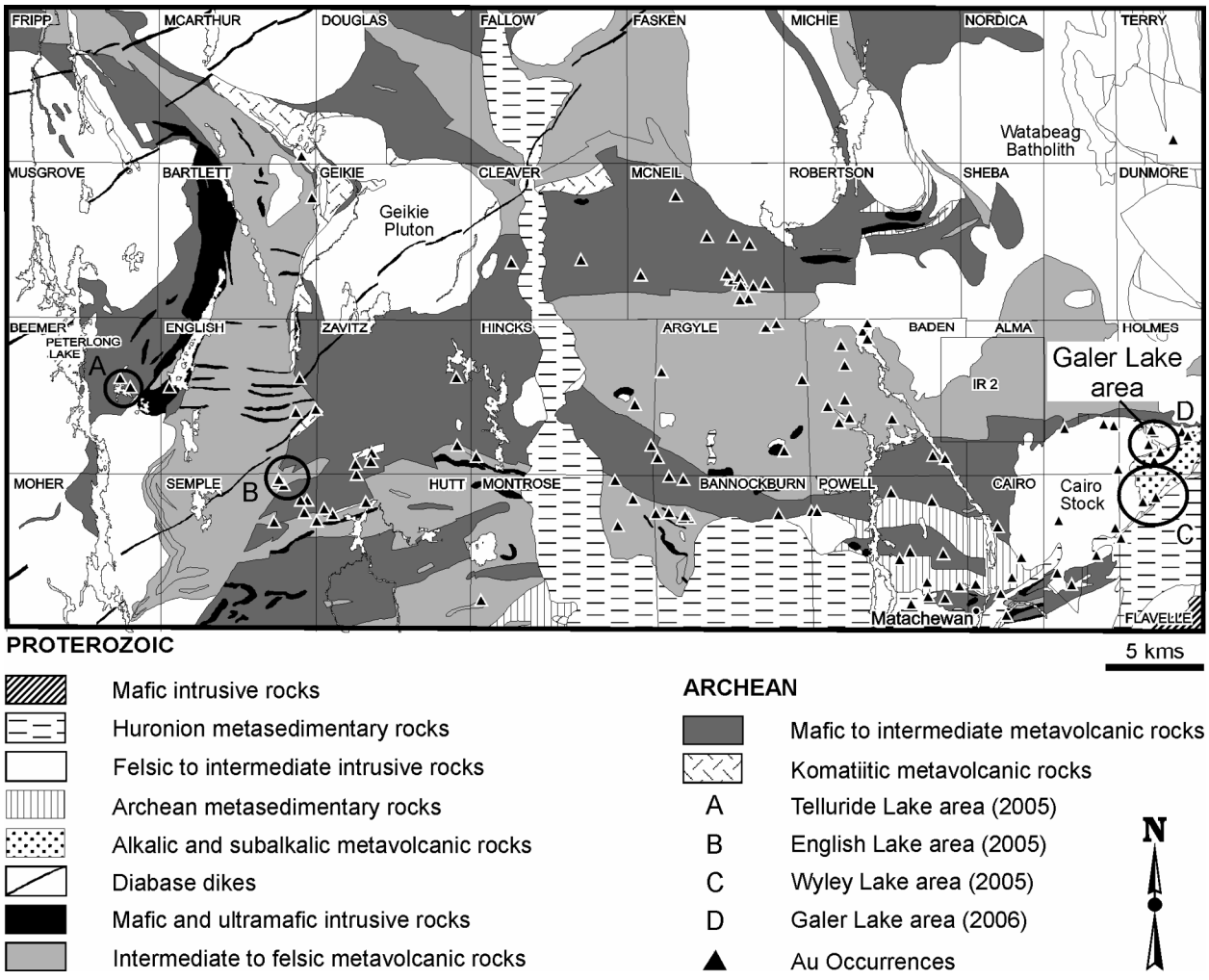

Figure 29.3. Location of the Galer Lake case study area and case study areas sampled in 2005.

The Kenty Mine consisted of 2 vertical shafts that were sunk in 1932, resulting in the production of approximately 1250 tons of ore of unknown grade from the #1 shaft (Fumerton and Houle 1993). Reserves have been reported as 62 100 tonnes at 2.4 g/t for the #1 shaft area and 43 300 tonnes at 4.7 g/t for the #2 shaft area (Fumerton 1995). Apparently a third shaft was sunk at a later date and further work, including bulk sampling, was undertaken in the early 1990s (Bernier 1994).

Previous till sampling by Bernier (1994) outlined a broad area (3 km wide by 4.5 km long) with anomalous levels of particulate gold in till centred on the Kenty Mine area. This area returned a very strong gold grain in till anomaly of 342 grains. Within this anomalous area, 4 lakes returned gold values in lake sediment between 4 and 7 ppb (Takats 2005). The highest value of 7 ppb was obtained from a small lake within 500 m of Bernier's highest gold grain result. Neither of these anomalies can be related to the main Kenty gold occurrences (#1 and #2 shafts). However, a number of other gold grain anomalies in till were obtained by Bernier (1994) most of which are located down-ice of the Kenty Mine #2 shaft area.

The second area investigated during the 2006 field season was the Galer Lake area in Holmes Township northeast of Matachewan. Specifically, the area covering Galer Lake and Cowie Lake between the Galer Lake fault and the Kincaid fault was investigated. This area has a number of gold showings including the Geraldine, Cowie, Loki-1 and Loki-4 occurrences. The bedrock geology was recently mapped by Berger (2006) who indicates the area is underlain primarily by alkalic metavolcanic rocks and syenite. Berger (2006) describes the presence of significant hydrothermal alteration (pervasive iron-carbonate and silica) associated with both the Kincaid and Galer faults in this area and has recommended further exploration. Approximately 150 m to the north of Cowie Lake (which lies down-ice of the Kincaid fault), a till sample returned 12 gold grains, which is anomalous for this area (Bajc et al. 1996). This may be related to mineralization associated with the Kincaid fault. The presence of a 9 ppb Au anomaly from Cowie Lake (Bajc et al. 1996) may be associated with a known gold showing near its western shore (Cowie Lake Au-Cu occurrence) or related to mineralization up-ice towards the Kincaid fault.

In order to further define and refine the gold dispersion plume(s) previously identified within these case study areas, "C' horizon till samples, lake sediment samples and stream sediment samples were collected. At the Kenty Mine area, a total of 21 "C' horizon till samples, 14 lake sediment samples, 7 stream sediment samples and 9 rock samples were collected. Within the Galer Lake area, case study sampling consisted of a total of 21 "C" horizon till samples, 23 lake sediment samples and 3 rock samples. Till samples (typically between 15 to 20 kg) were taken to better define the extent and direction of glacial dispersion trains related to the gold occurrences. A smaller approximately 1.5 kg sample was also taken for analysis by conventional fine-fraction (–63 μm) geochemistry. A representative number of pebbles were also collected at each site for lithological examination. At selected lake sediment sample sites, 2 samples were collected using the OGS torpedo coring apparatus and one large sample with an Ekman dredge. The Ekman dredge was used in order to obtain a bulk sample for tabling and micropanning to isolate any gold grains. Rock samples were collected in order to further characterize the gold content and possible pathfinder elements of the known occurrences.

SAMPLE PREPARATION AND ANALYSIS

Till and stream sediment samples were collected in large plastic bags after being passed through a 5 mm screen. Approximately 30 to 50 pebbles were collected from each sample for pebble lithology study. Lake sediment samples (~1 to 1.5 kg) collected by torpedo coring were placed in breathable fabric bags and allowed to partially air dry prior to oven drying at 35 to 40°C. Samples collected by Ekman dredge (~4 to 10 kg) were double bagged in large plastic bags.

The bulk samples of till and lake sediment will be submitted to Overburden Drilling Management for tabling to isolate a heavy mineral concentrate, followed by micropanning to accurately determine gold content. Gold grain morphology will be classified as described by Averill (2001) and a gold concentration in ppb will be calculated based on the size dimensions of the grains recovered.

The lake sediment samples obtained by gravity coring (~1 to 1.5 kg), after drying, will be gently disaggregated followed by sieving at 60 mesh to isolate the –250 μm size fraction. Based on previous experience, the resulting prepared sample pulp will range between 50 and 150 g. The entire prepared pulp will be separated into aliquots and consumed for replicate analysis by instrumental neutron activation analysis (INAA) (thermal and epithermal irradiation) and fire assay–inductively coupled plasma mass spectrometry (FA-ICP–MS). After a suitable period of cooling, the INAA briquettes will be submitted to Overburden Drilling Management for micropanning to isolate any gold grains and determine grain morphology.

In addition to the gold analysis, 0.5 g of material from each sample will be digested in nitric acid-aqua regia followed by ICP–MS to determine approximately 50 trace elements. Selected samples will undergo a commercially available weak leach (Mobile Metal Ion Process™ (MMI) and Enzyme Leach^{SM}) analysis, and for comparison, also analyzed using the stronger leaches ammonium acetate (pH 5 or 7) and sodium pyrophosphate.

The INAA analysis will also provide arsenic data and a suite of approximately 30 other elements. Quality control will be monitored through the use of replicate analysis of OGS reference materials and certified reference materials. Loss-on-ignition (LOI) is determined at 500°C, using an automated gravimetric technique.

PROJECT OUTCOMES AND STATUS

The initial goals of the sampling, preparation and analytical strategy of this project, which will potentially have an immediate impact on OGS lake sediment methodologies, are fourfold:

1. Determine the optimum initial (field) sample size for lake sediments, optimum preparation methods and optimum subsample size for analysis;
2. Determine the optimum and most cost-effective analytical method for gold;
3. Determine the dominant mode of gold transport into the lake basin (physical versus hydromorphic transport);
4. Determine the effect of local landscape conditions on the geochemistry of gold and the detected signatures in surficial media and in particular, lake sediment.

All lake sediment samples collected in 2005 have been prepared in the laboratory by the author. This has resulted in several observations that bring into question whether the current preparation procedures are resulting in a subsample pulp that is truly representative of the original sample material (with reference to gold content). As a result, preparation procedures for all lake sediment samples collected in 2006, including the OGS lake sediment surveys (Dyer, this volume, Article 28; Felix, this volume) have been modified. These changes will maintain the consistency and quality of all the geochemical data currently obtained, with the anticipation of more consistent, reliable and reproducible gold results.

It is anticipated that all sample analysis for this project will be complete in early 2007 and a final report published before the end of 2007.

REFERENCES

Averill, S.A. 2001. The application of heavy mineral indicator mineralogy in mineral exploration with emphasis on base metal indicators in glaciated metamorphic and plutonic terrains; *in* Drift exploration in glaciated terrain, Geological Society, London, Special Publication No.185, p.69-81.

Ayer, J.A. and Trowell, N.F. 2002. Geological compilation of the Swayze area, Abitibi greenstone belt; Ontario Geological Survey, Preliminary Map P.3511, scale 1:100 000.

Ayer, J.A., Trowell, N.F., Josey, S., Nevills, M. and Valade, L. 2003. Geological compilation of the Matachewan area, Abitibi greenstone belt; Ontario Geological Survey, Preliminary Map P.3527, scale 1:1000 000.

Bajc, A.F. 1996. Regional distribution of gold in till in the Peterlong Lake–Radisson Lake area, southern Abitibi Subprovince; potential exploration targets; Ontario Geological Survey, Open File Report 5941, 57p.

——— 1997. A regional evaluation of gold potential along the western extension of the Larder Lake–Cadillac Break, Matachewan area: results of regional till sampling; Ontario Geological Survey, Open File Report 5957, 50p.

Bajc, A.F. and Crabtree, D.C. 2001. Results of regional till sampling for kimberlite and base metal indicator minerals, Peterlong Lake–Radisson Lake area, northeastern Ontario; Ontario Geological Survey, Open File Report 6060, 65p.

Bajc, A.F., Hamilton, S.M., Ayer, J. and Jenson, L.S. 1996. New exploration targets in the Peterlong Lake–Radisson Lake area, southern Abitibi Subprovince: till, lake sediment and lake water sampling programs; Ontario Geological Survey, Open File Report 5942, 129p.

Bajc, A.F. and Paterson, J.T. 2000a. Quaternary geology of the Radisson Lake area, northeastern Ontario; Ontario Geological Survey, Map 2610, scale 1:50 000.

——— 2000b. Quaternary geology of the Peterlong Lake area, northeastern Ontario; Ontario Geological Survey, Map 2611, scale 1:50 000.

Berger, B.R. 2004. Geology of Burt–Holmes area, District of Timiskaming; *in* Summary of Field Work and Other Activities 2004, Ontario Geological Survey, Open File Report 6145, p.5-1 to 5-9.

——— 2006. Geological synthesis along Highway 66 from Matachewan to Swastika; Ontario Geological Survey, Open File Report 6177, 125p.

Berger, B.R. and Préfontaine, S. 2005. General geology of Powell Township, District of Timiskaming; *in* Summary of Field Work and Other Activities 2005, Ontario Geological Survey, Open File Report 6172, p.5-1 to 5-10.

Bernier, M.A. 1994. Particulate gold and heavy mineral abundance in surficial sediments, western Swayze greenstone belt; Ontario Geological Survey, Open File Report 5898, 63p.

——— 1998. Quaternary geology, Rollo Lake area; Ontario Geological Survey, Map 2488, scale 1:50 000.

Bernier, M.A. and Kaszycki, C.A. 1995. Till, humus and B-horizon soil geochemical database, surficial sediment sampling program, Swayze greenstone belt, northern Ontario, District of Timmins, 1992–1994; Ontario Geological Survey, Miscellaneous Release—Data 15.

Bernier, M.A., Kaszycki, C.A., Wilkinson, L. and Harris, J.R. 1995. Proportionally sized circle plot of particulate gold abundance in surficial sediments (–10 mesh size fraction), Swayze greenstone belt, Superior Province Ontario; Ontario Geological Survey, Preliminary Map P.3326, or Geological Survey of Canada, Open File Map 3130, scale 1:150 000.

Dyer, R.D. 2005. Gold dispersion and geochemical response in surficial media: implications for data interpretation and exploration; *in* Summary of Field Work and Other Activities 2005, Ontario Geological Survey, Open File Report 6172, p.24-1 to 24-8.

Fumerton, S.L. 1995. Summary tables on mineral prospects in the Swayze greenstone belt; Ontario Geological Survey, Open File Report 5913, 105p.

Fumerton, S.L and Houle, K.A. 1993. Mineral showings, occurrences, deposits and mines of the Swayze greenstone belt, interim report; Ontario Geological Survey, Open File Report 5871, v.1, v.2, 763p.

Heather, K.B. and Shore G.T. 1999. Geology, Rollo Lake, Swayze greenstone belt, Ontario; Geological Survey of Canada, Open File 3384b, scale 1:50 000.

Ontario Geological Survey 2001. Peterlong Lake–Radisson Lake area high density lake sediment survey: gold and PGE data – Operation Treasure Hunt; Ontario Geological Survey, Open File Report 6053, 46p.

Préfontaine, S. and Berger, B.R. 2005. General geology of Bannockburn and Montrose townships, District of Timiskaming; *in* Summary of Field Work and Other Activities 2005, Ontario Geological Survey, Open File Report 6172, p.6-1 to 6-7.

Rickaby, H.C. 1935. Geology of the Swayze gold area; Ontario Department of Mines, Annual Report, 1934, v.43, pt.3, p.1-36.

Takats, P.A. 2005. Central Swayze area high-density regional lake sediment and water geochemical survey, northeastern Ontario; Ontario Geological Survey, Open File Report 6173, 132p.

30. Project Unit 05-011. A Seamless Paleozoic Geology Map for Southern Ontario: A Progress Report

D.K. Armstrong[1] and J.E.P. Dodge[1]

[1]Sedimentary Geoscience Section, Ontario Geological Survey

INTRODUCTION

This project was initiated in 2005 to provide critical data required for source water protection initiatives in the Province. Project objectives and methodology were described by Dodge, Armstrong and Kelly (2005). The initial phase of this project involved digital compilation of available 1:50 000 scale Paleozoic bedrock geology maps, incorporating bedrock geology data from other sources where Ontario Geological Survey (OGS) map coverage may be lacking or dated, creation of a common working legend, and development of preliminary attribute tables.

The second phase of this project has involved field investigations to check so-called "boundary faults" between map sheets and to familiarize project staff with mapped stratigraphic units and their variability across the Province. The latter is required to ensure an accurate common legend for the final seamless map.

In areas where the Paleozoic bedrock is covered by thick Quaternary deposits, and where detailed maps are not available, other data sources are being used to check and, if necessary, modify the available regional-scale bedrock maps (e.g., OGS 1991; Uyeno, Telford and Sanford 1982; Liberty and Bolton 1971; Liberty 1969; Sanford 1969). Additional data sources include water well records, petroleum exploration well records and an updated topographic map of the bedrock surface for southern Ontario (*see* Gao et al., this volume).

The primary goal of this project is to create a seamless map from available, mainly published sources and not to extensively re-map the Paleozoic geology of southern Ontario. Once the project is complete, deficiencies and errors in published bedrock maps will be highlighted for potential future investigation.

This *Summary of Field Work* paper will highlight the preliminary findings of field investigations for the summer of 2006.

FIELD INVESTIGATIONS

Field investigations during the summer of 2006 focussed on areas in southern Ontario covered by 1:50 000 scale Paleozoic geology maps published by the OGS (Figure 30.1). These OGS maps essentially, and not coincidentally, cover areas where bedrock is exposed or covered by relatively thin drift, including most of eastern Ontario; the Ordovician outcrop belt from the Kingston area to Georgian Bay; the Silurian outcrop belt along the Niagara Escarpment, from the Niagara Peninsula to the Bruce Peninsula and on to Manitoulin Island; and a small Devonian outcrop belt, north of eastern Lake Erie.

Field work during the summer of 2006 was conducted in 6 geographic and stratigraphic areas, which are labelled A through F in Figure 30.1.

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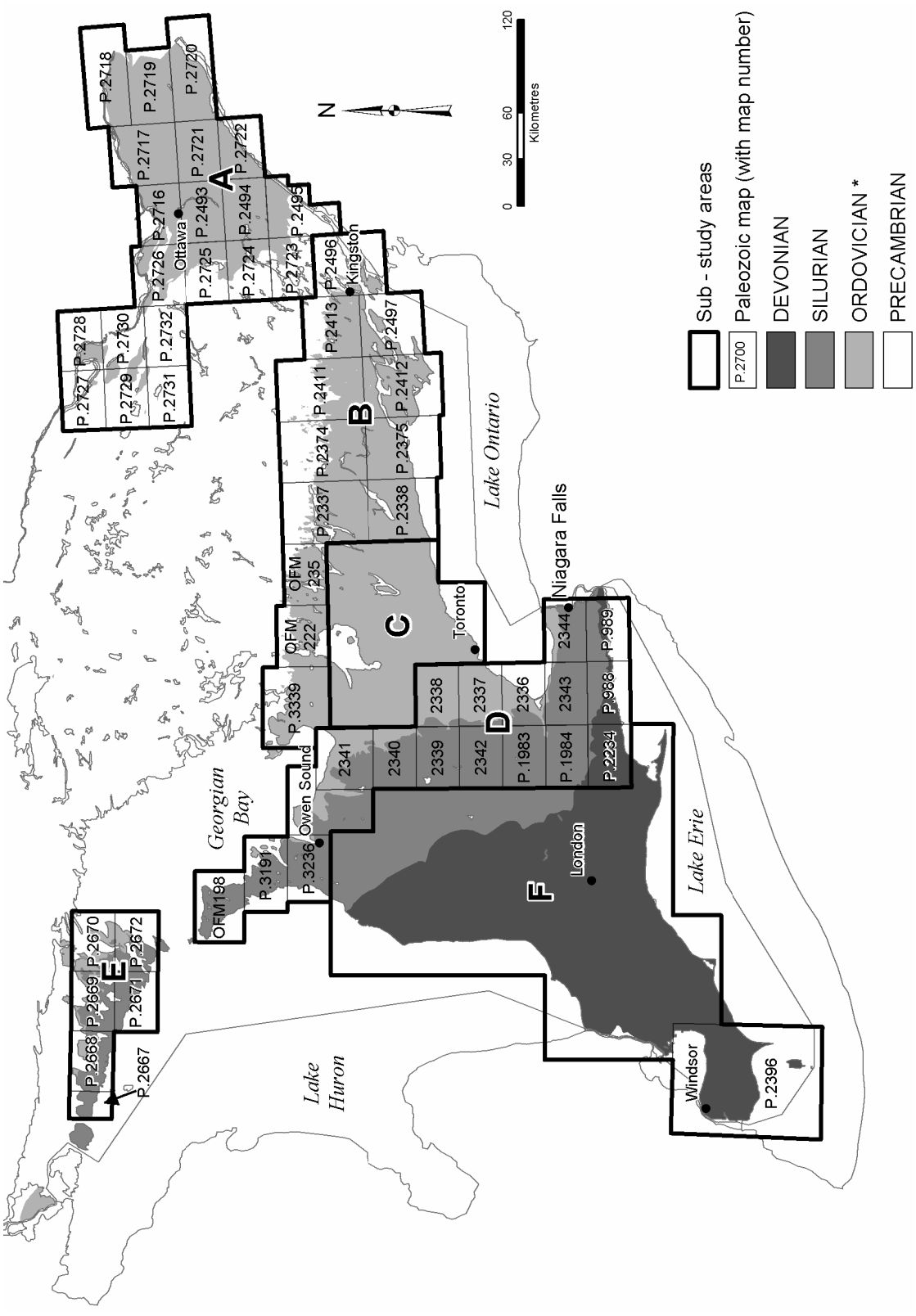

Figure 30.1. Simplified Paleozoic geology map of southern Ontario showing distribution of Paleozoic maps published by the Ontario Geological Survey (small boxes labelled with map numbers) and field work areas for 2006 field season (large boxes labelled A through F). Explanation of map numbers: OGS Map = [number]; OGS Preliminary Map = P.[number]; OGS Open File Map = OFM [number]. (Note for Legend: "Ordovician*" includes Cambrian in eastern Ontario.)

Area A – Eastern Ontario

Area A is covered by 20 1:50 000 scale preliminary Paleozoic geology maps (labelled in Figure 30.1). The Paleozoic strata in this area consist of Cambrian through to Upper Ordovician strata that were extensively faulted during Mesozoic extensional tectonism (Johnson et al. 1992; Williams 1991).

The most recent mapping by the OGS in eastern Ontario was largely carried out in the early 1980s by D.A. Williams and R.R. Wolf. They were involved in mapping of all except 3 map sheets, the Brockville–Mallorytown, Merrickville and Kemptville map sheets (maps P.2495, P.2494 and P.2493; *see* Figure 30.1), which were mapped by D.M. Carson. Significant "boundary faults" exist between the Carson maps and those of the surrounding Williams and Wolf maps. Subsequent mapping by D.A. Williams resolved these "boundary faults", as shown in page-size compilation maps in Williams (1991) and Johnson et al. (1992). Williams' 1:50 000 scale revised working maps were obtained for this project and have been digitized for inclusion in the seamless map.

Field work in eastern Ontario was conducted in May of 2006 with the assistance of D.A. Williams (retired) and F.R. Brunton (OGS). Stratigraphically significant and representative outcrops were examined, resolved "map boundary faults" were assessed, and the general structural interpretation for this region as presented in Williams (1991) was also assessed.

Area B – South-Central Ontario

Area B is located in south-central Ontario and is underlain by Cambrian to Middle Ordovician strata. This area is bounded to the north by the Paleozoic–Precambrian unconformity and characterized by the Middle Ordovician escarpment, which trends roughly parallel to the unconformity, from the Kingston-Gananoque area to the Midland area on Georgian Bay. Quaternary drift cover generally thickens to the south and west of this escarpment.

Area B is covered by 12 1:50 000 OGS Paleozoic bedrock map sheets (*see* Figure 30.1). Nine of these maps, from the Peterborough–Campbellford map sheet east, were most recently mapped by D.M. Carson in the early 1980s. The 3 westernmost maps (Fenelon Falls, Orillia and Penetanguishene map sheets) were mapped by D.K. Armstrong and assistants in the early 1990s. Field work for this project found that map boundary faults at the formation level are generally minor and could be readily resolved. At the sub-formation level (i.e., members), facies changes within the Middle Ordovician Bobcaygeon and Gull River formations resulted in differing breakdowns of these formations (e.g., 3 members on one map sheet versus 2 members on another) such that they can cannot be easily correlated from map to map.

The situation is similar for the Lindsay Formation in the Prince Edward County area, which Carson subdivided into 2 members, both of which make up the lower member of the Lindsay Formation as per Johnson et al. (1992).

One of the map sheets in Area B, the Gananoque sheet (P.2496), is known to contain some significant mapping errors. These errors were addressed with the help of working maps by D.A. Williams and were field checked during the course of this summer's field work.

Area C – South Lake Simcoe

Area C consists of a thick drift covered area between Lake Simcoe and Lake Ontario, south and west of Area B (*see* Figure 30.1). Paleozoic bedrock in this area ranges from Middle to Upper Ordovician in age. This area has not been mapped in detail by the OGS, and so the best available data sources are

regional-scale maps by Liberty (1969), Sanford (1969) and OGS (1991). Subsurface data sets such as water well and petroleum well records, in addition to a new bedrock topography map (*see* Gao et al., this volume), will be used to blend these maps with the more detailed mapping of surrounding areas.

Area D – Niagara Escarpment

Area D includes the Niagara Escarpment and immediately adjacent areas from the Niagara Peninsula to the Bruce Peninsula (*see* Figure 30.1). Paleozoic strata range from Upper Ordovician shale units east (and north) of the Escarpment through to Middle Devonian carbonate-dominated units along the north shore of eastern Lake Erie.

Area D is covered by 17 OGS Paleozoic maps: 3 maps completed on the Bruce Peninsula by D.K. Armstrong and assistants in the late 1980s; 9 maps along the Escarpment from Collingwood to Niagara Falls by P.G. Telford, B.A. Liberty, I.J. Bond and B.H. Feenstra in the mid-1970s; and 5 maps to the south and west of the Escarpment to Lake Erie completed by Telford and assistants. There are no published Paleozoic bedrock maps for the section of the Niagara Escarpment between Collingwood and Owen Sound. Data from published OGS Quaternary maps and Aggregate Resources Inventory Papers (ARIPs) will be used to cover this gap.

This area includes units deposited in the Appalachian Basin and their correlative units in the Michigan Basin (*see* Johnson et al. 1992) and, as such, there is considerable lateral lithologic and stratigraphic variability. Most of this variability occurs in relatively thin units that occur in narrow outcrop belts at the base and below the Niagara Escarpment, so by lumping them into larger units (i.e., groups), they can be portrayed in a seamless fashion. Efforts will be made in the final seamless map to indicate outcrops of specific formational units.

Field work during the summer of 2006 focussed on confirming mapping in the Collingwood to Owen Sound gap (*see* text above), resolving "boundary faults" especially between the gap and adjacent maps, and clarifying the sometimes ambiguous mapping of the thin units east of the Niagara Escarpment, especially on the Bruce Peninsula.

Area E – Manitoulin Island

Area E consists of Ordovician and Silurian strata on Manitoulin Island. The 6 1:50 000 scale OGS maps covering the island were all done by M.D. Johnson and P.G. Telford in the early to middle 1980s, so there are only a few relatively minor boundary faults. In general, field work on Manitoulin Island for this project involved examination of key outcrops to familiarize project staff with the bedrock units on the island and evaluate how they may differ from their correlative stratigraphic units on the Bruce Peninsula.

Area F – Southwestern Ontario

Area F includes largely drift-covered Devonian and Upper Silurian strata of southwestern Ontario. Only 1 1:50 000 Paleozoic map, P.2396 in the Windsor–Essex area, has been published by the OGS within this area, largely because of a paucity of outcrops. More regional-scale maps published by the GSC (e.g., Uyeno, Telford and Sanford 1982; Liberty and Bolton 1971; Sanford 1969) were created using the sparse but significant outcrop and quarry exposures in the area and subsurface data sources such as petroleum exploration drilling records.

Field work for this project involved examining the existing few key outcrops and some newly available drill cores. These observations will be combined with detailed examination of digital subsurface data sets to refine the existing map for this area.

FUTURE WORK

The last phase of this project will culminate with the generation of a "seamless map". Boundary faults that exist between individual map sheets will be corrected using data collected from the field. Map coverages for thick-drift covered areas will be evaluated using available subsurface data sets which include the new bedrock topographic surface map (*see* Gao et al., this volume); available cores and borehole logs, water well records; as well as digital subsurface bedrock data obtained from the Ontario Oil, Gas and Salt Resources Library. Other work will include the standardization of all attribute tables, creating a geological symbols library for ESRI® ArcMap® 8.x and developing a provincial legend that will translate all original map legends to a common legend. It is anticipated that a final seamless map will be completed early in 2007.

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REFERENCES

Dodge, J.E.P., Armstrong, D.K. and Kelly, R.I. 2005. Paleozoic geology map of southern Ontario; *in* Summary of Field Work and Other Activities 2005, Ontario Geological Survey, Open File Report 6172, p.28-1 to 28-3.

Johnson, M.D., Armstrong, D.K., Sanford, B.V., Telford, P.G. and Rutka, M.A. 1992. Paleozoic and Mesozoic geology of Ontario; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 2, p.907-1008.

Liberty, B.A. 1969. Paleozoic geology of the Lake Simcoe area, Ontario; Geological Survey of Canada, Memoir 335, 201p.

Liberty, B.A. and Bolton, T.E. 1971. Paleozoic geology of the Bruce Peninsula area, Ontario; Geological Survey of Canada, Memoir 360, 163p.

Ontario Geological Survey 1991. Bedrock geology of Ontario, southern sheet; Ontario Geological Survey, Map 2544, scale 1:1 000 000.

Sanford, B.V. 1969. Geology, Toronto–Windsor area, Ontario; Geological Survey of Canada, Map 1263A, scale 1:250 000.

Uyeno, T.T., Telford, P.G. and Sanford, B.V. 1982. Devonian conodonts and stratigraphy of southwestern Ontario; Geological Survey of Canada, Bulletin 332, 55p.

Williams, D.A. 1991. Paleozoic geology of the Ottawa–St. Lawrence Lowland, southern Ontario, Ontario Geological Survey, Open File Report 5770, 291p.

31. Project Unit 05-012. Karst Compilation for Southern Ontario: An Update

F.R. Brunton[1], J.E.P. Dodge[1] and J. Shirota[1]

[1]Sedimentary Geoscience Section, Ontario Geological Survey

INTRODUCTION

This report summarizes findings of an Ontario Geological Survey two-year regional-scale, reconnaissance-level mapping program of karst features within Phanerozoic strata of southern Ontario. The 2006 field season focussed on exposed and thin-drift regions proximal to the Niagara Escarpment and younger Devonian cuestas of southwestern Ontario. This physiographic region encompasses the western St. Lawrence Lowlands (Chapman and Putnam 1984; Sanford 1993), including Manitoulin and adjacent islands (Figure 31.1). This regional-scale survey of karst will incorporate and build upon currently active and past local and regional karst studies in southern Ontario (e.g., Ford 1961, 1974, 1983, 1987; Pluhar and Ford 1970; Ford and Quinlan 1973; Cowell and Ford 1975, 1980, 1983; Cowell and Woerns 1977; Goodchild 1978, 1984; Ford and Williams 1989; D.W. Cowell and Associates, Inc. 1989; Tinkler and Stenson 1992; Cowell et al. 1994a, 1994b; Enyedy-Goldner 1994; Buck 1994a, 1994b, 1999, 2003; Worthington, Ford and Beddows 2000; Worthington 2003; Kunert and Coniglio 2002; Buck, Worthington and Ford 2003; Strynatka 2003; Russell 2004; Abbey, Hurley and Merry 2004).

The main purpose of this multi-year karst inventory project is to provide a geological framework and characterization of the physical–chemical responses of the various Paleozoic bedrock units throughout southern Ontario to karstification. It builds upon recent field studies carried out by OGS staff and others, the purposes of which were to assess particular physical characteristics of soils and the nature of jointing within selected thin-drift and exposed limestone plains in southern Ontario (Andjelkovic and Cruden 1999; Strynatka 2003; Russell 2004). The karst inventory project includes 2 field-based components: 1) a two-year karst mapping initiative of south-central and southeastern Ontario (2005) and southwestern Ontario (2006); and 2) a contracted assessment of bedrock character beneath selected thin-drift areas within the various limestone plains of southern Ontario (Brunton, Dodge and Shirota 2005). The subsurface three-dimensional (3D) karst (borehole) study was conducted by Golder Associates during the fall and winter of 2005–2006 and is currently undergoing final preparation. Results of the borehole study will be incorporated into the final karst inventory report and geographic information system (GIS)-based maps, scheduled for release in the spring of 2007.

Summary of Field Work and Other Activities 2006,
Ontario Geological Survey, Open File Report 6192, p.31-1 to 31-9.

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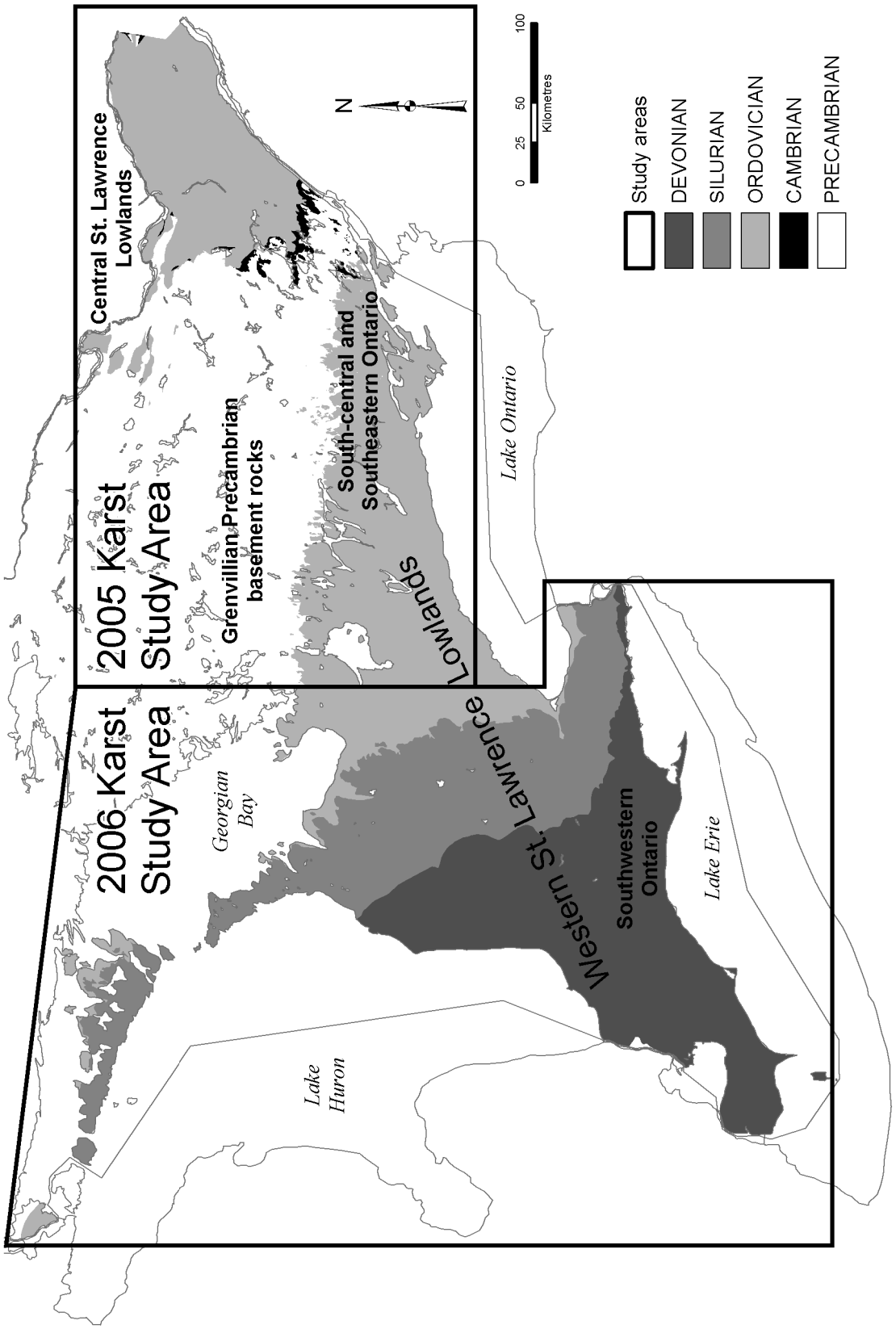

Figure 31.1. Location map showing karst study areas for the 2005 and 2006 field seasons and general bedrock geology.

KARST IN SOUTHERN ONTARIO

Karst is a term used to describe landscapes that display distinctive features resulting from chemical dissolution and precipitation of bedrock known as carbonates (e.g., limestone, dolostone, and marble), gypsum and salt. Such landscapes are typified by a wide range of closed surface depressions, a well-developed underground drainage system and a paucity of surface streams. The highly varied interactions among chemical, physical and biological processes have a broad range of geological effects including dissolution, precipitation, sedimentation, subterranean collapse and/or ground subsidence. Diagnostic features include sinkholes (dolines), sinking streams, karren, and caves and large springs resulting from solutional interactions of circulating groundwater, which may exit to entrenched effluent streams. Although all of these features are present across the southern Ontario portion of the St. Lawrence Lowlands region, they are best developed in the Silurian–Devonian carbonates situated within southwestern Ontario, including Manitoulin Island.

It is interesting that for a landscape covering more than 20% of the North American continent, "karst" is a term that is foreign to most Ontarians. The main reason for this is that most of the limestone plains throughout the western and central St. Lawrence Lowlands have had the surficial expressions of karst either removed by erosion during the various glacial events over the past few million years and/or are presently covered by thick gravel, sand, and clay (glacial drift) units that were deposited primarily during the retreat of the Laurentide Ice Sheet approximately 11 000 years ago (Barnett 1992). Such glacial deposits would have filled in and/or partially eroded surficial bedrock expressions of caves and sinkholes. At present, only select regions of exposed or thin drift limestone plains, representing about 10% of southern Ontario, allow for the nature of karstification to be described and interpreted. Extensive physical erosion of the bedrock surface also occurred during the last ice age, either through active abrasion by the moving ice and/or subsequent meltwater surges or flooding events that occurred during retreat of the ice lobes (e.g., Spencer 1890; Straw 1968; Karrow 1973; Barnett 1990; Shaw and Gilbert 1990; Kor, Shaw and Sharpe 1991; Brennard and Shaw 1994; Shaw 1996; Kor and Cowell 1998).

Karst landscapes are caused mainly by chemical erosion of bedrock by acidic surface and ground waters over a substantial time span—generally thousands to millions of years. Chemical leaching of these mainly sedimentary rocks creates enhanced permeability, especially along major joint sets in the upper tens of metres of exposed or thinly buried bedrock, resulting in conduit-style groundwater flow and greater connectivity between surface waters and groundwater aquifers. Therefore, shallow and, in some cases, even deeper groundwater aquifers in karsted terrains are more susceptible to biological and chemical contamination. Most of this underground water moves by laminar flow within interconnected narrow fissures (fractured bedrock) commonly referred to as channels or conduits. When these channels become enlarged above, at or below the water table, they may form subsurface maze and/or crevice cave networks. The water flow within these larger open cavernous structures may become turbulent. It appears that once conduits are 1 mm in diameter or greater, they may become significant in the karstification process (Worthington 2001, 2002; Worthington, Davies and Ford 2000).

Caves contain a variety of dissolution features, sediments and speleothems (deposits with various forms and mineralogy, chiefly calcite), all of which may preserve a record of the geological and climatic history of the area. Karst deposits and landforms may persist for extraordinarily long times in relict caves and paleokarst—something that has not been thoroughly investigated in many areas of Ontario. The limestone-dolostone bedrock karst features of southern Ontario are generally regarded as immature, even though interconnected maze and crevice caves within the Ordovician carbonates exceed 6 to 10 km in length and are among some of the longest in Canada (cf. Ford and Quinlan 1973; Ford 1983; White 1988; Ford and Williams 1989; Palmer 1991; Gordon 2005). The Paleozoic bedrock geology of states such as Kentucky, home of the Mammoth Caves, which are amongst the largest cave networks in North America, are very similar to Ontario; the main differences being that Kentucky was not glaciated, and the state's tectonic proximity to the various orogenic phases that formed the Appalachians.

FIELD OBSERVATIONS

Ontario Geological Survey field work associated with this two-year, reconnaissance-level, karst mapping initiative includes characterization of bedrock karst features, including documentation of site location; site description and photography; measurements of spacing and depth and strike of major joint sets; and, most importantly, general notes on lithologic units involved and geographic setting (i.e., location relative to key structural elements such as faults, folds and proximity to Precambrian basement inliers, mini-cuesta or escarpment margins, and other key physiographic features such as swamps, beaver ponds, streams, and position relative to paleodrainage areas, which are prime sources of acidified waters).

Field work and consultations and discussions with numerous land owners, staff of various Conservation Authorities, karst geologists, and cavers has resulted in the compilation of more than 400 caves and numerous other karst features, such as sinkholes, throughout southern Ontario. Field investigations of many of the more significant features have revealed some interesting regionally significant relationships. Almost all of the Ordovician limestone units display good joint-set development and variable degrees of dissolution at particular locations in the study area. Some of the major joints can persist through tens of metres of bedrock and extend from one formation to the next. However, cave development is largely restricted to the stratigraphic interval spanning the contact of the Bobcaygeon and Gull River formations. The main controls on cave formation appear to be 1) proximity to the region along which the Paleozoic–Precambrian unconformity spans; 2) proximity to major river systems and adjacent swampy areas (fluvial karst regions); and 3) proximity to margins of mini-escarpments or cuestas between the major rivers (i.e., situated at inferred margins of paleodrainage systems). Often, the caves are larger and joint-controlled—passageways are better developed where the Bobcaygeon Formation forms a thin caprock on the Gull River Formation.

Karst investigations carried out in southeastern Ontario during the spring of 2006 support the field investigations made in 2005 for the Ordovician and Cambrian sedimentary rocks (*see* Brunton, Dodge and Shirota 2005). Cave geometries appear to largely follow the regional joint patterns and are best developed at the stratigraphic interval spanning the upper Gull River and lower Bobcaygeon formations. In part, this is due to the fact that most of the major rivers have incised downward into the upper Gull River Formation, allowing sufficient volume and contact time with organic-rich, acidified surface and ground waters to enable significant joint dissolution and the creation of substantive crevice- or maze-like caves. The Bobcaygeon Formation forms the caprock of many of the small-scale cuestas within the Carden Plain through the Napanee–Kingston region. The longest reported cave networks in southern Ontario occur near Pembroke, along the Ottawa River, and possess more than 10 km of interconnected labyrinths. Some of the caves in and around the Belleville area also have upwards of 5+ km of interconnected pathways and possess multiple entrances and resurgences.

Karst mapping for the remainder of the 2006 field season (May–September, 2006) focussed on the Silurian–Devonian carbonates of southwestern Ontario and Manitoulin Island. The majority of published karst studies in Ontario have focussed on the Silurian carbonates of the Niagara Escarpment region, despite the fact that the longest and most areally extensive and accessible cave networks occur within Ordovician limestones of south-central and eastern Ontario (Ongley 1965; Gordon 2005). The Middle Devonian limestones within Huron and Bruce counties display significant sinkhole development, evidence of disappearing streams and underground streams, water wells that breathe (i.e., allow gas and water exchange from surface), and other hydrogeologic evidence (e.g., tufa deposits within rivers) suggesting laterally extensive and deeper karst (up to 100 m or more). Unfortunately, the significant overburden cover throughout much of southwestern Ontario makes it difficult to assess the true regional extent of this significant karst terrain. Only minor caves and have been reported (Ford 1974).

Regional-scale karst inventories of largely Silurian carbonates on Manitoulin Island through to Niagara Falls (Niagara Escarpment) and southwestward into the overlying Devonian carbonates reveal that the same fundamental controls on karst development exist as were observed in the Ordovician carbonates of south-central and southeastern Ontario. Significant cave and clint and grike formation in the Silurian succession of the Niagara Escarpment region occurs both proximal to significant escarpment or cuesta margins (mostly within 1 km to a few tens of kilometres) and/or within a few hundred metres of incised river systems that flow over the thin-drift portions of these bedrock plains. One of the first GIS-based karst geomorphology studies in Ontario was conducted on Manitoulin Island (Enyedy-Goldner 1994). Field mapping during 2006 confirmed many of her field observations, although the stratigraphic framework she employed differed from that used in this study. Karst is immature and reflected in various forms of karren (i.e., microkarst in the form of surface water sheet and channel flow: rillenkarren, rinnenkarren and rundkarren; and tectonic/structural controlled grikes: cleft karren or kluftkarren) on glacially sculpted dolostone-limestone pavements where finely crystalline mudstones or wackestones are exposed at surface (e.g., Manitoulin Formation plateau of Manitoulin Island; Fossil Hill plateau—"Saucer" part of Cup and Saucer trail on Manitoulin Island and on Bruce Peninsula). More significant clint and grike and cave development were evident where more thickly bedded, fossiliferous, dolomitized grainstones-wackestones overlie finer crystalline wackestones to mudstones (e.g., Fossil Hill–St. Edmund formational contact, and Lions Head–Wiarton/Colpoy Bay members contact within the Amabel Formation).

Three prominent thin-drift plains or cuestas are present on Manitoulin Island and to a lesser degree along the Bruce Peninsula. From oldest to youngest, these plateaus are capped by the Manitoulin, Fossil Hill and Amabel formations, respectively. Clint and grike development and potential cave development were least developed in the Manitoulin Formation: here, microkarst features prevail. Despite extensive bedrock exposure, sinkholes are relatively uncommon and were found largely in the Fossil Hill and Amabel formations. One of the only reported caves on Manitoulin Island is the Mindemoya Cave. It is situated on the west side of Lake Mindemoya and its formation appears to be controlled by dissolution along a regional joint set within the Fossil Hill Formation dolostone. Cave development is focussed in the uppermost beds of the underlying St. Edmund Formation. The sharp contrast in crystallinity and megafauna or skeletal content between the finely crystalline dolostones of the St. Edmund Formation and the overlying Fossil Hill Formation enabled sinkhole and cave development to penetrate a few tens of metres into the escarpment or cuesta edge. Although this formational contact was investigated at different locations across the island, the only other caves encountered were crevice caves formed at the edge of the Amabel Formation cuesta face along the Cup and Saucer trail. Caves have also been reported from the Wikwemikong Unceded Reserve on eastern Manitoulin Island, but this region was not part of the karst mapping inventory. One of the most intriguing features of Manitoulin Island is the general lack of significant rivers draining the large lakes found upon the Silurian caprock carbonates (*see* "Discussion" in Enyedy-Goldner 1994). Extensive and penetrative regional joints and sinkholes within the Amabel and Fossil Hill formation cuestas focus rain and surficial lake and river waters into the subsurface limiting the development of large surface water drainage networks. The underlying Cabot Head Shales appear to act as a regional aquitard, enabling interior lake levels to remain fairly constant on the island, and the focussing of acidified surface and shallow groundwaters through the upper Silurian dolostones.

In contrast to the general lack of caves on Manitoulin Island, the Bruce Peninsula region of the Niagara Escarpment cuesta boasts the largest concentration of escarpment-edge wave-cut caves and interior joint-controlled cave networks, sinkholes, clint and grike formation, and surface microkarst features in southern Ontario (*see* Cowell 1974, 1976; Cowell and Ford 1980, 1983; Cowell et al. 1994a, 1994b; Buck 1994a, 1994b, 1999, 2003; The Bruce–Grey Geology Committee 2004). In particular, the Fathom Five National Marine Park, situated in the northern part of the Bruce Peninsula and including adjacent islands, contains more than 200 of the approximately 450 caves known in southern Ontario. Some of the more significant caves have been gated to protect the exquisite speleothems from vandalism. The more significant of these caves is the joint-controlled Root Cave, which possesses some of the largest

speleothems known in central and eastern Canada. The potential of such speleothems to provide important paleoclimatic information for southern Ontario, in the form of oxygen and carbon isotopic records, makes the protection of these sites all the more important. Apart from a few significant and extensive joint-controlled sinkholes and cave networks in the Wodehouse, Shelburne, Guelph and Hamilton areas (Cowell and Ford 1975; Tovell 1992; Buck, Worthington and Ford 2003; Brunton, Dodge and Shirota 2005), all of which occur inboard but within a few kilometres of the Niagara Escarpment cuesta edge, the majority of caves and well-developed or penetrative joint-controlled grikes are crevice cave networks that extend from the cliff margin into the escarpment (*see* Ongley 1965; Tovell 1992; Gordon 2005).

General stratigraphic controls on karst development in the Devonian succession are more difficult to discern because much of the Devonian succession is either poorly exposed or buried beneath thick glacially derived sediments (*see* Ford 1974; Abbey, Hurley and Merry 2004; Brunton, Dodge and Shirota 2005). Small caves and extensive joint-controlled, karst-influenced networks have been described from the latest Silurian Bertie–Bass Islands formations succession west of the Niagara region and vicinity of the Lake Erie shoreline, and the Middle Devonian Lucas–Dundee and Amherstburg–Bois Blanc formations transitions. Some of the largest and most extensive sinkhole fields known in southern Ontario occur in the Middle Devonian Lucas–Dundee formations mixed limestone-dolostone succession located north of London to Goderich and Walkerton areas (*see* Abbey, Hurley and Merry 2004; Hurley et al. 2005). Subsurface investigations are currently underway to determine the extent of karstification and the controls on aquifer delineation in this region of thick glacial cover. Similar studies are currently underway within dolostones of the Late Silurian Guelph–Amabel formations in the Guelph–Cambridge region of the Niagara Escarpment. A GIS-based karst compilation map for southern Ontario will be completed in the spring of 2007.

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REFERENCES

Abbey, D., Hurley, J. and Merry, A.G. 2004. Sinkhole investigation in the Ausable Bayfield Conservation Authority watershed and surrounding area; *in* Summary of Field Work and Other Activities 2004, Ontario Geological Survey, Open File Report 6145, p.29-1 to 29-6.

Andjelkovic, D. and Cruden, A.R. 1999. Relationships between fractures in Paleozoic cover rocks and structures in the Precambrian basement, south-central Ontario; *in* Summary of Field Work and Other Activities 1998, Ontario Geological Survey, Miscellaneous Paper 169, p.275-280.

Barnett, P.J. 1990. Tunnel valleys: evidence of catastrophic release of subglacial meltwater, central-southern Ontario, Canada; Geological Society of America, Abstracts with Programs, v.22, no.7, p.48.

——— 1992. Quaternary geology of Ontario; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 2, p.1011-1088.

Brennard, T.A. and Shaw, J. 1994. Tunnel channels and associated landforms, south-central Ontario: their implications for ice-sheet hydrology; Canadian Journal of Earth Sciences, v.31, p.505-522.

Brunton, F.R., Dodge, J.E.P., and Shirota, J. 2005. Karst in southern Ontario; *in* Summary of Field Work and Other Activities 2005, Ontario Geological Survey, Open File Report 6172, p.27-1 to 27-7.

Buck, M.J. 1994a. The St. Edmunds cave system, Bruce Peninsula; *in* Guidebook for Excursion B5: Coast, karst and glaciation on the Bruce Peninsula, Ontario, International Association of Geomorphologists, Third International Geomorphological Conference, August 29-31, 1993, McMaster University, Hamilton, Ontario, p.46-48.

Buck, M.J. 1994b. The St. Edmunds Cave System; The Toronto Caver, Summer Issue, p.7-8.

Buck, M.J. 1999. Supplementary inventory of caves on Flower Pot Island, Fathom Five National Marine Park; Fathom Five National Marine Park, internal report, 53p.

Buck, M.J. 2003. Management of Flowerpot Island caves; Fathom Five National Marine Park, internal report, 61p.

Buck, M.J., Worthington, S.R.H. and Ford, D.C. 2003. Earth science inventory and evaluation of the Eramosa karst area of natural and scientific interest; Ontario Ministry of Natural Resources, Guelph District, south-central Region, 51p.

Chapman, L.J. and Putnam, D.F. 1984. The physiography of southern Ontario, 3rd ed.; Ontario Geological Survey, Special Volume 2, 270p. Accompanied by Preliminary Map P.2715, scale 1:600 000.

Cowell, D.W. 1974. Karst geomorphology of the northern Bruce Peninsula; Ontario Ministry Natural Resources, Environmental Planning Series, Miscellaneous Report, v.5, 152p.

——— 1976. Karst geomorphology of the Bruce Peninsula, Ontario; unpublished MSc thesis, McMaster University, Hamilton, Ontario, 231p.

Cowell, D.W. and Associates, Inc. 1989. Surface water quality, Bruce Peninsula and Fathom Five National Parks: April–May, 1989; Environment Canada, Inland Waters Directorate, Water Quality Branch, Burlington, Ontario, 39p.

Cowell, D.W., Fisher, J.D., Delorme, R.J., Stewart, C.J., Buck, M., Ferwerda, P., Janes, T. and Czok, R. 1994a. Geomorphological inventory of Bruce Peninsula National Park and Fathom Five National Marine Park, v.I. Surface geomorphological inventory: St. Edmunds Township, Cabot Head and islands between Tobermory and Manitoulin; v.II. Underwater geomorphological inventory: Fathom Five National Marine Park; Reports and maps prepared for Canadian Parks Service, Ontario Region by Geomatics International Incorporated, v.I, 120p., v.II, 87p.

Cowell, D.W., Fisher, J.D., Delorme, R.J. and Stewart, C.J. 1994b. Geomorphological research on the northern Bruce Peninsula and Tobermory Islands; *in* Leading Edge '94, Hockley Valley Resort, Mono Township, Ontario, Oct. 26-28, 1994, Conference Proceedings, p.336-349.

Cowell, D.W. and Ford, D.C. 1975. The Wodehouse Creek karst, Grey County, Ontario; Canadian Geographer, v.19, p.196-205.

——— 1980. Hydrochemistry of the dolomite karst: the Bruce Peninsula of Ontario; Canadian Journal of Earth Sciences, v.17, p.520-526.

——— 1983. Karst hydrogeology of the Niagara Escarpment, Bruce Peninsula, Ontario; *in* V.T. Stringfield symposium on karst hydrology; Journal of Hydrology, v.16, p.163-168.

Cowell, D.W. and Woerns, N. 1977. Earth Science candidate nature reserves in the Niagara Escarpment planning area; Ontario Ministry of Natural Resources, Park Planning Branch, Miscellaneous Report, 165p.

Enyedy-Goldner, S.R. 1994. The karst geomorphology of Manitoulin Island; unpublished MSc thesis, McMaster University, Hamilton, Ontario, 312p.

Ford, D.C. 1961. The Bonnechere caves, Renfrew County, Ontario: a note; Canadian Geographer, v.3, p.22-25.

——— 1974. Natural caves and associated karst features at Nanticoke, Ontario; Final report to the Steel Company of Canada Limited, Nanticoke, Ontario; 3p. and 1 map.

——— 1983. Effects of glaciation upon karst aquifers in Canada; Journal of Hydrology, v.61, p.149-158.

——— 1987. Effects of glaciation and permafrost upon the development of karst in Canada; Earth Surface Processes and Landforms, v.12, p.507-521.

Ford, D.C. and Quinlan, J.F. 1973. Theme and resource inventory study of the karst regions of Canada; Department of Energy, Mines and Resources, National and Historical Parks Branch, Project A, contract 73-32, p.9-21.

Ford, D.C. and Williams, P.W. 1989. Karst geomorphology and hydrology; Unwin Hyman, London, United Kingdom, 601p.

Goodchild, M.F. 1978. Final report – cave safety study, Flowerpot Island, Georgian Bay Islands National Park; Report prepared for Parks Canada, Cornwall, Ontario, 92p.

——— 1984. Final report – resource management study of caves, Tobermory Islands unit, Georgian Bay Islands National Park; Report prepared for Parks Canada, Cornwall, Ontario, 130p.

Gordon, M. 2005. Rock watching: adventures above & below Ontario; The Boston Mills Press, Erin, Ontario, 192p.

Hurley, J., Merry, A.G., Brunton, F.R., Wadley, S. and Abbey, D. 2005. Karst delineation and sinkhole investigation in the Ausable Bayfield Conservation Authority watershed and surrounding area; *in* Summary of Field Work and Other Activities 2005, Ontario Geological Survey, Open File Report 6172, p.31-1 to 31-8.

Karrow, P.F. 1973. Bedrock topography in southwestern Ontario: a progress report; Geological Association of Canada, Proceedings, v.25, p.67-77.

Kor, P.S.G. and Cowell, D.W. 1998. Evidence for catastrophic subglacial meltwater sheetflood events on the Bruce Peninsula, Ontario; Canadian Journal of Earth Sciences, v.35, p.1180-1202.

Kor, P.S.G., Shaw, J. and Sharpe, D.R. 1991. Erosion of bedrock by subglacial meltwater, Georgian Bay, Ontario: a regional view; Canadian Journal of Earth Sciences, v.28, p.623-642.

Kunert, M. and Coniglio, M. 2002. Origin of vertical shafts in bedrock along the Eramosa River valley near Guelph, southern Ontario; Canadian Journal of Earth Sciences, v.39, p.43-52.

Ongley, E.D. 1965. A study of caves in southern Ontario; unpublished BA thesis, University of Toronto, Toronto, Ontario, 117p.

Palmer, A.N. 1991. Origin and morphology of limestone caves; Geological Society of America Bulletin, v.103, p.1-21.

Pluhar, A. and Ford, D.C. 1970. Dolomitic karren of the Niagara escarpment, Ontario, Canada; Zeitschrift für Geomorphologie, v.14, p.411-428.

Russell, D.F. 2004. Nutrient management project: characterization of fractured Paleozoic bedrock in thin drift areas of southern Ontario; *in* Summary of Field Work and Other Activities 2004, Ontario Geological Survey, Open File Report 6145, p.34-1 to 34-7.

Sanford, B.V. 1993. St. Lawrence Platform: economic geology; *in* Sedimentary cover of the craton in Canada; Geological Survey of Canada, Geology of Canada, No.5, p.787-798. [also Geological Society of America, Geology of North America, v.D1.]

Shaw, J. 1996. A meltwater model for Laurentide subglacial landscapes; *in* Geomorphology sans frontières, John Wiley & Sons Ltd., p.181-236.

Shaw, J. and Gilbert, R. 1990. Evidence for large-scale subglacial meltwater flood events in southern Ontario and northern New York State; Geology, v.18, p.1169-1172.

Spencer, J.W. 1890. Origin of the basins of the Great Lakes of America; American Geologist, v.7, p.86-97.

Straw, A. 1968: Late Pleistocene glacial erosion along the Niagara Escarpment of southern Ontario; Geological Society of America Bulletin, v.79, p.889-910.

Strynatka, S.A. 2003. Nutrient management project: characterization of thin drift cover over various Paleozoic bedrock formations in southern Ontario; *in* Summary of Field Work and Other Activities 2003, Ontario Geological Survey, Open File Report 6120, p.26-1 to 26-5.

The Bruce–Grey Geology Committee 2004. Geology and landforms of Grey & Bruce Counties; The Owen Sound Field Naturalists, Stan Brown Printers Ltd., Owen Sound, Ontario, 192p.

Tinkler, K.J. and Stenson, R.E. 1992. Sculpted bedrock forms along the Niagara Escarpment, Niagara Peninsula, Ontario; Géographie physique et Quaternaire, v.46, p.195-207.

Tovell, W.M. 1992. Guide to the geology of the Niagara Escarpment, with field trips; Niagara Escarpment Commission (and Ontario Heritage Foundation), Ashton-Potter Ltd., Concord, Ontario, 159p., including Field trips A-J, appendices, and index.

White, W.B. 1988. Geomorphology and hydrology of karst terrains; Oxford University Press, New York, 464p.

Worthington, S.R.H. 2001. Depth of conduit flow in unconfined carbonate aquifers; Geology, v.29, p.335–338.

——— 2002. Test methods for characterizing contaminant transport in a glaciated carbonate aquifer; Environmental Geology, v.42, p.546-551.

——— 2003. A comprehensive strategy for understanding flow in carbonate aquifers; *in* Karst modeling, The Karst Waters Institute, Charles Town, West Virginia, Special Publication 5, p.30-37.

Worthington, S.R.H., Davies, G.J. and Ford, D.C. 2000. Matrix, fracture and channel components of storage and flow in a Paleozoic limestone aquifer; *in* Groundwater flow and contaminant transport in carbonate aquifers, Balkema, Rotterdam, p.113-128.

Worthington, S.R.H., Ford, D.C. and Beddows, P.A. 2000. Porosity and permeability enhancement in unconfined carbonate aquifers as a result of solution; *in* Speleogenesis: evolution of karst aquifers, National Speleological Society, Huntsville, Alabama, p.463-472.

32. Project Unit 06-024. Three-Dimensional Mapping of Quaternary Deposits in the Brantford–Woodstock Area, Southwestern Ontario

A.F. Bajc[1]

[1]Sedimentary Geoscience Section, Ontario Geological Survey

INTRODUCTION

Field work for a project of three-dimensional (3D) mapping of Quaternary geology in the Brantford–Woodstock area (Figure 32.1) was initiated in the summer of 2006. This project is a continuation of a similar 3D mapping study carried out previously within the Regional Municipality of Waterloo to the north (Bajc 2002; Bajc et al. 2003; Bajc 2004; Bajc and Karrow 2004; Bajc and Newton 2005; Bajc and Hunter 2006) and is one of several projects currently being undertaken by the Ontario Geological Survey (OGS) as part of its groundwater mapping program.

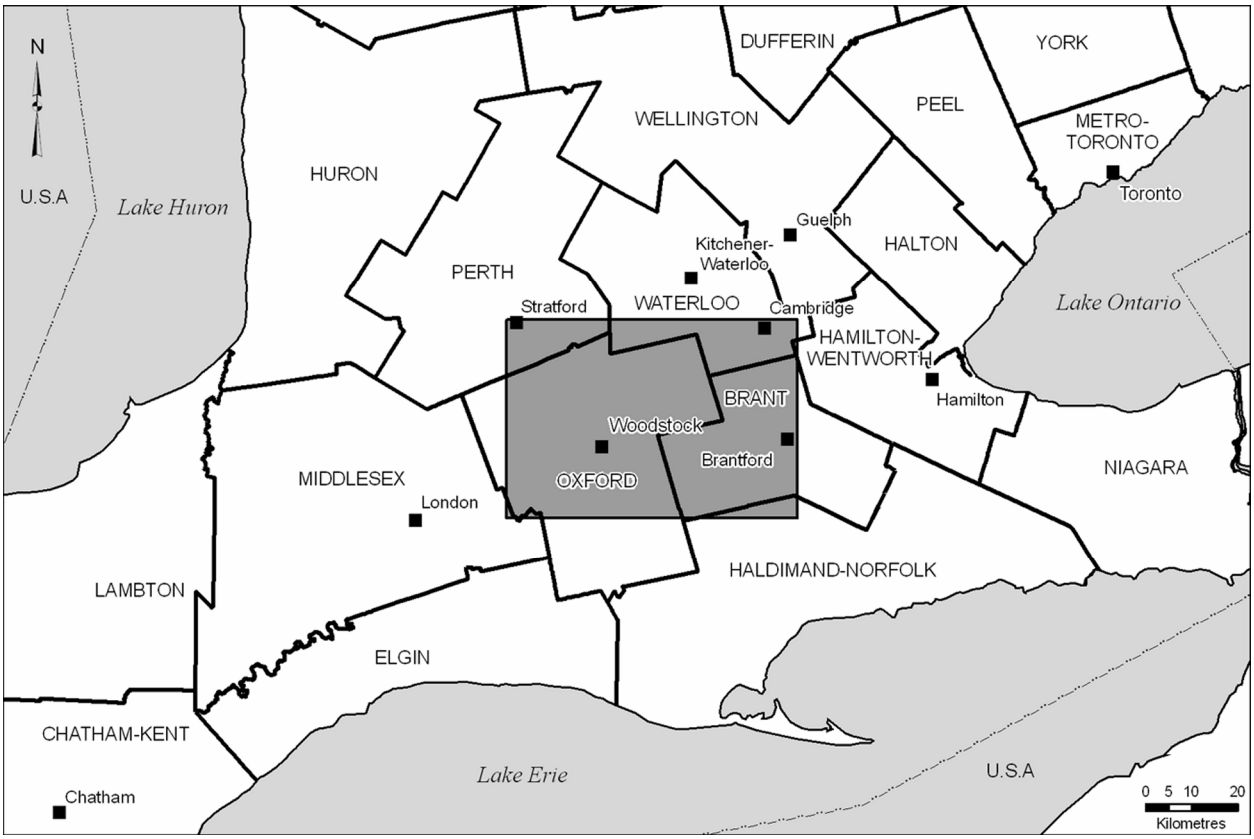

Figure 32.1. Location of the Brantford–Woodstock area in southwestern Ontario.

Summary of Field Work and Other Activities 2006,
Ontario Geological Survey, Open File Report 6192, p.32-1 to 32-6.

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The objectives of this project are to develop interactive 3D models of Quaternary geology that can 1) aid in studies involving groundwater extraction, protection and remediation; 2) assist with the development of policies surrounding land use and nutrient management; and 3) help to better understand the interaction between ground and surface waters. This area was chosen for study as the population base, with the exception of the City of Brantford, relies exclusively on groundwater for domestic and agricultural use. Steady growth of the cities of Cambridge and Woodstock, especially with the opening of the new Toyota plant at Woodstock in 2008, will undoubtedly apply pressure to the groundwater resource. A better understanding of the geometry and inherent properties of the Quaternary sediments that overlie the bedrock surface within this region will assist with the development of source water protection plans and with the development of a geoscience-based management plan for the groundwater resource.

LOCATION AND POPULATION

The Brantford–Woodstock area is situated in the interlake area of southwestern Ontario and occupies an area of just over 2700 km² (*see* Figure 32.1). It lies within the Woodstock (40 P/2), western half of the Brantford (40 P/1), southern half of the Stratford (40 P/7) and southwest corner of the Cambridge (40 P/8) 1:50 000 scale NTS map areas. The Upper Thames, Grand River and a small portion of the Long Point conservation management areas lie within the study area. Provincial series highways 401 and 403 transect the study area and provide excellent transportation routes to Toronto, Windsor and the Niagara peninsula. Much of the population base resides within the cities of Brantford and Cambridge in the east and Woodstock, Ingersoll and Stratford in the west.

REGIONAL GEOLOGIC SETTING

Bedrock Geology

The Brantford–Woodstock area is underlain by southwesterly dipping strata of mid-Silurian to mid-Devonian age. The northwest-trending Onondaga Escarpment, with its caprock of cherty limestone belonging to the Bois Blanc Formation, bisects the study area and separates dolostones, shales and gypsum of the Bass Islands, Salina and Guelph formations to the east (i.e., below the escarpment) from Detroit River Group (Lucas and Amherstburg formations) and Dundee Formation limestone and dolostones to the west. Exposures of the Detroit River Group carbonates occur at a series of quarries in Beachville owned and operated by Carmeuse Lime as well as at the Lafarge-owned Zorra Quarry situated a few kilometres to the northwest of the town. At Innerkip, Bois Blanc and Bass Islands formation carbonates were quarried at a number of sites until the late 1930s. These quarries are now either flooded or rehabilitated.

Bedrock wells screened in the Salina Formation generally produce heavily mineralized (saline, sulphurous and iron-rich) waters, whereas, those located in carbonate terrains to the east and west generally yield higher quality, yet hard, waters.

Quaternary Geology

Drift thickness within the study area ranges between 0 and 115 m with bedrock cropping out in the extreme northeast corner of the study area near the hamlet of Branchton and within and adjacent to the Thames River valley in the southwest corner of the study area. The greatest accumulations of drift occur within the Waterloo Moraine in the northeastern corner of the study area as well as within a series of

north-trending moraines associated with the final retreat of Erie lobe ice. Significant thicknesses of drift occur south of Woodstock, where drumlinized and fluted ground moraine partially bury glaciofluvial deposits comprising the Woodstock Moraine as well as in the northwest corner of the study area where kame and kettle topography associated with the Lakeside Moraine occurs.

The bedrock surface slopes gently from the northwest, where it has an elevation of about 330 m asl, to the southeast, where it occurs at roughly 160 m asl. The Onondaga Escarpment is clearly indicated on the bedrock topography map in the southeast corner of the map area, but becomes less well defined towards the northwest. The buried Dundas Valley, also referred to as the Wellesley buried valley to the northwest in Waterloo Region, occurs in the extreme northeastern corner of the study area. Its exact position is not clearly defined as few wells extend to bedrock within this area.

PHYSIOGRAPHY

The Brantford–Woodstock area contains a diverse suite of landforms and physiographic domains. These include 1) a tract of rolling, sandy hills comprising the Waterloo Moraine and Washington spur; 2) a series of spectacular north-trending moraines that formed along the retreating margin of the Lake Erie ice lobe (Ingersoll, St. Thomas, Norwich, Tillsonburg, Paris and Galt moraines); 3) the Woodstock drumlin field situated south and west of the city of Woodstock and believed to be formed by advancing Huron lobe ice; 4) a zone of partially buried kame and kettle topography located in the northwest corner of the study area and likely deposited along the retreating Huron lobe ice margin and later overridden by advancing ice that deposited Tavistock Till; 5) a series of southwest-trending glaciofluvial spillways, now occupied by misfit streams and rivers (Thames and Middle Thames rivers and Trout Creek), that carried meltwaters to the southwest into high level lakes in the Lake Erie basin; and 6) highly dissected glaciolacustrine plain on the east side of the Galt Moraine in the vicinity of Brantford.

STRATIGRAPHY AND HISTORY

A rich pre-Late Wisconsinan record exists within the Brantford–Woodstock area. Previously reported occurrences of sub-till organics include 1) the Innerkip site, which, based on paleoecological analysis, has been interpreted as a possible interglacial deposit (Pilny and Morgan 1987); 2) inclusions of organic-bearing silt of boreal affinity in pre-Late Wisconsinan till at the Zorra Quarry north of Ingersoll (Westgate and Dreimanis 1967); 3) a 5 m sequence of "black sand and very black muck" reported in a water well record near Ingersoll beneath 40 m of Late Wisconsinan tills (Cowan 1975); 4) a 2 m thick undated sequence of greenish-black clayey silt containing fibrous organic matter encountered beneath 40 m of Late Wisconsinan till in a borehole just south of Ingersoll (Sado 1980); 5) pieces of wood recovered from a water well south of Ayr, radiocarbon dated at 42 740±1030 years BP (TO-11948) and which is believed to be recovered from a stratified unit underlying Catfish Creek Till approximately 30 m below ground surface (A.F. Bajc, OGS, unpublished data, 2005); and 6) detrital wood recovered from a borehole just west of Cambridge at an approximate depth of 40 m below Wentworth Till and radiocarbon dated at 30 760±210 years BP (TO-11663) (A.F. Bajc, OGS, unpublished data, 2005). The potential for further discoveries within the study area remains high.

Pre-Late Wisconsinan tills have also been reported from the study area, the most notable of which is Canning Till. The type section of Canning Till occurs along the Nith River in the east-central part of the study area (Karrow 1987). It has been traced as far west as the Zorra Quarry north of Ingersoll. Very little is known about the age or provenance of this clayey, stone-poor till that often displays a red to grey-mauve colour. It does, however, occur beneath organic-bearing silts recently recovered from a borehole on the north campus of the University of Waterloo (Bajc and Hunter 2006) as well as, based on

preliminary observations, beneath organic-rich silts and very fine-textured sands in the Zorra Quarry. A drill hole placed a few hundred metres east of the reported buried wood occurrence south of Ayr contained a layer of Canning Till beneath Catfish Creek Till. The upper surface of this mauve-grey, clayey silt till appeared to be weathered indicating a sustained nonglacial interval. At present, all that can be concluded is that the Canning Till is pre-Middle Wisconsinan in age. Red shale fragments, presumed to be derived from the Queenston shale below the Niagara Escarpment are commonly observed within this till. An Erie–Ontario ice lobe advancing to the northwest is likely responsible for the tills deposition. Bedrock underlying Canning Till at the Zorra Quarry is striated at 130°. A sense of flow has yet to be observed.

The Late Wisconsinan is represented by several till units, the most significant of which is the Catfish Creek Till. This till was named by de Vries and Dreimanis (1960) at its type section south of London, Ontario. It occurs in the subsurface over much of southwestern Ontario and represents the deposit of the Nissouri Phase when ice pushed into southern Ohio 17–25 ka BP (Karrow 1988). Exposures of Catfish Creek Till along the north shore of Lake Erie indicate an early and late phase of deposition of this till that reflects ice flow out of both the Huron and Erie basins. Lobal facies of Catfish Creek Till have also been reported from the Zorra Quarry (Westgate and Dreimanis 1967). Two layers of Catfish Creek Till separated by ice-marginal stratified deposits were reported from both the Zorra and Beachville quarries suggesting a northwest-trending ice margin (Krzyskowski and Karrow 2001). Within the study area, Catfish Creek Till occurs as a dense, stony, overconsolidated, silty to sandy till. Inliers of this till have been mapped at various locations throughout the western half of the study area. Catfish Creek Till is also commonly observed along the walls of deeply incised valleys, in quarry exposures near Ingersoll and occasionally on the floors of gravel pit operations.

A period of ice recession following the Nissouri Phase resulted in widespread deposition of glaciolacustrine sediments in southern Ontario. This nonglacial interval, referred to as the Erie Phase, is represented by pollen-bearing lacustrine silts sandwiched between Catfish Creek Till and Tavistock Till at Wildwood Lake, which is located just off the west-central edge of the study area. The Waterloo Moraine likely formed during this period of ice withdrawal as well. Erie Phase deposits have not been radiocarbon dated directly, but were most likely deposited between 16.5 and 15.5 ka BP. The deposition of fine-grained sediments over vast areas strongly affected the textures of till units subsequently deposited.

The Port Bruce Phase was a period of glacier expansion within the lower Great Lakes basins. Glacier profiles had diminished significantly by then resulting in ice flow patterns that were strongly affected by local topography. The Erie–Ontario lobe advanced northwestward depositing a silty sandy till to the north and a silty clayey till to the south. The westernmost observed occurrence of this till (Port Stanley Till) is at the Zorra Quarry. Meanwhile, the Huron lobe was advancing southeastward depositing Tavistock Till, which has a clayey silt texture to the north and a silty sandy texture to the south. The Woodstock drumlin field was constructed at this time. Parts of the drumlin field may have formed prior to this advance during the deposition of the Port Stanley Till. The southeasternmost occurrence of Tavistock Till is located just south of Woodstock, west of the Ingersoll Moraine. Piotrowski (1987) favoured a more easterly limit defined by the Ingersoll and St. Thomas moraines.

Subsequent retreat of the Erie–Ontario and Huron ice lobes occurred during the Mackinaw Phase. The Ingersoll, St. Thomas, Norwich, Tillsonburg, Paris and Galt end or recessional moraines were constructed along the retreating Erie–Ontario ice margin during this period of ice recession. The Paris and Galt moraines, composed of stony, silty, sandy Wentworth Till, were probably constructed following a significant readvance over Grand River outwash deposits. The marked change in till texture to the south between Port Stanley and Wentworth tills is probably a reflection of the overriding and incorporation of these coarse-textured deposits. To the west, a minor fluctuation of the Huron lobe resulted in the deposition of silty sandy Stratford Till upon clayey silt Tavistock Till. Glaciofluvial valley-fill sequences, grading to high level lakes in the Erie basin, were deposited along the margin of the retreating

Huron lobe within the valleys of the Thames and Middle Thames rivers and Trout Creek. In the extreme northwest corner of the study area, thin deposits of glaciolacustrine silt and clay were laid down in isolated ponds that formed on the Tavistock and Stratford till plains.

Glaciofluvial outwash and deltaic deposits graded to high level Erie basin lakes (glacial lakes Maumee and Arkona) were deposited in the lowlands between the Erie lobe moraines. Shallow water (littoral) sands were deposited further south at lower elevations. Basinal (quiet water) deposits of glaciolacustrine silt and clay (glacial lakes Whittlesey and Warren) were laid down on the back side of the Galt Moraine and subsequently dissected as Erie basin water levels declined.

NEW FINDINGS

New exposures at the Lafarge-owned Zorra Quarry expose a spectacular sequence of Quaternary sediments (Photo 32.1). A channel-fill sequence of organic-bearing silts and very fine sand containing fossil molluscs and tiny wood fragments was discovered on the north and east face of the quarry. The channel-fill sequence appears to be overlain by reddish-coloured Catfish Creek Till and underlain by both fine- and coarse-grained facies of Canning Till. The organic sediment will be processed for pollen, plant and animal macrofossils and a sample submitted for radiocarbon dating.

CONCEPTUAL GEOLOGIC MODEL

The conceptual geologic model developed previously for the Region of Waterloo will be applied to the Brantford–Woodstock area if at all possible. The main units to be modelled include 1) glacial lakes Whittlesey–Warren clays; 2) Wentworth Till and associated morainic deposits; 3) Grand River glaciofluvial and/or glaciolacustrine sands and gravels; 4) Tavistock, Stratford and Port Stanley tills; 5) Waterloo Moraine and equivalent deposits; 6) Lower Maryhill Till and equivalent deposits; 7) Catfish Creek Till; 8) pre-Catfish Creek Till sands and gravels; 9) Canning Drift; and 10) older deposits.

WORK PLAN

A standardized database of subsurface information will be constructed initially using the Ministry of the Environment water well database, the Ministry of Transportation foundations database (Geocres), the Ministry of Natural Resources oil and gas database, and section descriptions or borehole logs contained within OGS field notes, university theses and other research projects undertaken for the Region of Waterloo or Grand River, Upper Thames and Long Point conservation authorities. An initial overburden drilling program is scheduled for the summer of 2007 to assist with the refinement of the conceptual

Photo 32.1. Exposure of Quaternary sediments at Zorra Quarry. The section is approximately 28 m high.

geologic model as well as with the interpretation of the records contained within the Ministry of the Environment water well database. A second drill program will be undertaken following an initial assessment and interpretation of all available subsurface data and the identification of data gaps and areas of complex geology requiring additional subsurface information. As was undertaken in the Waterloo Region 3D study, Datamine Studio® will be used as the model-building tool.

REFERENCES

Bajc, A.F. 2002. Mapping the subsurface of Waterloo Region; *in* Summary of Field Work and Other Activities, 2002, Ontario Geological Survey, Open File Report 6100, p.31-1 to 31-6.

——— 2004. Three-dimensional mapping of Quaternary deposits in Waterloo Region, southwestern Ontario; *in* Summary of Field Work and Other Activities, 2004, Ontario Geological Survey, Open File Report 6145, p.24-1 to 24-4.

Bajc, A.F., Endres, A.L., Hunter, J.A. and Pullan, S.E. 2003. An update on three-dimensional mapping of Quaternary deposits in Waterloo region, southwestern Ontario; *in* Summary of Field Work and Other Activities, 2003, Ontario Geological Survey, Open File Report 6120, p.24-1 to 24-7.

Bajc, A.F. and Hunter, J.A. 2006. Results of 2003–2004 overburden drilling programs in the Region of Waterloo, southwestern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 205.

Bajc, A.F. and Karrow, P.F. 2004. 3-dimensional mapping of Quaternary deposits in the Regional Municipality of Waterloo, southwestern Ontario; Geological Association of Canada—Mineralogical Association of Canada, Joint Annual Meeting, St. Catharines 2004, Field Trip Guidebook FT-7, 72p.

Bajc, A.F. and Newton, M.J. 2005. Three-dimensional modelling of Quaternary deposits in Waterloo Region, Ontario: A case study using Datamine Studio® software; *in* Summary of Field Work and Other Activities, 2005, Ontario Geological Survey, Open File Report 6172, p.25-1 to 25-8.

Cowan, W.R. 1975. Quaternary geology of the Woodstock area, southern Ontario; Ontario Geological Survey, Geological Report 119, 91p.

de Vries, H., and Dreimanis, A. 1960. Finite radiocarbon dates of the Port Talbot interstadial deposits in southern Ontario; Science, v.131, p.1738-1739.

Karrow, P.F. 1987. Quaternary geology of the Hamilton–Cambridge area, southern Ontario; Ontario Geological Survey Report 255, 94p.

——— 1988. Catfish Creek Till: an important glacial deposit in southwestern Ontario; 41st Canadian Geotechnical Conference, Kitchener, Ontario, Preprints, p.186-192.

Krzyskowski, D. and Karrow, P.F. 2001. Wisconsinan inter-lobal stratigraphy in three quarries near Woodstock, Ontario; Géographie physique et Quaternaire, v.55, no.1, p.3-22.

Pilny, J.J. and Morgan, A.V. 1987. Paleoentomology and paleoecology of a possible Sangamonian site near Innerkip, Ontario; Quaternary Research, v.28, p.157-174.

Piotrowski, J.A. 1987. Genesis of the Woodstock drumlin field, southern Ontario, Canada; Boreas, v.16, p.249-265.

Sado, E.V.S. 1980. The Quaternary stratigraphy and history of the Lucan map area, southwestern Ontario; unpublished MSc thesis, University of Waterloo, Waterloo, Ontario, 145p.

Westgate, J.A. and Dreimanis, A. 1967. The Pleistocene sequence at Zorra, southwestern Ontario; Canadian Journal of Earth Sciences, v.4, p.1127-1143.

33. Project Unit 03-021. Three-Dimensional Geological Modelling of Thick Quaternary Deposits in the Barrie Area, Central Ontario

A.K. Burt

[1]Sedimentary Geoscience Section, Ontario Geological Survey

INTRODUCTION

Groundwater is an important resource for many of Ontario's residents. In recent years, the recognition of the need to protect existing groundwater resources has increased substantially. Numerous pieces of legislation have been or are being introduced that focus on the protection and utilization of the provinces groundwater resources. Identification of groundwater aquifers is an important component of any protection or source water initiative.

A critical component of mapping groundwater aquifers is a thorough understanding of the three-dimensional (3D) distribution of Quaternary (surficial) sediments. The 3D distribution of these sediments form recharge and discharge zones, local and regional aquitards and aquifers. Accurate 3D models will allow new aquifers to be located and the estimation of volume of groundwater resources. Of equal importance, the models can be used to identify aquifers susceptible to contamination and potential pathways for contaminants.

This report provides an update of a multi-year project aimed at the construction of a 3D geologic model of Quaternary sediments in the Barrie area using Datamine Studio®: a software package developed for the mining industry. New software scripts have been written to adapt the software to overburden mapping for groundwater modelling applications (Bajc and Newton 2005). The modelling software has many inputs including data from drilling and associated downhole geophysics, seismic surveys, drilling logs, water well records, the interpretation of natural and man-made exposures, published surficial maps and a digital elevation model (DEM). The Barrie area modelling project is following the protocols and procedures established for a similar project that has been undertaken in the Waterloo region (Bajc and Newton 2005; Burt and Bajc 2005).

The glacial history and surficial geology of the study area has been described and discussed in several previous publications (Barnett 1988, 1997; Finamore 1981; Finamore and Bajc 1984; Gwyn 1972; Burt 2004; Burt and Russell 2005; Slattery 2003); detailed descriptions, visual logs, laboratory results and photos of the 2004 drilling program have been released on CD-ROM (Burt and Russell 2006). The latter portion of this report is focussed on the results of the 2005 and early 2006 drilling programs.

LOCATION

The study area encompasses approximately 1200 km^2 between Georgian Bay and Lake Simcoe, and is centred on the Oro Moraine (also referred to as Bass Lake kame moraine and the Oro sandhills) located north of the City of Barrie in central Ontario (Figure 33.1). Lakes Couchiching and Simcoe form a

Summary of Field Work and Other Activities 2006,
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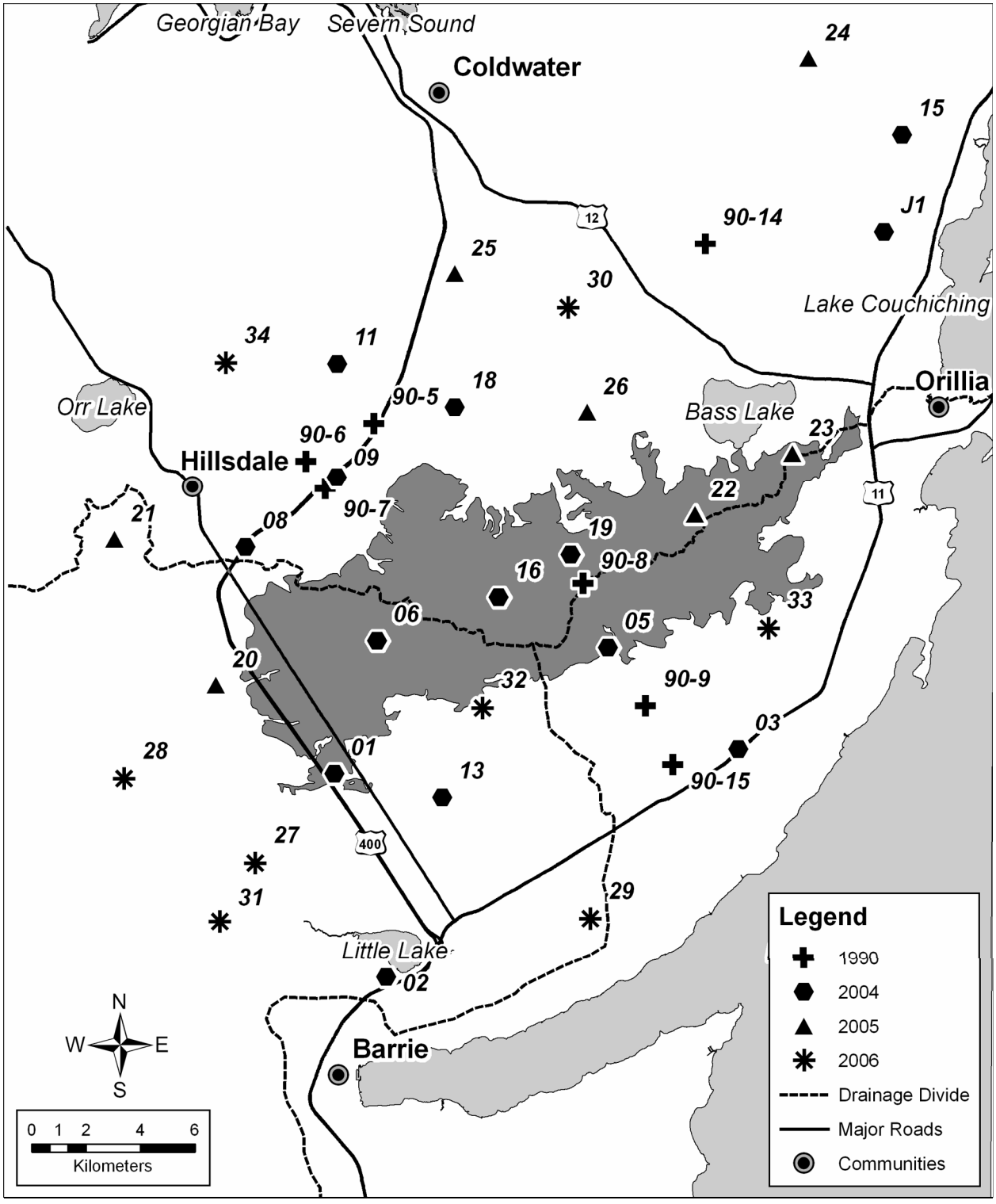

Figure 33.1. Location of the study area. The Oro Moraine, shown in dark grey, is the most prominent landform within the study area. Boreholes completed in 2004, 2005 and early 2006 are indicated. Note that the borehole names have been shortened for clarity on the diagram. For example, borehole BH-29-AKB-2006 is marked as 29. Boreholes completed in 1990 (Barnett 1991) are also shown.

natural geological and hydrological boundary to the east and southeast of the study area. The transition from thick overburden to exposed bedrock, roughly coinciding with Severn Sound, forms the northern boundary. The western boundary is arbitrarily located at the edge of a large, low-lying clay plain. Portions of 5 townships, Essa, Oro–Medonte, Severn, Springwater and Tay, represented on 1:50 000 scale NTS map sheets 31 D/5, 31 D/6, 31 D/11, 31 D/12, 31 D/13 and 31 D/14 are included within the study area. The metropolitan areas of Barrie, on Lake Simcoe, and Orillia, on Lake Couchiching, are the largest urban centres within the study area and have a combined population of nearly 200 000.

Lakes Couchiching and Simcoe are the largest water bodies in the study area. Smaller lakes include Bass, Little and Orr. The Oro Moraine forms a large drainage divide oriented roughly northeast across the study area. Although the surface of the moraine has been deeply incised by surface drainage, there are currently no perennial streams. Southeast of the moraine, surface water drains directly into Lake Simcoe. Southwest of the moraine surface water drains into Georgian Bay via the Nottawasaga River system, whereas north and northwest of the moraine, it drains into Georgian Bay through Severn Sound.

MODEL INPUTS

There are many sources of data for the 3D model, each with different levels of detail and accuracy. The most accurate and most detailed source of data are a series of continuously cored boreholes drilled by the Ontario Geological Survey in 1990, 2004, 2005 and 2006 (*see* Figure 33.1 for borehole locations). The 1990 drill program resulted in 7 holes totalling 525 m within the current study area boundaries (Barnett 1991). In 2004, 14 sonic holes were drilled totalling 1185 m (Burt and Russell 2005, 2006). Monitoring wells were installed at 10 of these sites, some of which are currently being incorporated into the provincial groundwater monitoring network. PVC risers were installed at one additional site to facilitate downhole geophysics. Downhole geophysics was done at a total of 11 sites. In 2005, 7 PQ diameter holes were drilled totalling 403 m. A monitoring well was installed at one of these sites. At the time of writing, the 2006 PQ diameter drilling program was in progress. As of the end of September, 8 holes totalling 518 m had been completed with a further 3 holes planned. Two monitoring wells have been installed. The 2005 and 2006 monitoring wells will also be incorporated into the provincial groundwater monitoring network. The OGS borehole data are supplemented by a continuously cored hole drilled by the Conservation Authorities Moraine Coalition in 2005 and a series of rotary (mud) drill boreholes currently being drilled by the Lake Simcoe Conservation Authority. Holes drilled using rotary (mud) drilling do not have the same level of detail as the continuously cored holes, but still provide an important source of stratigraphic information. The geological information from each hole has been classified into summary geological materials for greater ease of modelling (Table 33.1).

There are several additional sources of drilling data including consultant reports (author currently has data from <100 sites), the Ministry of Transportation geotechnical records and the Ministry of Environment water well records, but these data are less detailed and, in most cases, are less accurate than the continuously cored holes.

Table 33.1. Summary geological materials used for 3D modelling. Material categories (*) used only in the translated MOE water well data sets. Remaining material categories are used in all data sets.

Geological Material	Number of Records in MOE database
Precambrian bedrock	933
Paleozoic bedrock	1601
Gravel	2455
Sand	10469
Silt	2424
Clay	4305
Diamicton: silty to sandy	1819
Diamicton: silty to clayey	2863
Diamicton: undetermined *	1206
Organic	1545
Fill	631
Previously dug *	450
Unknown *	59

The Ministry of Transportation (MTO) foundation drilling database yielded over 500 sites (clustered in groups of 2 to 10 or more) located along highways 11, 12, and 400 with over 2100 stratigraphic records that have been summarized into the same 11 materials as the continuously cored holes. The majority of these sites were augered, although there are some sites that were investigated using washboring. At several very thin overburden sites, the results of penetration tests were included to better define the bedrock surface. The MTO sites were investigated for engineering rather than geological purposes and so the drilling is typically shallow, with less than 60 sites reaching depths greater than 20 m below surface, and the quality and level of detail is lower than the OGS continuously cored holes.

The most plentiful, but least accurate, source of data is the Ministry of the Environment (MOE) water well database which includes information on wells drilled from 1946 to November 2003. Only those wells that have a margin of spatial error that is 500 m or less have been included in this study resulting in a total of 6375 MOE water wells with over 28 000 stratigraphic records. It should be noted that, although many site-specific studies only use water wells with a margin of spatial error of 200 m or less (resulting in the number of MOE water wells being reduced from 6375 to less than 3000), the present study is aimed at producing a generalized, regional-scale model. The MOE water well database has 3 material fields that contain geological information including materials, descriptions or qualifiers and unknowns. While 19 of the more than 80 terms used in the complete MOE database are not used within this study area, there are still far too many potential combinations to use the information ‘as is’. As with other 3D geological modelling projects, a two-step translation process was used (Burt and Bajc 2005; Russell et al. 1998) to transform the data into a usable format. In step one, many of the original terms were grouped together under a single term. For example, the MOE terms ‘quicksand’, ‘fine sand’, ‘medium sand’, ‘coarse sand’, ‘sand’ and ‘sandy’ all became ‘sand’ (Table 33.2). All of the unique combinations of new terms (and retained original terms) were then extracted from the database and one of 13 interpreted materials assigned creating a translation table (*see* Table 33.1). This translation table was used to convert the MOE database into a series of formations ready for modelling.

Table 33.2. Summary terms extracted from MOE water well database. *Modified from* Russell et al. 1998.

New Term	Original MOE Code and Term	
Rock	20 quartzite	46 quartz
	21 granite	47 schist
	26 bedrock	64 crystalline
	40 flint	
Limestone	15 limestone	16 dolostone
Shale	17 shale	
Sandstone	18 sandstone	
Boulders	13 boulders	
Gravel	11 gravel	31 coarse gravel
	12 stones	72 gravelly
	29 fine gravel	87 stoney
	30 medium gravel	
Sand	7 quicksand	10 coarse sand
	8 fine sand	28 sand
	9 medium sand	81 sandy
Silt	6 silt	84 silty
Clay	5 clay	61 clayey
Diamicton	14 hardpan	34 till
Organic	3 muck	33 marl
	4 peat	35 wood fragments
Fill	1 fill	25 overburden
	2 topsoil	
previously dug	23 previously bored	24 previously drilled
unknown	00 unknown	27 —
terms with little or no geological value (original terms retained)	60 cemented	75 light coloured
	62 clean	77 loose
	63 coarse-grained	78 medium-grained
	65 dark-coloured	79 packed
	66 dense	80 porous
	67 dirty	83 sharp
	68 dry	85 soft
	69 fine-grained	86 sticky
	70 fossiliferous	89 thin
	71 fractured	90 very
	73 hard	91 water-bearing
	74 layered	

There are several sources of geophysical information within the study area including downhole geophysics (11 of the 14 boreholes drilled in 2004) and seismic surveys completed under contract by a geophysical company and by the Geological Survey of Canada. Although not in the project area proper, data from a marine seismic reflection program exist for Lake Simcoe (Todd et al. 2003). The remaining inputs for the geological model are published surficial maps, a digital elevation model and the description of natural and man-made exposures.

BEDROCK GEOLOGY

Exposures of bedrock in the study area are limited in extent and are confined to a narrow east-trending band across the northern boundary. Outcrops straddle the Black River Escarpment, which represents the contact between older Proterozoic rocks of the Grenville Province to the north and Middle Ordovician rocks to the south.

Rocks of the Grenville Province consist of layered biotite gneiss and migmatite, quartzofeldspathic gneiss, orthogneiss and paragneiss around the northern tip of Lake Couchiching. Westward toward Georgian Bay, the rocks consist of tonalite, granodiorite, monzonite, granite, syenite and derived gneisses (Ontario Geological Survey 1991). Exposures occur along roads and in fields, where rounded knobs protrude through flat-lying surficial sediments.

The bedrock geology of the study area is dominated by rocks of Middle Ordovician age (Liberty 1969). The lowermost unit, the Shadow Lake Formation, is composed of interbedded siliciclastic shale and sandstone, and unconformably overlies the Proterozoic basement rocks. Overlying the Shadow Lake Formation is the Gull River Formation, a generally fine- to very fine-grained to argillaceous, sparsely to locally very fossiliferous, thin- to medium-bedded limestone. The Bobcaygeon Formation overlies the Gull River, and is composed of fine- to coarse-grained, moderately fossiliferous, irregular- to medium-thick-bedded limestone with calcareous shale partings and interbeds in the upper members. The uppermost unit in the area is the Verulam Formation, a medium- to coarse-grained bioclastic limestone with calcareous shale partings in the lower member.

These rock formations form the lowermost units of the geological model. With the exception of the shallow drift areas in the northern and northeastern portion of the study area, very few boreholes and water wells intersect bedrock, so that information about the topographic nature of the bedrock surfaces have been extrapolated from surrounding areas with more data.

QUATERNARY GEOLOGY

There are 4 major physiographic regions within the study area; the laterally extensive Simcoe uplands (Chapman and Putnam 1984), the northeast-trending Oro Moraine which overlies the Simcoe uplands, a tunnel valley network that bisects the Simcoe uplands and, finally, a thin low-lying clay plain found in the northern portions of the study area.

The distinctive deposits found in each physiographic region are the result of south to southwest advances and subsequent retreats of the Simcoe Lobe of the Laurentide Ice Sheet during the Late Wisconsinan glaciation. The region was ice covered until the Mackinaw Interstade, ca 13 300 years BP, at which time the ice front retreated north of the Lake Simcoe area (Dreimanis 1977). Ice advanced across the area during the Port Huron Stade, ca 13 000 years BP, retreated during the Two Creeks Interstade, ca 12 500 BP, and advanced for the last time ca 11 800 years BP (Dreimanis 1977). This final advance took place at approximately the same time as the Greatlakean advance of the Michigan lobe. Ponding of meltwater, leading to the formation of glacial lakes, occurred with each cycle of advance and retreat.

The Newmarket and informally named ‘northern’ tills, which blanket the Simcoe uplands (Chapman and Putnam 1984), are the most extensive surficial deposits throughout the south and northwest portions of the study area (Figure 33.2). The till surfaces are typically gently to steeply rolling to streamlined and are locally overlain by fine- to coarse-grained glaciolacustrine and outwash deposits. Modern streams have incised the till surface. The till exposures become smaller and increasingly streamlined moving north and east from the moraine. There are several small exposures of an older, undifferentiated silty till

as well as an exposure of Kettleby Till located above the Main Algonquin shoreline adjacent to Lake Simcoe (Ontario Geological Survey 2003).

During 2004, 2005 and early 2006, a series of 9 boreholes were drilled into the Simcoe uplands both north and south of the Oro Moraine (Figures 33.1, 33.3 and 33.4). Four of the boreholes extended 100 m or more below surface, but only one reached bedrock. These boreholes reveal 3 primary packages of sediment.

Boreholes BH-11-AKB-2004, BH-02-SRS-2004 and BH-03-AKB-2004 each have a thick lower drift package of interbedded silty to sandy diamicton, clay-rich diamicton, subaqueous fan or outwash sand and glaciolacustrine silt and clay. Previously drilled boreholes OGS-90-5 and OGS-90-15 also reveal a thick lower drift sequence (Barnett 1991). Shallower boreholes BH-26-AKB-2006, BH-29-AKB-2006 and BH-30-AKB-2006, as well as borehole OGS-90-9, terminated in diamicton units that are tentatively correlated with the lower drift. Unfortunately, few MOE water well records, and no MTO records, extend down to the lower drift sequence, and so the thickness and extent of individual units will remain poorly defined in the 3D model.

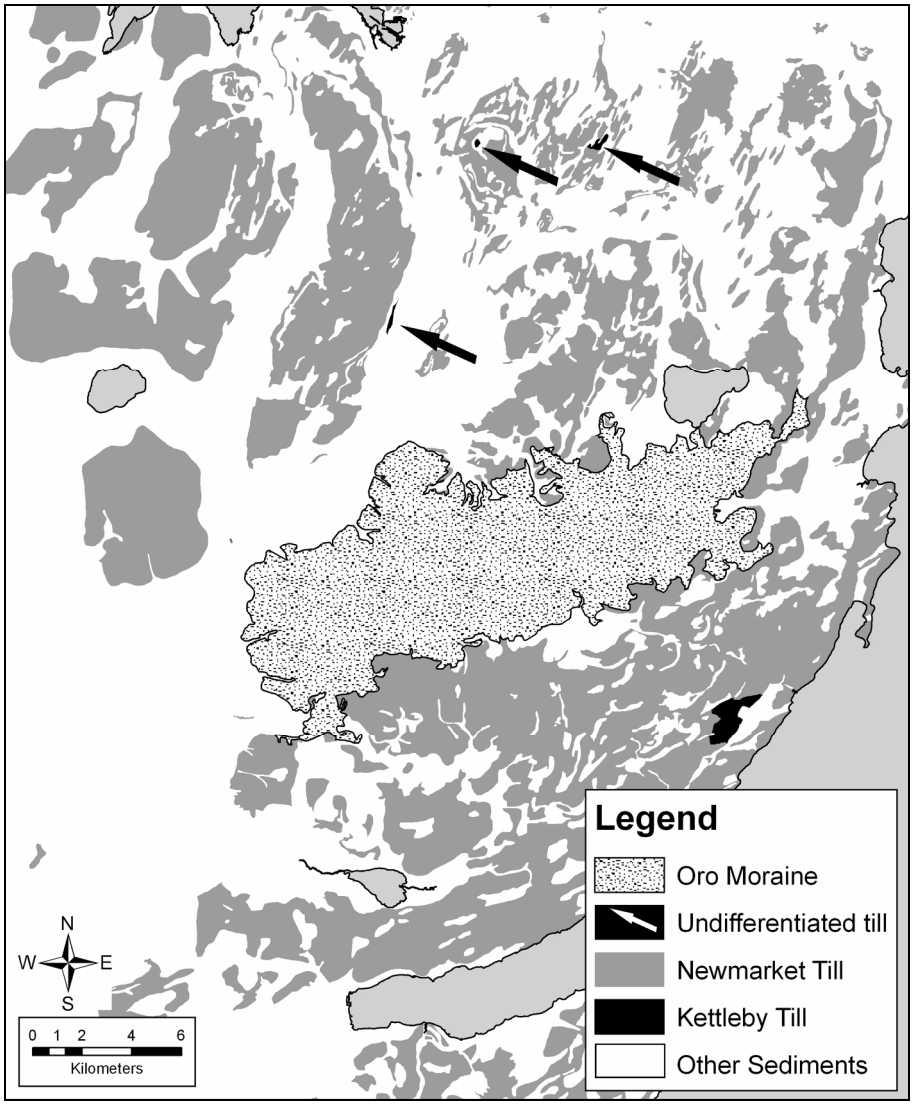

Figure 33.2. Surface tills in the study area. The Simcoe uplands physiographic region closely follows the mapped extents of Newmarket and 'northern' tills.

The lower drift is overlain by thick rhythmically bedded glaciolacustrine silt and clay and sandy subaqueous fan deposits. Sand draped and interbedded with thin silt and clay suggests deposition in a distal fan environment, whereas thin gravelly beds likely reflect deposition within channels or between channels closer to the sediment source. Oscillations between these coarse- and fine-textured sediments were likely caused by a combination of changes in ice margins the opening and closing of conduits and channel avulsions. Thin diamicton beds found throughout this interval are likely debris flow deposits.

The uppermost sediment package is Newmarket or 'northern' till that is locally overlain by glaciolacustrine and outwash deposits. The till cover is typically 5 to 10 m thick, but, on occasion, is as much as 25 m thick.

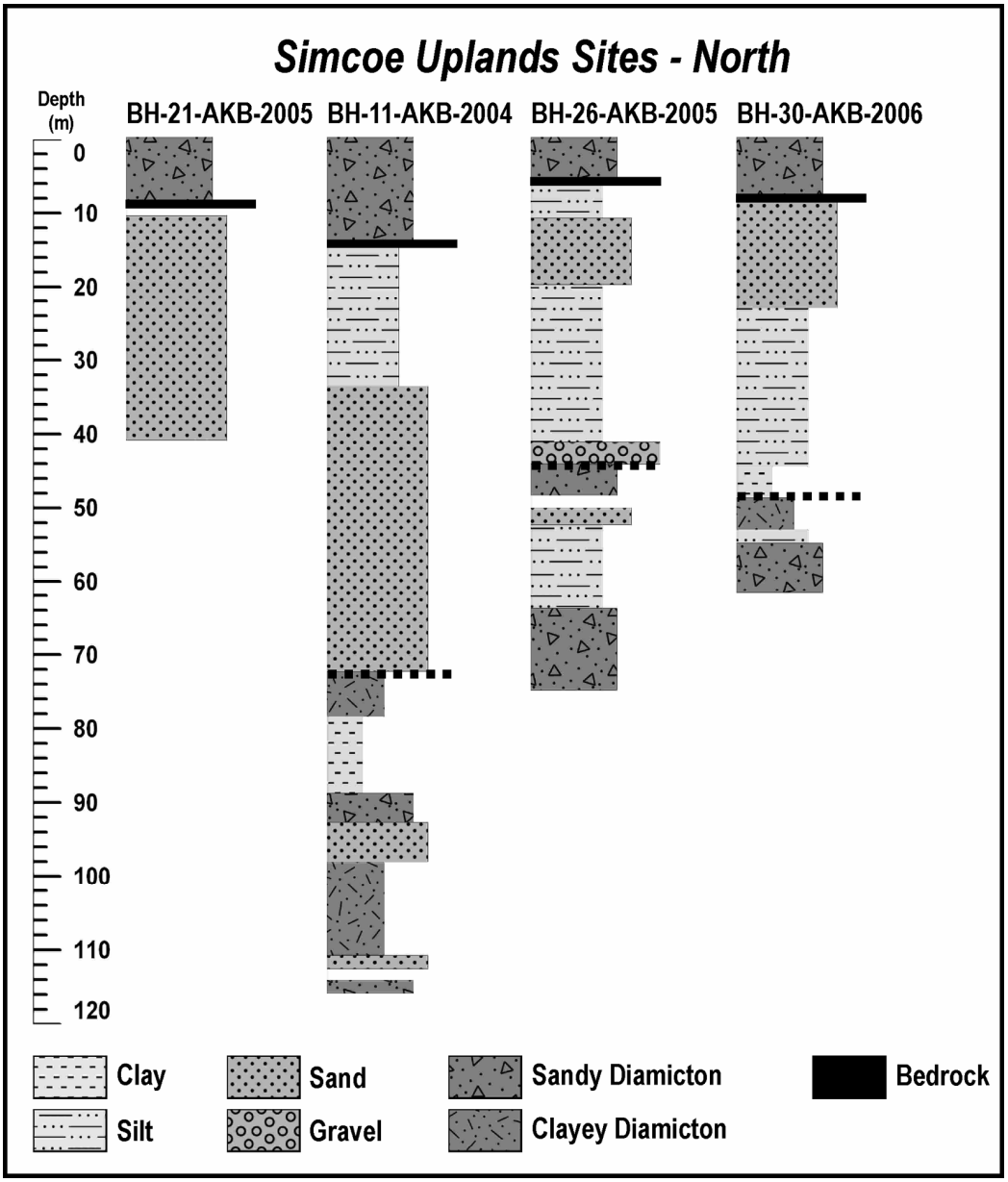

Figure 33.3. Summary geological logs of Simcoe uplands sites located north of the Oro Moraine. The dashed line indicates the upper limit of the lower drift package. The solid line indicates the base of the Newmarket and 'northern' tills. These boundaries are preliminary and may change as the modelling proceeds. The logs are displayed moving west to east. Borehole locations are indicated on Figure 33.1. *See* Burt and Russell (2006) for detailed information on the 2004 drilling program.

The most prominent feature in the central study area is the approximately 165 km^2 Oro Moraine, which extends from Bass Lake westward to Highway 400 (*see* Figure 33.1). The Oro Moraine has been interpreted as an end moraine formed during a standstill of the Lake Simcoe lobe (Deane 1950); as an interlobate moraine overridden by ice from the Lake Simcoe basin (Gravenor 1957); as a remnant deposit of an earlier sandy moraine built by the Georgian Bay lobe that was subsequently overridden from the northeast (Chapman and Putnam 1984); as an interlobate feature deposited in 3 main stages as a series of coalescing subaqueous fans and within open and closed conduits within a widening interlobate zone (Barnett 1986, 1989); and as a series of stacked subaqueous fans (Slattery 2003). Preliminary interpretation of available data indicates that stratigraphically, the Oro Moraine sediments overlie the lower drift, glaciolacustrine and upper till packages of the Simcoe uplands.

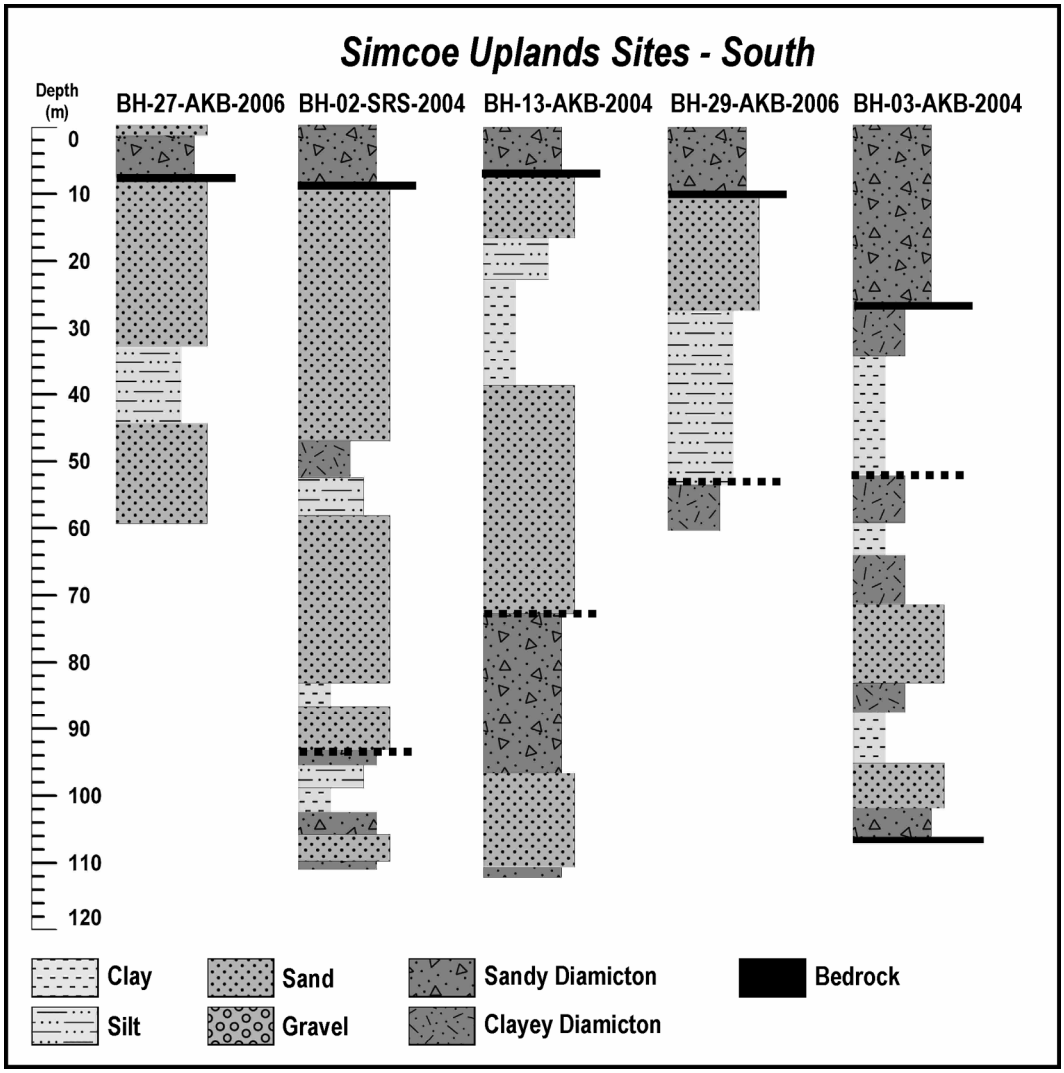

Figure 33.4. Summary geological logs of Simcoe uplands sites located south of the Oro Moraine. The logs are displayed moving west to east. The dashed line indicates the upper limit of the lower drift package. The solid line indicates the base of the Newmarket and 'northern' tills. These boundaries are preliminary and may change as the modelling proceeds. Borehole locations are indicated on Figure 33.1. *See* Burt and Russell (2006) for detailed information on the 2004 drilling program.

During the summers of 2003 and 2005 field observations supporting a subaqueous fan depositional environment were made in pits across the moraine (Figure 33.5). Detailed descriptions of channel and interchannel sediments from upper to distal fan locations may be found in Slattery (2003). The moraine morphology of local topographic highs with deeply incised surfaces and the distribution of proximal to distal facies in pits across the moraine support the theory of several fans coalescing to form the moraine. Pit C is of particular interest as there is evidence of a conduit that would have fed one or more fans (*see* Figure 33.5).

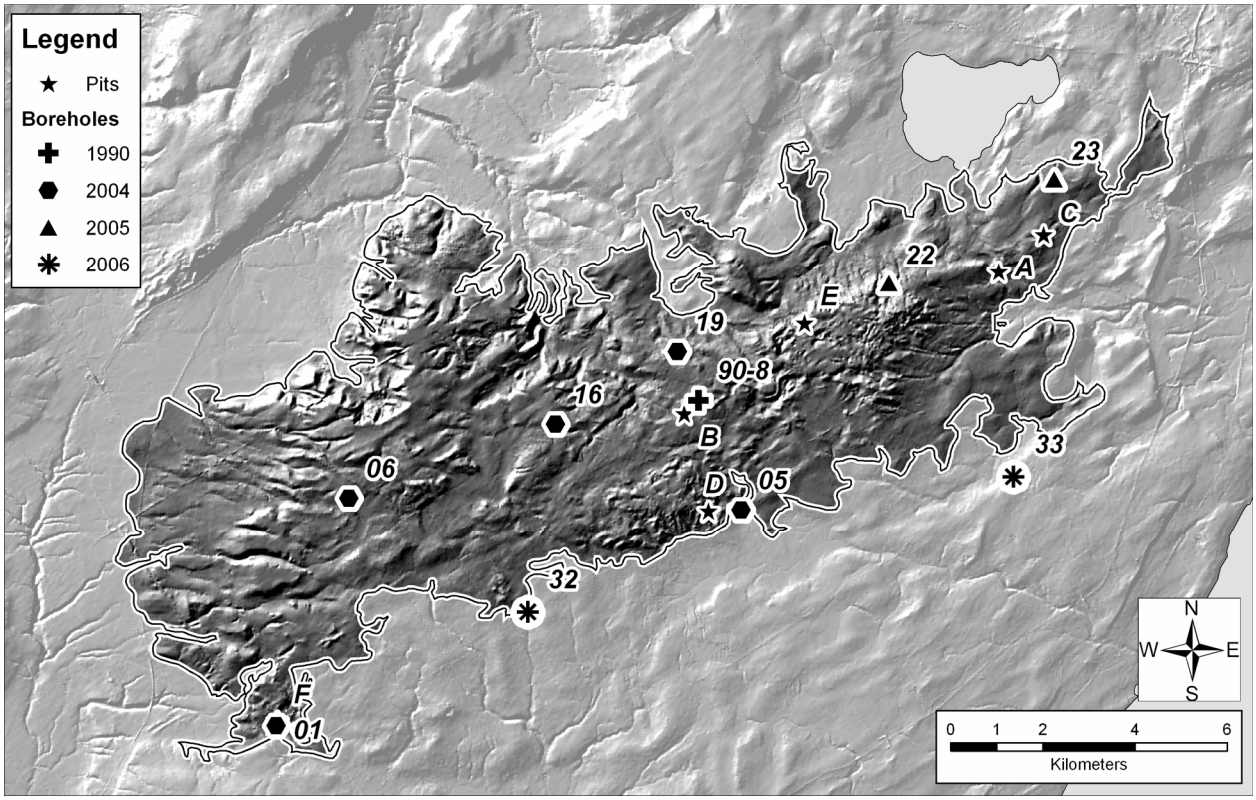

Figure 33.5. Hillshade map of the Oro Moraine and surrounding Simcoe uplands and valley areas (*see* Figure 33.1 for general location). The area highlighted is the mapped extent of surficial glaciofluvial ice-contact stratified drift. Only those boreholes drilled on and adjacent to the moraine are marked.

Four boreholes (BH-06-AKB-2004, BH-16-SRS-2004, BH-19-AKB-2004 and BH-22-AKB-2005) have been drilled into the moraine (Figures 33.1 and 33.6). Borehole BH-22-AKB-2005, located at the apex of a probable fan structure, intersected a thick package of cobbles and gravel extending 22 m below surface, which may represent a conduit to proximal fan depositional environment. The lower 60 m of borehole BH-22-AKB-2005 is characterized by several thick fining-upward sequences of cobbles and gravel to sand and occasionally silt indicative of multiple phases of fan deposition. Boreholes BH-06-AKB-2004 and BH-16-SRS-2004, as well as borehole OGS-90-8, were drilled in the western and central regions of the moraine. The upper gravelly sand and sand deposits suggest deposition in upper or mid-subaqueous fan locations. The diamicton units and lower sediments of the boreholes have yet to be fully interpreted. Borehole BH-19-AKB-2004, characterized by thick glaciolacustrine fine-textured sands, silts and clays overlain by silty to sandy diamicton, bears a close resemblance to the adjacent Simcoe uplands sites.

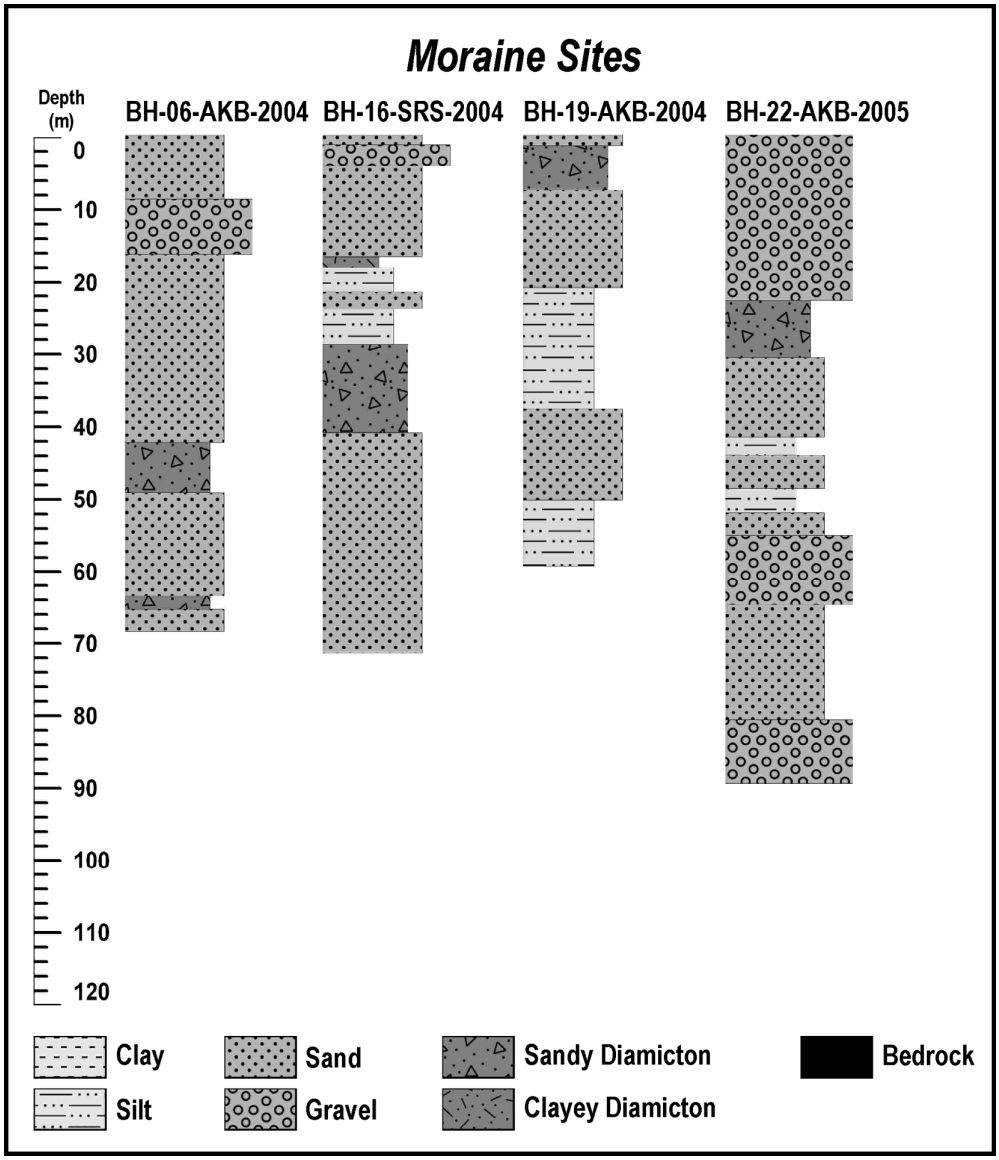

Figure 33.6. Summary geological logs of sites located along the axis of the Oro Moraine. The logs are displayed moving west to east. Borehole locations are indicated on Figures 33.1 and 33.5. *See* Burt and Russell (2006) for detailed information on the 2004 drilling program.

The complex nature of the moraine margin deposits at depth are revealed in boreholes BH-01-SRS-2004, BH-05-SRS-2004 and BH-33-AKB-2006, drilled at or near the edges of the moraine (Figure 33.7). These sites are characterized by the lower drift sequence (boreholes BH-01-SRS-2004 and BH-05-SRS-2004) and overlying subaqueous fan and glaciolacustrine silt and clay typical of Simcoe uplands sites at depth. The upper portions of all 3 sites are characterized by proximal to mid-fan sand and gravel interbedded with sandy diamicton. Borehole BH-32-AKB-2006 and BH-23-AKB-2005 are also located peripheral to the moraine, but do not have the coarser grained moraine facies observed in boreholes BH-01-SRS-2004, BH-05-SRS-2004 and BH-33-AKB-2006.

Six boreholes (boreholes BH-08-SRS-2004, BH-09-SRS-2004, BH-18-AKB-2004, BH-20-AKB-2005, BH-31-AKB-2006 and BH-34-AKB-2006) have been drilled into the broad, flat-bottomed and steep-sided valleys that dominate the western side of the study area (Figures 33.1 and 33.8). Theories on the formation of the large valley systems both within the study area and further south include subaerial erosion prior to the last glaciation, the presence of late-stage ice tongues (Deane 1950) and tunnel valleys formed by rapid meltwater release (Barnett 1990; Russell et al. 2003). Several key lines of evidence used

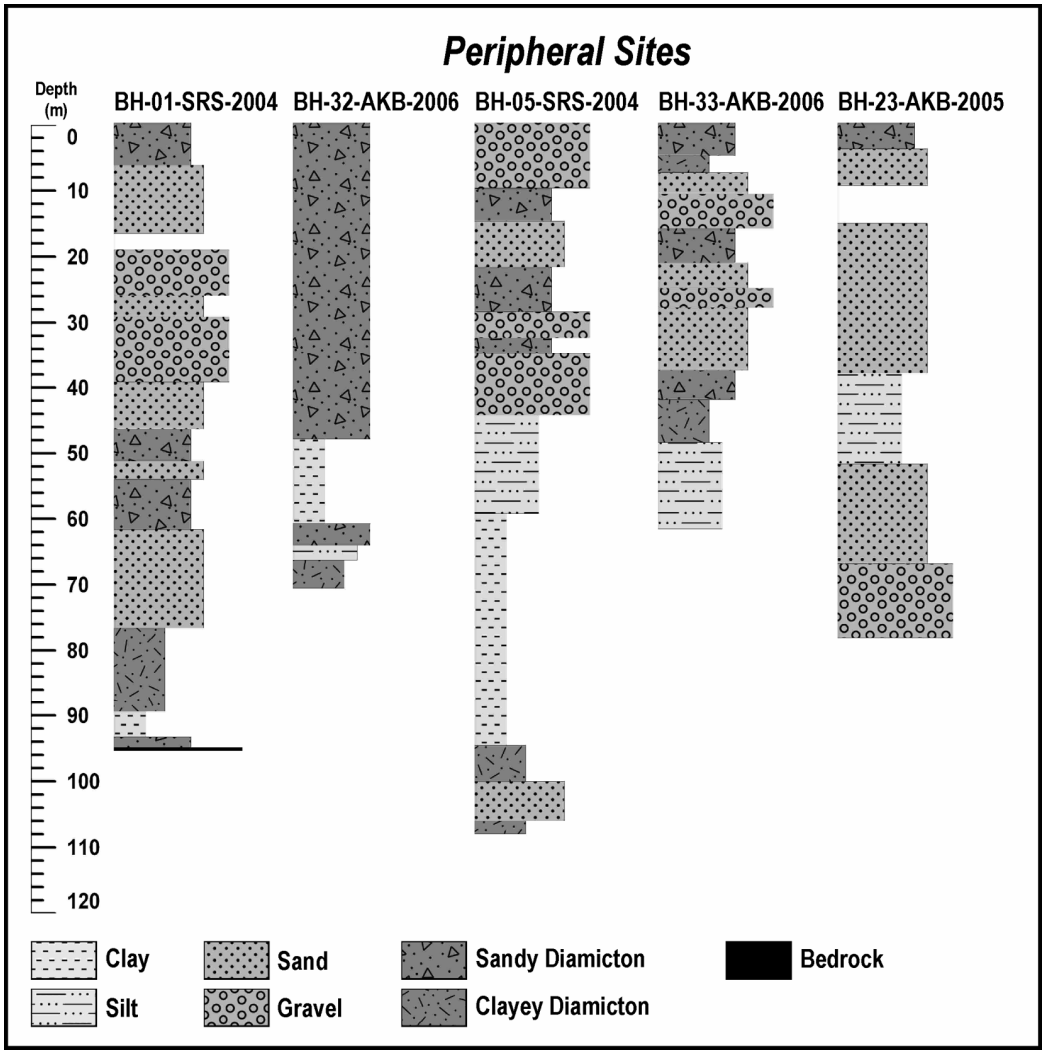

Figure 33.7. Summary geological logs of sites located along the periphary of the Oro Moraine. The logs are displayed moving west to east. Borehole locations are indicated on Figures 33.1 and 33.5. *See* Burt and Russell (2006) for detailed information on the 2004 drilling program.

to interpret the network of large valleys in the Oak Ridges Moraine area are applicable to the current study area including 1) modern streams are underfit compared to the valley network; 2) the channels are incised below the present day lake levels; 3) the absence of major delta deposits at modern and paleo shorelines; and 4) the nature of the valley-fill sequences (Russell et al. 2000, 2003).

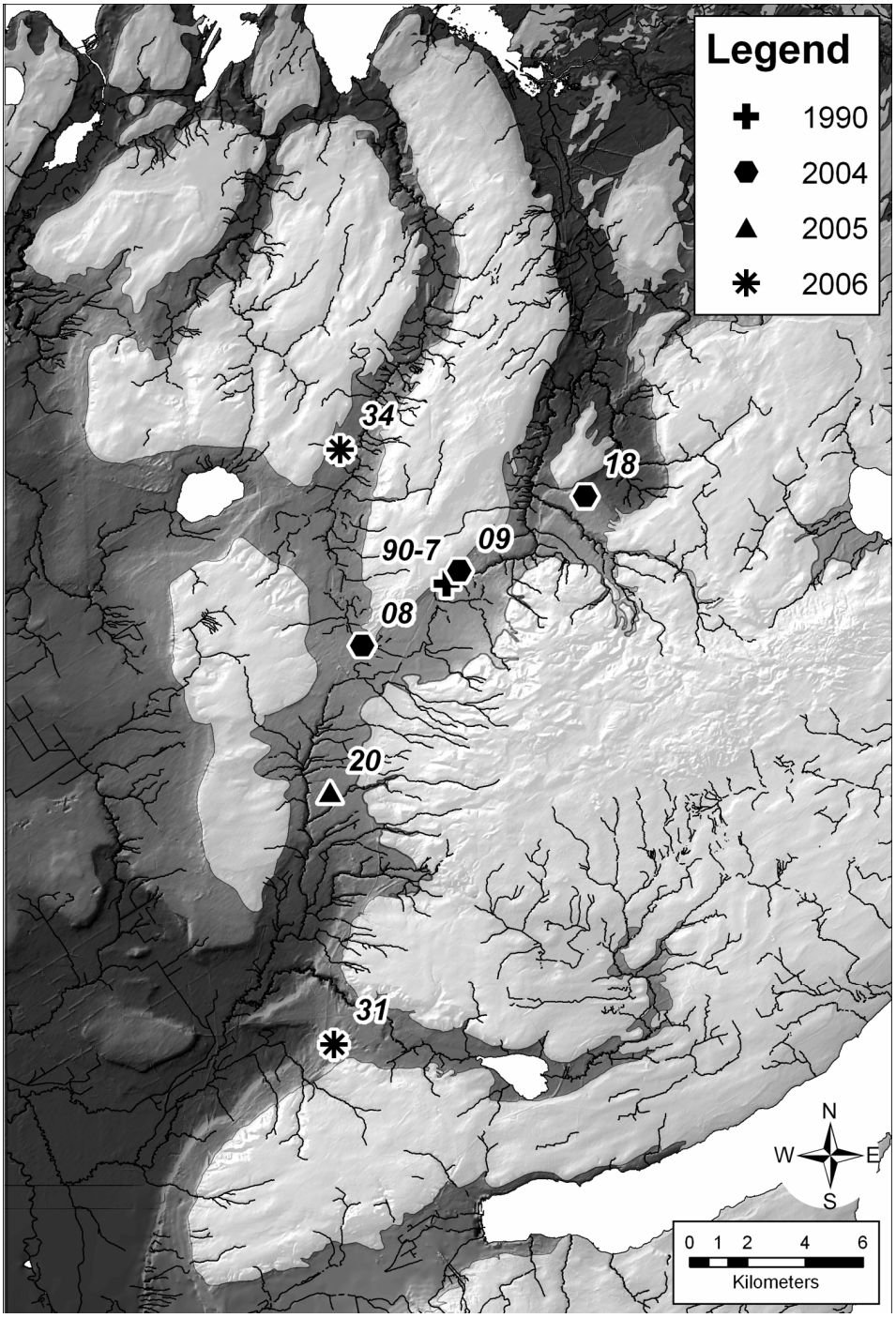

Figure 33.8. Digital elevation model of the western portion of the study area. The extensive tunnel valley network (shown in mid to dark grey) contrasts strongly with the Simcoe uplands and Oro Moraine sediments (shown in light grey). Modern streams are shown in black and lakes in white. Boreholes drilled into the tunnel vally network are indicated including a borehole completed in 1990 (Barnett 1991).

Diamicton units directly overlying bedrock in boreholes BH-08-SRS-2004, BH-09-SRS-2004 and BH-18-AKB-2004 are likely older erosional remnants (Figure 33.9). Diamicton was also observed above bedrock in borehole OGS-90-7 (Barnett 1991). The valleys were then infilled with a combination of both high-energy channel sediments, including thin gravel beds and thick planar, cross-bedded and ripple cross-laminated sands, and low-energy glaciolacustrine sediments including rhythmically bedded, fine-textured sand and laminated to thinly bedded silt and clay. The mid-valley-fill diamicton beds observed in boreholes BH-08-SRS-2004, BH-09-SRS-2004 may have been formed by debris flows off adjacent uplands.

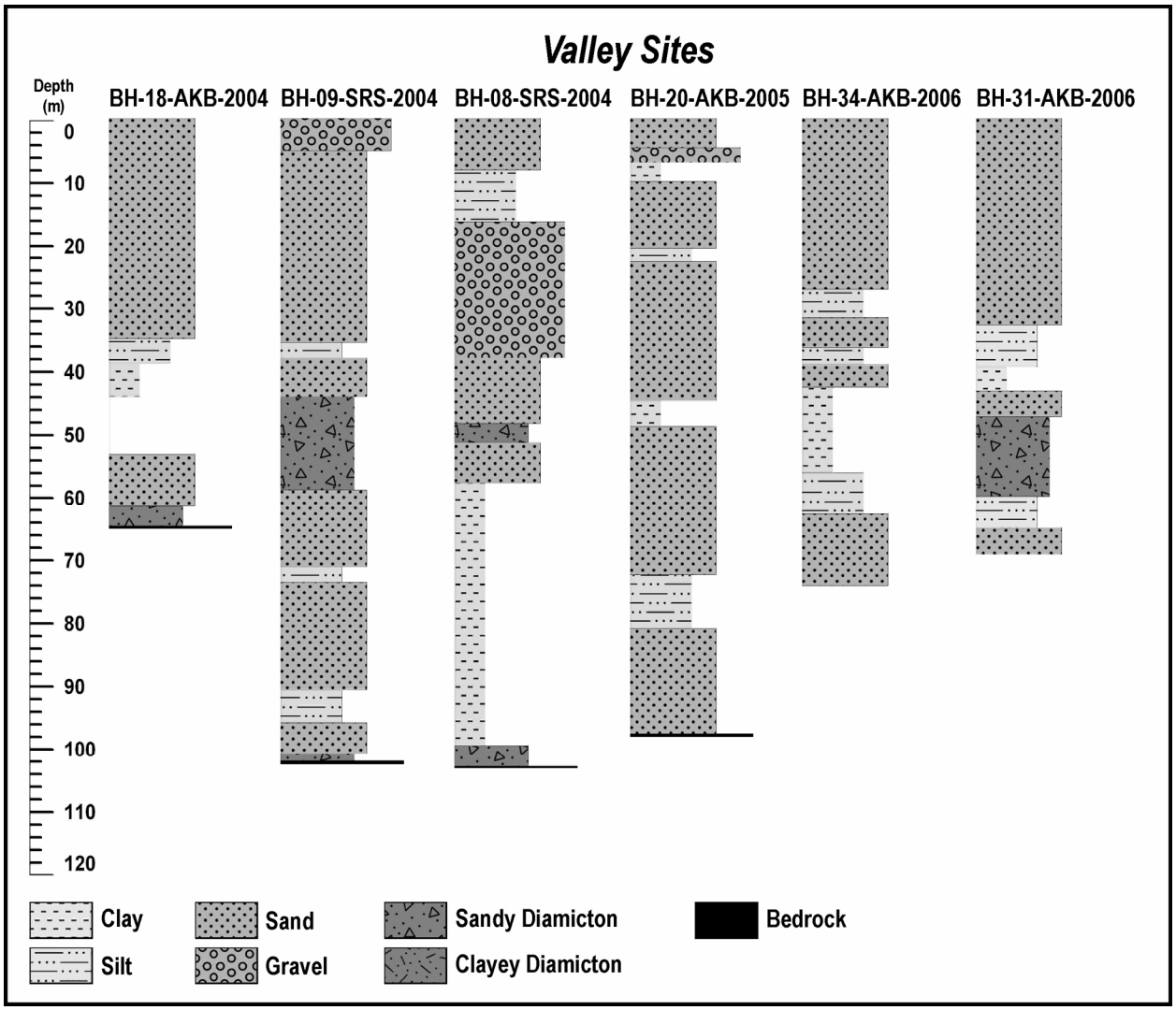

Figure 33.9. Summary geological logs of valley sites. The logs are pictured north to south along the most prominent valley (boreholes BH-18-AKB-2004, BH-09-SRS-2004, BH-08-SRS-2004 and BH-20-AKB-2005) followed by logs from 2 connecting valleys. Borehole locations are indicated on Figures 33.1 and 33.8. *See* Burt and Russell (2006) for detailed information on the 2004 drilling program.

Borehole BH-24-AKB-2005 (Figures 33.1 and 33.10) was drilled in one of several broad valleys in the far north of the study area. These valleys were classified as part of a mid-sized, but deep, channel network by Russell et al. (2003), but have more in common with the structurally controlled re-entrant bedrock valleys observed along the Paleozoic–Proterozoic boundary to the east of Lake Simcoe. As shown on Figure 33.10, Paleozoic rocks crop out on the interfluves of the broad valley network, whereas Proterozoic rocks crop out to the north. Observation of the shape of the Paleozoic rock outcrops shows that both the rock outcrops and the broad valleys are aligned with the regional bedrock joint orientations. Borehole BH-24-AKB-2005 intersected Proterozoic bedrock 6.1 m below surface indicating that the valley was formed by the removal of the Paleozoic rocks. This also occurred in an adjacent valley where there are small outcrops of Proterozoic rocks in a similar relative position as borehole BH-24-AKB-2005.

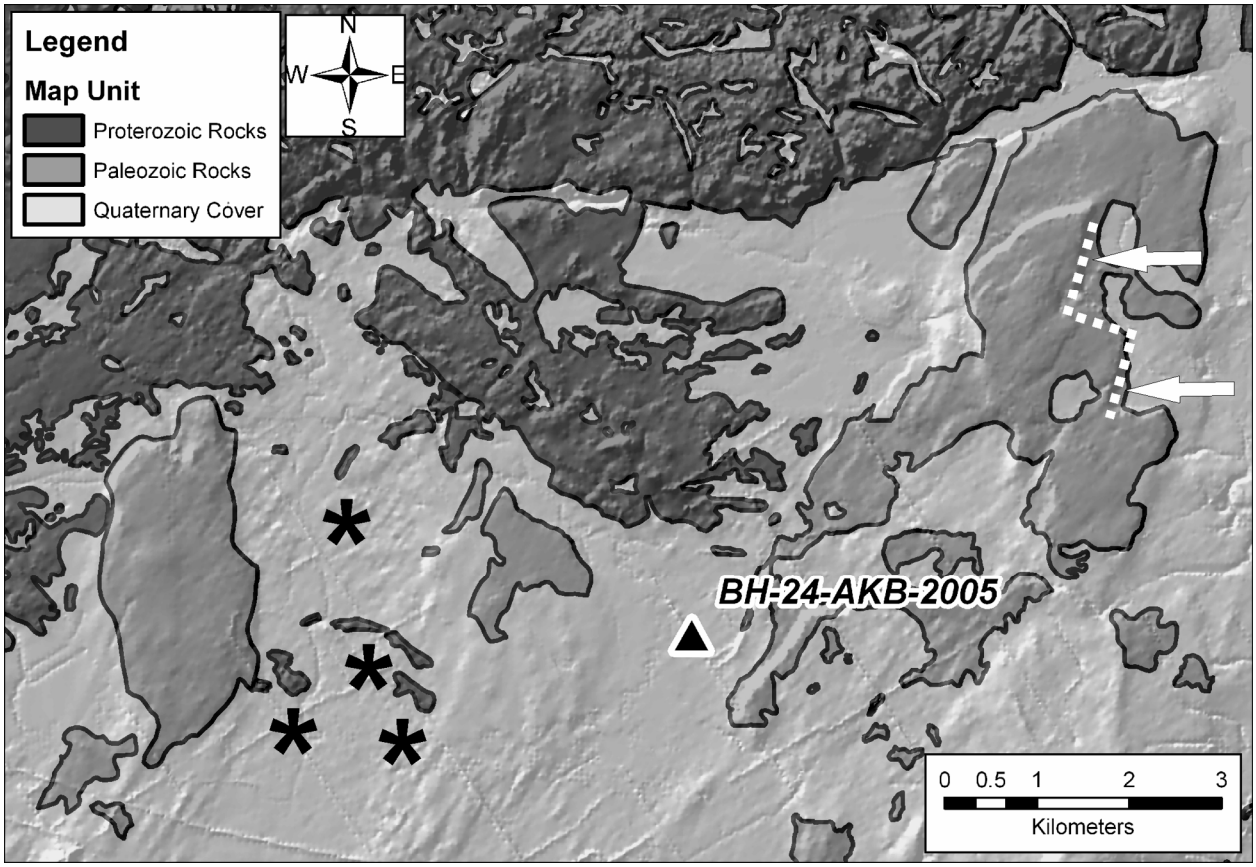

Figure 33.10. Draped hillshade map of part of the broad structurally controlled re-entrant valley network in the northern part of the study area. Evidence of the regional bedrock joint orientation can be seen in the shape of some Paleozoic rock outcrops (dashed line and arrows). Small outcrops of Proterozoic rocks (*) are also marked. See Figure 33.1 for borehole BH-24-AKB-2005 location.

The broad valleys located across the northern portion of the study area are infilled with thin (typically <1 m thick) basal units of gravel overlain by diamicton (boreholes BH-24-AKB-2005 and BH-25-AKB-2005; Figure 33.11). The upper portion of the fill sequences are glaciolacustrine silts and clays. These deposits were also observed in shallow roadcuts and ditches. Adjacent to Severn Sound, the fine-grained glaciolacustrine deposits are overlain by postglacial lacustrine sediments, whereas organic deposits consisting of peat, muck and marl are found in low-lying areas. There are both glaciolacustrine and postglacial shoreline deposits along the margins of the valleys (Ontario Geological Survey 2003).

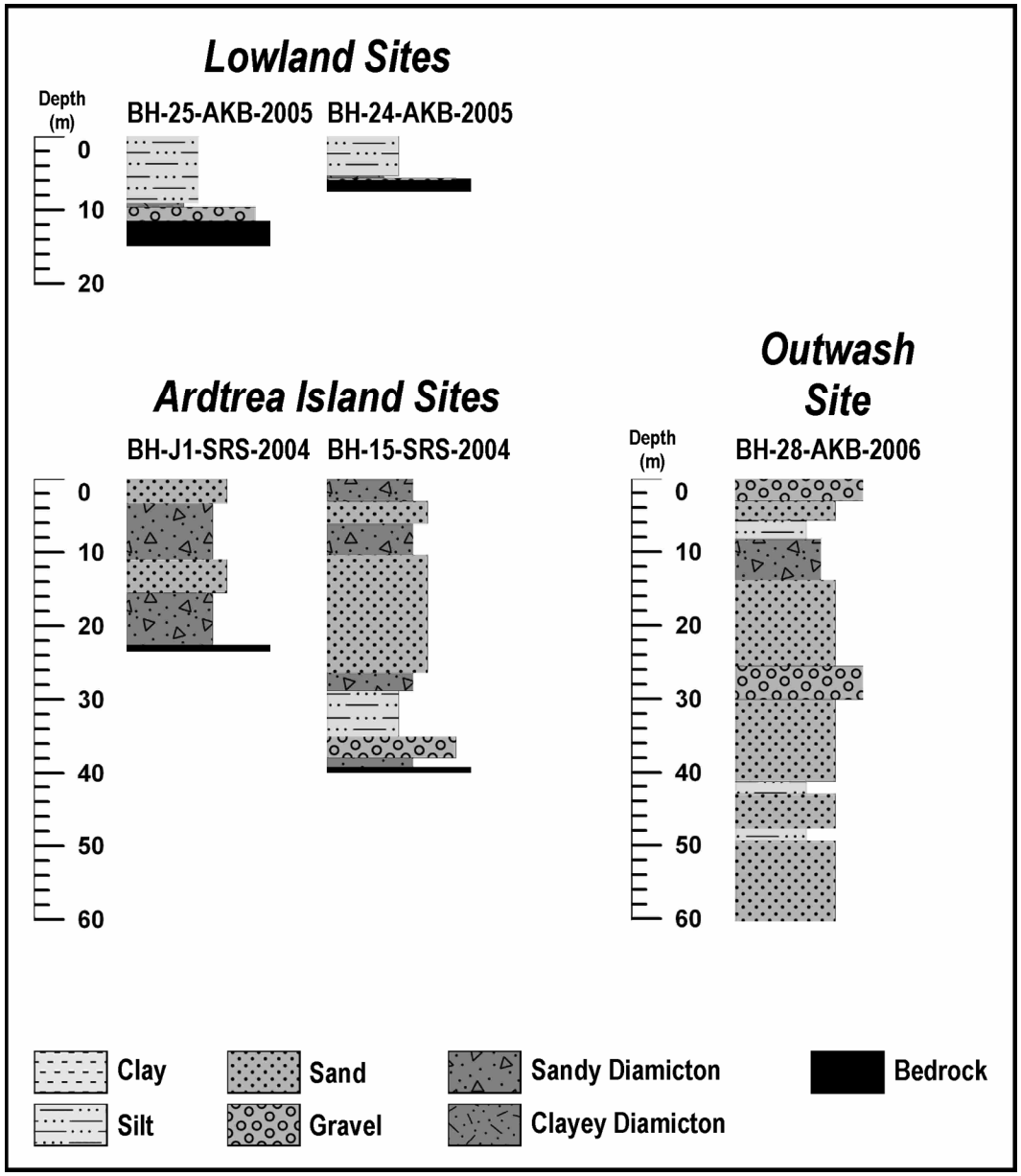

Figure 33.11. Summary geological logs of northern lowland valley sites, Ardtrea Island sites and an outwash site. Each set of logs are pictured west to east. Borehole locations are indicated on Figure 33.1. The Artrea Island sites were discussed in Burt and Russell (2005). *See* Burt and Russell (2006) for detailed information on the 2004 drilling program.

PROJECT STATUS

The final drilling program for this project will be completed in the fall of 2006. The results of the 2005 and 2006 drilling programs will be released together in a Miscellaneous Release—Data (MRD), in the same format as for the 2004 drilling program (Burt and Russell 2006), which included written logs, graphic logs, representative photographs and the results of carbonate content and grain size analyses.

All available subsurface data sets have been assembled and translated into geological materials. Three-dimensional modelling using Datamine Studio® is ongoing. It is anticipated that the modelling will be completed in 2007.

REFERENCES

Bajc, A.F. and Newton, M.J. 2005. Three-dimensional modelling of Quaternary deposits in Waterloo Region, Ontario: a case study using Datamine Studio® software; *in* Summary of Field Work and Other Activities 2005, Open File Report 6172, p.25-1 to 25-8.

Barnett, P.J. 1986. Quaternary geology of the eastern halves of the Barrie and Elmvale areas, Simcoe County; *in* Summary of Field Work and Other Activities 1986, Ontario Geological Survey, Miscellaneous Paper 132, p.193-194.

——— 1988. Quaternary geology of the eastern half of the Elmvale area, Simcoe County; *in* Summary of Field Work and Other Activities 1988, Ontario Geological Survey, Miscellaneous Paper 141, p.405-406.

——— 1989. Quaternary geology of the Barrie and Elmvale area; *in* Summary of Field Work and Other Activities 1989; Ontario Geological Survey, Miscellaneous Paper 146, p.205-206.

——— 1990. Tunnel valleys: evidence of catastrophic release of subglacial meltwater, central-southern Ontario, Canada; Geological Society of America, Northeastern Section, Syracuse, New York, Abstracts with Programs, v.22, p.3.

——— 1991. Preliminary report on the stratigraphic drilling of Quaternary sediments in the Barrie area, Simcoe County, Ontario; Ontario Geological Survey, Open File Report 5755, 80p.

——— 1997. Quaternary geology, eastern half of the Barrie and Elmvale areas; Ontario Geological Survey, Map 2645, scale 1:50 000.

Burt, A.K. 2004. Three-dimensional mapping of Quaternary (surficial) deposits in the Barrie area, central Ontario; *in* Summary of Field Work and Other Activities 2004, Ontario Geological Survey, Open File Report 6145, p.35-1 to 35-5.

Burt, A.K. and Bajc, A.F. 2005. Three-dimensional groundwater mapping in stratigraphically complex glacial deposits: current projects in Ontario, Canada; Geological Society of America, Abstracts with Programs, v.37, no.7, p.144.

Burt, A.K. and Russell, D.F. 2005. Three-dimensional modelling of thick Quaternary deposits in the Barrie area, central Ontario; *in* Summary of Field Work and Other Activities 2005, Ontario Geological Survey, Open File Report 6172, p.26-1 to 26.9.

——— 2006. Results of 2004 Oro Moraine drilling program in the Barrie area, central Ontario; Ontario Geological Survey, Miscellaneous Release—Data 198.

Chapman, L.J. and Putnam, D.F. 1984. The physiography of southern Ontario; Ontario Geological Survey, Special Volume 2, 270p.

Deane, R.E. 1950. Pleistocene geology of the Lake Simcoe district, Ontario; Geological Survey of Canada, Memoir 256, 108p.

Dreimanis, A. 1977. Late Wisconsinan glacial retreat in the Great Lakes region, North America; Annals of New York Academy of Sciences, v.288, p.70-89.

Finamore, P.F. 1981. Quaternary geology of the Orillia area (31 D/11), Victoria and Simcoe counties, southern Ontario, *in* Summary of Field Work 1981, Ontario Geological Survey, Miscellaneous Paper 100, p.111-113.

Finamore, P.F. and Bajc, A.F. 1984. Quaternary geology of the Orillia area, southern Ontario; Ontario Geological Survey, Preliminary Map P.2697, scale 1:50 000.

Gravenor, C.P. 1957. Surficial geology of the Lindsay–Peterborough area, Ontario, Victoria, Peterborough, Durham and Northumberland counties, Ontario; Geological Survey of Canada, Memoir 288, 60p.

Gwyn, Q.H.L. 1972. Quaternary geology of the Alliston–Newmarket area, southern Ontario; Ontario Division of Mines, Miscellaneous Paper 53, p.144-147.

Liberty, B.A. 1969. Paleozoic geology of the Lake Simcoe area, Ontario; Geological Survey of Canada, Memoir 355, 201p.

Ontario Geological Survey 1991. Bedrock geology of Ontario, east-central sheet; Ontario Geological Survey, Map 2543, scale 1:1 000 000.

——— 2003. Surficial geology of southern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 128, v.1 and v.2.

Russell, H.A.J., Brennand, T.A., Logan, C. and Sharpe, D.R. 1998. Standardization and assessment of geological descriptions from water well records, Greater Toronto and Oak Ridges Moraine areas, southern Ontario; *in* Current Research 1998-E; Geological Survey of Canada, p.89-102.

Russell, H.A.J., Sharpe, D.R, Brennand, T.A., Barnett, P.J. and Logan, C. 2003. Tunnel channels of the Greater Toronto and Oak Ridges Moraine areas, southern Ontario; Geological Survey of Canada, Open File 4485, scale1:250 000.

Russell, H.A.J., Sharpe, D.R., Pullan, S.E. and Barnett, P.J. 2000. Form and sedimentary fill of tunnel channels beneath the Oak Ridges Moraine, southern Ontario: the Holland Marsh–King City channel system; Geological Survey of Canada, Open File 3841.

Slattery, S.R. 2003. Subsurface mapping of the Barrie area, central Ontario; *in* Summary of Field Work and Other Activities 2003, Ontario Geological Survey, Open File Report 6120, p.25-1 to 25-8.

Todd, B.J., Hunter, J.A.M., Good, R.L., Burns, R.A., Douma, M., Pullan, S.E. and Lewis, C.F.M. 2003. Seismostratigraphy of Quaternary sediments beneath Lake Simcoe, Ontario: results of 1992 and 1993 expeditions of the *MV J. Ross Mackay*; Geological Survey of Canada, Open File 3037.

34. Project Unit 05-013. Bedrock Topography and Overburden Thickness Mapping, Southern Ontario

C. Gao[1], J. Shirota[1], R.I. Kelly[1], F.R. Brunton[1] and S. van Haaften[1]

[1]Sedimentary Geoscience Section, Ontario Geological Survey

INTRODUCTION

The following article outlines protocols and a methodology developed by the Ontario Geological Survey (OGS) to generate digital regional bedrock elevation and overburden thickness maps for southern Ontario. Advances in data storage and retrieval of the extensive petroleum, engineering and water well records as well as geological observations acquired over the last 50 years have made updated maps both timely and possible. Using ESRI® ArcGIS® analysis functions such as kriging, these data can be integrated and analyzed to generate bedrock topography maps. The approximate thickness of the Quaternary sediments is determined by subtracting the bedrock elevation surface from the provincial digital elevation model (DEM).

Bedrock elevation and drift thickness information is important in bedrock aggregate resource assessments, groundwater studies, geotechnical work and other land-use applications. For instance, Ontario's current aggregate resources inventory mapping program, which was initiated in the late 1970s, assesses the aggregate resources for both naturally formed sand and gravels, and crushed stone derived from bedrock (Ontario Mineral Aggregate Working Party 1977; Cowan 1978; Kelly and Rowell 1995; Baker 2003). The resultant Aggregate Resources Inventory Paper (ARIP) publications form important components in municipal land-use planning and resource management to ensure that adequate resources of mineral aggregate remain available for future use. A key component of an ARIP is a bedrock resources map outlining areas of thin surficial sediment cover where bedrock aggregate resources can be obtained at lower cost.

Since 2003, several pilot projects have been undertaken to develop drift thickness mapping for mineral aggregate and groundwater studies across southern Ontario (van Haaften et al. 2004; Gao et al. 2005; Shirota, Brunton and Kelly 2005). Feedback from users of the resultant maps has led to many improvements to the methodology. As a result, it was decided to expand the drift thickness mapping methodology to generate the bedrock topography and overburden thickness maps of southern Ontario. The bedrock of southern Ontario comprises both Paleozoic sedimentary and Precambrian metamorphic and igneous rocks (Ontario Geological Survey 1991; Johnson et al. 1992). Glaciations during the Quaternary period of the recent geological past resulted in both the physical erosion and sculpting of the bedrock surface and subsequent burial of much of the bedrock by varied thicknesses of till, clay, sand and gravel deposits (Barnett, Cowan and Henry 1991; Barnett 1992; Ontario Geological Survey 2003). In comparison with previous bedrock topography studies (Karrow 1973; Chapman and Putnam 1984; Flint and Lolcama 1986; Eyles, Boyce and Mohajer 1993; Eyles et al. 1997; Brennand et al. 1998; Edgecombe 1999; Eyles 2002), additional quality control measures were undertaken so that problematic data were able to be tracked and eliminated. As such, this new approach has enabled better delineation of the bedrock topography, in particular, the regional extent of significant buried bedrock valleys across southwestern Ontario.

Summary of Field Work and Other Activities 2006,
Ontario Geological Survey, Open File Report 6192, p.34-1 to 34-10.

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DATA

Data sources used in the current project to provide information on bedrock elevations include water wells, geotechnical boreholes, oil and gas wells, bedrock elevation points extracted from geological maps and other data sets. Base map information such as lakes, municipal boundaries, roads and railways came from the Natural Resources and Values Information System provided by the Ministry of Natural Resources (MNR). This ministry also provided the DEM for most of the ground elevation data. In some areas, the elevation values were adjusted to the Shuttle Radar Topography Mission grid provided by the National Aeronautics and Space Administration (NASA) (2006). The bathymetric data under Lake Erie and Lake St. Clair came from the National Oceanic and Atmospheric Administration (NOAA) (1999). The MNR also has a hydrologically manipulated DEM with actual stream elevations imposed on the surface. This hydrologically adjusted version should not be used for the bedrock topography methodology outlined in this report (Gao et al. 2005).

Water wells provided by Ministry of the Environment (MOE) contribute a large portion of the data used in the determination of the topography of bedrock surface. However, the data quality is inconsistent and the water wells frequently contain georeferencing errors and inaccurate descriptions or misused geological terminology. Quality assurance/quality control of the water well data set is, therefore, critical and water wells that fail to pass the filtering process were excluded from kriging (Gao et al. 2005).

The OGS houses the Urban Geology Automated Information System (UGAIS), a databank of geotechnical boreholes, assembled in the 1970s from various geology, hydrology and engineering related projects across southern Ontario. This database includes a field indicating the depth of bedrock. This field and the DEM were used to calculate the elevations of the bedrock surface at each of the borehole locations. The data set was also filtered for errors related to georeferencing (Gao et al. 2005).

Oil and gas drill records for Ontario, maintained by the Ontario Oil, Gas and Salt Resources Library, Ministry of Natural Resources (MNR), contain information on bedrock units and their relative depths. In this database, the bedrock surface is the top of the youngest bedrock unit. However, in some cases, the record was found to have skipped some of the upper bedrock units making it difficult to define the true bedrock surface elevation. For this reason, this database was updated by MNR and a revised database including the addition of a field indicating bedrock subsurface elevations was provided to the OGS.

Bedrock elevation information was also extracted from the surficial geology map of southern Ontario (Ontario Geological Survey 2003) and existing bedrock geology maps. Bedrock outcrops were assigned the DEM values as bedrock elevations at each of the locations. In addition, artificial points were sampled at a grid spacing of approximately 400 m by 500 m from bedrock or thin-drift areas where the overburden cover is known to be less than 1 m thick. The bedrock elevation was calculated by subtracting 1 m from the DEM at each location of the locations.

Other data sets include drilling records, bedrock elevation points, such as geophysical picks and bedrock outcrops recorded by geologists of the OGS and Geological Survey of Canada (GSC) during the course of their field work, and borings from unpublished groundwater studies for the City of Hamilton (SNC Lavalin Engineers & Constructors 2004).

METHODS

Data Preparation

All water wells passing the filtering process were searched for bedrock depth. Using a translation table, water well layers were coded with 'O' for overburden, and 'P' or 'Pr' for Paleozoic or Precambrian bedrock, respectively (Gao et al. 2005). For each water well, an algorithm was designed to search for 2 consecutive bedrock layers of P or Pr. If no stratigraphic violation such as Pr/P occurs, the top of the first bedrock layer is the depth to bedrock at this location because 2 consecutive rock strata are considered a strong indication of true bedrock. It is unlikely that an incorrectly recorded boulder would occur twice in a row. If 2 consecutive bedrock strata are not found, the deepest stratum decides whether the well is a rock well or an overburden well not reaching bedrock. If the deepest stratum is bedrock, the top of this stratum becomes the bedrock depth at this location. If it is overburden, the well is considered to be an overburden well not reaching bedrock.

Erroneous, inversed stratigraphy of Pr/P, i.e., Precambrian overlying Paleozoic, may exist in the succession of well layers after the coding process. A search was conducted and water wells containing such stratigraphic violations were removed.

Water wells containing undefined entries in the primary material field such as PREVIOUSLY DUG, UNKNOWN TYPE or symbols of '**' and '-' without descriptions were processed separately. In addition, many entries were considered as ambiguous or questionable descriptions. These ambiguous descriptions include BASALT, CONGLOMERATE, GREYWACKE, GYPSUM, IRON FORMATION, MARBLE, SANDSTONE, SLATE and SOAPSTONE in Paleozoic bedrock areas of southern Ontario. For instance, numerous water wells containing SANDSTONE are present across southern Ontario where only limited occurrences of sandstone bedrock exist. It was found that this description is often used to describe sandy drift deposits in this region. As such, water wells containing these entries were queried out (that is, identified) and inspected. To gain insight into the lithological terms used by drillers, most of the water wells containing CHERT and FLINT were also checked. In total, over 30 000 water well records were queried out and processed using specially designed routines or inspected for manual assignment of bedrock depths. Bedrock elevations were calculated by subtraction of bedrock depths from the DEM.

The existence of water wells with deep bedrock depths in thin-drift areas (<1 m overburden) indicates a potential contradiction between the drilling record and geological observations. Since the surficial geology is mapped at a regional (1:50 000) rather than a local scale, it is quite possible that water wells reaching bedrock at greater depths (20 m for example) exist in a thin-drift area. Such wells can, if valid, be potentially used to define small bedrock depressions. For the current OGS aggregate resources inventory mapping program, a drift thickness of 8 m is a threshold value in resource designation (Ontario Mineral Aggregate Working Party 1977; Cowan 1978; Kelly and Rowell 1995; Baker 2003). Bedrock polygons with less than 8 m of drift cover are areas where crushed stone may be obtained at lower cost and, therefore, a high potential exists for resource protection, depending on aggregate suitability of the rock. For this reason, about 2300 water wells with a bedrock depth deeper than 8 m in thin-drift areas were queried out and manually checked. After inspection, 181 wells were removed due mostly to the incorrect use of terminology and the misinterpretation of water well layers.

After appending a field indicating the bedrock elevation at each of the data locations, the working database was searched and a number of data points, mostly water wells, were found to have duplicate locations. More than one or contradictory bedrock elevations with differences of up to 58 m were found at some of the duplicate locations. Duplicate data points with the same bedrock elevation or minor variations were considered high-quality data because they corroborate the assigned bedrock depths at the same

Table 34.1. Data used for mapping the bedrock topography of southern Ontario

Source	Count
Geotechnical boreholes	14 478
Oil and gas wells	15 043
Outcrops	36 112
Water wells	164 924
Water wells (not reaching bedrock)	16 212
Other*	6 686
Total	253 455

*Consisting of ~1700 OGS–GSC data points, mostly boreholes; ~3000 borings from SNC Lavalin Engineers & Constructors (2004); and >2000 duplicate points (*see* text for explanations).

location. Those with a significant difference in bedrock depth are likely caused by errors such as misplaced georeferences, geological misinterpretation and the use of ambiguous terminology; although the specific error sources for the discrepancy are difficult to determine. As such, well records at the duplicate locations with a difference exceeding 2 m in elevation were excluded. For those with less than 2 m of difference, the average bedrock elevations were used. After the above data filtering and preparation procedures were carried out, about 240 000 data points with assigned bedrock elevations were obtained (Table 34.1).

Bedrock Elevation Surface Interpolation

ESRI® ArcGIS® ordinary kriging was used for interpolation with a variable radius until the computing process finds 12 points or samples. For thick-drift areas where overburden is more than 1 m thick, data points reaching bedrock were used to krige an initial bedrock elevation surface or grid, a process referred to as *elevation kriging*. Then, overburden water wells that go deeper than the interpolated surface were selected and appended to the data set, which was kriged again to refine the bedrock elevation surface (Gao et al. 2005).

For thin-drift areas, where the overburden cover is less than 1 m thick, a slightly different approach was adopted. During the pilot mapping projects, it was found that the drift thickness calculated from the kriged bedrock elevation surface failed to capture the geological observations using the data points converted from thin-drift areas at a grid spacing of approximately 400 m by 500 m. This is attributable to the local relief or unevenness of the ground surface. Theoretically, a good match could be achieved using all of the DEM data points available. Practically, however, it is rather inefficient for computers to process such a large data set. Since it is directly reflected by the ground surface in thin-drift areas, the bedrock surface can be generated by simply subtracting the known drift depths from the DEM, a process referred to as *thickness kriging*.

To stitch together the bedrock elevation surfaces kriged by both methods, a buffer zone of 2-pixel width was created between them. The average elevations of the pixels were used to enforce a gradual change in elevation between these polygons. Pixel size is related to the intended map resolution. The bedrock elevation surface and thickness maps of southern Ontario were released as raster data sets with a spatial resolution of 0.001 decimal degrees, which equals approximately 100 m by 100 m of pixel size.

Inspection of Anomalous Areas

The initial kriged and down-pushed bedrock surface contained many excessive peaks and holes. More than 1200 data points marking prominent anomalies and outlining some large linear depression features were selected for inspection (Figure 34.1). To aid the inspection process, records around each of the data points within a 1 km buffer zone were queried out for comparison.

Water well logs were checked and compared with the adjacent data for possible erroneous bedrock depth assignment. It was found that the recorded thickness of layers and the material descriptions themselves often provided clues to winnow out some of the problematic water wells. Most problems were related to the misinterpretation of boulders as bedrock and the incorrect use of geologic terminology. For instance, many highly pinched peaks were caused by water wells containing, below overburden layers, a very thin bottom layer of SHALE, LIMESTONE or GRANITE as exemplified by water wells 6900003, 6900376 and 6913380 in Figure 34.2. These thin layers likely represent boulders, but likely, have been mistakenly interpreted by drillers as bedrock. As such, these water wells were deleted.

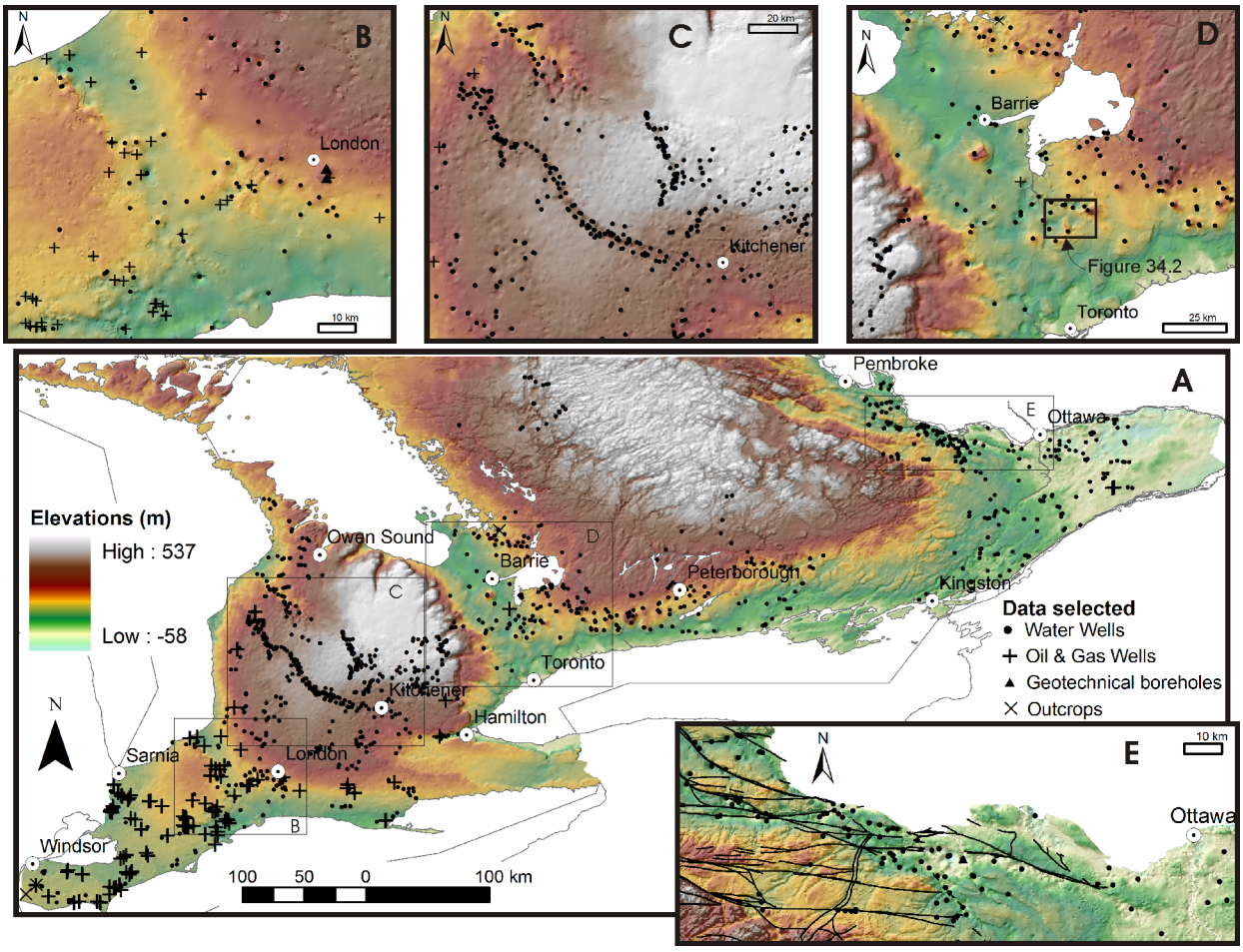

Figure 34.1. Kriged bedrock surface and inspected data points that mark prominent peaks and holes in addition to some large linear features. A) Overview of southern Ontario. B) Close-up of a northwest-southeast aligned valley, west of London. C) Close-up of a deep, narrow valley, northwest of Kitchener. D) The buried Laurentian Valley; boxed area is enlarged in Figure 34.2. E) West of Ottawa, many deep holes exist along the geological faults (solid lines).

Table 34.2. Typical problems related to the use of ambiguous or incorrect descriptions in water wells, southern Ontario*.

Well ID: 1519357	**Well ID: 4202259**	**Well ID: 4202150**
Depth / Layers	**Depth / Layers**	**Depth / Layers**
5.18 m: OVERBURDEN	3.05 m: SAND	0.61 m: TOPSOIL
17.37 m: STONES, LIMESTONE	***74.07 m: GRANITE***	***52.12 m: TOPSOIL, GRANITE***
18.29 m: STONES, LIMESTONE	74.37 m: CLAY	
148.44 m: STONES, LIMESTONE	96.62 m: GRANITE	
151.79 m: STONES, SANDSTONE		
153.92 m: STONES, LIMESTONE		

* These water wells were ascribed incorrectly to overburden wells not reaching bedrock during the automation process.
Bold italic text indicates the correct uppermost bedrock layers.

When logging the water wells, drillers occasionally misuse the terms clay and shale bedrock. Misinterpretations or misidentifications of lithology, when it occurs, leads to anomalous areas on the kriged bedrock surface. For instance, the 2 layers of SHALE in water well 6920788 (*see* Figure 34.2) appear dubious not only because they are unconfirmed by the adjacent water wells, but also because this well, which caused an anomalous peak, is located on the Oak Ridges Moraine where the drift is known to be thick. Consequently, this well was removed.

There were numerous cases where STONES, although normally used by drillers for overburden, was found to indicate bedrock, thereby causing deep but unrealistic holes on the kriged bedrock surface. As exemplified by water well 1519357 (Table 34.2), some drillers prefer using STONES in the primary

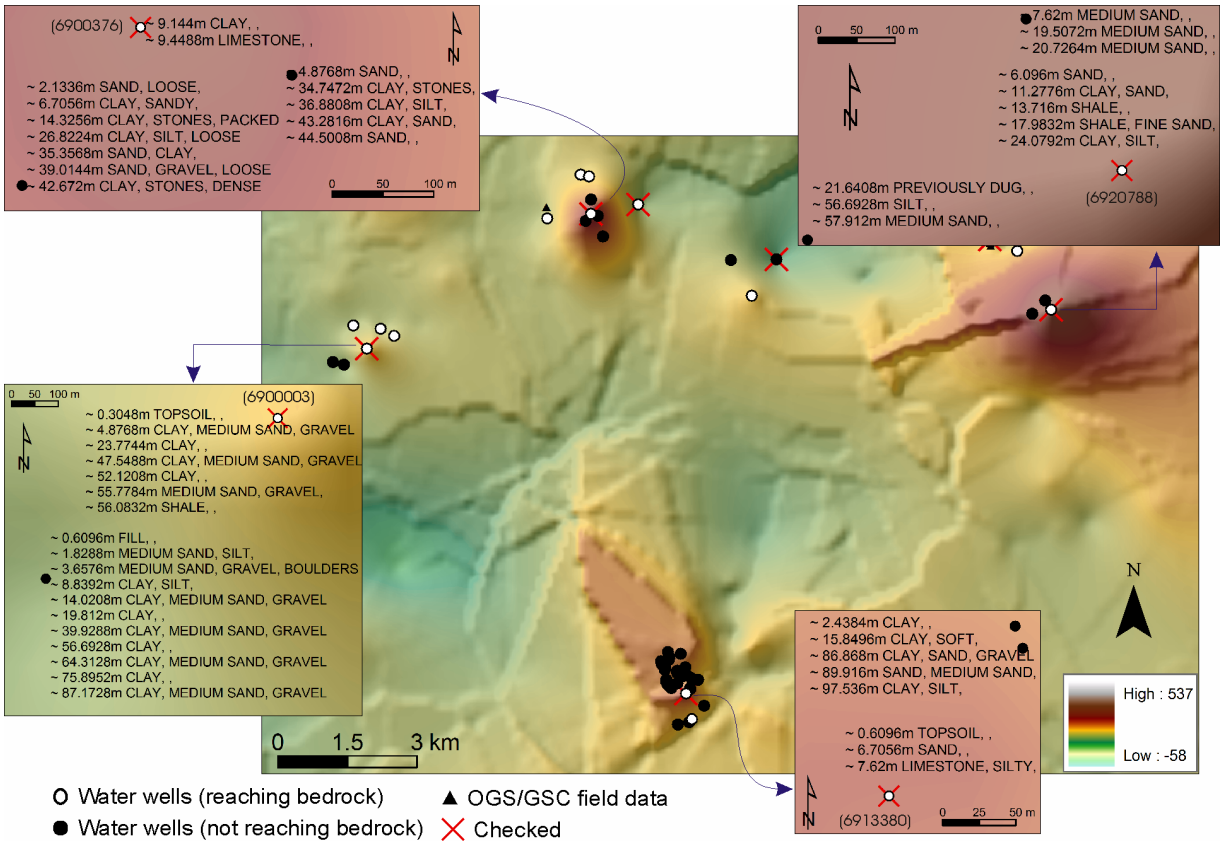

Figure 34.2. Excessive peaks caused by water wells containing incorrectly interpreted dubious beds, York Region (*see* Figure 34.1D for location). After closer inspection of the data, the 4 water wells shown were removed.

Table 34.3. Inspected data points, southern Ontario.

Source	Count	Removed	Bedrock depth corrected
Water wells	775	169	2
Water wells (not reaching bedrock)	344	162	
Oil and gas wells	112	6	
Outcrops	26	12	
Geotechnical boreholes	3		
	1260	349	

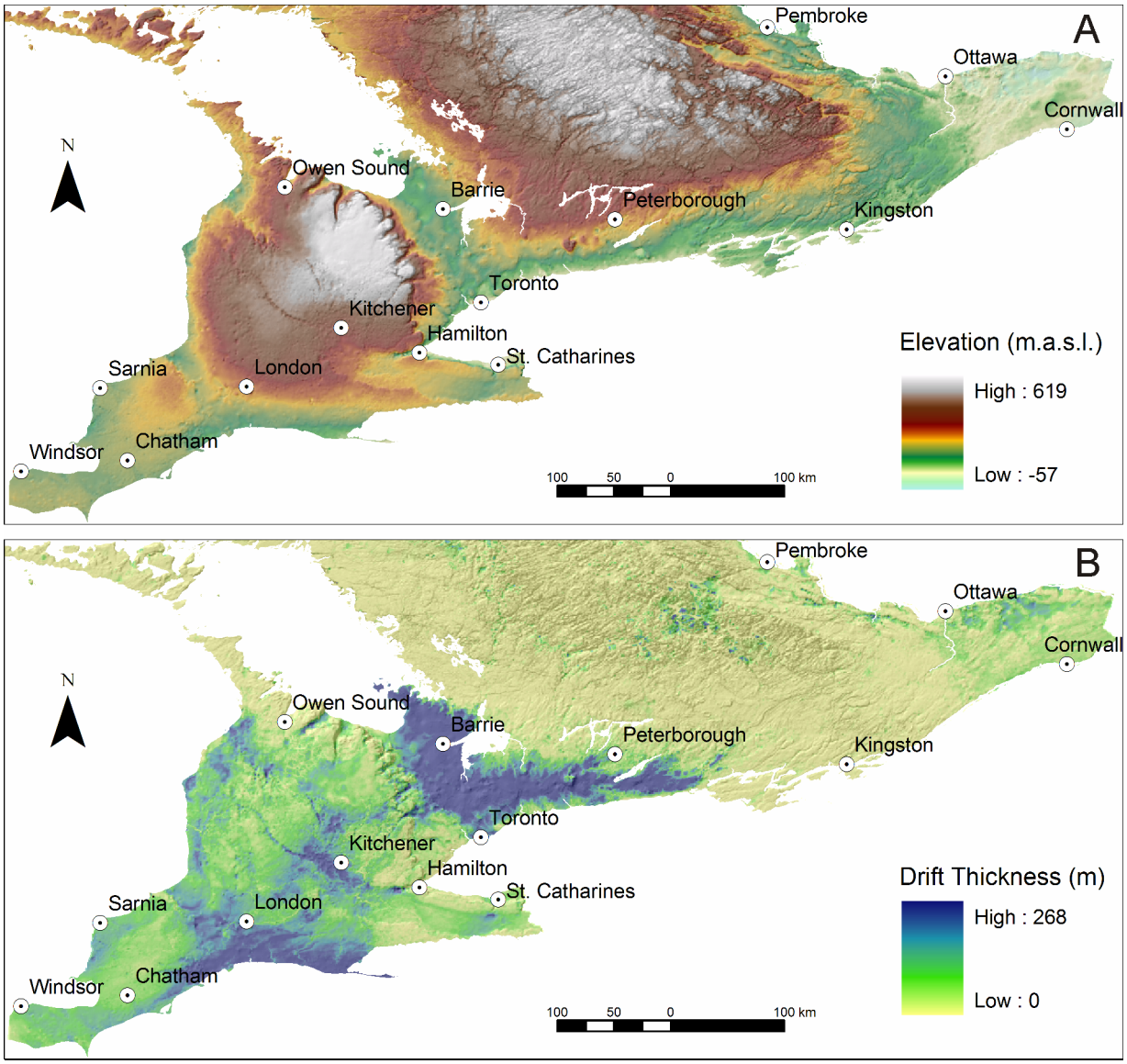

Figure 34.3. A) Bedrock topography and B) drift thickness of southern Ontario.

material field for bedrock; in this case, constructing a well log characterized by many layers of this description. In the previous automated process in coding and bedrock assignment, these layers were treated as overburden, thereby assigning unusually deep bedrock depths to the water wells. Many of the wells were mislabelled as overburden wells not reaching the bedrock (*see* Table 34.2). Such wells usually produce deep holes on the kriged bedrock surface. As such, over 3000 water wells bottomed by layers of STONES as the primary material were queried out and removed from the working database.

The size or thickness of the well layers was often found to be very useful in winnowing out water wells with an erroneous bedrock depth assignment. Recorded, thick layers of LIMESTONE or GRANITE exceeding 20 m for example should be regarded as genuine bedrock even if they are underlain by thin layers of overburden-like descriptions such as CLAY. This is illustrated by water well 4202259 that reaches the GRANITE bedrock at depth of 3.05 m (*see* Table 34.2). In the automation process, however, the computer algorithm that searches for 2 consecutive bedrock layers skipped this layer, ascribing it to an overburden well not reaching bedrock. Consequently, a hole-like deep depression was created at this site.

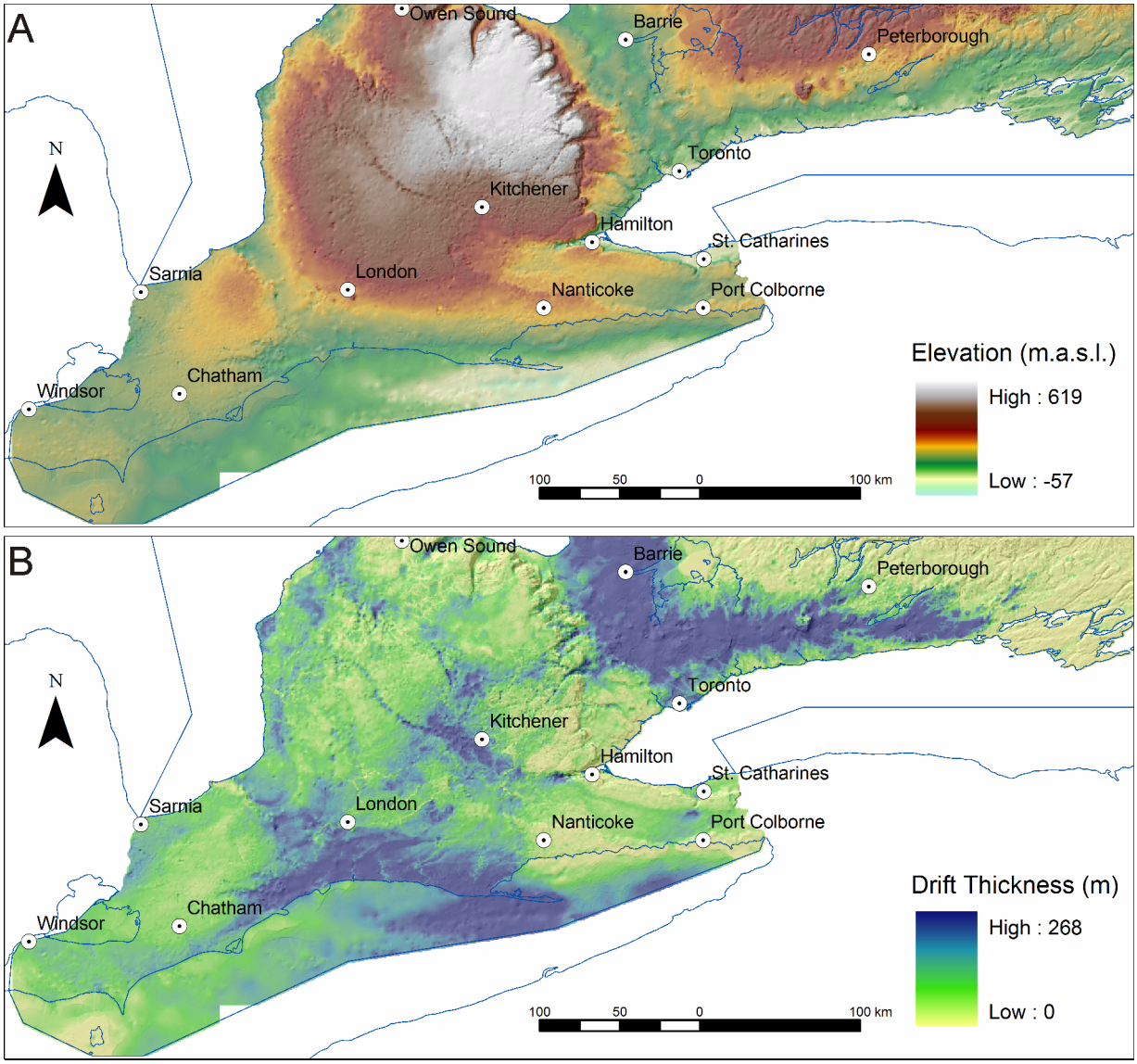

Figure 34.4. Enlarged view of southwestern Ontario, showing the A) bedrock topography and B) drift thickness under Lake Erie.

Other data were also selected for inspection (Table 34.3; *also see* Figure 34.1). The top of bedrock in oil and gas wells and geotechnical boreholes were difficult to verify because of the unavailability of actual log records. Requests were sent to the Ontario Oil, Gas and Salt Resources Library to review 6 oil and gas wells that generated prominent anomalies. It was reported that the top of bedrock in these records could not be verified (T.R. Carter, MNR, personal communication, 2006). As a result, they were removed from the working database.

PROJECT STATUS

After the removal of the problematic data identified through the quality control steps described above, the data set was kriged to refine the bedrock topography and to calculate the drift thickness of southern Ontario (Figures 34.3 and 34.4). These digital maps are scheduled for release as digital publications during the next year. The information on the bedrock topography and drift thickness may be used for groundwater studies, aggregate resource assessments, geotechnical studies and other land-use applications. The files for release are in raster (grid) format, and they are results of interpolation processes rather than cartographic designing. Therefore, there is no specific map scale at which this product is intended to be used. For this reason, the actual data points used for the interpolation will be included in this release. If this product is to be used at a scale of 1:100 000 or larger, it is highly recommended that the data points and their density are analyzed for a more knowledge-based interpretation.

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REFERENCES

Baker, C.L. 2003. Aggregate resource inventory program; *in* Summary of Field Work and Other Activities 2003, Ontario Geological Survey, Open File Report 6120, p.18-1 to 18-3.

Barnett, P.J. 1992. Quaternary geology of Ontario; *in* Geology of Ontario; Ontario Geological Survey, Special Volume 4, Part 2, p.1011-1090.

Barnett, P.J., Cowan, W.R. and Henry, A.P. 1991. Quaternary geology of Ontario, southern sheet; Ontario Geological Survey, Map 2556, scale 1:1 000 000.

Brennand, T.A., Moore, A., Logan, C., Kenny, F.M., Russell, H.A.J., Sharpe, D.R. and Barnett, P.J. 1998. Bedrock topography of the Greater Toronto and Oak Ridges Moraine areas, southern Ontario; Geological Survey of Canada, Open File 3419, scale 1:200 000.

Chapman, L.J. and Putnam, D.F. 1984. The physiography of southern Ontario; Ontario Geological Survey, Special Volume 2, 270p.

Cowan, W.R. 1978. Toward the inventory of Ontario's mineral aggregates; The Canadian Mining and Metallurgical Bulletin, v.71, no.789, p.105-113.

Edgecombe, R.B. 1999. Bedrock topography and sedimentary infill of the Dundas Valley, Hamilton, Ontario; unpublished MSc thesis, McMaster University, Hamilton, Ontario, 122p.

Eyles, N. 2002. Ontario rocks: three billion years of environmental change; Fitzhenry & Whiteside Ltd., Toronto, 339p.

Eyles, N., Arnaud, E., Scheidegger, A.E. and Eyles, C.H. 1997. Bedrock jointing and geomorphology in southwestern Ontario, Canada: an example to tectonic predesign; Geomorphology, v.19, p.17-34.

Eyles, N., Boyce, J. and Mohajer, A.A. 1993. The bedrock surface of the western Lake Ontario: evidence of reactivated basement structures?; Géographie physique et Quaternaire, v.47, p.269-283.

Flint, J.J. and Lolcama, J. 1986. Buried ancestral drainage between Lake Erie and Ontario; Geological Society of America Bulletin, v.97, p.75-84.

Gao, C., Brunton, F.R., Shirota, J. and van Haaften, J.S. 2005. Aggregate resource inventory mapping in Ontario: a GIS-based approach; *in* Summary of Field Work and Other Activities 2005, Ontario Geological Survey, Open File Report 6172, p.22-1 to 22-11.

Johnson, M.D., Armstrong, D.K., Sanford, B.V., Telford, P.G. and Rutka, M.A. 1992. Paleozoic and Mesozoic geology of Ontario; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 2, p.907-1010.

Karrow, P.F. 1973. Bedrock topography in southwestern Ontario: a progress report; Geological Association of Canada, Proceedings, v.25, p.67-77.

Kelly, R.I. and Rowell, D.J. 1995. Upgrade of aggregate resource inventory papers for the Regional Municipalities of Durham, Halton, Peel and Waterloo and the Counties of Dufferin and Wellington, southern Ontario; *in* Summary of Field Work and Other Activities 1995, Ontario Geological Survey, Miscellaneous Paper 164, p.171-172.

National Aeronautics and Space Administration 2006. Shuttle Radar Topography Mission (SRTM) digital topographic data, version 2. Seamless DEM data downloaded in 2006 through http://www2.jpl.nasa.gov/srtm/ under "SRTM V2 released" [access checked October 10, 2006].

National Oceanic and Atmospheric Administration 1999. Bathymetry of Lake Erie and Lake Saint Clair; National Oceanic and Atmospheric Administration, National Geophysical Data Center, World Data Center for Marine Geology and Geophysics, Report MGG-13. Custom grid data downloaded in 2006 from http://www.ngdc.noaa.gov/mgg/greatlakes/erie.html [access checked October 10, 2006].

Ontario Geological Survey 1991. Bedrock geology of Ontario, southern sheet; Ontario Geological Survey, Map 2544, scale 1:1 000 000.

——— 2003. Surficial geology of southern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 128.

Ontario Mineral Aggregate Working Party 1977. A policy for mineral aggregate resource management in Ontario; Ministry of Natural Resources, 232p.

Shirota, J., Brunton, F.R. and Kelly, R.I. 2005. Bedrock topography and drift-thickness maps, southern Ontario; *in* Summary of Field Work and Other Activities 2005, Ontario Geological Survey, Open File Report 6172, p.28-1 to 28-6.

SNC Lavalin Engineers & Constructors 2004. Groundwater resource characterization and wellhead protection partnership study, draft report to City of Hamilton; unpublished draft report, SNC Lavalin Engineers & Constructors, 168p.

van Haaften, S., Shirota, J. Gao, C. and Brunton, F. 2004. Depth to bedrock: 3-dimensional bedrock and overburden thickness methodology for mineral aggregates and groundwater geology mapping in Ontario, Abstract; *in* Geological Association of Canada—Mineralogical Association of Canada, Joint Annual Meeting, St. Catharines, Program with Abstracts, v.29, p.157.

35. Project Unit 06-025. Characterization of the Vars–Winchester Esker Aquifer, South Nation River Watershed, Eastern Ontario

A.-M. Chapman[1], A. Pugin[2], S.E. Pullan[2], J.A. Hunter[2], D. Cummings[2], D.R. Sharpe[2] and H.A.J. Russell[2]

[1]South Nation River Conservation Authority, 15 Union St., Berwick, Ontario K0C 1G0
[2]Geological Survey of Canada, 601 Booth St., Ottawa, Ontario K1A 0E8

INTRODUCTION

The Ontario Geological Survey (OGS), along with the Ministry of Environment and the Eastern Ontario Water Resources Committee, is funding a multi-disciplinary study of the Vars–Winchester esker aquifer (Figure 35.1). In partnership with the Geological Survey of Canada (GSC) and the University of Ottawa, the South Nation River Conservation Authority has undertaken the field work to delineate and characterize the Vars–Winchester esker aquifer, from which the communities of Vars, Limoges, Embrun, Winchester and Chesterville draw water (Figure 35.2). This study will provide data that will help municipalities in their delineation of wellhead protection areas.

BACKGROUND

The development of hydrogeological models to estimate groundwater flow in the Vars–Winchester esker aquifer has been hampered by a lack of knowledge of the size, shape and internal heterogeneity of the esker aquifer. The geology and hydrogeology of the Vars–Winchester esker aquifer has been studied by a number of consultants near municipal-well locations (e.g., INTERA 2005). However, the nature of the esker aquifer between municipal wellhead areas is virtually unknown. This has sometimes contributed to the development of wellhead protection areas that are at odds with the local geology. Specifically, some preliminary numerical models suggest wellhead protection zones be placed perpendicular to the actual trend of the esker (Robinson Consultants Inc. 2004). It is believed that results such as these are related to a poor understanding of the geology of the esker and that additional geological data will improve the accuracy of model projections.

SCOPE OF THE STUDY

The field work undertaken in this study will focus on the regions not covered in previous municipal groundwater and other studies. Combining the knowledge gained from this study and data from existing studies will provide a comprehensive understanding of the esker and create a more accurate hydrogeological model for the region. The primary objective of this study is to obtain a detailed understanding of three-dimensional composition, variable hydrogeological characteristics and groundwater flow within the Vars–Winchester esker complex.

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Ontario Geological Survey, Open File Report 6192, p.35-1 to 35-9.

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GEOLOGICAL SETTING

The South Nation River watershed covers an area of ~5000 km^2 that slopes gently (~0.5 m per km) northeastward toward the Ottawa River. The watershed has relatively low relief with the highest elevation in the west. Uplands east (Gatineau Hills) and west (Frontenac Arch) of the watershed consist of Precambrian rocks of the Grenville Province. Paleozoic carbonate and minor siliciclastic rocks of the St. Lawrence Lowlands crop out sporadically across the watershed (*see* Figure 35.1).

Surficial sediment deposited by the Laurentide Ice Sheet and postglacial Champlain Sea crops out across most of the watershed (e.g., Gorrell 1991). For purposes of this project, the surficial geological succession has been simplified to 6 units, 5 of which crop out in the study area (*see* Figure 35.1):

1. Sub-till sediment of various textures crop out at Pointe Fortune and may directly overlie bedrock within the watershed (Anderson et al. 1990).
2. The silty sand Fort Covington Till is observed in drumlinized uplands and intercepted in boreholes, and forms a regional unit that is locally eroded (MacClintock and Stewart 1965).
3. Glaciofluvial sediment is mapped extensively in eskers and may occur laterally as thinner units beneath Champlain Sea sediment (Gorrell 1991; INTERA 2005).
4. Glaciolacustrine and glaciomarine muddy rhythmically bedded sediment of the Champlain Sea forms a regional unit that covers the eskers in many areas (Gadd 1986, 1988).

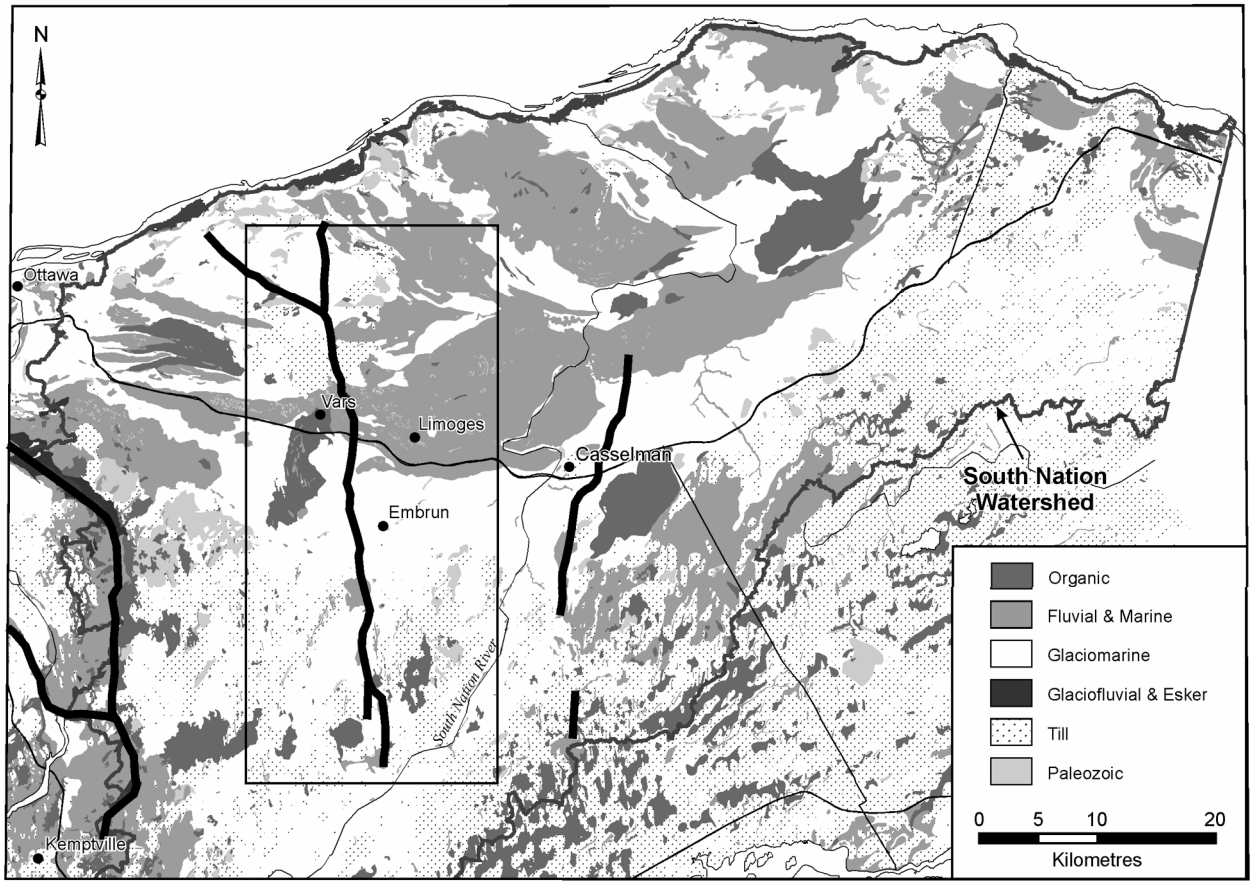

Figure 35.1. Simplified geology of the northern part of the South Nation River watershed (*modified from* Ontario Geological Survey (2003); esker locations derived *from* Gorrell (1991)). Box outline shows the general location of the Vars–Winchester esker study area.

5. A variety of subaerial, post-Champlain Sea, deposits are lumped together, including alluvial sediment of the proto-Ottawa River, modern alluvium and eolian dunes.
6. Organic deposits form significant wetland areas.

METHODS

The hydrogeological investigations in the area are following a basin analysis approach outlined by Sharpe et al. (2002) for regional hydrogeological studies. Initial work has focussed on collection and synthesis of archival data and development of a conceptual geological model. Early data collection has focussed on filling data gaps based on assessment of existing data in the areas outlined below.

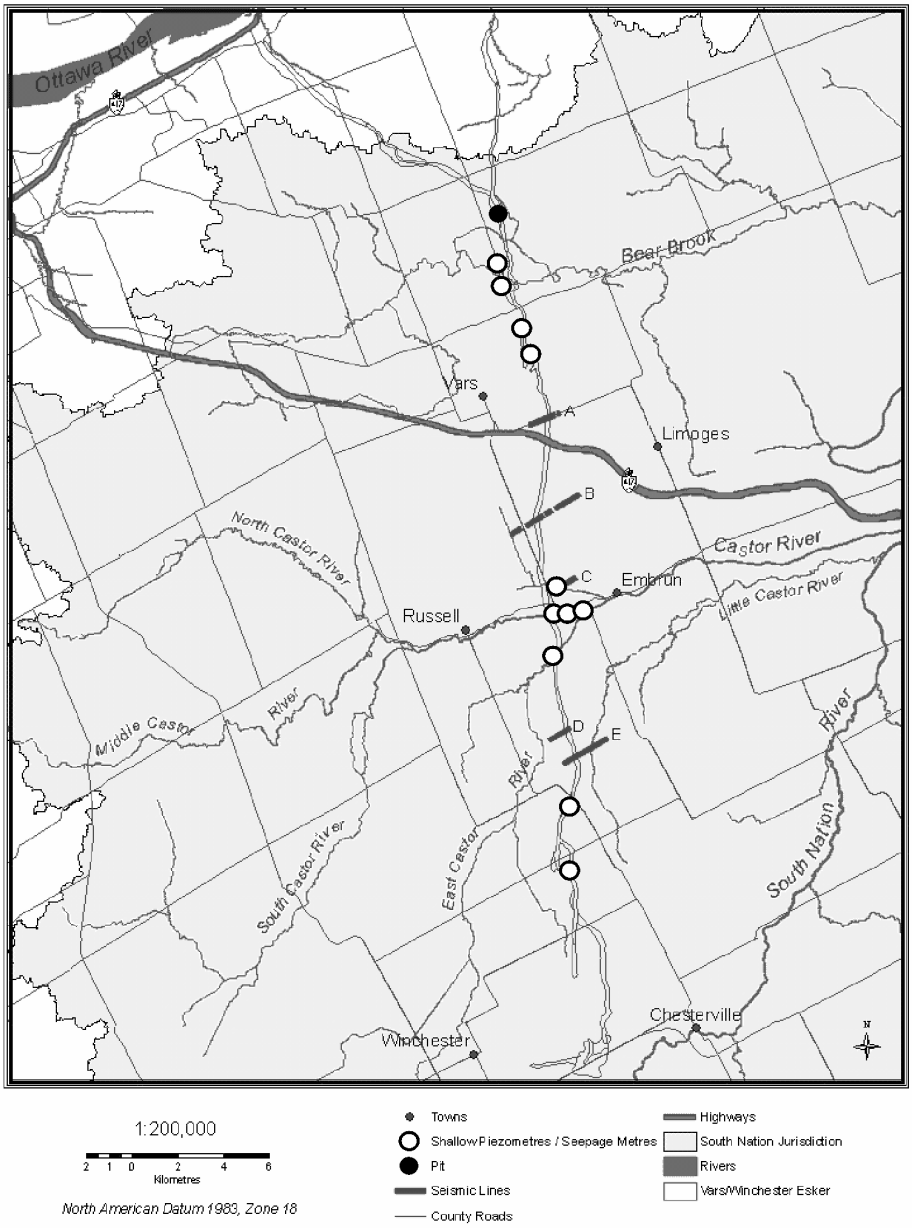

Figure 35.2. The Vars–Winchester esker study area with location of field sites, summer 2006.

DATABASE DEVELOPMENT

Data collation and integration has been initiated in 3 key areas: digital library; relational database; and geographic information system (GIS)-based coverage.

Municipal offices and agencies were visited during May to July 2006 to help compile a digital library. Relevant geotechnical reports, hydrogeological reports and groundwater quality reports were catalogued and entered in a relational database. The reports were also scanned and converted to portable document format (PDF) files, whereas maps and figures were converted to a JPEG (Joint Photographic Experts Group) format with a digital camera. These files are archived on a server for access by project participants.

Borehole and hydrogeological data contained in reports are being entered systematically into a Microsoft® Access relational database for the complete watershed with a focus on the Vars–Winchester corridor. This archival source of geotechnical and hydrogeological data complements key data obtained from the South Nation River Conservation Authority's Source Water Protection database, which includes the Ministry of Environment's Water Well Information System (WWIS). Integration of disparate geological descriptions is being facilitated by use of the GSC material coding scheme (Russell et al. 1998).

Geographic information system (GIS)-based geological map coverage has been obtained from Ontario Geological Survey (2003). The mapped location of eskers has been captured from Gorrell (1991). This geological coverage is complemented by cultural coverage from the Ministry of Natural Resources (MNR). The MNR digital elevation map (10 m resolution) is being used as a topographic datum for all data sets.

Field Studies

Field work in the summer of 2006 focussed on 1) delineation and characterization of the heterogeneity of the esker aquifer where buried (esker–aquifer delineation); 2) characterization of the heterogeneity of the esker above the water table where exposed in gravel pits (aquifer–analogue work); and 3) understanding how water enters, exits and flows through the esker over time (water–balance work).

The volume and internal heterogeneity (structure) of the buried esker aquifer is being investigated using a combination of seismic reflection, ground-penetrating radar and drilling. During the summer of 2006, 8 line-kilometres of *P*-wave (compressional wave) reflection profiles were obtained from 4 transects across the buried esker and 3 line-kilometres of *S*-wave (shear wave) reflection profiles were obtained along 2 transects (Figure 35.2). *P*-wave data are generally excellent (Figure 35.3) and produce high-resolution images of the subsurface architecture where surface materials are fine grained and water saturated (Benjumea et al. 2001). These data were obtained with a 36-channel receiver array of single 50 Hz geophones at 3 m spacing planted in the ditch alongside the road and a 12-gauge in-hole shotgun source at 6 m spacing. The shear-wave data have been acquired with a new landstreamer (horizontal geophones attached in an array to small metal sleds that are dragged along the edge of the road), which has undergone its first test as part of this project. Shear-wave data commonly provides a higher resolution of near-surface (0 to 5 m) sediment, which is useful where the esker crops out at the surface or is shallowly buried. One ground-penetrating radar (GPR) profile was acquired in the southern section of the survey area using the pulse EKKO IV system with 50 MHz antennas. The high quality of this profile demonstrates that GPR is a useful shallow-subsurface (0 to 5 m) imaging tool where surface sediment is coarse grained. A subbottom profiling transect was also acquired, using the Knudsen 320M subbottom profiler with 28 and 200 KHz transducers operated from a canoe, along the Castor River just south of Embrun.

A drilling program will be completed in the autumn of 2006. Approximately 15 deep piezometers and water wells will be installed in key areas of the esker to help refine groundwater-flow maps. Also, approximately 3 continuously cored boreholes, positioned strategically along a seismic transect of the esker, will be completed. These boreholes will also be logged using down-hole geophysical tools. Cores collected from these boreholes will provide data needed to calibrate (or "groundtruth") seismic profiles, seismic facies (e.g., Pugin, Pullan and Sharpe 1999) and geophysical well-logs.

The esker is also being studied above the water table where it crops out in gravel pits. This work provides insight into the porosity, permeability and dimensions of building blocks that are presumed to also exist in the esker aquifer "container" below the water table. This study element integrates sedimentological description of pit faces with grain-size analyses, sediment-peel collection, ground-penetrating radar surveying and shallow vibracoring (Figure 35.4). The principal study site is the Watson Road gravel pit near Sarsfield (*see* Figure 35.2).

Shallow piezometers, seepage meters and electrical methods are being employed to identify the interaction between surface water and the esker aquifer, such as recharge areas. During the summer of 2006, shallow piezometers, ranging from 0.5 to 1.5 m in depth, and seepage meters were installed at sites where surface waters cross above, or are adjacent, to surface expressions of the esker system. The data collected from the shallow piezometers will be used to estimate the vertical hydraulic gradient at each site. Falling-head tests were also done to verify the values of hydraulic conductivity and reduce error and uncertainty through sampling redundancy. The sites are being monitored until November 2006.

During autumn 2006, additional nested piezometer installations will be completed. The data from the piezometers will be used to identify groundwater recharge areas, quantify the recharge and map the direction of the groundwater flow direction within the esker complex.

The electrical conductivity and temperature of both the surface water and groundwater are being monitored concurrently with the monitoring of the seepage meters and shallow piezometers to further investigate the vertical interaction between surface water and water in the esker. Seepage meters were also installed in the South Nation, Castor and East Castor rivers, in areas where the electrical conductivity and the temperature of the water at the bottom of the river was different than the average data for the river, suggesting a potential discharge area.

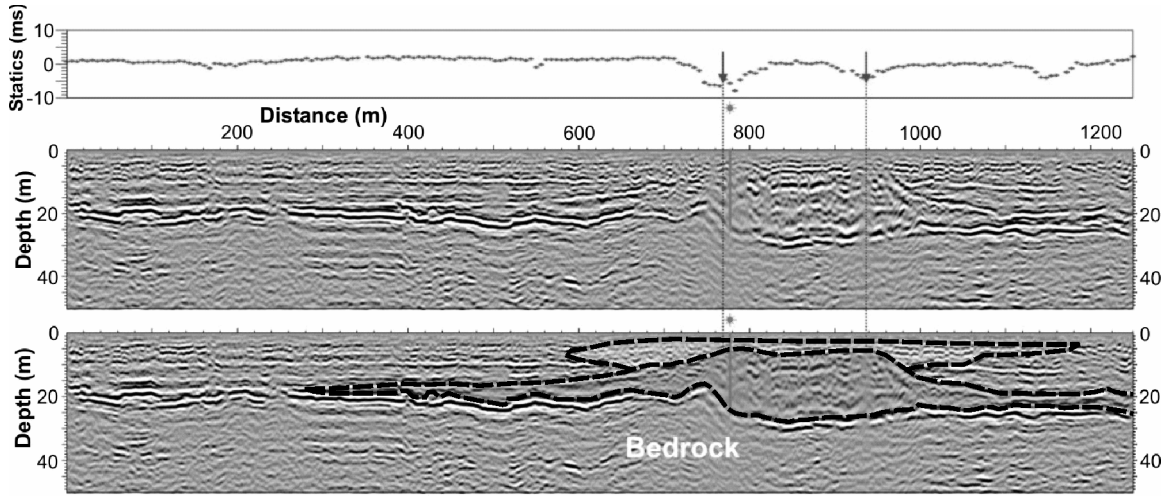

Figure 35.3. *P*-wave shallow seismic reflection profile from Russland Road east of Vars (centre panel). The upper panel is a plot of the near-surface statics (slight variations in travel time related to near-surface conditions), which indicates lower velocity (i.e., lower water content) sediments directly over the esker. In the lower panel (interpreted profile), the esker deposits are outlined by the lower dashed line, above the large-amplitude reflection that represents the bedrock surface. The reworked esker sediments in the near surface are shown in lighter gray outlined by the upper dashed line.

Model Development

Groundwater modelling studies are being completed at regional scales in a 3-step process: i) conceptual models (geological and hydrogeological); ii) three-dimensional numeric geological and hydrostratigraphic models; and iii) numeric groundwater flow models. Conceptual model development is based on event stratigraphic concepts permitting correlation of major depositional units (Walker 1992; Sharpe et al. 2002). This conceptual model is being used to constrain a rules-based database driven GIS approach to construction of the numeric geological and hydrostratigraphic models. Numeric three-dimensional models are being constructed as a series of stacked maps in ArcGIS® using Viewlog as a data analysis tool (WESA 2006). Subsequent flow modelling will be completed using the finite element groundwater modelling software FEFLOW®[1]. Wellhead protection areas will be redefined once the three-dimensional numeric geological and hydrostratigraphic models are completed.

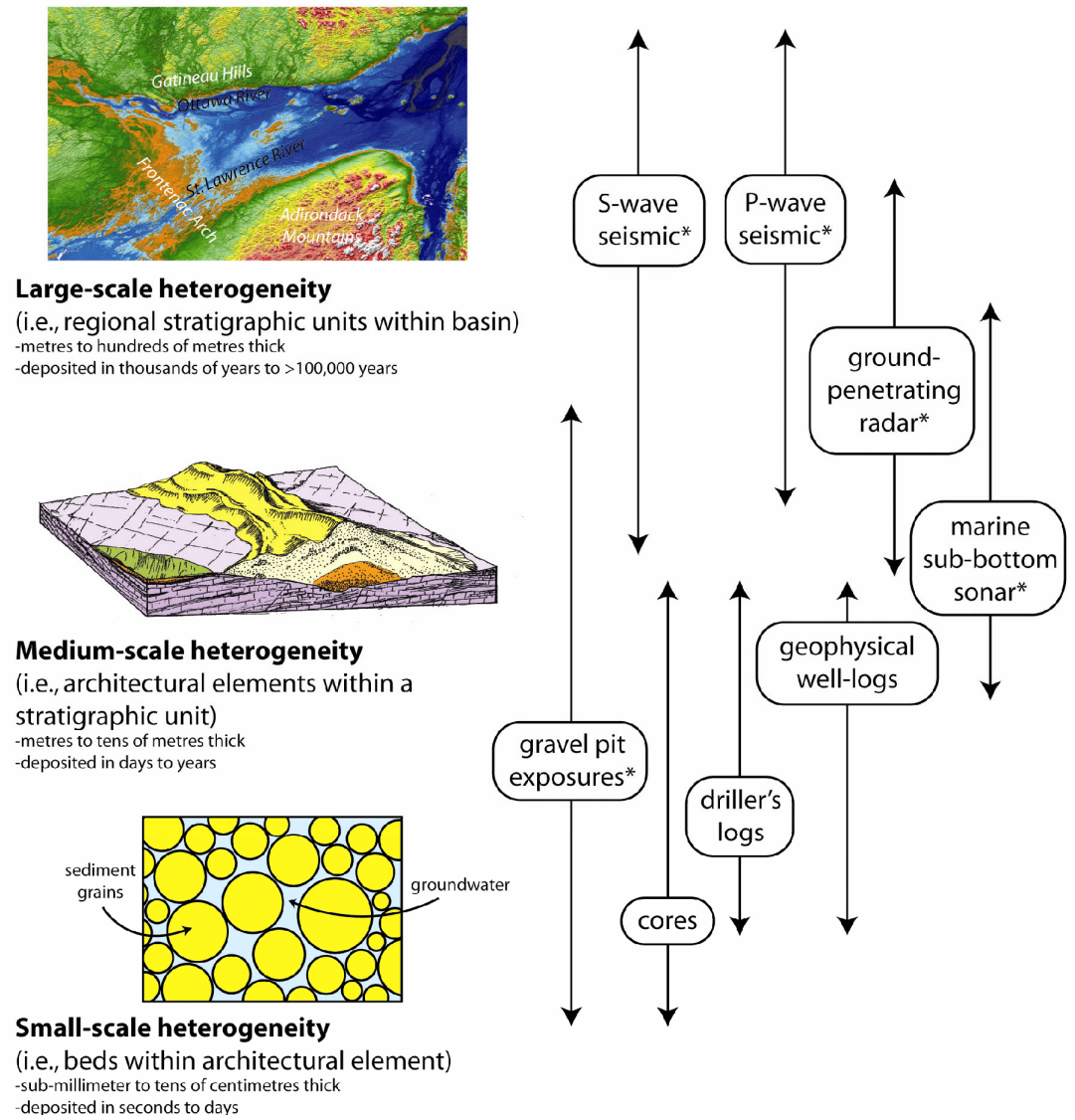

Figure 35.4. Heterogeneity of Quaternary deposits at various scales, and data being collected to assess this heterogeneity. Asterisks indicate data sets that have been partially collected as of September 2006.

[1] FEFLOW® Finite Element Subsurface FLOW System is copyright (2005) and is a registered trademark of WASY GmbH (Institute for Water Resources Planning and Systems Research), Berlin-Bohnsdorf, Germany.

PRELIMINARY RESULTS

Data collation and synthesis are contributing to the early development of a conceptual model of the esker setting (Figure 35.5). As new data are collected and analyzed the model will be refined.

Previous mapping of eskers in the area was able to identify the general trend of the Vars–Winchester esker aquifer, but provided little data regarding its shape, volume and internal heterogeneity (Gorrell 1991). Four *P*-wave seismic reflection profiles collected transverse to the esker suggest that the esker commonly overlies bedrock, is up to 25 m thick at the axis and has a "crest" that is typically ~200 m wide. The wedge-shaped flanks of the esker taper and thin laterally, extending 200 to 300 m on each side of the "crest" (*see* Figure 35.3). At the south end of the study area, the esker structure is more complex. The esker broadens and, locally, bifurcates with 2 crests separated by esker sediment. Flat, laterally continuous reflections interpreted to be basinal mud onlap the top-esker reflection, suggesting that the esker was immersed in standing water following deposition and buried by distal suspension-fallout deposits.

Surface sand along the trend of eskers has been interpreted previously as littoral deposits (e.g., Richard 1982). Ground-penetrating radar surveys and shear-wave surveys imaged these as clinoform deposits dipping basinward, away from the esker axis. This sediment potentially offers improved hydraulic connection between the ground surface and buried esker sediment (*see* Figure 35.3). Along 2 of the seismic transects, the esker is close to the ground surface and may be hydraulically connected to surface creeks and rivers which have downcut into Champlain Sea mud.

The esker consists of sand and gravel. Where exposed in gravel pits, the esker is convex-up in cross section, and consists predominantly of stratified sand and gravel, with minor (<1%) mud. Locally, at the base of pit faces multiple threads of gravel that are up to 15 m wide and >3 m high occur. Poorly sorted boulder gravel with coarse-textured sand matrix and local framework support provide highly permeable flow paths highlighted by iron and manganese staining. Given their convex-up tops and common unidirectional-flow indicators (dune cross-sets), the gravel bodies are interpreted to be meltwater-tunnel deposits or, possibly, proximal-fan deposits.

Lateral and overlying the gravel are medium-grained sand units (>150 m wide, >3 m thick) that may be lateral equivalents or downlap from the gravel bodies. Locally, these sand units may be interbedded with several centimetre-thick clay horizons reflecting rapid flocculation near ice-marginal conduits. The

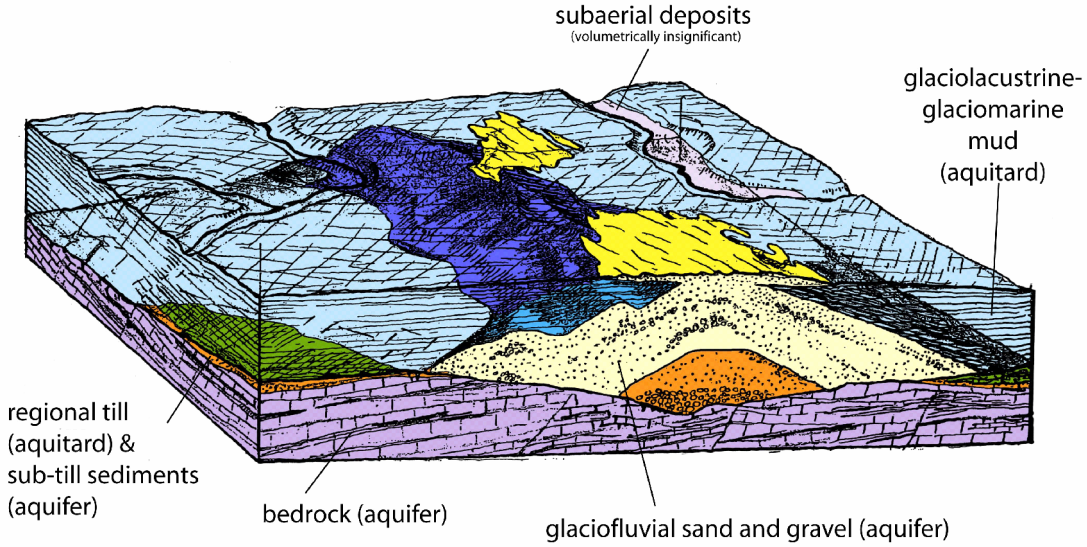

Figure 35.5. Preliminary conceptualization of the major stratigraphic elements in study area.

unit can be subdivided into multiple, compensationally stacked, upward-coarsening lobe-shaped elements (5–50 m wide, 0–3 m thick). Individual elements are interpreted to be fan lobes and the entire unit is interpreted to be a fan complex formed by multiple avulsions of the fan-lobe depocentre. This local architecture may complicate flow paths and locally compartmentalize flow units.

Overlying these sand units are offlapping fossilliferous mud. This relationship contrasts with the onlapping relationship observed in the geophysics at greater depth elsewhere. It suggests late-stage ice-marginal fan development over the esker core. This architecture may generate significant aquifer unit compartmentalization depending upon the length of time during which the late-stage fan was active. The initial impression is that the esker aquifer, at least where it is wide and fan-shaped, is compartmentalized into 2 hydrogeologically significant elements: 1) a moderately permeable sandy outer carapace (fan complex); and 2) one to several highly permeable gravel bodies (metres to tens of metres wide, metres high) at or near the base of esker (meltwater-tunnel deposits).

Faulting observed in surface exposure indicates that units may be dislocated by centimetres to metres. This faulting can disrupt high flow units and juxtapose high and low permeability units producing additional complexity to understanding aquifer heterogeneity.

At a number of locations, the South Nation and Castor rivers traverse and incise into the esker. Geophysics collected along the course of the Castor River imaged the esker beneath the river. Seepage meters are monitoring whether eskers recharge streams and whether there is flow from stream into eskers. Preliminary piezometric analysis, based in part on previous work for South Nation, indicates the esker crosses a number of water divides (CH2MHill 2001). The installation of new piezometers will help test the current placement of flow-divide locations.

FUTURE WORK

Future geophysical work will include geophysical logging of the boreholes drilled for this project, additional acquisition of seismic reflection profiles along the esker, both to the north and south of the area studied to date. An evaluation of the effectiveness of electromagnetic and/or electrical methods in mapping the esker system on a more regional basis will be completed.

Additional piezometer fields and monitoring wells will be installed in portions of the esker that have not been studied to date. The piezometers will be primarily used to quantify groundwater recharge and map the direction of groundwater flow. Following the installation of the wells and piezometers, the water levels will be monitored monthly for at least 2 years. They will also be used to verify groundwater quality.

Following the collection of the above data, a detailed hydrogeological model of the esker aquifer will be designed, which will help determine new wellhead protection areas for nearby municipalities.

ACKNOWLEDGMENTS

The geophysical field work was carried out with the valuable assistance of Robert Burns, Tim Cartwright, Marten Douma and Ron Good of the Geological Survey of Canada, and Beth Sargent from the South Nation River Conservation Authority. The authors would like to thank Coralie Charland and Elyse Bustros from the University of Ottawa, under the supervision of Michel Robin, as well as Emil Laurin (South Nation River Conservation Authority), for their assistance for the hydrogeological field work. John Glew drew the preliminary conceptual stratigraphic depiction of the study area (Figure 35.5). The contribution of Marc Hinton to the project is much appreciated.

REFERENCES

Anderson, T.W., Mathews, J.V., Mott, R.J. and Richard, S.H. 1990. The Sangamonian Pointe-Fortune site, Ontario–Quebec border; Géographie Physique et Quaternaire, v.44, p.271-287.

Benjumea, B., Hunter, J.A., Good, R.L., Burns, R.A. and Ross, M. 2001. Application of high-resolution seismic-reflection techniques in Champlain Sea sediments near Lachute–Saint-Benoît, Quebec; *in* Current Research, Geological Survey of Canada, Current Research, no. 2001-D6, 15p.

CH2MHill 2001. Eastern Ontario Water Resources Management Study. Prepared for United Counties of Prescott and Russell, United Counties of Stormont, Dundas, and Glengarry, City of Ottawa, unpublished technical report, 204p.

Gadd, N.R. 1986. Lithofacies of Leda Clay in the Ottawa Basin of the Champlain Sea; Geological Survey of Canada, Paper 85-21, 44p.

Gadd, N.R. ed. 1988. The Late Quaternary development of the Champlain Sea Basin; Geological Association of Canada, Special Paper 35, 189p.

Gorrell, G.A. 1991. Buried sand and gravel features and blending sands in eastern Ontario; Ontario Geological Survey, Open File Report 5801, 256p.

INTERA 2005. Hydrogeological assessment study, Township of Russell landfill site: final report; unpublished technical report, 50p.

MacClintock, P. and Stewart, D.P. 1965. Pleistocene geology of the St. Lawrence Lowlands; New York State Museum and Science Service, Bulletin 394, 152p.

Ontario Geological Survey 2003. Surficial geology of southern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 128, v.1 and v.2.

Pugin, A., Pullan, S.E. and Sharpe, D.R. 1999. Seismic facies and regional architecture of the Oak Ridges Moraine area, southern Ontario; Canadian Journal of Earth Sciences, v.36, p.409-432.

Richard, S.H. 1982. Surficial geology, Winchester, Ontario; Geological Survey of Canada, "A" Series Map 1491A, scale 1:50 000.

Robinson Consultants Inc. 2004. Municipal Groundwater Study Township of Russell; prepared for Eastern Ontario Water Resources Committee, unpublished technical report, 111p.

Russell, H.A.J., Brennand, T.A., Logan, C. and Sharpe, D.R. 1998. Standardization and assessment of geological descriptions from water well records: Greater Toronto and Oak Ridges Moraine areas, southern Ontario; *in* Current Research, Part E, Geological Survey of Canada, Paper 1998-E, p.89-102.

Sharpe, D.R., Hinton, M.J., Russell, H.A.J. and Desbarats, A.J. 2002. The need for basin analysis in regional hydrogeological studies: Oak Ridges Moraine, southern Ontario; Geoscience Canada, v.29, p.3-20.

Walker, R.G. 1992. Facies, facies models and modern stratigraphic concepts; *in* Facies models: response to sea level change, Geological Association of Canada, GEOtext 1, p.1-14.

WESA 2006. Preliminary geological conceptual model, Source Protection Planning Committee: Interim Report; unpublished technical report, 196p.

36. Project Unit 06-027. Devonian Carbonate Investigation in the Grey–Sauble–Saugeen Area and Quaternary Geology Mapping of the Bruce Peninsula

B. Luinstra[1], F.R. Brunton[2] and W.R. Cowan[3]

[1]Consultant, Kincardine, Ontario
[2]Ontario Geological Survey, Ministry of Northern Development and Mines, Sudbury, Ontario
[3]Cowan Minerals Ltd., Sudbury, Ontario

INTRODUCTION

A partnership between the Ontario Geological Survey (OGS) and the Saugeen–Grey Sauble–Northern Bruce Peninsula Source Water Protection Partnership (SGBPP) has been formed to fill in geologic data gaps for source water protection initiatives being undertaken in the SGBPP area. The partnership involves 2 initiatives in the SGBPP area including 1) investigations into the Devonian–Silurian Paleozoic stratigraphy of the area; and 2) the compilation and field verification of Quaternary geology mapping for the Bruce Peninsula.

BACKGROUND

Middle Devonian carbonate rocks along the Lake Huron shoreline are host to important groundwater resources. In fact, for the majority of municipal and private well systems within the SGBPP study area, these carbonate sequences and their aquifers are the only economically viable sources of potable water. These aquifers are known to be high-quality aquifers, with ample water supplies and relatively good water quality. However, increased testing of these aquifers in recent years has revealed numerous naturally derived water-quality issues, including elevated levels of fluoride and iron. Interest has also increased as a result of numerous studies that have documented occurrences of karst phenomena, including sinkholes (Abbey, Hurley and Merry 2004; Hurley et al. 2005), and karst-influenced conduit flow (Worthington, Smart and Ruland 2003) in these rocks. Karst may provide conduits for contaminants to move rapidly from the surface into the bedrock aquifer systems. The general lack of bedrock exposure and low petroleum potential within the study area have greatly limited the development of detailed bedrock maps.

In response to some of the issues and shortcomings mentioned above, 6 core-recovery holes were drilled in the study area (Figure 36.1), specifically targeting the Devonian and upper Silurian bedrock units. This regional investigation, which focusses on the Devonian stratigraphy will also assist in the development of a three-dimensional conceptual geological model. This model will help identify the factors that may contribute to variability in naturally occurring groundwater quality. It may also help delineate some of the major geological controls on the development of karst phenomena in the area.

Summary of Field Work and Other Activities 2006,
Ontario Geological Survey, Open File Report 6192, p.36-1 to 36-5.

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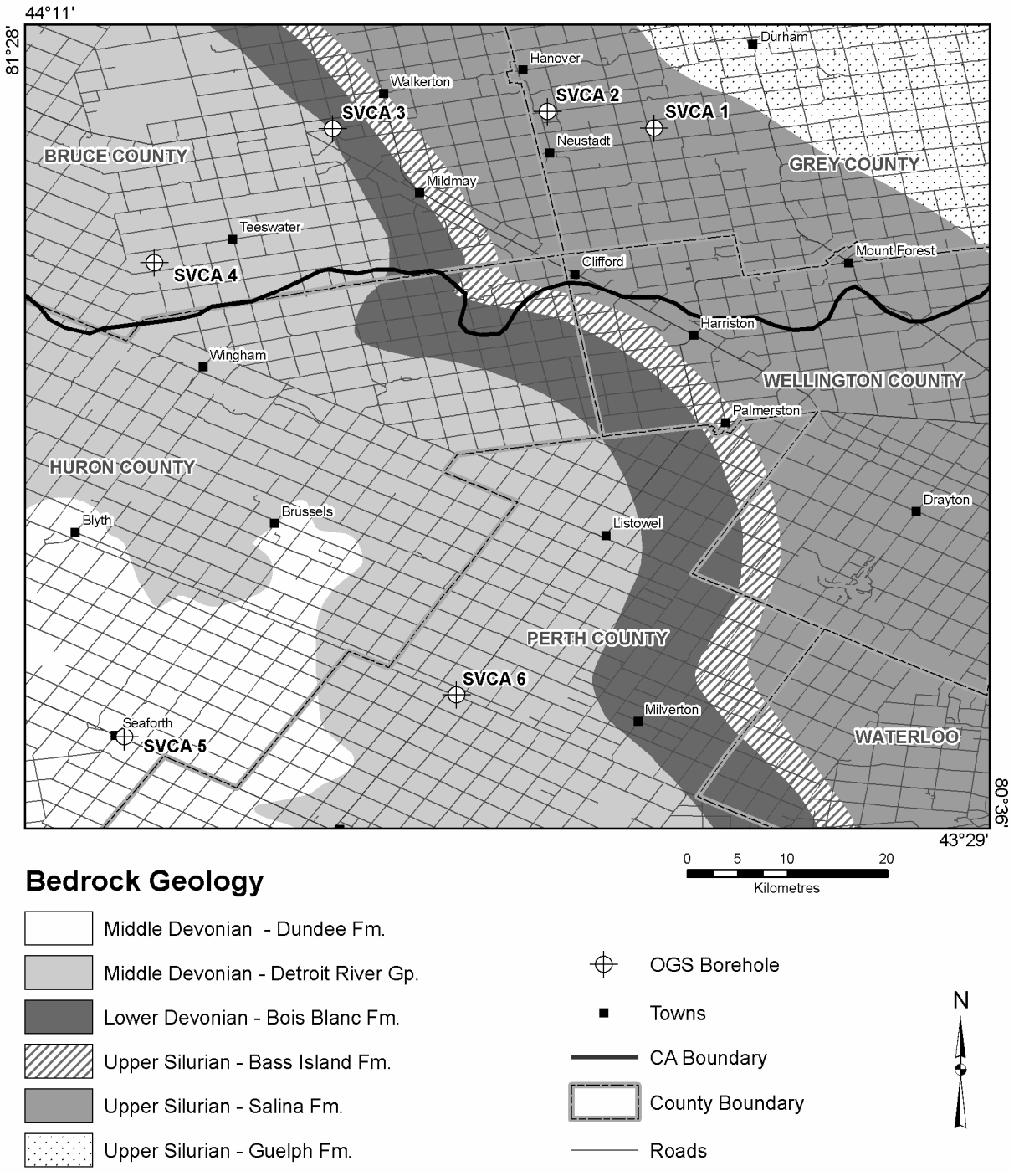

Figure 36.1. Locations of boreholes for Devonian carbonate investigations.

DRILLING RESULTS AND CORE SAMPLING

All 6 holes (SVCA 1 to SVCA 6) were drilled using a Christensen core system attached to a standard water well rig. This system produced core of three-inch (7.6 cm) diameter. Core was logged on site and split for more detailed analysis. The locations of the 6 drill holes were chosen to provide key stratigraphic information of the Devonian aquifer-bearing carbonate units and underlying upper Silurian succession (*see* Figure 36.1). The main aquifer-bearing bedrock formations within the study area are situated in the Dundee and Lucas formations.

Detailed sampling of cores from the 2 westernmost boreholes (SVCA 3 and 4) was carried out in late summer by OGS staff. These 2 boreholes were chosen because they provide the best stratigraphic record of the key aquifer-bearing units within the study area. A total of 160 lithologic and geochemistry samples were collected: 69 samples from SVCA 3, and 91 samples from SVCA 4.

Borehole SVCA 1 was drilled within the Headquarters Conservation Area. This hole was completed to a depth of 67 m (220 feet). Core was recovered over an interval of 23 to 67 m (75 to 220 feet). All core was split, photographed and boxed and is presently being stored at the Headquarters Conservation Area storage lot. This hole was both collared and completed in the Salina Formation.

Borehole SVCA 2 was drilled just southwest of the town of Walkerton in the Municipality of Brockton. This hole was completed to a depth of 103.6 m (340 feet). Core was recovered over an interval of 13.7 to 103.6 m (45 to 340 feet). This hole was collared in the Lower Devonian Bois Blanc Formation, and penetrated the Upper Silurian Bass Islands Formation and underlying Salina Formation.

Borehole SVCA 3 was drilled on Hardwood Hills Conservation Area land, immediately west of the town of Teeswater, in the Municipality of South Bruce. This hole was completed to a depth of 162.5 m (533 feet). Core was recovered over an interval of 52.1 to 162.5 m (171 to 533 feet). All core was split, photographed and boxed and is presently being stored at the Maitland Valley Conservation Authority storage lot in Wroxeter. This hole was collared in the Middle Devonian Lucas Formation (Detroit River Group), penetrated the Amherstburg Formation (basal carbonate of Detroit River Group) and Lower Devonian Bois Blanc Formation, and was completed in the Upper Silurian Bass Islands Formation.

Borehole SVCA 4 was drilled on municipally owned land in the town of Seaforth, Municipality of Huron East. This hole was completed to a depth of 202.4 m (664 feet). Core was recovered over an interval of 13.4 to 202.4 m (44 to 664 feet). All core was split, photographed and boxed and is presently being stored at the Maitland Valley Conservation Authority storage lot in Wroxeter. This hole was collared in the Dundee Formation, penetrated the Lucas, Amherstburg and Bois Blanc formations and was completed in the Bass Islands Formation.

Borehole SVCA 5 was drilled on municipally owned land in the town of Monkton, Town of North Perth. This hole was completed to a depth of 119.5 m (392 feet). Core was recovered over an interval of 27.4 to 119.5 m (90 to 392 feet). All core was split, photographed and boxed and is presently being stored at the Maitland Valley Conservation Authority storage lot in Wroxeter. This hole was collared in the Lucas Formation, penetrated the Amherstburg Formation and was completed in the Bois Blanc Formation.

Borehole SVCA 6 was drilled on Galbraith Conservation Area land, north of the town of Milverton, Municipality of Perth East. This hole was completed to a depth of 134.1 m (440 feet). Core was recovered over an interval of 34.1 to 134.1 m (112 to 440 feet). All core was split, photographed and boxed and is presently being stored at the Maitland Valley Conservation Authority storage lot in Wroxeter. This hole was collared in the Amherstburg Formation, penetrated the Bois Blanc and Bass Islands formations and was completed in the Salina Formation.

QUATERNARY GEOLOGY MAPPING OF THE NORTHERN BRUCE PENINSULA

Quaternary geology information is crucial to understanding watershed characteristics and water budgeting in the SGBPP area. Published Quaternary geology maps exist for most of southern Ontario, but not for the northern portion of the Bruce Peninsula. W.R. Cowan is completing the Quaternary mapping of northern Bruce Peninsula (Figure 36.2) at a scale of 1:50 000. The mapping consisted of the compilation of previous field mapping efforts and confirmatory field work.

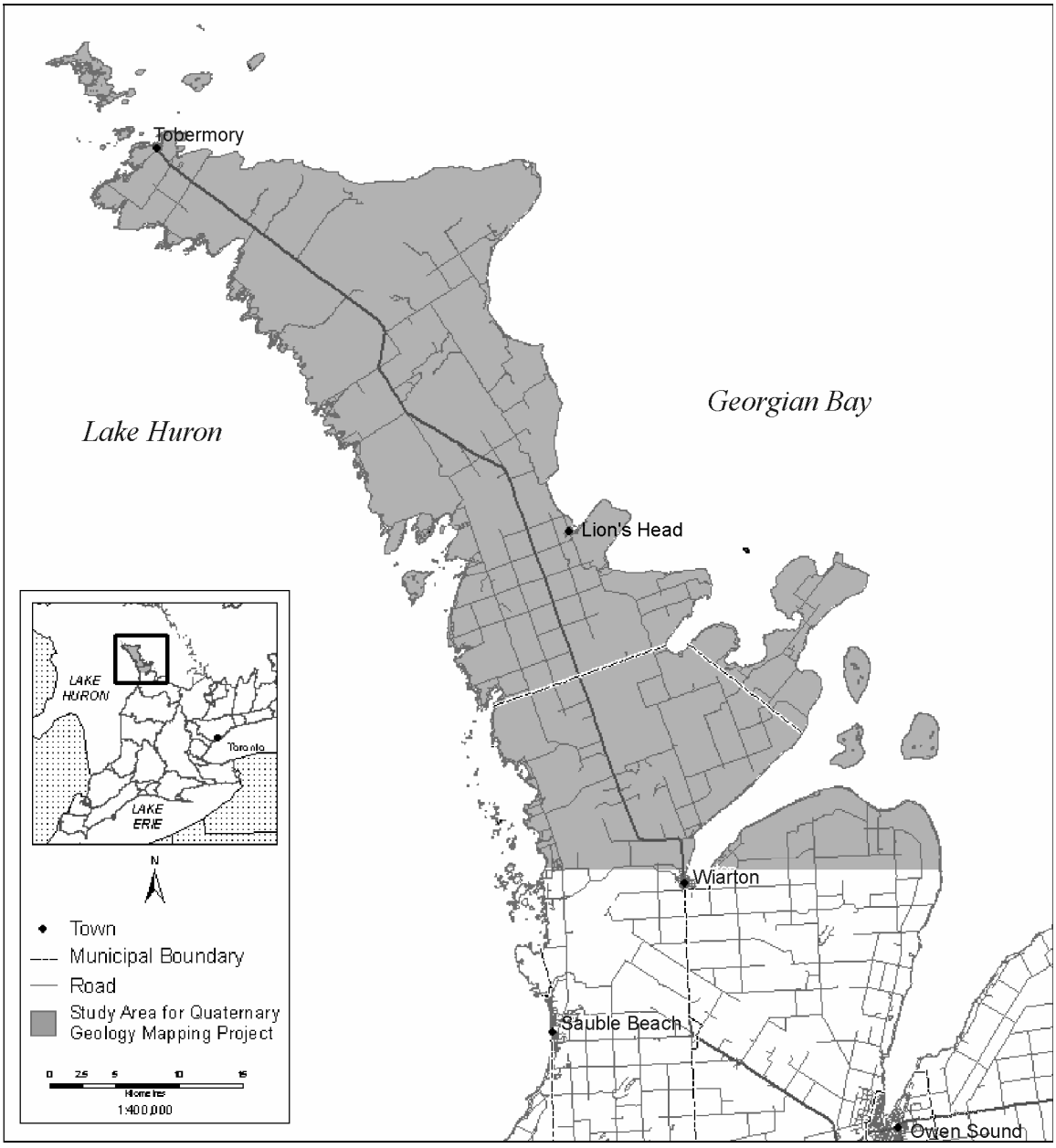

Figure 36.2. Study area for the northern Bruce Peninsula Quaternary geology mapping project.

FUTURE WORK

Most of the core from the Devonian–Silurian bedrock drilling is presently stored at the Maitland Valley Conservation Authority storage lot in Wroxeter. It will eventually be shipped to OGS warehouse in Sudbury for more detailed analysis and long-term storage. It is planned to run downhole geophysics tools (including cameras or view loggers and multi-level loggers) down the boreholes, and to collect groundwater samples for water chemistry analysis. Most of the boreholes will be completed as regional monitoring wells. Some will be assessed for their potential as communal water supply wells. Information gathered from this study will help to characterize the bedrock aquifers of the SGBPP area. Proper delineation of the Dundee and Lucas formations contribute to the understanding of a number of source water issues, including sources of elevated fluoride and iron in the regional watershed.

Field work for Quaternary geology mapping was completed in August of 2006, and preliminary field maps have been created. The final versions of the Quaternary geology map and the accompanying report are scheduled for completion by March 2007.

REFERENCES

Abbey, D., Hurley, J. and Merry, A.G. 2004. Sinkhole investigation in the Ausable Bayfield Conservation Authority watershed and surrounding area; *in* Summary of Field Work and Other Activities 2004, Ontario Geological Survey, Open File Report 6145, p.29-1 to 29-6.

Hurley, J., Merry, A.G., Brunton, F.R., Wadley, S. and Abbey, D. 2005. Karst delineation and sinkhole investigation in the Ausable Bayfield Conservation Authority watershed and surrounding area; *in* Summary of Field Work and Other Activities 2005, Ontario Geological Survey Open File Report 6172, p.31-1 to 31-8.

Worthington, S.R.H., Smart, C.C. and Ruland, W.W. 2003. Assessment of groundwater velocities to the municipal wells at Walkerton; *in* Canadian Geotechnical Society and International Association of Hydrogeologists (Canadian chapter), 2002 Joint Annual Conference, Niagara Falls, Ontario, Proceedings, p.1081-1086.

37. Project Unit 06-028. City of Guelph Groundwater Resource Assessment Project

D.W. Belanger[1], F.R. Brunton[2], S.M. DiBiase[3], G. Yungwirth[3], A. Zandbergs[4] and G.H. Funk[4]

[1]Waterworks Division, City of Guelph
[2]Ontario Geological Survey, Ministry of Northern Development and Mines, Sudbury, Ontario
[3]Golder Associates Ltd., Mississauga, Ontario
[4]Gartner Lee Limited, St. Catharines, Ontario

INTRODUCTION

As part of its groundwater mapping program, the Ontario Geological survey (OGS) has partnered with the City of Guelph, and enlisted the services of Golder Associates Ltd. and Gartner Lee Limited, to study the bedrock influences and controls on the groundwater quality in the Guelph area (Figure 37.1). The study will identify the bedrock characteristics and stratigraphy of the Guelph area while constructing the bedrock monitoring well network.

BACKGROUND

The City of Guelph derives its water almost entirely from bedrock aquifers. It has 17 active municipal wells for water supply and 16 of these wells draw groundwater from the Guelph and Amabel formations. Previous groundwater studies have identified the Amabel Formation in the Guelph area as having a high-porosity middle section of cavernous, interconnected voids. This highly transmissive zone within the Amabel Formation is locally known as the Production Zone. Some municipal wells completed within the Production Zone have yields greater than 6500 m^3/day.

DESCRIPTION OF THE PROJECT

The project consists of 2 separate areas of investigation: the Arkell Spring Grounds area; and the City area (*see* Figure 37.1). The Arkell Spring Grounds area contains 3 of the City's most productive bedrock wells and an extensive monitoring well network is being installed in the area (shown as GL boreholes in Figure 37.1). The other monitoring wells (GA boreholes in Figure 37.1) are intended to provide a preliminary monitoring well network for the remaining municipal wells. Gartner Lee Ltd. is conducting the Arkell Spring Grounds component of the project, whereas Golder Associates Ltd. is conducting the City component of the project program.

For each of the study areas, the monitoring program consists of the following:

- Coring of the deepest borehole (to the base of the Amabel Formation) at each location;
- Digital photographs of the bedrock core;
- Splitting of the bedrock core and providing the core in labelled boxes to the OGS;
- Geological logging of the boreholes to define stratigraphy and hydrogeologic properties;

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- Geophysical logging of the entire depth of the boreholes including gamma, electrical conductivity (or equivalent), video, caliper, acoustic or optical televiewer and dynamic flow;
- Hydraulic testing (i.e., packer tests) of the bedrock portions of selected boreholes to define hydraulic properties of certain hydrostratigraphic units; and
- Collection of groundwater samples from selected intervals and submission of the samples for general chemistry, major ions and dissolved metals.

Based on the results of the above, the City of Guelph will select intervals for the installation of multi-level groundwater monitoring wells. The monitoring well screened-intervals will typically be installed in the overburden, shallow bedrock and deep bedrock. Where the overburden is thin, the well screened-intervals will be placed in the shallow, intermediate and deep bedrock. Following installation, the monitoring wells will be developed and groundwater samples submitted to the University of Waterloo Environmental Isotope Laboratory for the analysis of $\delta^{18}O$, $\delta^{2}H$ and tritium (^{3}H) content.

RESULTS

As of September 2006, boreholes had been completed at the locations shown in Figure 37.1. Between May and September of 2006, 10 boreholes were advanced in the Arkell Spring Grounds area and 5 boreholes in the City area. Five additional boreholes will be completed in the City area. All boreholes fully penetrated the Amabel Formation and terminated in the Reynales or Cabot Head Shale.

Overburden thickness in the study areas ranges from 2.4 m (borehole GL4) at the Eramosa River to 42.7 m (borehole GL3) in the area of the Paris Moraine. Overburden thickness is generally thin in the vicinity of major surface water bodies. All boreholes advanced in the vicinity of the Speed River (GA4), the Eramosa River (GL10) and Blue Springs Creek (GL8, GL9, GL7, GL4) had overburden thicknesses of less than 4 m.

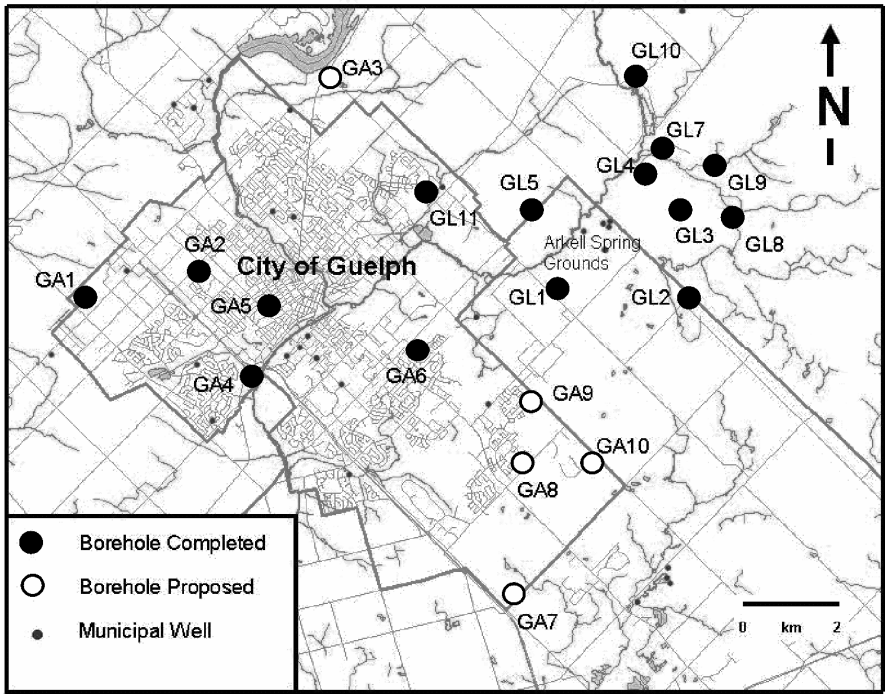

Figure 37.1. Borehole location map.

The Guelph Formation was encountered in only 2 boreholes (GL1 and GL 5) in the Arkell Spring Grounds area, however, it was encountered in all the boreholes in the City area. The Guelph Formation is known to thin to the east and pinches out in the Arkell area. The drill cores collected for this project provide significant insights into the regional stratigraphic makeup and karst-controlled nature of the aquifers found within these Niagara Escarpment caprock carbonates. The study area is located on and proximal to the Algonquin Arch, a basement structure that has displayed episodic epeirogenic movement throughout the Phanerozoic and which has influenced deposition and erosion within the Ontario portion of the western and eastern margins of the Appalachian and Michigan Basins, respectively (*see* Johnston et al. 1992). Preliminary observations in core from the Arkell Spring Grounds reveal that the Dyer Bay, Rockway and/or Reynales and Fossil Hill formations are present and rest disconformably on Cabot Head shales in the Guelph region. Examination of the basal Lions Head member of the Amabel Formation in the same core suggests that this rock unit may be, in part, equivalent to the Rockway and/or Reynales formations of the Appalachian Basin. This would make the overlying Colpoy Bay and Wiarton members the only rock units of the Amabel Formation, and the "Production Zone" of the Amabel aquifer[1].

This re-interpretation of the Amabel Formation may better explain the existence of the "Production Zone" in the Amabel Aquifer. At the Rockwood Conservation area, situated southeast of Guelph, caves are present within the Colpoy Bay–Wiarton members of the Amabel Formation near the contact with the basal Lions Head member. This suggests that the Colpoy Bay and Wiarton members are susceptible to dissolution and the formation of highly transmissive aquifers.

According to currently accepted stratigraphic nomenclature, both members of the overlying Guelph Formation are also present in the study area: 1) an upper member consisting of fossiliferous carbonate rocks; and 2) a lower member referred to as the Eramosa (Brunton and DeKeyser 2004; Brunton, DeKeyser and Coniglio 2005).

The Eramosa member comprises bituminous, argillaceous, low diversity to poorly fossiliferous dolostones and minor limestone. The Eramosa member, where exposed at surface, may display significant karstification due to its uniform crystallinity (e.g., Buck, Worthington and Ford 2003), but, where buried beneath Guelph Formation, the lagoonal mud-rich and microbial Eramosa member acts as a regional aquitard, separating overlying unconfined bedrock aquifers of the Guelph Formation from confined aquifers of the underlying Amabel Formation. Minor cave development has been observed in the Guelph Dolime Quarry within the transition beds of the upper Eramosa tabulate coral- and stromatoporoid-bearing, finely crystalline dolostones and the overlying, medium to coarse crystalline and more fossiliferous dolostones of the Guelph Formation. Formation thicknesses are provided in Table 37.1.

The Eramosa member of the Guelph Formation was encountered in a number of the boreholes, but was absent in a number of the more easterly boreholes, most notably, boreholes GL7, GL8 and GL9 (in the area of Blue Springs Creek). The Eramosa member was not found in GA2, although boreholes to the north (GA1) and south (GA5) of GA2 contained considerable thicknesses of Eramosa member.

The Amabel Formation was encountered in all boreholes and ranged in thickness from 24 to 48 m. The Amabel Formation was found as the subcrop formation in the easterly portions of the Arkell Springs Ground area. A generalized lithologic description of the stratigraphic units encountered during the 2006 drilling program is presented in Table 37.2.

[1] The aquifers of the Guelph and Amabel formations are referred to locally as the "Guelph-Amabel Aquifer," but the presence of the low-permeability Eramosa member between these 2 formations dictates that they should be considered separate bedrock aquifers. Many wells (including some municipal supply wells) that extend into the underlying Amabel Formation are completed as open holes, and groundwater drawn from these wells is a mixture of both the Guelph and Amabel aquifers. In some localities, it is suspected that the Eramosa member is absent or more permeable and that there is a hydralic connection between the Guelph and Amabel aquifers; however, there is insufficient evidence to demonstrate this relationship. For the purposes of this study area, the Guelph and Amabel aquifers are considered to be separate and hydraulically separated by the Eramosa member.

Table 37.1. Formation thicknesses by borehole, 2006 drilling program, based on preliminary core logging by Gartner Lee Limited and Golder Associates Ltd.

Bore Hole	Guelph Formation Thickness (m)	Eramosa Member Thickness (m)	Unsubdivided Amabel Thickness (m)
GL1-06	>14.5	18.6	32.9
GL2-06	—	>18.1	37.6
GL3-06	—	—	>36.3
GL4-06	—	—	>38.4
GL5-06	>11.6	18.0	32.7
GL7-06	—	—	>34.0
GL8-06	—	—	>36.0
GL9-06	—	—	>33.4
GL10-06	—	—	>38.5
GL11-06	—	—	>23.6
GA1-06	>5.0	38.5	48.5
GA2-06	>40	—	41.0
GA4-06	>2.5	9.5	47.0
GA5-06	>9.0	20.0	35.0
GA6-06	>11.0	23.0	35.0

"<" Indicates that the formation was encountered at the top of bedrock.
— indicates not available

Table 37.2. Generalized lithologic description by Gartner Lee Limited and Golder Associates Ltd. of the stratigraphic units in the Arkell Springs Ground area.

Stratigraphic Unit	Description of Lithology
Guelph Formation	Dolostone; medium brown to dark greyish brown, aphanitic to phaneritic; fossiliferous; medium- to massive-bedded with thin shale laminations; medium hard; broken fracturing; fair to good Rock Quality Designation (RQD) values; slightly weathered; vuggy; moderate porosity.
Eramosa Member	Dolostone; dark brown to dark greyish brown; aphanitic; argillaceous; medium- to thick-bedded with thinly laminated shale or bituminous shale; medium hard; blocky fracturing; good RQD values; slightly weathered; low porosity; occasional calcareous blebs.
Unsubdivided Amabel	Dolostone; light to medium, occasionally dark grey; aphanitic, clastic; fossiliferous; thick- to massive-bedded with occasional styolites; broken to blocky fracturing; poor to excellent RQD values; slightly weathered; vuggy; moderately to highly porous.
Reynales Formation	Dolostone; dark grey to greenish grey, greyish brown; aphanitic; cryptocrystalline; argillaceous; common thin shale laminations or beds; no fossils; medium hard; broken fracturing; poor to good RQD values; slightly weathered; low porosity.
Cabot Head Formation	Shale; dark green, reddish brown; aphanitic; soft to medium hard; broken fracturing; poor to good RQD values; slightly weathered; common disseminated pyrite; occasional calcareous blebs.

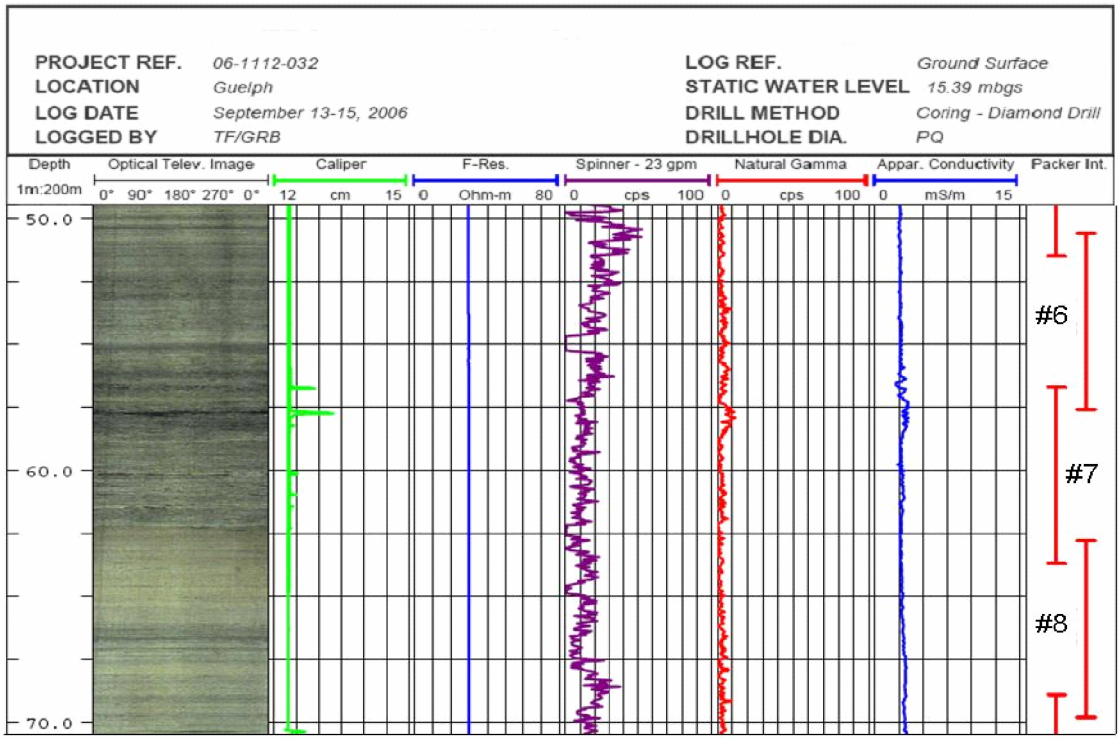

Figure 37.2. Geophysical log and optical televiewer image of the depth interval from 50 to 70 m below ground surface in borehole GA6.

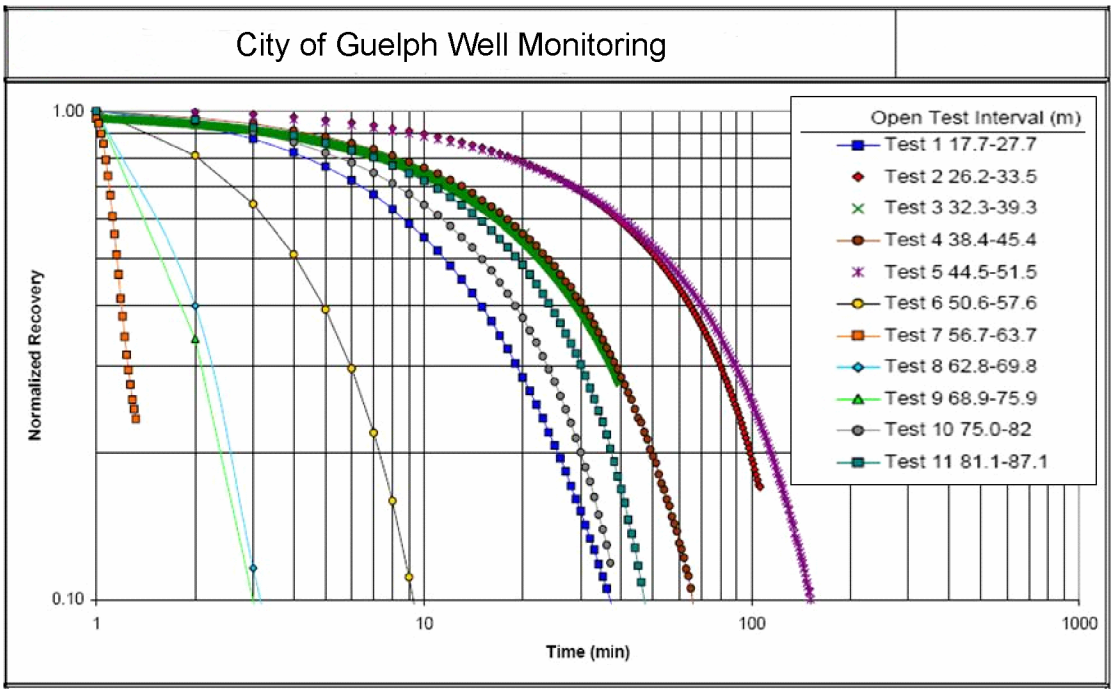

Figure 37.3. Packer test response of head recovery in isolated depth intervals of borehole GA6.

Geophysical logging of the boreholes has been initiated, but is only partially complete. Some preliminary results, for the depth interval of 50 to 70 m in borehole GA6, are shown in Figure 37.2. This interval contains a significant open fracture set at about 58 m and another set at about 60 m. Hydraulic testing (packer tests) of the same borehole at these intervals indicated a relatively high hydraulic conductivity (Figure. 37.3). The packer test results show that the highest hydraulic conductivity is measured in Test #7 at the depth interval of 57.7 to 63.7 m. High hydraulic conductivity results are also found in Tests #6 and #8 above and below this interval. These intervals are typical of the Production Zone and illustrate the high transmissivity of the Amabel Formation.

SUMMARY

The City of Guelph groundwater resources assessment project has completed a series of boreholes and geophysical surveys in the area of the City of Guelph and Arkell. This work has significantly advanced the understanding of the bedrock stratigraphy and the bedrock groundwater resources. Further work, including additional hydraulic testing and monitoring of groundwater levels in the bedrock will provide further information on the hydrogeologic properties of the City's water supply aquifer.

REFERENCES

Brunton, F.R. and DeKeyser, L.-K. 2004. Industrial mineral potential of the Guelph Formation and the Eramosa Member of the Amabel Formation, southwestern Ontario; *in* Summary of Field Work and Other Activities 2004, Ontario Geological Survey, Open File Report 6145, p.19-1 to 19-5.

Brunton, F.R., DeKeyser, L.-K. and Coniglio, M. 2005. Regional industrial minerals and diagenetic study of the Guelph, Eramosa, and Amabel formations, southwestern Ontario; *in* Summary of Field Work and Other Activities 2005, Ontario Geological Survey, Open File Report 6172, p.35-1 to 35-7.

Buck, M.J., Worthington, S.R.H. and Ford, D.C. 2003. Earth science inventory and evaluation of the Eramosa karst area of natural and scientific interest; Ontario Ministry of Natural Resources, Guelph District, south-central Region, 51p.

Johnston, M.D., Armstrong, D.K., Sanford, B.V., Telford, P.G. and Rutka, M.A. 1992. Paleozoic and Mesozoic geology of Ontario; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 2, p.907-1008.

38. Project Unit 05-016. Groundwater Resource Assessment for Halton Region

A. Kodippili[1] and R. Wootton[1]

[1]Conservation Halton, Campbellville, Ontario

INTRODUCTION

In partnership with the Ontario Geological Survey (OGS), Conservation Halton has undertaken a study to characterize the groundwater resources within its watershed (Figure 38.1), including a 5 km buffer zone extending beyond its periphery. The total coverage of the study area, including the buffer zone, is approximately 1740 km^2. This study will provide a higher quality database and improved understanding of the groundwater systems in the watershed that will benefit future groundwater management practices.

The study area is divided into 2 distinct geological settings by the Niagara Escarpment (*see* Figure 38.1). West of the Escarpment, rocks of Silurian age outcrop and subcrop, whereas east of the Escarpment, rocks of Ordovician age outcrop and subcrop.

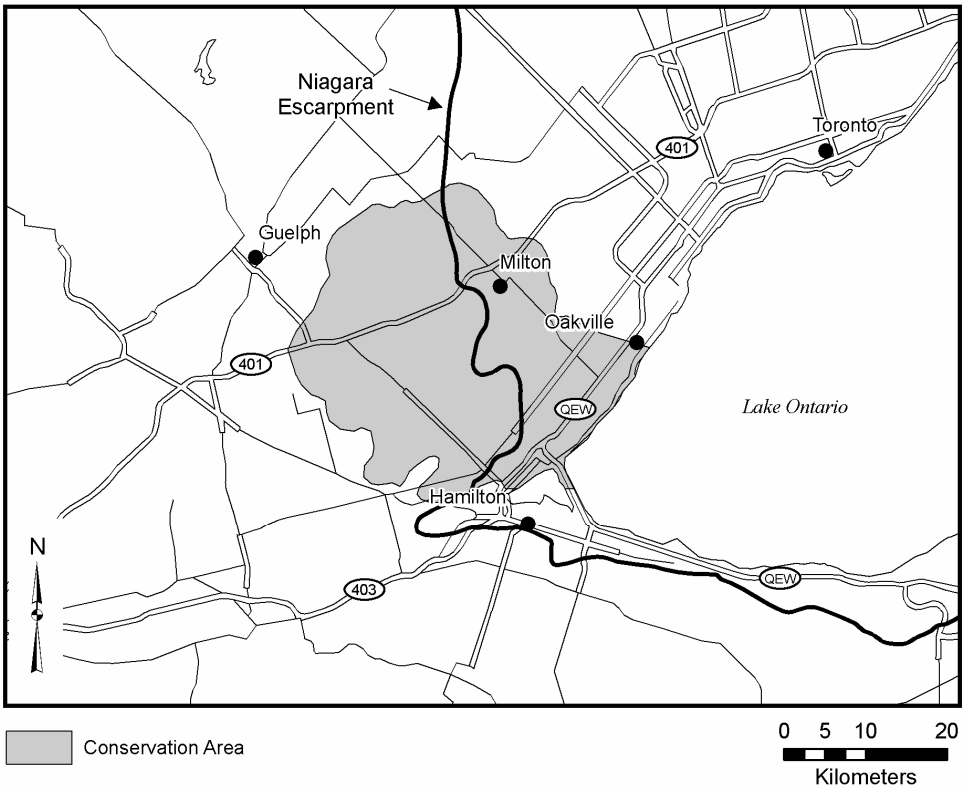

Figure 38.1. Conservation Halton watershed area.

Summary of Field Work and Other Activities 2006,
Ontario Geological Survey, Open File Report 6192, p.38-1 to 38-4.

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BACKGROUND

Recent studies in and near the Conservation Halton watershed have utilized data mainly from the Ministry of Environment's Water Well Information System (WWIS) database (e.g., SNC Lavalin Engineers & Constructors 2004). However, water well records from the WWIS provide minimal technical information for characterizing the hydrogeology of the area. Therefore, the current study has as its focus the collection of additional groundwater related information from various technical data sources and its compilation into one database platform.

Even though water wells are widely distributed in the study area, a large number of wells have poor positional accuracy data in the WWIS. Of the 16 220 WWIS wells in the study area, 51% could not be used for this study because of the problems with positional accuracy. As part of the current study, field- and office-based initiatives were conducted in an attempt to improve positional accuracy so that wells could be utilized.

OBJECTIVE

The primary objective of this study is to characterize groundwater resources of the Conservation Halton watershed. The study includes identifying data sources; obtaining, compiling and evaluating the integrity of technical data; and generating a series of groundwater maps. These maps will provide insight into the nature of the aquifers, regional groundwater flow patterns, ambient groundwater quality and aquifer vulnerability.

DEVELOPMENT OF GROUNDWATER DATABASE

With an Earthfx data model platform (Earthfx Inc. 2003), the groundwater geospatial database (integrating Microsoft® Access and ESRI® ArcGIS® applications) is primarily a data compilation from boreholes and wells maintained by Conservation Halton. It includes spatial data, geographic information, well construction, borehole geology, water level, water quality and pumping test data. The database also integrates a digital elevation model (DEM), relational databases, spatial data layers and raster images.

It was found that 102 water wells had been replicated in the groundwater database because the various data sources had assigned these wells different names. These duplicate records were identified and flagged for deletion.

In order to avoid further data duplication, specific protocols are followed to co-ordinate well locations from WWIS and non-WWIS data sources.

FIELD SURVEY TO LOCATE WATER WELLS

Out of 16 220 MOE water wells located in the study area, 51% of the wells were flagged for deletion from the database because of poor positional accuracy. This being a significant percentage, it was decided to undertake a field survey to locate as many of these wells as possible and provide better positional accuracy using a handheld global positioning system (GPS) unit.

The field survey focussed on areas where water wells are sparsely distributed, because this would help to fill in "data gaps" in the areas that needed it most. Within these "data gap" areas, the most recently constructed water wells were given higher priority because they tended to contain more technical information than older wells.

Table 38.1. Data sources for the information in the groundwater database of this study.

Data Sources	Total No. of Wells
Conservation Halton – Regular Monitoring	12
Unpublished technical reports	1484
Part of Earthfx database compilation covering the study area	56
Part of urban geology of Hamilton database that covers the study area (Bélanger and Morin 1995)	3142
Hamilton Conservation Authority groundwater database	480
Ministry of Environment WWIS	16220
Technical reports from Ministry of Transportation files	2027
Oil and gas well records from the Ontario Oil, Gas and Salt Resources Corporation (OGSRC) database	80
Ministry of Environment Provincial Groundwater Monitoring Network (PGMN) database	21

Table 38.2. Data from these categories of technical reports are entered into the groundwater database of this study.

Study Type	No. of Projects
Environmental Impact Study	11
Foundation Investigation	58
Geotechnical study (Some MTO files needs to be updated)	>220
Hydrogeological study	81

A total of 498 well owners were contacted. The co-ordinates of 130 wells were confirmed in the field using the handheld GPS. Locations are accurate to within 5 m. An additional 149 well locations were georeferenced using aerial photographs to an accuracy of 10 m or less.

Of the remaining 219 well owners who were contacted, 80 locations could not be found because of insufficient information, 61 locations were from residences that have since been replaced with new developments, 43 locations had no visible wellhead, 26 locations had owners who did not wish to participate in the study; and 9 locations were not considered safe to enter.

DATA AND DATA SOURCES

Two types of data are being used for this study: 1) GIS-compatible digital data; and 2) descriptive data from technical reports. Most of the technical reports contain geographical information that allows the data to be manually entered into a GIS-compatible database. Table 38.1 summarizes the data sources for the groundwater database.

Data from a total of 3511 wells and boreholes from technical reports are currently entered into the groundwater database. This includes information on geology, water level, groundwater quality, and geo-hydraulic properties. However, some of these data may be discarded in the future because of insufficient positional accuracy. The technical reports are categorized according to the type of study (Table 38.2).

The 80 wells from the Ontario Oil, Gas and Salt Resources Corporation (OGSRC) database (*see* Table 38.1) are located in the townships of Barton, Beverly, Chinguacousy, East Flamborough, Esquesing, Nassagaweya, Nelson, Puslinch, Trafalgar and West Flamborough. Data include stratigraphy and geology, groundwater level and general water quality. Some wells were drilled down to the Cambrian and Precambrian strata. The positional accuracy of all OGSRC wells are reported to be within 3 to 5 m.

Figure 38.2 shows the positional accuracy of the wells presently within the groundwater database of this study.

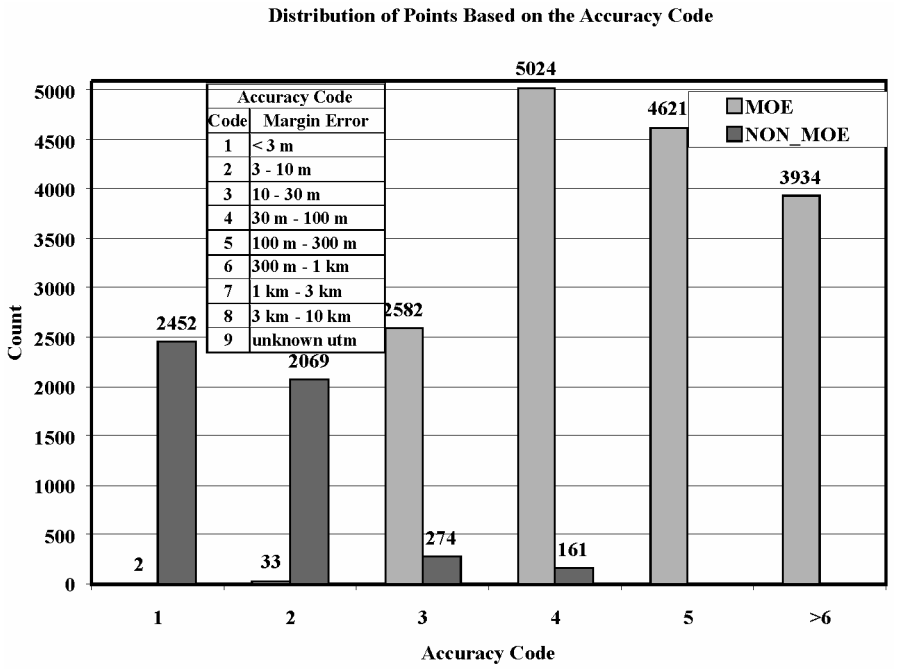

Figure 38.2. Relative positional accuracy of the wells from the Ministry of Environment WWIS (MOE) and other sources (NON MOE) contained within the groundwater database of this study.

FUTURE WORK

Data compilation and entry into the groundwater database is almost complete. Upon completion of data compilation, the database will be used to generate a series of thematic map surfaces (e.g., water table elevation, sand and gravel thickness) of the Conservation Halton watershed. In all, 12 map surfaces will be generated from GIS-based point source and interpolated data. The map surfaces will be evaluated to provide a better understanding of the groundwater systems, and to develop conceptual geological and hydrogeological models of the Halton watershed.

REFERENCES

Bélanger, J.R. and Morin, F. 1995. Urban geology database of Hamilton, Ontario; Geological Survey of Canada, Open File 3023, digital data.

Earthfx Incorporated 2003. Data management system for the Conservation Authority Moraine Coalition and York Peel Durham groundwater management group, 2002 report; unpublished report, Earthfx Incorporated, 82p.

SNC Lavalin Engineers & Constructors 2004. Groundwater resources characterization and wellhead protection partnership study, draft report to City of Hamilton; unpublished draft report, SNC Lavalin Engineers & Constructors, 168p.

39. Project Unit 06-030. Sedimentary Geoscience Observation Database: An Update

E.G. Drouin[1]

[1]Sedimentary Geoscience Section, Ontario Geological Survey

INTRODUCTION

Over the years, the Sedimentary Geoscience Section (SGS) of the Ontario Geological Survey (OGS) has generated large volumes of project-related data, including lake sediment and lake water geochemistry, indicator mineral data and overburden geochemistry. To meet increasing demand from clients for easily accessible data in a digital format, SGS recently compiled data from 79 previously published individual data sets into the Sedimentary Geoscience Observations (SGO) database (Ontario Geological Survey 2005).

The database has been released as a digital publication of data (MRD 153) and contains data current to mid-2003. Since publication of MRD 153, the OGS had generated a number of new project data sets that are the focus of the current project.

OBJECTIVE

The objective of the current project is to update the SGO database with "Miscellaneous Release—Data" (MRD) publications released from mid-2003 to 2006. In that time period, 15 MRDs have been released by SGS.

The database is currently in Microsoft® Access format and is quite large. Addition of the new data sets may extend the SGO database beyond its workable size capacity, therefore, a few options are being assessed to try and decrease the size of the database. These include

- Elimination of duplicate data, especially in the geochemistry table where there are currently 5.9 million records. The database contains a number of columns with the same data. An example is shown in Table 39.1
- The creation of "look-up" tables. For example, within the database, there is a column "within_range" that has 3 words repeated 5.9 million times. By using "look-up" tables, the words would be replaced by a single number, thereby saving some much needed space. Incorporating such tables might make data loading a bit more complicated, however, tests are being conducted to determine what changes in the data loading process might be required.
- Moving the database to the Oracle™ software package. This would resolve the problem of database size, however, this may introduce other issues related to the distribution of data by internet or other means.

Summary of Field Work and Other Activities 2006,
Ontario Geological Survey, Open File Report 6192, p.39-1 to 39-4.

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Table 39.1. Example of duplicate columns in "geochemistry" table.

analytical_method_cd	digestion_cd	unit_of_measure	std_digest	std_method	std_unit
DCP	total digestion	ppm	total digestion	DCP	ppm
DCP	total digestion	ppm	total digestion	DCP	ppm
DCP	total digestion	ppm	total digestion	DCP	ppm
DCP	total digestion	ppm	total digestion	DCP	ppm
DCP	total digestion	ppm	total digestion	DCP	ppm
NAA	none	ppm	none	NAA	ppm
NAA	none	ppb	none	NAA	ppb
NAA	none	ppm	none	NAA	ppm
NAA	none	ppm	none	NAA	ppm
NAA	none	ppm	none	NAA	ppm
NAA	none	ppm	none	NAA	ppm
NAA	none	ppm	none	NAA	ppm
NAA	none	ppm	none	NAA	ppm
DCP	total digestion	ppm	total digestion	DCP	ppm
DCP	total digestion	ppm	total digestion	DCP	ppm
DCP	total digestion	ppm	total digestion	DCP	ppm
DCP	total digestion	ppm	total digestion	DCP	ppm
DCP	total digestion	ppm	total digestion	DCP	ppm
INAA-EP	none	ppm	none	INAA-EP	ppm
INAA-EP	none	ppb	none	INAA-EP	ppb

INDIVIDUAL DATA SETS

Data sets currently within the SGO database and those scheduled for loading are available as individual MRD publications. The MRDs contain data from surficial geochemistry surveys and indicator mineral surveys, and some data sets include both kinds of data. MRD data sets are commonly published in combination with hard-copy geoscientific reports, which are also published by the OGS. The MRDs scheduled to be added to SGO include MRDs 101, 116, 122, 124, 129, 130, 131, 137, 145, 150, 161, 188, 198, 199 and 201.

LOADING INDIVIDUAL DATA SETS INTO THE SEDIMENTARY GEOSCIENCE OBSERVATION DATABASE

Work is currently underway to reduce the size of the SGO database and convert the 15 individual datasets to be added to SGO from Microsoft® Excel to Microsoft® Access. Once that work has been completed, loading of individual data sets to the SGO will commence. To be able to load the MRD data into SGO, converted data will be uploaded into individual SGO-structured Access databases, one for each MRD data set. The individual MRD Access databases will undergo quality assurance checks, and then the data will be loaded into the main Access database. The SGO database model, as implemented in Microsoft® Access, is shown in Figure 39.1.

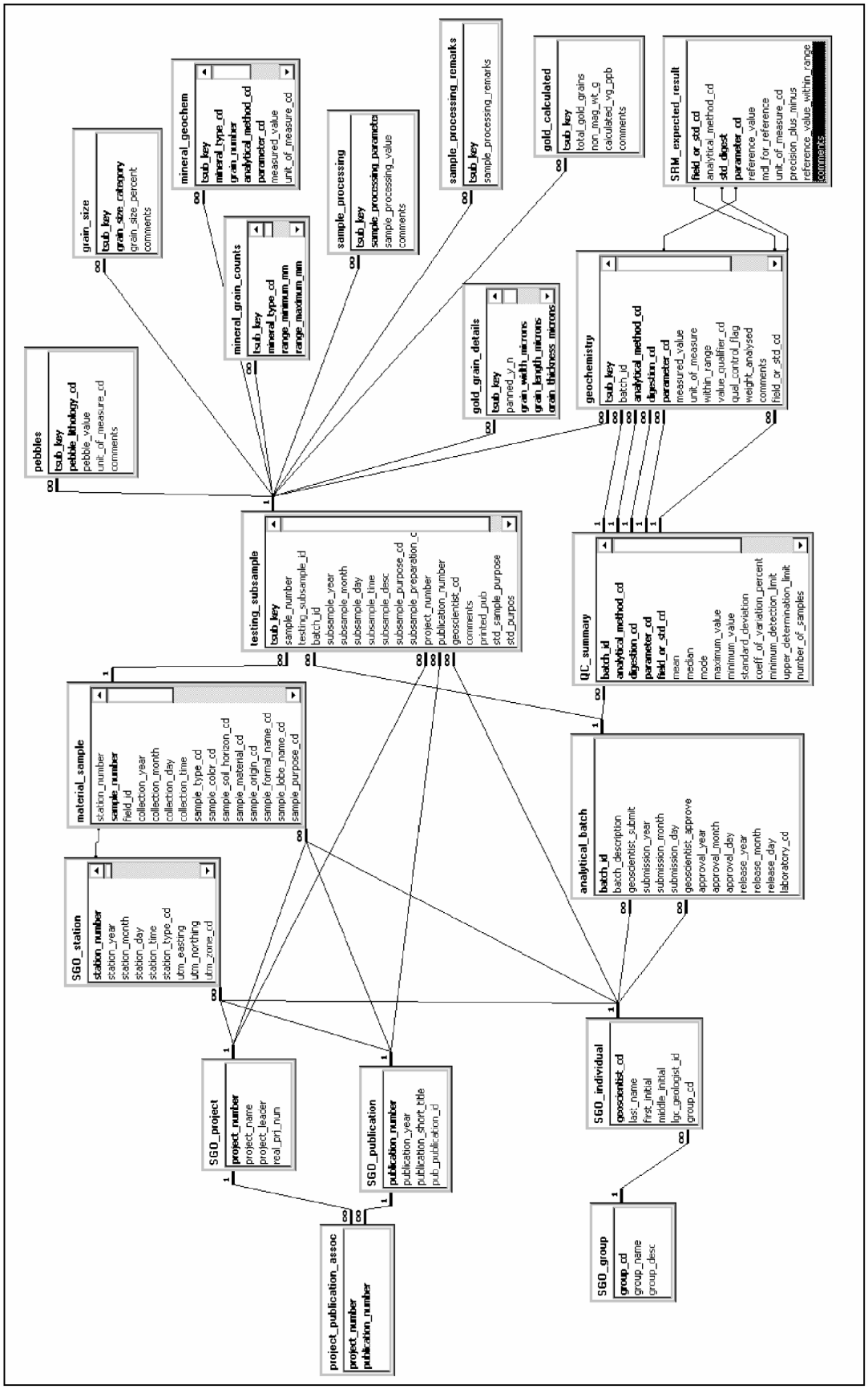

Figure 39.1. Sedimentary Geoscience Observation database structure (Ontario Geological Survey 2005).

DATA ACCESS

There are currently several ways to acquire the entire SGO database or the individual data sets that comprise the SGO.

- Individual MRD data sets are available through Ministry publication sales outlets on CD.
- The entire SGO database is available on a single DVD (MRD 153) through Ministry publication sales outlets.
- MRD data sets and the SGO database can be downloaded from the Ministry's Geology Ontario portal: www.ontario.ca/geology.

With addition of the new data sets, the Ministry is also looking at other ways of making the SGO database accessible online and in expanding its usefulness to clients. For example, the database may be set up so that clients would be able to run queries and download specific data (i.e., gold in lake sediments) for regions of the province.

REFERENCES

Ontario Geological Survey 2005. Ontario geochemistry and indicator mineral database; Ontario Geological Survey, Miscellaneous Release—Data 153.

Geoscience Laboratories

40. QA/QC: Summary of 2005–2006 Quality Control Data at the Geoscience Laboratories

J. Schweyer[1]

[1]Geoscience Laboratories, Ministry of Northern Development and Mines, 933 Ramsey Lake Road, Sudbury, Ontario

INTRODUCTION

The Geoscience Laboratories (Geo Labs) utilizes an extensive quality control program. Each analytical test method uses a number of different quality control checks (blanks, duplicates, instrument controls and reference materials) to monitor the quality of results. The purpose of this paper is to summarize the results of the reference materials (international and in-house) used to monitor results for samples between April 2005 and September 2006. Results have been summarized for the X-ray fluorescence (method codes XWF-101 and XWP-100), ferrous iron (method code FeO), carbon/sulphur (method code IRC), and water determination (method code IRW) methods. This summary allows clients to make an informed decision about the precision and accuracy routinely obtained at the Geo Labs for the above mentioned methods.

The Geo Labs has a large number of certified and in-house reference materials available for quality assurance and method development. Most methods have a set of reference materials that are routinely cycled with client samples. The Geo Labs offers clients the opportunity to select specific reference materials to be analyzed with their samples. Any client requests are forwarded to the Data and Client Services Co-ordinator who will include a note with the submitted samples indicating which specific reference materials the client has requested. This allows the client to matrix-match the reference materials to their samples submitted for analyses.

SUMMARY OF REFERENCE MATERIAL RESULTS

The results were summarized by analytical method (Tables 40.1, 40.2 and 40.3). Within each analytical method, the number of determinations (n), average, standard deviation (SD), and certified value (if applicable) are listed for each reference material used. Often reference materials have different levels of confidence in their results. The data in Tables 40.1 to 40.3 follow a common convention for presentation in which certified values are underlined, whereas provisional values and/or information values are given in regular text. Certified values have the greatest confidence. There is usually less confidence in provisional values due to either the limited number of results used to calculate the mean, a limited number of methods used, or greater variability of results between laboratories.

FUTURE WORK

Only a selected number of analytical methods are summarized in this year's paper for *Summary of Field Work and Other Activities*. It is hoped, for future volumes of *Summary of Field Work and Other Activities*, that Geo Labs staff will present an annual review of all of the quality control data for each of the methods used at the Geo Labs.

Summary of Field Work and Other Activities 2006,
Ontario Geological Survey, Open File Report 6192, p.40-1 to 40-4.

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Table 40.1. Summary of reference material data for XWF-101 method (units = wt.%).

International Reference Materials		SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	TOTAL	LOI
BCS-301 (n=11)	Average ± SD	7.9 ± 0.3	0.152 ± 0.003	4.5 ± 0.2	32.6 ± 0.4	1.28 ± 0.07	1.79 ± 0.03	23.4 ± 0.2	0.10 ± 0.01	0.346 ± 0.005	0.822 ± 0.009	98.6 ± 0.5	25.70
	n	11	11	11	11	11	11	11	11	11	11	11	
	Certificate	7.4	0.16	4.26	34.03	1.25	1.73	22.6	0.07	0.32	0.8		25.77
BIR-1 (n=66)	Average ± SD	47.6 ± 0.4	0.98 ± 0.03	15.6 ± 0.3	11.4 ± 0.1	0.173 ± 0.005	9.5 ± 0.1	13.0 ± 0.2	1.79 ± 0.08	0.027 ± 0.005	0.025 ± 0.004	99.6 ± 0.7	
	n	66	66	66	66	66	66	66	66	66	66	66	
	Certificate	47.96 ± 0.19	0.96 ± 0.01	15.5 ± 0.15	11.3 ± 0.12	0.175 ± 0.003	9.7 ± 0.079	13.3 ± 0.12	1.82 ± 0.045	0.03 ± 0.003	0.021 ± 0.001		
GSR-3 (n=77)	Average ± SD	44.6 ± 0.5	2.32 ± 0.03	13.9 ± 0.2	13.3 ± 0.1	0.178 ± 0.003	7.63 ± 0.08	8.90 ± 0.09	3.23 ± 0.07	2.31 ± 0.02	0.96 ± 0.02	99.4 ± 0.5	2.09
	n	77	77	77	77	77	77	77	77	77	77	77	
	Certificate	44.64 ± 0.16	2.36 ± 0.1	13.83 ± 0.20	13.4 ± 0.29	0.17 ± 0.01	7.77 ± 0.26	8.81 ± 0.14	3.38 ± 0.07	2.32 ± 0.08	0.95 ± 0.04		2.24
MO-7 (n=31)	Average ± SD	41.2 ± 0.5	3.30 ± 0.04	17.1 ± 0.3	12.1 ± 0.1	0.168 ± 0.002	6.23 ± 0.06	14.28 ± 0.10	1.94 ± 0.06	0.758 ± 0.008	1.06 ± 0.02	98.5 ± 0.6	0.42
	n	31	31	31	31	31	31	31	31	31	31	31	
	Certificate	40.79 ± 0.05	3.39 ± 0.01	17.6 ± 0.05	12.35 ± 0.02	0.15 ± 0.01	6.46 ± 0.05	14.62 ± 0.05	2.05 ± 0.01	0.75 ± 0.01	1.08 ± 0.03		
NIST-8606 (n=63	Average ± SD	46.0 ± 0.9	0.35 ± 0.02	7.2 ± 0.1	14.6 ± 0.1	1.5 ± 0.1	1.78 ± 0.03	22.8 ± 0.3	0.73 ± 0.03	0.78 ± 0.02	0.40 ± 0.03	97.0 ± 1.0	1.12
	n	63	63	63	63	63	63	63	63	63	63	63	
	Certificate	46.67 ± 0.16	0.36 ± 0.01	7.27 ± 0.19	14.66 ± 0.07	1.49 ± 0.05	1.83 ± 0.06	23.03 ± 0.20	0.77 ± 0.03	0.82 ± 0.03	0.4		
SARM-40 (n=18)	Average ± SD	3.4 ± 0.3	0.030 ± 0.004	0.46 ± 0.02	2.42 ± 0.08	0.17 ± 0.02	2.15 ± 0.07	49.5 ± 0.5	0.06 ± 0.01	0.017 ± 0.004	2.17 ± 0.08	99.5 ± 0.2	39.13
	n	18	18	18	18	18	18	18	18	18	18	18	
	Certificate	3.08	0.05	0.41	2.75	0.18	1.97	49.77	0.05	0.03	2.05		

In-House Reference Materials		SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	TOTAL	LOI
LK-NIP-1 (n=32)	Average ± SD	49.5 ± 0.4	1.15 ± 0.02	15.5 ± 0.2	13.5 ± 0.1	0.190 ± 0.004	7.23 ± 0.10	10.1 ± 0.3	2.37 ± 0.08	0.463 ± 0.009	0.115 ± 0.008	100.2 ± 0.4	0.14 ± 0.04
	n	32	32	32	32	32	32	32	32	32	32	32	32
MRB-15 (n=88)	Average ± SD	76.3 ± 0.4	0.41 ± 0.01	11.5 ± 0.2	2.84 ± 0.05	0.057 ± 0.002	0.24 ± 0.04	1.16 ± 0.02	3.4 ± 0.1	2.19 ± 0.04	0.032 ± 0.010	99.9 ± 0.4	1.71 ± 0.05
	n	88	88	88	88	88	88	88	88	88	88	88	88
MRB-29 (n=68)	Average ± SD	50.0 ± 0.4	1.92 ± 0.05	12.8 ± 0.2	13.4 ± 0.2	0.185 ± 0.003	6.33 ± 0.09	9.1 ± 0.2	2.41 ± 0.07	0.70 ± 0.01	0.23 ± 0.02	100.1 ± 0.5	3.09 ± 0.08
	n	68	68	68	68	68	68	68	68	68	68	68	68
NPD-1 (n=102)	Average ± SD	54.2 ± 0.3	1.14 ± 0.02	13.8 ± 0.2	12.6 ± 0.2	0.189 ± 0.003	4.75 ± 0.07	7.9 ± 0.2	2.65 ± 0.08	1.35 ± 0.02	0.128 ± 0.010	100.2 ± 0.5	1.34 ± 0.07
	n	102	102	102	102	102	102	102	102	102	102	102	102

Note: Data underlined are certified values, whereas regular text are provisional values.

Table 40.2. Summary of reference material data for FeO, IRC and IRW methods (units = wt.%).

International Reference Materials		FeO		CO2	S	H2O-	H2O+
FER-1	Average ± SD	23.00 ± 0.79	PR-1	1.078 ± 0.019	0.793 ± 0.025		
	n	4		70	97		
	Certificate	23.34		1.08	0.793 ± 0.016		
FER-3	Average ± SD	13.57 ± 0.13	NIST-8604	0.065 ± 0.014	2.723 ± 0.042		
	n	5		10	11		
	Certificate	13.63		0.6	2.87 ± 0.06		
NIM-L	Average ± SD	1.123 ± 0.060	NIST-8605	0.889 ± 0.017	1.590 ± 0.042		
	n	7		2	2		
	Certificate	1.13		0.93	1.64 ± 0.03		
NIM-N	Average ± SD	7.24 ± 0.14	FER-4	4.89 ± 0.14	0.117 ± 0.017		
	n	18		24	24		
	Certificate	7.3		4.86 ± 0.08	0.11 ± 0.01		
NIM-G	Average ± SD	1.29 ± 0.12	STSD-2	5.66 ± 0.26	0.0534 ± 0.0097		
	n	14		13	14		
	Certificate	1.3		5.86	0.06		
NIM-D	Average ± SD	12.96 ± 0.94					
	n	13					
	Certificate	14.63					

In-House Reference Materials		FeO	CO2	S	H2O-	H2O+
MRB-11	Average ± SD		18.80 ± 0.64	0.100 ± 0.020		
	n		100	125		
MRB-12	Average ± SD				0.285 ± 0.044	5.40 ± 0.13
	n				55	55
MRB-29	Average ± SD	5.75 ± 0.14	0.611 ± 0.018	0.0102 ± 0.0024		
	n	46	66	98		
MRB-32	Average ± SD	8.77 ± 0.19	1.48 ± 0.19	1.423 ± 0.056		
	n	34	2	4		

Note: Data underlined are certified values, whereas regular text are provisional values.

Table 40.3. Summary of reference material data for XWP-100 method (units = ppm).

International Reference Materials		Ag	As	Ba	Bi	Co	Cr	Cs	Cu	Ga	K	Mn	Mo	Na	Nb	Ni
BIR-1	Average ± SD	2 ± 2	-1 ± 1	12 ± 9	-1 ± 1	51 ± 4	383 ± 13	1 ± 5	136 ± 3	16.6 ± 0.8	226 ± 12	1,367 ± 25	-1.1 ± 0.5	17,270 ± 670	0.7 ± 0.5	161 ± 4
	n	29	57	54	23	38	70	20	58	51	21	22	43	20	61	50
	Certificate	0.036	0.4	7	0.02	52 ± 2	370 ± 8	0.005	126	16	224 ± 25	1324 ± 23	0.5	13858 ± 356	0.6	170 ± 6
GSD-11	Average ± SD	4 ± 1	198 ± 8	265 ± 16	54 ± 3	9 ± 2	53 ± 7	17 ± 3	77 ± 1	18.6 ± 0.8	28,150 ± 600	2,593 ± 34	6.3 ± 0.6	3,380 ± 150	24.9 ± 0.6	21 ± 3
	n	24	62	50	20	32	69	19	60	49	21	22	42	20	52	44
	Certificate	3.2 ± 0.2	188 ±6	260 ± 8	50 ± 2	8.5 ± 0.3	40 ± 1	17.4 ± 0.5	78.6 ± 1.1	18.5 ± 0.6	27230 ± 250	2490 ± 33	5.9 ± 0.3	3642 ± 80	25 ± 1	14.4 ± 0.4
In-House Reference Materials																
LK-NIP-1	Average ± SD	4.0 ± 0.3	0 ± 1	164 ± 9	0.8 ± 0.6	59 ± 3	180 ± 6	1 ± 6	162 ± 2	20.7 ± 0.9	4,110 ± 170	1,536 ± 71	0.5 ± 0.8	9,500 ± 1,60	5.0 ± 0.8	147 ± 3
	n	3	10	8	3	3	12	3	5	8	3	3	5	3	10	5
NPD-1	Average ± SD	2 ± 1	7 ± 2	304 ± 16	-0.9 ± 1.0	46 ± 4	137 ± 8	3 ± 5	140 ± 3	21.1 ± 0.8	11,650 ± 290	1,503 ± 30	-0.5 ± 0.8	2,900 ± 1,30	5.3 ± 0.5	62 ± 2
	n	21	47	38	18	25	52	15	47	38	15	16	32	15	41	35
OKUM-1	Average ± SD	2 ± 2	-0.7 ± 1.0	16 ± 7	-0.4 ± 1.0	101 ± 6	2,880 ± 87	0 ± 6	45 ± 2	10.1 ± 0.8	398 ± 27	1,638 ± 79	-1.3 ± 0.5	7,210 ± 180	0.4 ± 0.6	890 ± 17
	n	31	51	48	23	39	73	21	61	44	21	24	47	21	58	59

International Reference Materials		Pb	Rb	Sb	Sc	Sn	Sr	Ta	Th	Ti	U	V	W	Y	Zn	Zr
BIR-1	Average ± SD	4 ± 1	0.5 ± 0.5	-2 ± 2	44 ± 3	0 ± 3	108 ± 1	3 ± 2	1 ± 1	5,660 ± 110	-0.5 ± 1.0	302 ± 40	5 ± 3	15.1 ± 0.5	64 ± 3	16 ± 1
	n	62	59	20	30	48	60	49	55	25	41	30	25	60	34	63
	Certificate	3	0.25	0.58	44 ± 1	0.65	110 ± 2	0.04	0.03	5755 ± 60	0.01	310 ± 11	0.07	16 ± 1	70 ± 9	15.5
GSD-11	Average ± SD	626 ± 8	404 ± 4	16 ± 2	6 ± 1	387 ± 15	27.8 ± 0.7	6 ± 1	23 ± 1	2,148 ± 32	10.1 ± 0.7	58 ± 13	109 ± 3	44 ± 3	345 ± 6	148 ± 3
	n	66	51	20	35	39	55	42	49	25	42	36	23	53	38	57
	Certificate	636 ± 10	408 ± 6	14.9 ± 0.7	7.4 ± 0.2	370 ± 29	29 ± 1.4	5.7 ± 0.3	23.3 ± 0.7	2098 ± 40	9.1 ± 0.6	46.8 ± 1.2	126 ± 4	42.7 ± 2.1	373 ± 6	153 ± 6
In-House Reference Materials																
LK-NIP-1	Average ± SD	3 ± 1	12.9 ± 0.3	0 ± 3	39 ± 6	8 ± 1	169 ± 2	3 ± 4	4 ± 1	6,910 ± 310	1 ± 2	263 ± 13	6 ± 1	22.0 ± 0.7	94 ± 1	82 ± 4
	n	12	10	3	5	6	10	8	10	3	6	5	3	10	5	10
NPD-1	Average ± SD	99 ± 2	48.9 ± 0.9	-2 ± 4	41 ± 3	3 ± 3	174 ± 2	3 ± 2	4.4 ± 0.9	6,740 ± 150	0.4 ± 1.0	290 ± 34	3 ± 2	25.6 ± 0.6	202 ± 5	108 ± 5
	n	49	42	16	24	34	43	31	38	17	32	26	16	42	30	44
OKUM-1	Average ± SD	1 ± 1	1.2 ± 0.5	-3 ± 4	39 ± 4	1 ± 5	15.0 ± 0.7	4 ± 2	0 ± 2	2,650 ± 100	-1 ± 1	202 ± 26	4 ± 3	9.9 ± 0.3	60 ± 2	18.4 ± 0.7
	n	59	59	21	43	40	59	42	51	26	44	41	28	60	36	59

Note: Data underlined are certified values, whereas regular text are provisional values.

Geology Ontario

41. Geology Ontario: Research—Discover—Download

B.J. Berdusco[1] and Z.B. Madon[2]

[1]Business Solutions Section, Land and Resources Cluster
[2]Precambrian Geoscience Section, Ontario Geological Survey

INTRODUCTION

In 2004, the Ministry of Northern Development Mines (MNDM) was approached by representatives from the mining and mineral exploration industries regarding the delivery of geoscience related products via the Internet. Citing challenges with the then current Earth Resources Mineral Exploration web Site (ERMES), these clients suggested that, since MNDM was a leader on the global mining stage, the Ministry should have a Web site that reflects this status. As a result, the Ministry made a commitment to improve Internet tools in support of all clients who require access to the Ministry's geoscience related data, map and report holdings.

In the spring of 2004, the Business Solutions Section (BSS) of the Lands and Resources Cluster (LRC) was tasked with the development of a new Internet delivery system or data portal that concentrated on providing increased access to Ministry databases and records (research), increased search functionality (discovery) and the downloading of all publications, data and assessment files on record with the Mines and Minerals Division (MMD).

BACKGROUND

With a project manager and a small group of individuals seconded from various sections within MNDM, the Geology Ontario Project was initiated. The project team held several meetings initially to scope out the requirements and to assign responsibilities. The project specifications were constrained by the following core requirements:

- create a delivery Web site using an "out-of-the-box" solution that meets current needs
- concentrate on delivering all OGS publications (PUBS), mineral exploration assessment files (AFRI), the Mineral Deposit Inventory (MDI), the Ontario Drill Hole Database (ODHDB), the Lithogeochemical Database (LGC), land tenure information (CLAIMapsIII), digital data releases (both geophysical data [GDS] and Miscellaneous Releases—Data [MRD]) and Abandoned Mines Information (AMIS) – totalling in excess of 300 gigabytes of data including over 2 million text pages and 168 000 thousand maps.

Work on the Geology Ontario Web portal began on several fronts, including the selection of a software vendor to provide the Web service, a benchmarking study, a client survey, development of appropriate metadata records for all data holdings and conversion of various existing digital image files to a more useful, popular and Web-friendly format. This initial work was followed up with business-impact and threat-risk studies, focus group sessions and a Quality Assurance–Quality Control process to test the Web portal functionality.

Summary of Field Work and Other Activities 2006,
Ontario Geological Survey, Open File Report 6192, p.41-1 to 41-4.

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BENCHMARKING STUDY

Over a hundred geoscience Web sites were examined in order to document industry best practices and to ensure that the Geology Ontario Web portal would provide the necessary services to meet client requirements. Benchmarking is a crucial step in helping define customer requirements, establishing objectives, developing productivity measures and remaining competitive. The study tabulated the following information for each site visited: data discovery methods (i.e., map search tools, text search tools), data content and data format.

Over 50% of the sites offer text-based search tools, whereas more than 30% offer map-based search tools. Approximately 25% of these use ArcIMS® technology. The remainder maintain either simple listings in some order (i.e., chronological, alphabetical, by subject matter) because of the low volume of downloadable data or do not offer any data for download, but simply provide a link to their publications office. Most of the sites with downloadable data have some form of metadata and many of these conform to the US Federal Geographic Data Committee (FGDC) standards or are compliant with the library catalogue standard z39.50. Some sites even produce thumbnail images of the document or map.

Almost all of the downloadable sites supply geoscience publications, both maps and reports, as well as regional thematic data encompassing their entire jurisdiction. These would typically include regional planimetric, geological and geophysical maps, mineral deposit and regional geochemical data and, in some cases, regional terrain models (DEMs) and satellite imagery. Some sites offer mineral land tenure maps and assessment file reports, as well.

By far, the most popular format for disseminating both reports and maps is the Adobe Systems® PDF (portable document format). Geographic information system (GIS) and vector data downloads are available in various formats but the ESRI® Arcview® or ArcInfo® formats predominate. Tabular data stored in spreadsheets are generally provided in Microsoft® Excel® and ASCII CSV formats. Very few sites supply image and/or grid data (satellite images, geophysical data), so no dominant format emerged in this regard. Rather, they appear to be spread evenly across the following types: Lizardtech® MrSID®, Geosoft® GRD or GXF®, ERMapper® ERS®, TIFF, JPG and BMP.

All sites, with the exception of one, provide free downloads. Some sites require individuals to register on-line before being allowed to download, particularly sites that provide access to very large files such as geophysical data and satellite imagery. Disclaimers and liability waivers vary from being non-existent to appearing before each download. Some sites offer the possibility of downloading data in more than one format and, for maps, in more than one projection. Most sites provide only current data for download—generally less than 5 to 10 years old.

METADATA DEVELOPMENT AND DATA CONVERSION

Metadata pertaining to MNDM publications is currently housed in 2 systems. In 1994, the Ministry developed a publications database containing attributes on all publications produced since 1891. In 2002, the Ministry began entering metadata into a centralized metadata server based on the Government of Ontario Information Technology Standard (GOITS) 72.0. GOITS 72.0 is a metadata standard that was derived from the FGDC standard for metadata. Though new efforts have concentrated on the centralized metadata server, MNDM continues to populate the older publications database simply because this database contains records for all publications.

The Ministry has created a process of extracting metadata specific values from the publications database and populating the metadata catalogue available in ArcIMS®. In this implementation, MNDM has utilized the FGDC compliant catalogue, but will review moving their metadata to the new ISO standard in the near future. The metadata server is a Z39.50 protocol compliant server enabling direct querying from library search engines.

Metadata values were also used to populate fields within the PDF documents themselves. The purpose of populating these fields or meta-tags is to facilitate the rapid discovery of pertinent information either through the Web site search engine or through other common search engines such as Google® and Yahoo®. These search engines not only index content, but also index information contained within PDF meta-tags.

The Ministry also embedded meta-tag data within the client submitted work assessment files to facilitate discovery of assessment related documents.

Since the majority of publications and assessment files were scanned in the early 1990s, MNDM utilized raster to PDF conversion software available from JRAPublish® and converted approximately 2 000 000 pages and 168 000 maps to 85 000 PDF documents. These documents, in turn, were subjected to optical character recognition software and converted to "PDF searchable" format. The Ministry built a 40 000 entry geoscientific and geographic names dictionary to enhance word pattern recognition by the conversion software.

The net result is that the majority of these millions of raster images can now be searched for content using the dtSearch® engine that has been implemented on the Geology Ontario Web site.

Simple and complex Boolean functions coupled with meta-tag search fields ensure that clients are provided with simple tools that return powerful results. For example, using the following Boolean syntax: **visible w/3 gold** returns those occurrences where the word visible is found within 3 words of the word "gold". Though this may seem like an obvious query to perform, what must be realized is that performing this type of query will also return occurrences of "no visible gold". A simple modification of the above query to **visible w/3 gold not w/2 no** will remove the occurrences of "no visible gold". Combining these Boolean queries with meta-tag data further assists the client in narrowing down results and pinpointing their searches.

For the future, it is envisioned that metadata will be entered, stored and managed through ESRI® ArcCatalog®. Not only will searches align with the Z39.50 protocol, but data distributed through the Web site will also include necessary attributes for utilizing data within the proper spatial context. In addition, ArcCatalog® conforms to the out-of-the-box philosophy that has contributed to the reduction in total cost of ownership of the development and maintenance of internet-facing, GIS-related Web applications.

LIMITATIONS

Geology Ontario has been built in a fashion that facilitates maintenance and updating. This project did not correct pre-existing inherent discrepancies within the various data sets. Also, the substantial number of unique files that exist within the individual Resident Geologist Offices were not converted nor loaded into Geology Ontario.

Text recognition software is fallible. Given the wide range in quality of the original scanned documents, successful recognition varies greatly. While this software has been successful at recognizing text in hand printed documents, other documents, which appeared to be of a better quality, visually, did

not convert successfully to the PDF searchable format. In addition, the custom dictionary of geoscientific and geographic terms did not always improve the word pattern recognition process.

Despite these limitations, Geology Ontario is now aligned with business processes in the Mines and Minerals Division and, as a direct result, can be easily updated with new records. The Ministry envisions updating the Geology Ontario with a frequency on par with the numerous Publication Releases that occur throughout the year.

As advances are made in word pattern recognition software, the documents within Geology Ontario can be re-processed and re-indexed in an effort to achieve a higher success rate when queried.

SUMMARY

The Geology Ontario project is a unifying endeavour focussed on merging services provided by the Mines and Minerals Division at the Ministry of Northern Development and Mines into a single access point for geoscience data and reports and Crown Land mining tenure in the Province. Committed toward developing solutions that take advantage of inherent functionality in commercial software, the LRC and MNDM continue to develop solutions that minimize the total cost of ownership.

Geology Ontario is designed to be fed by all sections of the Mines and Minerals Division. Future publications, maps and reports originate in the Precambrian Geoscience Section, Sedimentary Geoscience Section and Resident Geologist Program and flow through the Publication Services Section to Geology Ontario. The Abandoned Mines Information System has data maintained by the Mining Lands Section, which also maintains data on mining claims and mining land tenure. The new Laboratory Information Managements System will be used to update the Lithogeochemical Database. The Electronic Assessment System in the Geoscience Assessment Office will provide additional assessment files for updating the Assessment File Raster Image (AFRI) database and document repository on Geology Ontario. More geoscientific themes will be added to the map viewing component so that `informed decision making' functionality will continue to grow.

Careful design consideration has meant that the vast amount of data in Geology Ontario (www.ontario.ca/geology) can be accessed as a component of a data warehouse. Map themes are also available so that individuals and organizations can integrate the many themes into their own GIS compilations in the privacy of their homes or offices simply by linking in Geology Ontario. In addition, Geology Ontario has taken advantage of hyperlinking technologies such that additional information can be linked directly to Geology Ontario from other MNDM Web sites such as the Drill Core Library Online and Mining Claims Information.

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Metric Conversion Table

Conversion from SI to Imperial			Conversion from Imperial to SI		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
		LENGTH			
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
		AREA			
1 cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
		VOLUME			
1 cm^3	0.061 023	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.307 951	cubic yards	1 cubic yard	0.764 554 86	m^3
		CAPACITY			
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
		MASS			
1 g	0.035 273 962	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 747	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 622 6	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.102 311 3	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 90**	t
		CONCENTRATION			
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	Multiplied by	
1 ounce (troy) per ton (short)	31.103 477	grams per ton (short)
1 gram per ton (short)	0.032 151	ounces (troy) per ton (short)
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note: Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.

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