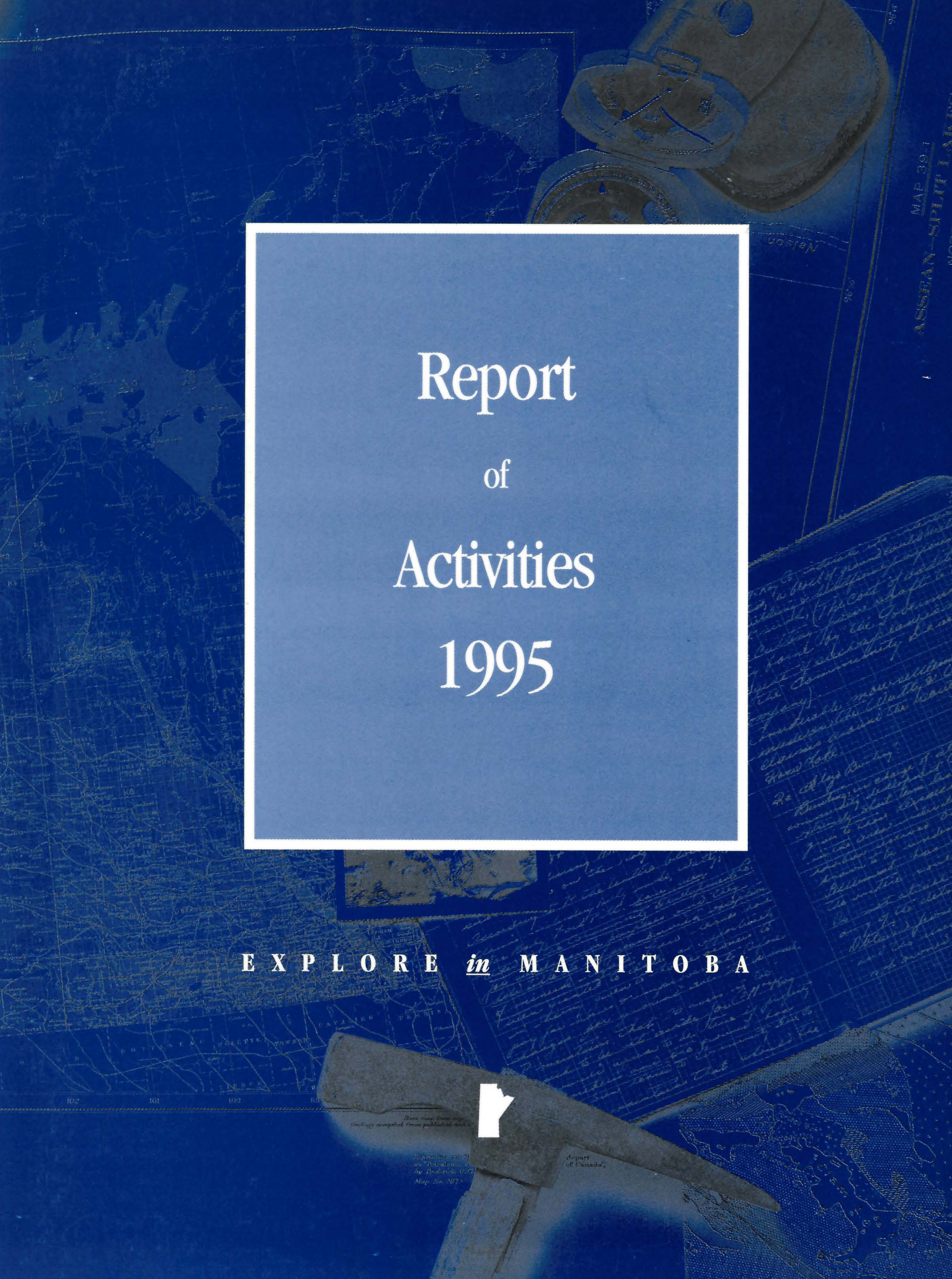


Report of Activities 1995

EXPLORE *in* MANITOBA

MANITOBA ENERGY AND MINES

MINISTER, Hon. Darren Praznik
Room 314, Legislative Building
Winnipeg, MB R3C 0V8
(204) 945-6429 Fax: (204) 945-8374

DEPUTY MINISTER, Michael Fine
Room 314, Legislative Building
Winnipeg, MB R3C 0V8
(204) 945-4172 Fax: (204) 945-8374

BRANCH/SECTION STAFF

360 - 1395 Ellice Avenue, Winnipeg, MB R3G 3P2
Area Code: 204 Fax: 945-0586, 945-1406

MARKETING

Director	Kate Thomas	945-1874
Business Development	Lyle Skinner	945-6585
MEAP Administrator	John Nesbitt	945-6521
Publications	Shelly Lizak	945-6541
Public Relations and Market Research Coordinator	Elaine Stevenson	945-2691
Publication and Graphic Production	Dave Baldwin	945-6551

GEOLOGICAL SERVICES

Director	Dave McRitchie	945-6559
Geological Surveys	Dave McRitchie	945-6559
Mineral Investigations	George Gale	945-6561
Geophysical, Geochemistry and Terrain Sciences	Ifti Hosain	945-6540
Geoscience Information Services	Paul Lenton	945-6553
Core Shed, University of Manitoba	Doug Berk	269-5688
Core Storage, 10 Midland Street, Winnipeg	Doug Berk	945-6550
		(Fax) 948-2164
Rock Storage Facility, Perimeter Hwy. at Brady Road	Doug Berk	261-1405
Thompson Office: 204 - 59 Elizabeth Road, Thompson, MB R8N 1X4	Peter Theyer	677-6886
		(Fax) 677-6888
Flin Flon Office: 143 Main Street, Flin Flon, MB R8A 1K2	Tom Heine	687-4222
		(Fax) 687-5308
The Pas Office: 3rd and Ross Avenue, P.O. Box 2550, The Pas, MB R9A 1M4	Dave Prouse	627-8251
		(Fax) 627-8387

MINES

Director	Art Ball	945-6505
Mining Recording	Sheena Shetty	945-6528
Mining Engineering	Barry Hadfield	945-6517
The Pas Office: 3rd and Ross Avenue, P.O. Box 2550, The Pas, MB R9A 1M4	Fred Heidman	627-8268
		(Fax) 627-8387
Brandon Office: 340-Ninth Street, Brandon, MB R7A 6C2	Les Cels	726-7118
		(Fax) 726-6749
Russell Office: 402 Main Street N., Russell, MB R0J 1W0	Jack Adams	773-3343
		(Fax) 773-2411

PETROLEUM

Director	Bob Dubreuil	945-6573
Geology/Administration	Carol Martiniuk	945-6570
Special Projects/ Computer Programmer	Keith Lowdon	748-1627
Engineering and Inspection	John Fox	945-6574
Virden Office: 227 King Street W., P.O. Box 1359, Virden, MB R0M 2C0	Bruce Dunning	748-1557
		(Fax) 748-2208
Waskada Office: 106 Railway Avenue, P.O. Box 220, Waskada, MB R0M 2E0	Ian McGregor	673-2472
		(Fax) 673-2767

ENERGY MANAGEMENT

Director	Clare Moster	945-1111
Energy Monitoring and Planning	Ron Pritchard	945-2671
Energy Efficiency and Alternative Energy	Grant McVicar	945-3674

ADMINISTRATIVE SERVICES

Executive Director	Garry Barnes	945-4317
Financial Services	Craig Halwachs	945-3675
Personnel Services	JoAnne Reinsch	945-4437
Computer Services	Andy Bibik	945-2172

Manitoba
Energy and Mines
Geological Services

REPORT OF ACTIVITIES 1995

1995
This publication is available in large print, audiotape or braille on request

Minister of
Energy and Mines
Minister responsible for Manitoba Hydro

Room 314
Legislative Building
Winnipeg, Manitoba CANADA
R3C 0V8

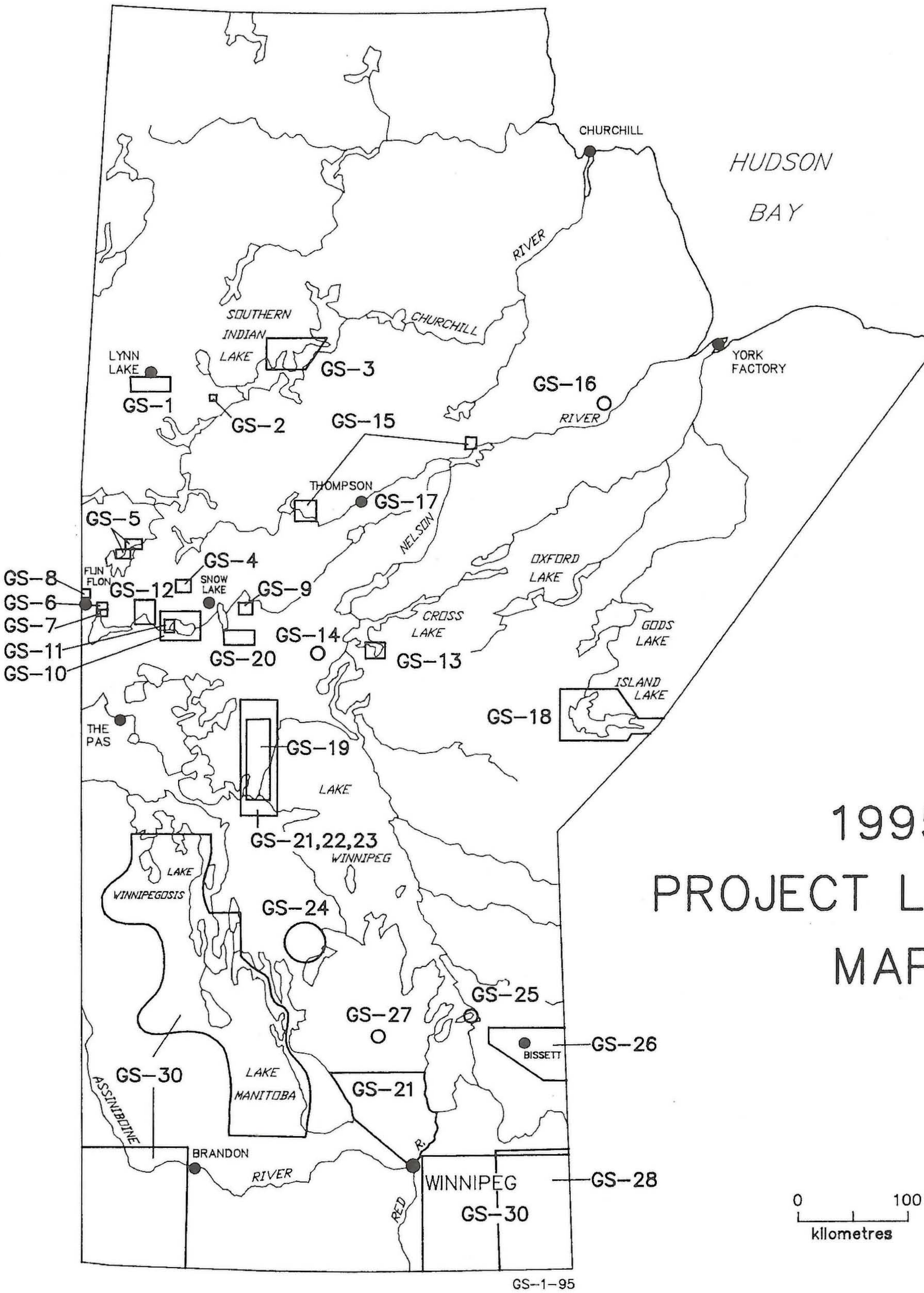
It is our goal to make Manitoba the best place in Canada, and possibly the world, to invest in mining. As the Minister of Energy and Mines, I look forward to this year's annual convention to launch new initiatives developed in partnership with the mining industry.

The mining industry forms an integral part of Manitoba's economy. With this importance in mind, we have embarked on an aggressive exploration and mining strategy that will facilitate all ranges of industry players. Our new "one-stop-shopping approach" to new mine approvals will eliminate Government red tape. The new Mineral Exploration Assistance Program (MEAP), developed in cooperation with the mining industry, is designed to encourage grassroots exploration and open up under-explored areas of the province. In keeping with the rapid changes in technology, Manitoba is spending One-half Million Dollars on new mapping and digitization of our Geoscience database. As the reports contained in this book indicate, there has been a significant amount of activity in geological survey work and exploration in the province during the past year, reflecting the increased interest in mining in Manitoba.

I look forward to meeting with you at this year's Manitoba Mining and Minerals Convention to discuss future mining opportunities.

Darren Praznik

1995
Celebrate Manitoba's 125th! Fêtons les 125 ans du Manitoba!



1995 PROJECT LOCATION MAP

TABLE OF CONTENTS

INTRODUCTORY SUMMARY

by W.D. McRitchie

McRitchie, W.D., 1995: Introductory summary; **in** Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 1-3.

GENERAL

Geological Services Branch (GSB) programs in 1995 encompassed a broad range of projects supporting the private sector's exploration efforts in the Flin Flon-Snow Lake region, the southwest extension of the Thompson Nickel Belt and in southern Manitoba. An array of more dispersed projects supporting exploration elsewhere in the province was conducted in the Lynn Lake region, on Pipestone Lake, near Bissett and in southwest Manitoba.

Relogging of sub-Phanerozoic cores from the Thompson Nickel Belt extension and in Shield marginal areas south of Snow Lake resulted in new preliminary geological reports that include maps showing the drill hole locations and lithologies intersected.

Winnipeg-based activities included increased interaction with land-use staff of the Mines Branch, and close cooperation with the expanded programming of the Marketing Branch especially in industrial minerals and commodity studies. Compilation programs continued to develop new map sheets in the 1:250 000 synoptic bedrock geology series, sub-Phanerozoic compilations, revisions to the lower Paleozoic stratigraphic maps and aggregate and crushed stone availability in the Winnipeg region. Two new Mineral Deposit Series reports were released; one for part of the Leaf Rapids region and one for part of the Bissett region. Mineral deposit reports currently in progress include one remaining report for the Lynn Lake area, five for the Flin Flon district, one in the Island Lake area and one for the sub-Paleozoic extension of the Flin Flon-Snow Lake region.

Geological Information System projects include production of a new 1:1 000 000 scale Wetlands map for the province based on data and analysis provided by the University of Alberta. The project is being conducted in cooperation with LINNET. A schema for the Minerals Database, developed in preliminary form last year, has been revised and expanded to include further detail on mineral occurrence geology.

The first draft of the 1:100 000 NATMAP compilation of the Shield Margin area is nearing completion. The preliminary geological map for the Reed Lake area will be incorporated into the compilation thereby completing the entire Manitoba segment of the compilation by early 1996. Release of the final maps and accompanying database on CD-ROM is scheduled early 1997.

The GSB has been restructured to give higher profile and effectiveness to digital data management by establishing an expanded Data Management Section. The new section incorporates cartographic staff from the former Graphics Services Section. Enhanced capabilities will be facilitated by accelerated hardware and software acquisition and staff retraining, to ensure a smooth transition to a fully functional Unix-based ARCINFO system prior to conclusion of the NATMAP programs, which have provided much of this support to date.

Throughout the year GSB staff responded to numerous requests from industry and the general public for information on sundry aspects of Manitoba's geology and unrealized mineral development potential. A two day prospecting course was offered by the Thompson office May 13-14, for 19 registrants.

Construction of a rock and core viewing facility has been recently completed at Thompson. The facility is designed to provide clients and staff with a safe and comfortable work area in which drill core and other sample media can be examined year round. Construction of a similar facility at the Centennial Mine base, Flin Flon, is proceeding this fall.

GSB staff gave technical presentations on Manitoba's mineral potential and new exploration concepts to local CIM branches in Manitoba. Talks and displays were also presented in Toronto, at the Annual Convention of the Prospectors and Developers Association, and in Montreal, at the International Conference on the Precambrian.

Land-use issues continue to require increased involvement from GSB geologists, especially in the context of the Capital Region study. The Branch continued to conduct mineral assessments in areas being considered for land use designations that handicap or preclude mineral development, *e.g.* Wildlife Management areas, National Park and Endangered Spaces Candidate areas.

Outreach activities have been limited to some degree by budgetary constraints. Nevertheless, several staff gave talks to Winnipeg school classes and led tours in provincial parks. Assistance was also provided in the drafting and writing of two Provincial Parks nature trail pamphlets and in guiding Wildlife Branch specialists to hybernaculae in the Interlake. At Flin Flon, a committee has been formed in cooperation with the Greenstone Community Futures Development Corporation, to prepare a geological and historical walking tour guide for the Flin Flon region. Talks and field tours were given to both grade and high schools in Flin Flon.

The Branch continues to be represented on several interdepartmental working groups including a newly formed Radarsat Steering Committee and the Land Information Committee.

The Mineral Exploration Liaison Committee has been reactivated to provide input to GSB programming, as well as to maintain a watching brief on land-use issues and other matters affecting mineral development. Meetings are to be scheduled biannually.

In 1996 the Annual Joint Meeting of the Geological Association of Canada and Mineralogical Association of Canada will be held in Winnipeg. Field trips, technical presentations, displays and symposia to be convened at this function will highlight numerous new products and concepts stemming from geological investigations in Manitoba over the last few years.

FEDERAL-PROVINCIAL COOPERATION AND NEW INITIATIVES

Provincial projects and outputs continue to be substantially augmented by contributions from the Geological Survey of Canada (GSC) under programs such as the NATMAP Shield Margin and Southern Prairies projects, the Lake Winnipeg Physical Environment Survey, and projects funded under the Canada-Manitoba Partnership on Mineral Development, the latter now in its last and final year. Final publication of EXTECH initiatives in the Ruttan and Snow Lake districts is scheduled for early 1996. Numerous interim reports, maps and digital databases are being issued by the NATMAP programs in conjunction with the Manitoba Mining and Minerals Convention in November 1995 and the GSC Minerals Colloquium in January 1996. Foremost of these will be a new 1:1 000 000 scale integrated geology, gravity and shaded relief magnetic map of the province, to be issued as a joint GSC-GSB Open File in digital and hard copy formats.

A March workshop involving numerous federal and provincial agencies reviewed progress on the Lake Winnipeg Physical Environment Survey. An interim report on the investigations mounted in Phase One of this program during 1994 was presented to Manitoba Hydro in August, with a more complete report on all findings scheduled for January 1996. A second phase of this highly innovative program will be initiated in the summer of 1996 subject to availability of funding.

Cancellation of the Mineral Development Agreements (MDA's), announced by the federal government in February 1995, was met with concern across the country by provincial and territorial agencies and also by industry clients who regarded MDA outputs as fundamental to their domestic exploration efforts. The province initiated reviews of its strategic needs and, with strong support from industry, committed to maintaining its level of funding in support of geological surveys and investigations.

The important role of the mineral industry in underpinning the provincial economy was further recognized in mid-year through Manitoba's introduction of a new five-year Strategic Plan embracing commitments to one-stop shopping, a more effective Mineral Exploration Assistance program (MEAP), and an acceleration of geological survey work in the northern Superior Province.

Additional funding for upgrading instrumentation at the Energy and Mines Analytical Laboratory was provided through a provincial New Initiatives program. Increased productivity and services at the laboratory are being coordinated through internal restructuring, as well as plans for increased cooperation with the analytical capabilities of the

Environmental Sciences Centre, Logan Avenue.

The significant budget constraints imposed by governments across Canada prompted the need to develop a new mechanism for coordinating future federal/provincial geoscience programming in the regions. A new National Geoscience Accord has been drafted by the National Geological Surveys Committee to clearly spell out the respective roles and mandates of the federal and provincial/territorial geological surveys in Canada. Bilateral agreements between the GSC and each of the provinces/territories are soon to be negotiated. These will lead to strategic geoscience workplans for each of the regions with active participation by industry in the development and monitoring of the program proposals and program delivery.

FIELD ACTIVITIES

Lynn Lake Region

In the Pukatawagan Bay area of Southern Indian Lake a mapping and sampling program documented well preserved mafic volcanic rocks and volcaniclastic metasediments similar to those exposed on Partridge Breast Lake. Associated high-magnesium ultramafic rocks with numerous gossan zones resemble picritic flows in the Lynn Lake area.

At Franklin Lake, a 4 km^2 area recently affected by forest fires was examined to better characterize structures and gold mineralization associated with a regionally important metallogenic feature, the Johnson Shear Zone. At Cartwright Lake, a small rhyolite body was investigated for geochemical alteration associated with VMS-type mineralization and in order to characterize the distribution and gold abundances of arsenopyrite-pyrite occurrences.

Discussions with Granduc Mining Corporation staff provided the impetus for a pilot petrographic and geochemical study of the Burnt Timber gold deposit. The study is designed to characterize the primary lithologies and alteration styles associated with the deposit. Additional sampling for ongoing isotope studies at Lynn Lake are planned for the 1996 field season, in cooperation with the Universities of Montreal and Windsor.

Multimedia vegetation and enzyme leach geochemical orientation surveys were completed on the Eden Lake rare earth element (REE) enriched occurrence. Test sampling of the mineralized zones was also undertaken for follow-up metallurgical studies. Ground scintillometer surveys initiated in 1989 were extended to cover more southerly exposures of the syenite.

Flin Flon-Snow Lake Region

As in previous years, this region continued to be the principal focus of GSB mapping and investigations in the province, with added emphasis being coordinated through the joint GSC-GSB Shield Margin NATMAP National Mapping Program, now in its final year. Quaternary investigations in the western part of the Flin Flon NATMAP area were completed. The final report on basal till surveys conducted over the last five year period will be released in the Spring of 1996. A structural analysis of the Elbow Lake shear zone (University of New Brunswick) and a structural study of the metavolcanic and metasedimentary rocks in the vicinity of Flin Flon (Queens University) were also completed.

Underground geological investigations at the Callinan deposit continued in cooperation with Hudson Bay Mining and Smelting Co. Limited and Hudson Bay Exploration and Development Company Limited. Key areas on surface were mapped to refine the structural and stratigraphic setting of the sequence hosting the Callinan and Main deposits.

Detailed mapping, structural studies and geochemical sampling of rhyolitic rocks in the vicinity of base metal deposits in the Baker Patton Complex provided new insights into the geological setting of this structurally complex, predominantly calc-alkaline volcanic sequence. Mapping continued in the Hotstone-Cleaver Lake area, south of the Baker Patton Felsic Complex, where subaqueous altered rhyolites have been identified in a previously undifferentiated mafic flow sequence.

A collaborative GSC-GSB mapping project was carried out in the Reed Lake-Tramping Lake area. A major (kilometres wide) tectonite belt discovered on western Reed Lake is regionally continuous to the north, through North Star Lake and into the Kisseynew belt. This shear-mylonite belt juxtaposes a mafic-ultramafic ocean floor plutonic complex east of Reed Lake (*ca.* 1.9 Ga?) against a heterogeneous arc sequence of intermediate-mafic flows, volcaniclastic rocks and rhyolite (*ca.* 1.9 Ga?) on west-central Reed Lake. East of the shear zone the structure is interpreted as a large scale imbricate stack comprising (from west to east) arc volcanic rocks, a fault-bounded slice of File Lake Formation greywacke, and a monotonous sequence of pillow basalts interpreted as ocean floor rocks. These relationships suggest the entire Snow Lake segment of the Flin Flon Belt forms a south-verging allochthon emplaced after deposition (*ca.* 1.84 Ga) of the File Lake Formation. The structural interpretation supports earlier evidence that the Snow Lake and Flin Flon VMS camps are unrelated, and represent remnants of distinct volcanic arcs that have been structurally juxtaposed.

To the north at Dow Lake, the Reed-North Star high strain zone becomes parallel to shallow northeast-dipping foliation in the structural footwall of the Loonhead Lake fault. This fault is a major thrust that separates the Amisk collage from the structurally overlying and younger Burntwood and Missi metasedimentary rocks of the Kisseynew Belt. Consequently, at Dow Lake three fundamentally different assemblages are juxtaposed (*i.e.* Flin Flon-Snow Lake-Burntwood), each with their own unique metallogeny.

Further west, where two or more of these three assemblages are structurally interleaved, a detailed mapping project centred on Yakushavich Island, Kississing Lake, demonstrated that refolding of an early recumbent structure has led to tectonic thickening of a potentially mineralized zone in the garnet-biotite gneiss. The garnet-biotite gneiss is structurally underlain and overlain by amphibolites that contain numerous occurrences of pyrrhotite and traces of chalcopyrite.

The Snow Lake mining camp is included in a new national GSC program studying the relationships between regional scale alteration, subvolcanic intrusions and volcanic-associated massive sulphide deposits. This three-year $1.4 million program is funded by Mining Industry Technology Council of Canada (MITEC), GSC and NSERC, and includes research in four Canadian mining camps. In the Snow Lake camp the program involves continued federal/provincial survey cooperation.

At Photo Lake specific conductance and H^+ analyses from outcrop chip samples on the DUB-21 grid were contoured and the interpretation presented at a meeting in Flin Flon. Interpretation and pH-conductivity measurements on the remainder of the samples is proceeding.

A brief geological mapping project at Dion Lake showed that low level base metal mineralization in quartzofeldspathic paragneisses occurs in 1 to 10 m wide zones that are locally fault controlled. Mineralization in the basaltic enclave southwest of Dion Lake is characterized by a southeast-trending zone with relatively higher values of copper and zinc, that extends across the Lee claims. The most promising mineralization is associated with fine grained quartzofeldspathic gneiss that may be derived from felsic volcanic rocks and coarse grained hornblende-garnet gneiss, of possible alteration zone origin, that occur in the Lee Claims Mineral Zone (LCMZ) and in a north-northeast trending unit east of Dion Lake. Future mapping may profitably investigate the significance of the southeast-trending LCMZ, and investigate any geophysical anomalies that may occur where this zone is intersected by major faults.

LITHOPROBE activities in the Trans-Hudson Orogen Transect (THOT) followed up work on reflection and refraction surveys conducted in earlier years. Field components were limited to highly focussed geological mapping and investigations in the Flin Flon region and ground gravity transects by the GSC along the routes of the earlier seismic surveys. GSB staff participated in THOT workshops including one in Winnipeg, October 16th. Staff also attended program planning sessions preparatory to the upcoming Western Shield Lithoprobe Transect in Ontario.

Thompson Nickel Belt

Geological work in the exposed sector of the Thompson Nickel Belt was largely directed toward initiating a major recompilation of the belt geology at a scale of 1:50 000. This year, work commenced on four sheets surrounding Ospwagan Lake. Elsewhere in the region a geochronological study was initiated in the Split Lake area in cooperation with the University of Montreal. Several Molson dykes and various intrusive and anatectic phases in the Split Lake block were sampled.

Migmatites and gneisses in the Thompson and Split Lake areas were examined as potential sources of dimension stone, but the investigated sites were too intensively fractured.

In the southwest sub-Paleozoic extension of the Thompson Nickel Belt near Grand Rapids, four new holes were drilled to basement in the Buffalo Lake area, giving much better control on the location of the boundary between the Nickel Belt and the neighbouring Superior Province.

Northern Superior Province

The Friends of the Nickel Belt field trip returned to the Cross Lake area to examine the titanium-vanadium-iron deposit in the Pipestone Lake Anorthositic Complex. Industry representatives, consultants and Cross Lake Band Members joined staff of the GSB and researchers from the University of Manitoba and Laurentian University. Two days were spent examining the principle massive oxide-bearing zones, the disseminated ilmenite-bearing north zone and Gossan Resources' drill core. A third day concentrated on the well preserved and exposed outliers of the anorthosite complex on the west channel of the Nelson River and Kiskitto Lake.

Grid mapping was completed on the main part of the Pipestone Lake Anorthositic Complex where four laterally extensive zones of ilmenite and magnetite have been delineated by drilling (Gossan Resources and Cross Lake Mineral Exploration Inc.). The field investigations represent the initial stages of two related M. Sc. projects to address the geology and genesis of the complex and its Ti-V-Fe oxide mineralization.

A feasibility study for mapping the West Channel Anorthosite Complex showed that detailed mapping of this complex will be severely handicapped by lack of exposure. However, relatively undeformed, unaltered oxide-bearing leucogabbro and gabbro, in association with linear magnetic highs, were intersected in drill core from Gossan Resources' ongoing exploration of the Kiski Zone.

A Mineral Deposit Report for the Island Lake area was compiled, together with an accompanying Mineral Deposit map.

Interlake

Mapping and compilation work on Paleozoic carbonates north of Grand Rapids continued as did sampling of spring waters and marls, in an attempt to find evidence of Mississippi Valley Type (MVT) mineralization in the host Silurian dolomites. New outcrops of the Silurian Fisher Branch Formation containing the marker fossil *Virgiana decussata* were discovered northeast and southeast of Buffalo Lake, over a strike length exceeding 30 km.

Temperature-depth profiles were obtained from seven coreholes in the Grand Rapids area by researchers from the University of North Dakota. The measurements provided information on terrestrial heat flow and fluid flow in the boreholes, and climate change over the past century. Preliminary results of two-dimensional heat conduction models suggest that the heat sinks are wedges of buried discontinuous permafrost located between 40 and 100 m depth.

In the southern Interlake region, a high-resolution gravity survey was conducted across the Lake St. Martin structure by researchers from the University of North Dakota. Preliminary results suggest the extent of structural disturbance associated with the crater may extend to 57 km in diameter, rather than the 44 km previously proposed.

GSB is also working cooperatively with the provincial Water Resources Branch in analyzing spring waters from the southern Interlake region, once again to look for evidence of MVT mineralization.

The effectiveness of various geophysical techniques to locate buried kaolin deposits in the Arborg-Sylvan area is being tested. Instruments used in 1995 included EM-31, VLF-EM, time domain electromagnetic, DC-resistivity, seismic refraction and gravity meters. The techniques were successful in outlining the kaolin channels and confirmed the existence of new probable channels delineated in the 1992 surveys. In-house surveys conducted by GSB staff were augmented by new surveys conducted by University of Manitoba field school students.

Southeast Manitoba

Geological mapping in the Garner-Beresford lakes region delineated the eastward extension of the komatiites southeast from Beresford Lake, and attempted to subdivide the Gem Lake Subgroup, which currently embraces assemblages with three distinct isotopic ages. The oldest members of the Gem Lake Subgroup compare favourably with Red Lake greenstone assemblages, which bodes well for prospects of nickel and gold mineralization. A joint field trip with staff from the Ontario Geological Survey examined 3.0 Ga platformal sequences at Wallace Lake as part of a larger study comparing rift sequences in the Baltic and Canadian Shields.

Seven bogs in southeast Manitoba, identified from aerial photo interpretation, were sampled to determine their potential as sources of horticultural quality sphagnum. Six of the sphagnum bogs contained sphagnum to a depth of only 0.5 m; the seventh bog was a willow swamp.

The geochemistry of metal-rich Ordovician black shales and their encrustations on Black Island, was examined as a first step toward initiating a black-shale geochemical database. The results of this program will also have application to gold and base metal exploration and to studies of the bioavailability of constituent metals in environmental baseline and monitoring programs.

Southern Manitoba

A reverse population flow from the City of Winnipeg to the surrounding municipalities has been occurring since the 1970's, resulting in a shift from a rural agricultural setting to a semi-urban environment in these municipalities. This has increased land-use and environmental pressures in these municipalities to restrict the extraction of sand, gravel and crushed stone. The GSB is assisting the province's Capital Region strategy by conducting mineral resource assessments in the capital region.

All deep Lower Paleozoic wells in the province have been verified for the interval between the Silurian Interlake Group to the top of Precambrian. The tops conform to stratigraphic nomenclature established by the Western Canada Sedimentary Basin Atlas Project. Several products of interest to exploration geologists are now readily available on demand, including overburden thickness and depth to Precambrian maps. The Stratigraphic database now contains 5140 wells, of which 1052 wells are Lower Paleozoic wells. The database is currently being used to generate a new stratigraphic map series for southwest Manitoba.

Field mapping was completed in the Virden area as the final phase of the Southern Prairies NATMAP project. Data collection emphasized engineering, environmental and groundwater applications, and data will be included in a digital database. A biostratigraphical analysis of core from the Wampum area in southeastern Manitoba is in progress. Four preliminary maps at 1:100 000 scale have been released for the NE and SE quarters of the Virden area (NTS 62F) and NW and SW quarters of southeastern Manitoba (NTS 52E). The Manitoba Water Resources water well database has been upgraded to construct 3-D subsurface models for these areas.

Till samples from the Westlake Plain in west-central Manitoba have been analyzed for kimberlite indicator minerals, geochemistry, matrix carbonate content and pebble lithology.

October 6, 1995

GS-1 GEOLOGICAL AND GEOCHEMICAL STUDIES IN THE SOUTHERN PART OF THE LYNN LAKE GREENSTONE BELT, NORTHWESTERN MANITOBA (PARTS OF NTS 64C/11, 64C/14, 64C/15)

by D.C. Peck, H.D.M. Cameron and D. Layton-Matthews

Peck, D.C., Cameron, H.D.M. and Layton-Matthews, D., 1995: Geological and geochemical studies in the southern part of the Lynn Lake greenstone belt, northwestern Manitoba (Parts of NTS 64C/11, 64C/14 and 64C/15); **in** Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 4-10.

SUMMARY

Detailed mapping and lithogeochemical studies were carried out at three locations in the southern part of the Lynn Lake greenstone belt. (1) At Franklin Lake, a broad deformation zone comprising multiple discrete mylonite zones and intervening regions of intense schistosity development was recognized in basalt and clastic sedimentary rocks belonging to the Wasekwan Group. The zone is correlative with the regionally extensive Johnson shear zone. Geochemical studies will focus on samples collected from sporadically developed, lenticular pyrite and/or pyrrhotite zones hosted by sheared basalt and greywacke/siltstone sequences. Quartz veining is ubiquitous, but most of the veins are barren of sulphides and are unlikely to contain Au. (2) Bedrock mapping and sampling of the Cartwright Lake rhyolite were conducted in order to identify geochemical alteration patterns (*e.g.*, Mg-Fe or K alteration) typically associated with VMS-type deposits, and to better characterize the Au abundance of erratically developed arsenopyrite-pyrite veins. Mapping revealed that the rhyolite body contains much more extensive pyroclastic deposits than was previously recognized. No mineralogical indications of widespread alteration in the rhyolite body were observed. Vein-type arsenopyrite-pyrite mineralization represents open-space fillings on cleavage planes or in late brittle fractures and is lithology specific. Analytical results for a suite of 34 mineralized samples indicate erratic Au enrichment in the veins, ranging from <6 ppb to 2860 ppb. (3) A pilot geochemical investigation of the Burnt Timber Au deposit has been initiated in order to elucidate the primary lithologies and alteration features of the host rocks.

INTRODUCTION

Recent (1994 and 1995) exploration of the Lynn Lake greenstone belt by Granduc Mining Corporation, INCO Limited and Hudson Bay Exploration and Development Company Limited, has focussed on gold and base metals. Most of the known mineral occurrences in the Lynn Lake greenstone belt are hosted by the Wasekwan Group (Bateman, 1945), an Aphebian (*ca.* 1910 Ma; Baldwin *et al.*, 1987), mafic to felsic volcanic succession with associated derived sedimentary and volcaniclastic rock types. The geology and mineral occurrences of the Lynn Lake greenstone belt are described by Bateman (1945), Milligan (1960), Gilbert *et al.* (1980), Fedikow *et al.* (1989, 1991) and in Mineral Deposit Series Reports (*e.g.*, Baldwin, 1989). The regional mapping coverage for the Lynn Lake greenstone belt is complete (1:50 000 scale mapping; see Gilbert *et al.*, 1980). Detailed geological investigations are now required to characterize known mineral deposits and metallogenic features (Olson, 1987; Gagnon, 1991) and in areas bared by recent forest fires (Peck *et al.*, 1994). To this effect, three new projects were initiated during the current field season. These include detailed geological and geochemical studies along the Johnson shear zone (Fedikow *et al.*, 1991), a metallogenic study of a small rhyolite body at Cartwright Lake, and a pilot geochemical study at the Burnt Timber mine.

JOHNSON SHEAR ZONE

The Burnt Timber (BT) mine (Granduc Mining Corporation) is the only operating mine in the Lynn Lake region. The BT mine is developed in one of several known gold occurrences hosted by, or occurring proximal to, a structurally complex, linear zone of ductile shearing, intense schistosity and local brittle deformation that generally follows the southern margin of the Lynn Lake greenstone belt (Fig. GS-1-1). This deformation zone is commonly referred to as the Johnson shear zone (Fedikow *et al.*, 1991), and although its metallogenic significance has long been recognized (Bateman, 1945; Fedikow *et al.*, 1991), the structural characteristics and tectonic significance of the Johnson shear zone have not been adequately defined. For example, despite significant gold mineralization at Cartwright Lake, Wasekwan Lake and Gemmell Lake (Peck, 1986; Fedikow *et al.*, 1991; Sherman, 1992), only one gold occurrence of economic significance (BT deposit) has been discovered along the ≈44 km strike length of the Johnson shear zone. Furthermore, the structural features of the zone are extremely variable; *e.g.*, it locally represents a discrete structure (up to 50 m wide) defined by intense cataclastic deformation and shearing (*e.g.*, Cartwright Lake area, Peck, 1986), whereas elsewhere, it is expressed as a series of widely spaced discrete shears and/or brittle faults, separated by broader regions of moderate to intense schistosity (*e.g.*, Franklin Lake area, this study). Most of the Au occurrences associated with the Johnson shear zone are hosted by sulphide or quartz-sulphide veins and alteration zones. Sulphide minerals associated with gold in the Johnson shear zone include pyrite, pyrrhotite, galena, sphalerite and chalcopyrite.

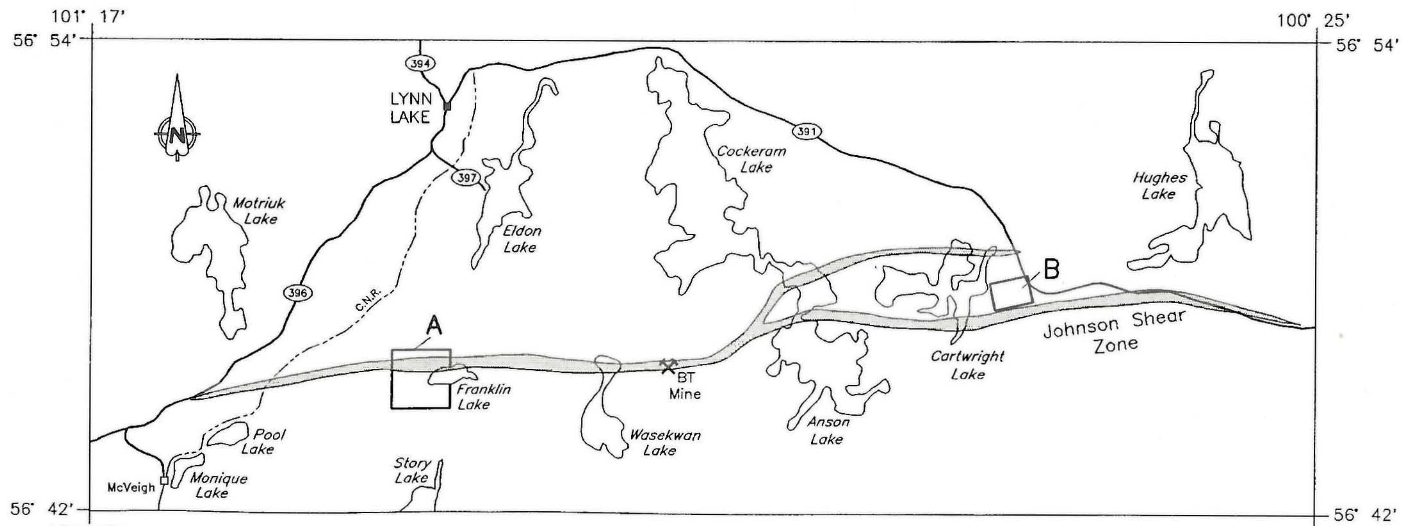


Figure GS-1-1: Location of study areas, Lynn Lake region (Box A-Franklin Lake study area; Box B-Cartwright Lake study area).

FRANKLIN LAKE AREA

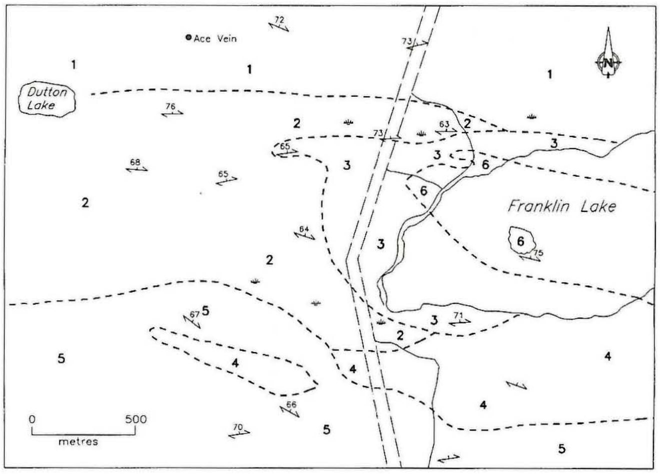
A 1993 forest fire resulted in limited amounts of new exposure of the Wasekwan Group and younger intermediate plutonic rocks (Pre-Sickle intrusive suite; Gilbert *et al.*, 1980) to the west of Franklin Lake and approximately 10 km east of the BT mine (Figs. GS-1-1, -2). A cursory inspection of an approximately 2 km x 2 km area affected by the fire and located immediately to the west of Franklin Lake (Fig. GS-1-2) was completed in 1994 (Peck *et al.*, 1994). The area contains a much wider zone of intense deformation associated with the Johnson shear zone than was previously recognized. In addition, a single, large outcrop of layered gabbro and leucogabbro and new exposures of the Wasekwan Group were recognized to the south and west of Franklin Lake (Peck *et al.*, 1994).

During the current investigation, the area was re-mapped at a scale of 1:5000 using enlarged aerial photographs. Limited bedrock sampling was undertaken in order to characterize the structural evolution of the area and document the Au content of rare sulphide-rich mylonite zones (see below). Recent exploration in the study area (Sherritt Gordon Mines Ltd., 1985-87, and Granduc Mining Corporation, 1994, confidential assessment files) has focussed on IP anomalies associated with sulphide-bearing vein systems and erratically distributed disseminated sulphides within mylonite zones.

The results obtained during the current study are summarized in Fig. GS-1-2 and described below, and are in good agreement with the existing geological descriptions for the area (Bateman, 1945; Gilbert *et al.*, 1980; and Kenaley, 1982). The geology of the study area incorporates mafic volcanic sequences and fine grained clastic sedimentary rocks belonging to the Wasekwan Group, and younger, massive to gneissic Pre-Sickle intrusive rocks. The area represents part of the south limb of a major, 30 km long, east-trending anticline (McVeigh Lake anticline), the axial trace of which is located immediately to the north of the study area (Gilbert *et al.*, 1980). The Johnson shear zone has been documented from outcrops along the north shore of Franklin Lake (Gilbert *et al.*, 1980), but the extent of its development within the study area is not well defined. Peak regional metamorphic grades for the study area were albite-epidote amphibolite facies (Kenaley, 1982). Brief descriptions for each of the major units are given below. The reader is referred to Gilbert *et al.* (1980), Kenaley (1982) and Syme (1985) for more detailed petrologic descriptions and geochemical investigations of the units.

The northern part of the study area is underlain by a >500 m thick succession of massive aphyric basalt and plagioclase-phyric basalt and/or andesite flows that are intercalated with subordinate mafic tuff, siliceous siltstone, rhyolite and felsic tuff (map unit 1, Fig. GS-1-2). Basalt forms massive flows varying from <1 m to several metres in thickness. Subordinate rhyolite, thinly bedded felsic tuff and siliceous siltstone form <1 to 3 m thick beds. The volcanic and sedimentary rocks are intruded by diabase and plagioclase phyric tonalite to diorite veins and dykes. The succession is correlative with the Fraser Lake mafic volcanic body (Gilbert *et al.*, 1980) and is locally characterized by the development of two distinct schistosities. A penetrative, dominantly west- to northwest-trending S_1 foliation is developed parallel to bedding fabrics and displays steep northerly dips. The S_1 fabric is cut by a younger, more intense, S_2 foliation that is developed in local high strain zones associated with discrete, narrow (1-3 m wide) shear zones and/or the axial planes of minor folds. Minor folding is conspicuous in many outcrops. Axial planes on larger folds are west- or southwest-trending and dip steeply to the north. Quartz veins are commonly observed within the unit, and are typically <10 cm wide and barren of sulphide. Most of the veins occur in areas of intense schistosity and are commonly folded.

Unit 1 hosts the Ace vein (also known as the Brown showing; see descriptions provided by Bateman, 1945, Kenaley, 1982, and Baldwin, 1989). The Ace vein is situated ≈500 m northwest of Dutton Lake and 1.4 km northwest of Franklin Lake (Fig. GS-1-2). The occurrence was briefly inspected during the current study. The showing comprises a series of trenches (now badly overgrown) that expose several narrow sulphide-bearing quartz veins developed within interbedded mafic tuff and siliceous siltstone intruded by a plagioclase-quartz porphyry. Sulphide minerals observed in the Ace vein include galena, sphalerite and subordinate pyrite and chalcopyrite. Free gold has also



PRE-SICKLE INTRUSIVE ROCKS

6 Granite, granodiorite

5 Tonalite and quartz diorite with subordinate granodiorite, diorite, gabbro and amphibolite

4 Heterolithic intrusive breccia

WASEKWAN GROUP

3 Greywacke, siltstone, locally interlayered with unit 2 basalt

2 Hornblende phyric basalt, subordinate aphyric and plagioclase phyric basalt, greywacke and siltstone

1 Aphyric and plagioclase phyric basalt and andesite with subordinate felsic tuff, rhyolite and siltstone

- - - geological boundary, approximate

70 foliation (dip measured, dip unknown)

• Au occurrence

—— trail or bush road

— — Powerline

Figure GS-1-2: General geology of the Franklin Lake area.

been recognized at this occurrence (Bateman, 1945). A general correlation is evident between galena abundance and Au contents (Baldwin, 1989).

Intercalated, massive (rarely pillowed), hornblende phyric, aphyric and plagioclase phyric basalt flows and subordinate associated mafic tuff, autoclastic volcanic breccia (flow-top breccia), hornblende greywacke and siltstone form a ≈1 km wide unit in the central-western part of the study area (map unit 2, Fig. GS-1-2). Amygdaloidal flows, containing 20 to 30%, elliptical quartz-carbonate amygdales, are locally observed in this unit. The unit has been correlated with the Fraser Lake mafic volcanic suite (Gilbert *et al.*, 1980). However, the great abundance of hornblende phyric flows in the Franklin Lake area suggests that unit 2 is more likely correlative with the McVeigh Lake porphyritic basalt sequence, which crops out immediately to the north and west of the study area (Gilbert *et al.*, 1980, Map GP-80-1). Unit 2 is poorly exposed in the study area. Massive, hornblende phyric flows predominate, but rare, highly deformed pillowed basalt flows, displaying epidotized and locally amygdaloidal pillows (<50 cm long) and well-developed, amphibolitized, dark-green selvages, are locally present. Hornblende phyric flows are typically 2 to 5 m thick and contain 10 to 30%, medium- to coarse-grained dark green hornblende phenocrysts set in a fine grained basaltic matrix. The equant and idiomorphic crystal shapes displayed by the hornblende crystals suggests they have pseudomorphically replaced primary pyroxene.

A pervasive schistosity defined by amphibole and/or biotite is ubiquitous within unit 2. Rootless, minor folds displaying S, M or Z asymmetry are commonly observed in the unit. Local mylonite and rare ultramylonite are commonly developed within unit 2 and are considered to be an expression of the Johnson shear zone. In contrast to unit 1, unit 2 strata seldom record more than one schistosity, which may reflect the obliteration of older S_1 during shearing. Foliations in unit 2 generally strike west and consistently dip north at 60 to 70° (Fig. GS-1-2). Locally intense quartz veining and epidote-quartz-calcite veining and alteration are characteristic of the most intensely deformed zones. In most cases, veining appears to have preceded, or been contemporaneous, with the final shearing event; *i.e.*, most of the veins are boudinaged and folded.

Elliptical, fine grained, pyrite and/or pyrrhotite stringer vein networks and disseminations are locally associated with mylonite in unit 2. The sulphide mineralization is generally conformable to the shear fabrics, although remobilization of sulphides into late, crosscutting, brittle fractures is commonly observed. Several small sulphide gossans occur at the unit 1 - unit 2 contact immediately east of the power line and west of Franklin Lake (Fig. GS-1-2). The gossans are contained within a 100 m long, 20 m wide mylonitic to strongly schistose basalt unit, and are not observed in sedimentary rocks to the south. Pyrite, pyrrhotite and minor chalcopyrite typically occur in abundances of 1% to 10% within mineralized lenses that are conformable to the shear fabric. Locally, the sulphides occur in thin quartz veins.

The third major Wasekwan Group unit exposed in the study area (map unit 3, Fig. GS-1-2) incorporates thinly to thickly bedded hornblende and biotite greywacke, siliceous to intermediate siltstone and rare mudstone and chert belonging to the Fraser Lake-Eldon Lake sedimentary succession (Gilbert *et al.*, 1980). Intercalated massive, aphyric and hornblende phyric basalt flows are observed within unit 3 near its contact with unit 2. Unit 3 sedimentary rocks are exposed within an arcuate zone adjoining the western shoreline of Franklin Lake (Fig. GS-1-2). The unit appears to be correlative with the metasedimentary rocks that occur proximal to, and may host, the Burnt Timber Au deposit (see below). Greywacke is distinguished by the presence of acicular hornblende porphyroblasts that locally account for 20% of the mode, and reach lengths of up to 5 mm. Bedding is developed on a scale of a few centimetres to several metres. Bed contacts are sharp and planar. A thin, highly siliceous, pyritic siltstone bed was observed in an area dominated by unit 2 hornblende phyric basalt, approximately 1 km to the west of Franklin Lake. Pyrite occurs in closely spaced veinlets <2 mm wide and as disseminations. Pervasive silicification like that at the BT deposit was not recognized in the sedimentary sequences at Franklin Lake.

Excellent exposures of Pre-Sickle intrusive rocks occur in the southern and eastern parts of the study area (Fig. GS-1-2). An intrusive breccia unit (map unit 4, Fig. GS-1-2) is well developed a few hundred metres inland from the southwestern shoreline of Franklin Lake, at the contact between unit 2 basalts and the Pre-Sickle plutonic rocks (unit 5; see below). The breccia reaches a maximum thickness of 250 m in the southeastern part of the study area (Fig. GS-1-2). It consists of variable proportions of fine- to medium-grained, commonly vari-textured matrix (tonalite, diorite or gabbro) and predominantly mafic lithic fragments. Fragments are subrounded to subangular and comprise hornblende phyric basalt (derived from unit 2), thinly bedded mafic tuff, diabase, amphibolite (replacement of pyroxenite) and rare sedimentary rocks. Flattened fragments form excellent strain indicators in areas where the breccia is transected by shear zones, locally developing aspect ratios of 5:1 or greater. Fragment abundance is typically <20% and generally increases to the north. Fragment size varies from a few centimetres to 1 metre. Most of the fragments appear to have been derived from older Wasekwan Group strata, but in some areas, the breccia contains predominantly locally derived plutonic rock fragments (porphyritic diorite, gabbro, pyroxenite).

The main body of Pre-Sickle intrusive rocks (unit 5) is part of a regionally extensive, composite intrusion (Gilbert *et al.*, 1980). In the study area, the intrusion predominantly consists of medium- to coarse-grained tonalite and quartz diorite, and subordinate granodiorite, diorite, gabbro, leucogabbro and amphibolite. Grain sizes generally increase to the south, away from the contact with the Wasekwan Group rocks. Textures within unit 5 vary from massive to gneissic. Shear fabrics are confined to narrow, isolated shear zones (a few cm wide), except near the contact with the Wasekwan Group, where broader zones of intense grain size reduction, schistosity and local mylonite are developed. Magnetite is locally present in abundances of up to 10%, and thin, semi-massive oxide bands (a few mm wide) were observed in coarse grained tonalite at one locality. Blebby to fine grained, disseminated pyrrhotite ± pyrite and chalcopyrite form irregularly distributed, pod-shaped gossan zones up to 3 m long and 1 m wide. The sulphides are best developed in the more mafic parts of unit 5.

Igneous layering is preserved in several locations within unit 5, but no conclusive top indicators were recognized. Layering involves diffuse modal variations (plagioclase:amphibole) that produce planar, centimetre- to decimetre-thick layers. Irregular, late-stage mafic (gabbro and amphibolite) veins are locally developed, and display extremely variable grain sizes. Subtle, metre to decametre-scale modal layering is also evident within unit 5, involving relative massive zones of quartz-rich tonalite ± granodiorite ± quartz diorite, and thinner, more mafic and better layered zones containing quartz diorite, diorite, leucogabbro and rare gabbro.

A large body of pink weathering, fine- to coarse-grained equigranular granite (Unit 6) containing local zones of orthoclase porphyritic granite and granodiorite crops out on an island in the western part of Franklin Lake and inland from the northwestern shoreline of the lake (Fig. GS-1-2). Irregular granite pegmatite veins and dykes locally intrude unit 2 and 3 strata immediately to the west of Franklin Lake. Unit 6 granitic rocks locally display well-developed mylonitic fabrics in discrete cataclastic deformation zones up to 10 m wide.

Late, planar, diabase dykes are rarely observed within the study area. The dykes are predominantly fine grained to aphanitic, dark coloured, aphyric, and <1 m wide and a few metres long. Rare plagioclase phyric dykes were also observed. The dykes commonly strike north or northwesterly, and intrude all of the major lithologic units.

Precise boundaries cannot be defined for the Johnson shear zone within the study area. The zone, as documented in the Franklin Lake area, encompasses a broad region, up to 1 km wide, of intense deformation that contains multiple discrete mylonite zones and rare, narrow (<5 m) ultramylonite zones separated by zones of intense schistosity development (grading to protomylonite). This broad deformation zone extends for approximately 1 km southward from the unit 1 - unit 2 contact to the unit 2 - unit 5 contact and into the northernmost parts of the large body of Pre-Sickle intrusive rocks in the southern part of the study area (Fig. GS-1-2). Mylonite is best developed within hornblende phyric basalt of unit 2 and siltstone and hornblende greywacke of unit 3. The intensity of deformation appears to increase northward across the zone, with the most abundant mylonite developed near the unit 1 - unit 2 contact. Mylonite development is typically marked by extreme comminution of phenocrysts, boudinage of quartz veins, translation of bedding into parallelism with the shear fabric, and the development of crenulations and rootless, asymmetric minor folds. Folding and shearing appear to have been contemporaneous through-

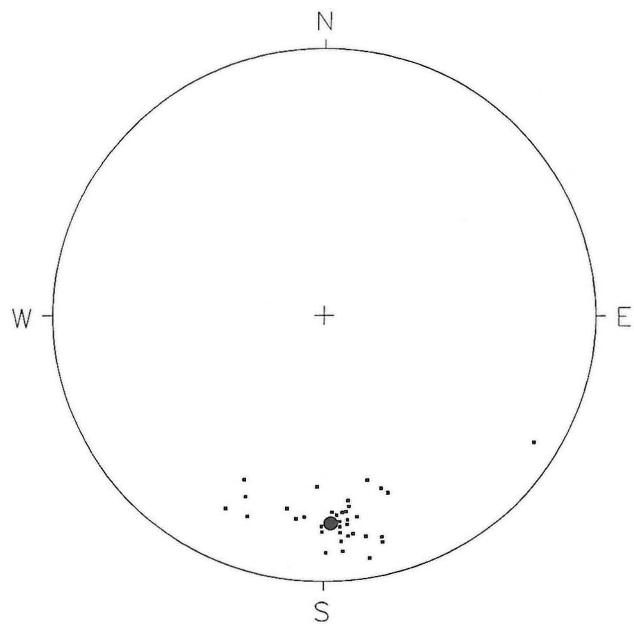


Figure GS-1-3: Equal area stereographic projection of poles to shear planes measured from strongly sheared outcrops of unit 2 and unit 3 rocks, Franklin Lake area. Solid circle represents the calculated average shear plane orientation (266°/66° north).

out the mylonite zones. Ultramylonite occurs as a planar laminated, very fine grained rock composed of alternating, mm-sized, amphibole-rich and quartzofeldspathic laminae.

A stereographic projection of shear fabric orientations measured within the broad deformation zone described above (Fig. GS-1-3) indicates a fairly consistent orientation for the predominant, penetrative foliation within the zone. The average orientation of shear planes in the study area (266°/66°N) is consistent with the regional shear fabric associated with the Johnson shear zone (Fedikow *et al.*, 1991).

With the exception of the Ace vein, no clear association between quartz veining and sulphides was observed in the study area. Quartz veins are a common feature throughout the area , but are most abundant in or proximal to mylonitized basalt and siltstone. Local, discontinuous epidote, quartz-sericite and carbonate veins and pod-shaped alteration zones occur throughout the area, but are preferentially associated with sheared basalt flows in units 1 and 2. Most veins are folded or boudinaged, and developed prior to the last major shearing event. Ongoing studies will examine the Au potential of (1) a pyritic siltstone bed observed within unit 2 (see above) that bears a strong resemblance to ore from the BT mine; and (2) lenticular pyrite-pyrrhotite zones in sheared unit 2 basalts. No further mapping or metallogenic studies in the area are warranted at this time.

Burnt Timber Deposit

Granduc Mining Corporation is the principal owner and operator of the BT open pit mine, a small, low-grade Au deposit located immediately to the west of Shortie Lake (see NTS 64C/15) in the southern part of the Lynn Lake greenstone belt (Fig. GS-1-1). The deposit occurs along the Johnson shear zone in an area dominated by exposures of the Cockeram Lake aphyric basalt, mafic to intermediate tuff and interbedded hornblende greywacke and siltstone (Map GP80-1-2, Gilbert *et al.*, 1980). The geology of the BT mine sequence and the nature of mineralizing event(s) have not been clearly resolved. To this end, a pilot study based on 30 drill core samples collected from diamond-drill hole BTE-95-1 from the BT gold deposit has been initiated. This project is being carried out jointly with Granduc Mining Corporation. One metre core samples were collected at approximately 3 m intervals. The sampled section incorporates unmineralized aphyric basalt from the hanging wall (north), intensely schistose to sheared, siliceous (silicified?) aphanitic, metasedimentary rocks (siltstone) and/or silicified metabasalt of the mine sequence, a small section of fault gouge associated with the regionally important T1 fault (a narrow brittle fault that defines the footwall to the deposit), and unmineralized basaltic rocks of the footwall. Gold mineralization is associated with disseminated and vein-type pyrite ± galena in siliceous, grey, aphanitic host rocks. A penetrative schistosity combined with locally pervasive silicification has obliterated primary fabrics in the mine sequence, to the extent that the host rock lithology is unclear.

Systematic geochemical and petrographic studies are planned in order to delineate primary lithologies and characterize the structural and hydrothermal evolution of the samples. It is hoped that a clearer picture of the regional metallogenic significance of the Johnson shear zone may result from the recognition of the controls of gold mineralization in the BT deposit.

Cartwright Lake Rhyolite

Only one major VMS deposit, the Fox deposit (Olson, 1987; Ferreira, 1993), has been discovered in the Lynn Lake greenstone belt. However, a number of geochemically favourable felsic volcanic sequences are recognized in the belt (Gilbert *et al.*, 1980; Syme, 1985). The largest of these, the Lynn Lake rhyolite complex, contains several small VMS-type sulphide occurrences (*e.g.*, Nicoba, Frances Lake and Y deposits; Fedikow and Ferreira, 1987, Baldwin, 1989). Geochemical alteration studies of the Lynn Lake rhyolite proved to be an effective means of pinpointing the known deposits (Fedikow and Ferreira, 1987). On the basis of these findings, a geochemical and petrologic study of the Cartwright Lake rhyolite was initiated. The objectives of this study are (1) to apply geochemical data to the recognition of rock alteration patterns indicative of a buried massive sulphide deposit; and (2) to use petrologic and geochemical data to refine the current tectonic and petrogenetic interpretation for the Cartwright Lake rhyolite (Gilbert *et al.*, 1980; Baldwin, 1983; Syme, 1985).

The Cartwright Lake rhyolite is a small, approximately 500 m by 1300 m rhyolite body that occurs 700 m to the east of Cartwright Lake (Fig. GS-1-4). It is part of the Hughes Lake calc-alkaline suite of the southern volcanic belt of the Wasekwan Group (Gilbert *et al.*, 1980). The geology of the rhyolite body is described by Gilbert *et al.* (1980) and Baldwin (1983). Preliminary geochemical findings (Syme, 1985) indicate that the Cartwright Lake rhyolite displays flat rare-earth element patterns and pronounced negative Eu anomalies, and as such, compares favorably with F3 tholeiitic rhyolites from the Superior Province, which are preferentially associated with VMS deposits (Lesher *et al.*, 1986). No economically significant sulphide occurrences have yet been reported from the Cartwright Lake rhyolite, despite extensive, recent exploration (Sherritt Gordon Mines Ltd., mid-1980s).

The current pilot study involved 1:1000 scale mapping and collection of about 40 representative samples of rhyolite flows, tuffs and volcaniclastic sedimentary rocks for a geochemical survey of the rhyolite body. Mapping was carried out using a partially overgrown 200 ft. (60 m) exploration grid established by Sherritt Gordon Mines Ltd. The results of the geochemical survey will be used to determine whether or not 'classic' alteration patterns commonly associated with VMS-type deposits (*i.e.,* Mg-Fe and K metasomatism) are developed in the Cartwright Lake rhyolite, and for petrogenetic modelling of the body. Additional sampling was conducted on arsenopyrite-pyrite stringer veins that are common within the rhyolite body, and are known to carry gold (Baldwin, 1983). Figure GS-1-4 provides a simplified geology of the Cartwright Lake rhyolite, and shows the locations of samples, diamond drill holes and sulphide occurrences in the study area.

The Cartwright Lake rhyolite is exposed in the hinge area of a tight, northeast-trending anticline (Gilbert *et al.*, 1980). Gilbert *et al.* (1980) subdivided the Cartwright Lake rhyolite into an upper division (subaerial) of massive, porphyritic rhyolite and subordinate felsic tuff and a lower division (subaqueous) of massive, porphyritic rhyolite flows, rhyolite microbreccia, vesicular rhyolite flows, felsic crystal tuff and minor, associated intermediate flows and mudstone. Detailed petrologic descriptions of the Cartwright Lake rhyolite are given by Gilbert *et al.* (1980) and Baldwin (1983), and indicate the rocks contain greenschist facies metamorphic mineral assemblages.

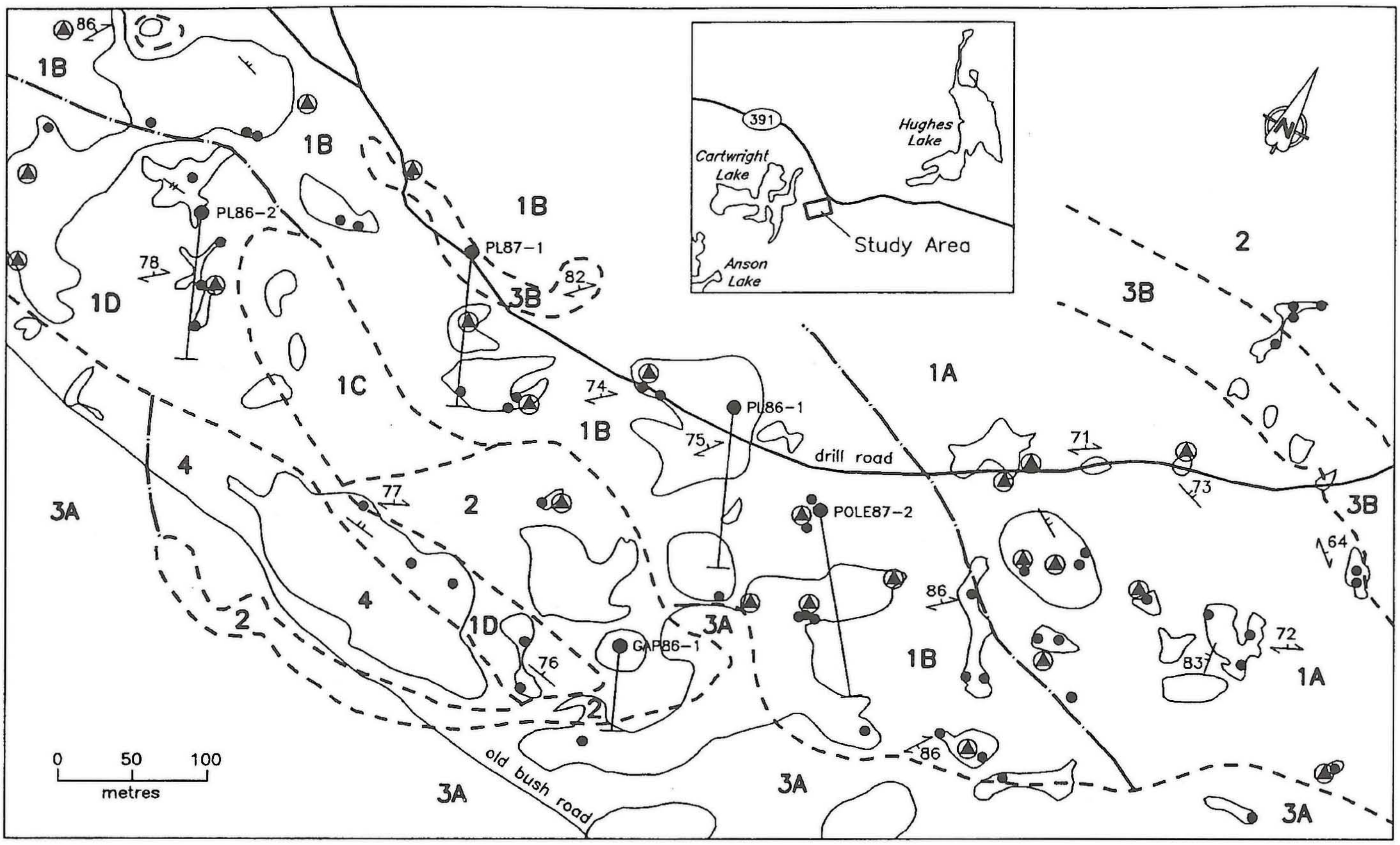
The area investigated during the current study covers approximately 80% of the Cartwright Lake rhyolite body (Fig. GS-1-4). The mapping results are summarized in Figure GS-1-4, which also provides locations of geochemical samples, drill holes and sulphide mineral occurrences. The rhyolite body reaches a maximum width of 500 m, and has a minimum length of 1 km. It is intruded by medium- to coarse-grained pre-Sickle gabbro and diorite (unit 3, Fig. GS-1-4) and is in apparent conformable contact with massive andesite (unit 4; correlative with Hughes Lake calc-alkaline andesite; Gilbert *et al.*, 1980) to the south (Fig. GS-1-4). Siliceous siltstone, locally interbedded with greywacke, quartz-pebble wacke, felsic tuff and massive rhyolite, occurs both to the northeast and southwest of the main rhyolite body (Fig. GS-1-4).

Results from the current study are in general agreement with the four-fold division of the Cartwright Lake rhyolite proposed by Baldwin (1983). The four subdivisions of the Cartwright Lake rhyolite recognized in the present study (Fig. GS-1-4) largely reflect changes in the proportions of pyroclastic rock types and massive flows. Subunit 1A is dominated by pyroclastic rocks, including laminated tuff, thickly bedded crystal tuff and lapilli tuff, and pyroclastic breccia, but also contains several massive rhyolite flows. Flows are typically porphyritic, containing 2 to 10% anhedral to subhedral quartz ± feldspar phenocrysts disseminated through an aphanitic, siliceous matrix. Aphyric flows are relatively uncommon in the Cartwright Lake rhyolite. Flow banding (microlamination) was locally observed in the massive flows. Crystal tuff forms well-laminated beds that commonly contain 10 to 20% angular quartz and feldspar phenocrysts and rare lithic (rhyolite and pumice) fragments. Lapilli tuff contains abundant, subrounded to lenticular rhyolite and pumice lapilli and sporadic rhyolite bombs. Subunit 1B is predominantly made up of massive flows, but also contains interflow sedimentary and pyroclastic deposits (felsic crystal tuff, greywacke, siltstone). Rocks of subunit 1C are mainly of pyroclastic origin (felsic crystal and lithic tuff, minor autoclastic breccia). Autoclastic breccia contains 70 to 80% poorly sorted angular rhyolite fragments set in a biotite-rich matrix. Subunit 1D exclusively comprises massive and brecciated (microbreccia and hyaloclastite; see Gilbert *et al.*, 1980) rhyolite flows.

Contacts between the subunits are gradational. Rare younging criteria (graded bedding in reworked tuffaceous units) confirmed Baldwin's (1983) suggestion that tops are to the northeast (Fig. GS-1-4). Bedding occurs on a variety of scales. Flows are commonly several metres thick; tuff beds and breccia units are commonly thickly bedded (several metres), but display a finer scale internal bedding (mm-scale laminations or cm-scale bedding). Bedding commonly strikes northwesterly and dips to the east, and is typically discordant to a superimposed penetrative cleavage or schistosity that strikes southwesterly and dips steeply to the north (Fig. GS-1-4). The observed cleavage (S_1) - bedding (S_0) discordance (Fig. GS-1-4) supports the contention that the rhyolite body occupies the hinge area of a major fold (Gilbert *et al.*, 1980). A spaced cleavage (S_2) associated with late, open cross folds with northeast-trending axial planes is locally developed. Rare, westerly trending, 2 to 5 m wide, discontinuous mylonite zones were also observed. Their presence may be a reflection of the proximity to the Johnson shear zone, which occurs approximately 300 m to the south of the Cartwright Lake rhyolite (Gilbert *et al.*, 1980).

No significant mineralogical alteration zones were identified. Geochemical data and petrographic observations for samples collected during the present study will be used to test for cryptic alteration patterns within the Cartwright Lake rhyolite.

Veining in the rhyolite body is locally intense, and includes the following types: (1) irregular, medium- to coarse-grained milky white quartz veins (up to 1 m wide), generally devoid of sulphides; (2) thin, planar to irregular, fine grained quartz-carbonate-feldspar stringers locally containing pyrite-arsenopyrite mineralization (see below) and generally emplaced along cleavage planes; and (3) rare, irregular, pink-weathering granitic veins with no associated sulphides. Sulphide mineralization is sporadically developed throughout the Cartwright Lake



1 CARTWRIGHT LAKE RHYOLITE

1A Felsic pyroclastic and reworked pyroclastic deposits (crystal and lapilli tuff, polymictic breccia) and subordinate massive, porphyritic rhyolite flows

1B Massive porphyritic rhyolite flows and subordinate felsic crystal tuff, siltstone and greywacke

1C Felsic crystal and lithic tuff, minor massive porphyritic rhyolite and derived autoclastic breccia

1D Massive and brecciated porphyritic rhyolite

2 CLASTIC SEDIMENTARY ROCKS

Siltstone, subordinate (pebbly) greywacke, mudstone, felsic or mafic tuff and massive rhyolite

3 INTERMEDIATE AND MAFIC INTRUSIVE ROCKS

3A Diorite, quartz diorite, minor gabbro (may include xenoliths derived from unit 2)

3B Gabbro (may include xenoliths derived from unit 1)

4 Andesite (locally contains gabbro sills)

outcrop

geological boundary (approximate, gradational)

75 foliation (dip measured, dip unknown, vertical)

bedding, tops unknown (dip measured, dip unknown, vertical)

70 bedding, tops known

geochemical sample location

arsenopyrite + pyrite occurrence

diamond drill hole location

Figure GS-1-4: Geology, sample locations and sulphide occurrences, Cartwright Lake rhyolite.

rhyolite and involves fine grained pyrite-arsenopyrite veins emplaced along anastomosing cleavage planes that are generally parallel to the regional foliation. The sulphides are locally contained within the thin planar quartz-calcite-plagioclase veins described above. Coarser grained, disseminated pyrrhotite-pyrite mineralization, also hosted by quartz veins, occurs sporadically in the rhyolite body. The pyrite-arsenopyrite veins are restricted to the most siliceous rock types (massive flows and rhyolite crystal tuff). They are typically less than 2 mm wide and a few cm long, and occur in multiple vein sets in strongly cleaved or sheared outcrops. Mineralized outcrops typically contain gossan stained sulphide zones up to a few metres long and 1 m wide. No laterally continuous zones were identified, although the sulphide occurrences were observed in all parts of the area mapped.

Total sulphide content in mineralized outcrops ranges from <1% to 5%. Analytical results for 34 sulphide-bearing samples from the Cartwright Lake rhyolite are given in Table GS-1-1. All samples contain vein-type arsenopyrite and/or pyrite mineralization. Sulphide abundances are <5% and average <2%. Most samples have extremely low Au concentrations and Ag contents (not shown) were <1 ppm for each of the samples. Nine samples contained anomalously high Au abundances (>50 ppb), but only one sample (98-95-330-1a, Table GS-1-1) displayed significant Au enrichment (2860 ppb Au). A second sample collected from the same outcrop (98-95-330-1b) contained only 31 ppb Au, despite having higher sulphide abundances. No significant correlations were detected between Au abundance and other variables such as sulphide content, base metal abundance, sample location or rock type. No base metal enrichment is associated with these occurrences (Table GS-1-1). D.A. Baldwin (unpublished data) obtained similar results for 10 mineralized samples from the Cartwright Lake rhyolite. Baldwin (1983) considered the veins to have originated during deformation and metamorphism with sulphides being preferentially emplaced into brittle fractures in the more competent units. The arsenopyrite-pyrite mineralization appears to have little economic potential given its erratic distribution, lack of continuity and low Au abundances, and no further work is recommended. More extensive mineralization may have developed in larger-scale brittle deformation zones in the area, particularly in the immediate vicinity of the Johnson shear zone.

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Table GS-1-1
Gold and base metal abundances for samples containing arsenopyrite-pyrite mineralization, Cartwright Lake rhyolite.
All analyses were performed at the Manitoba Energy and Mines Analytical Laboratory.
Gold is reported in ppb; base metals are reported in ppm.

Sample Number	Rock Type	Au	Cu	Ni	Zn	Pb
98-95-305-1a	Rhyolite	<6	80	18	140	11
98-95-307-2	Felsic Tuff	<6	52	6	241	<2
98-95-309-2	Felsic Tuff	<6	57	15	8	4
98-95-313-1a	Felsic Tuff	<6	70	17	30	17
98-95-313-1b	Felsic Tuff	10	46	11	55	16
98-95-313-1c	Felsic Tuff	5	64	16	41	<2
98-95-316-1	Felsic Tuff	132	64	14	24	7
98-95-316-2	Rhyolite	15	124	23	7	2
98-95-317-1	Felsic Tuff	51	78	18	25	<2
98-95-317-2	Felsic Tuff	<6	29	4	116	3
98-95-320-1	Rhyolite	253	66	12	33	13
98-95-322-1	Quartz Vein	<6	44	14	3	3
98-95-325-1a	Dacite	<6	57	11	61	23
98-95-327-1	Rhyolite	17	59	15	6	4
98-95-329-1a	Rhyolite	9	60	15	5	<2
98-95-330-1a	Rhyolite	2857	47	12	10	8
98-95-330-1b	Rhyolite	31	84	16	8	3
98-95-333-1	Rhyolite	13	84	13	8	<2
98-95-335-1	Rhyolite	11	67	16	6	<2
98-95-340-1a	Rhyolite	213	59	12	6	<2
98-95-340-1b	Rhyolite	<6	29	19	3	<2
98-95-342-1	Rhyolite	131	77	22	10	<2
98-95-343-1	Rhyolite	<6	58	16	39	3
98-95-347-1a	Rhyolite	10	40	8	13	<2
98-95-347-1b	Rhyolite	12	45	8	216	<2
98-95-347-1c	Rhyolite	421	62	18	12	<2
98-95-348-1a	Rhyolite	185	88	22	<1	<2
98-95-348-1b	Rhyolite	8	49	13	10	3
98-95-351-1	Rhyolite	<6	40	14	109	<2
98-95-351-2	Rhyolite	117	91	23	<1	<2
98-95-352-1	Rhyolite	<6	71	20	5	<2
98-95-353-1	Rhyolite	14	74	17	1	4
98-95-355-1	Rhyolite	<6	71	25	1	<2
98-95-356-1	Rhyolite	9	67	18	1	<2

GS-2 THE EDEN LAKE RARE EARTH ELEMENT OCCURRENCE-METALLURGY, GEOCHEMICAL AND GROUND SCINTILLOMETER SURVEYS (NTS 64C/9)

by R. Gunter, M.A.F. Fedikow, W.D. McRitchie and E. Kowalyk

Gunter, R., Fedikow, M.A.F., McRitchie, W.D., Kowalyk, E., 1995: The Eden Lake rare earth element occurrence-metallurgy, geochemical and ground scintillometer surveys (NTS 64C/9); **in** Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 11-16 .

SUMMARY

Mineralogical and geochemical studies of the Eden Lake rare earth element mineralized zone have identified britholite as the mineral of economic interest. Britholite occurs as fracture-controlled anhedral, irregular masses within an aegirine-bearing syenite phase of the Eden Lake monzosyenite complex. Associated minerals are fluorite, titanite, apatite and allanite. Mineralogical consistency within REE deposits (*e.g.* Strange Lake, Quebec; Thor Lake, N.W.T.) support the theory that the britholite is probably representative of the mineralogy of the REE enrichment in the remainder of the Eden Lake complex. Mineral separation studies indicate a 44% britholite concentrate can be obtained by magnetic separation. Similarities between the specific gravity between britholite and the amphiboles and pyroxenes also present the mineralized zone make gravity separation less effective.

Vegetation geochemical surveys, in which alder (*Alnus rugosa*) twigs were identified as the most effective tissue type for identifying REE mineralized zones, were supplemented with the collection of 24 B-horizon soil samples. Mineral phase-specific analyses will be undertaken on the samples using the enzyme leach in order to assess the effectiveness of both vegetation and soil surveys in exploration for this deposit type.

Ground scintillometer surveys, completed in the southern sector of the Eden Lake complex, identified nine localized "hot spots" ranging from 1000 to 4000 counts per second. The "hot spots" were attributed to small shear zones in the monzonite. Samples from the "hot spots" have been submitted for mineralogical analysis.

INTRODUCTION

In 1995 the continuing investigation of rare earth element enriched zones in the Eden Lake monzosyenite (Fig. GS-2-1) embraced three separate lines of investigation: 1) mineralogical and metallurgical studies based on a bulk sample taken from the "main zone" on the north end of the easternmost ridge; 2) an enzyme leach geochemical survey of B-horizon soils from sites previously tested by vegetation sampling; and 3) extension of ground scintillometer surveys, initiated in 1989, to cover outcrops of the monzosyenite on the southern fringe of the main ridges.

MINERALOGY

The mineral of economic interest in the Eden Lake REE occurrence is britholite $(Ce,Ca)_5(SiO_4PO_4)_3(OH,F)$. At Eden Lake, britholite occurs as anhedral, irregular masses of mosaic-like grains. The grains are partly metamict and typically slightly altered along grain boundaries. Chemical analyses of the Eden Lake britholite (Arden and Halden, in prep.) indicates that it has a chemical formula of $(Ca_{0.4568}\ RE_{0.5149}\ Y_{0.0283})_5\ ((SiO_4)_{0.8616}\ (PO_4)_{0.1384})_3\ (F,OH)$. It is unknown whether chemical variability exists within the britholite grains.

Britholite occurs in fracture-controlled concentrations with fluorite, titanite, apatite and allanite. It has not been found disseminated in the monzosyenite. The mineralized areas are distinctly different in appearance from the nonmineralized Eden Lake syenite due to an increase in the aegirine content with the appearance of britholite. All of the outcropping mineralized zones are macroscopically similar in appearance, grain size and mineralogy. This constancy of mineralogy indicates that the sample of britholite is probably representative of the mineralogy of the rare earth enrichment in the remainder of the Eden Lake monzosyenite.

Constancy in mineralogy is typical of alkali granites and syenites. The Strange Lake deposit (Quebec-Labrador), a 27.3 million tonnes deposit of 3.25% ZrO_2, 1.3% rare earth oxides, 0.66% Y_2O_3, 0.56% Nb_2O_5 and 0.12% BeO, is hosted by an alkali granite that has suffered late stage fracture-controlled alteration (Salvi and Williams-Jones, 1990). Strange Lake's unusual mineralogy is constant within the ore deposit. Thor Lake (N.W.T.), a rare metal deposit in granite, also has a constant mineralogy within the altered zone (Trueman *et al.*, 1988).

Britholite is an unusual source of rare earth oxides in commercial rare earth deposits. Rare earth ores are more commonly characterized by the minerals bastnaesite (rare earth fluorcarbonate), monazite (rare earth phosphate) and xenotime (yttrium phosphate).

Sampling

A sample for metallurgical testing weighing approximately 20 kg was taken from the same location as the mineralized samples investigated by Arden and Halden (in prep.). The bulk sample was composed of 1 kg or larger pieces to avoid possible contamination from fines. It contained britholite, aegirine, fluorite, titanite and potassium feldspar. The sample was macroscopically similar to the other outcropping britholite occurrences in the immediate area.

The sample was chemically analyzed by Lakefield Research Ltd. before concentration. The average britholite content was 8.5% (recalculated by Lakefield Research Ltd.).

Metallurgy

Lakefield Research Ltd. did a gravity and magnetic separation study on the 20 kg sample to determine if the britholite could be effectively concentrated. An optimum grinding range for the liberation of the britholite particles was not possible given the limited size of the preliminary sample. This sample was not collected to be representative for mineralogy or grade.

The gravity study indicated that the amphiboles and pyroxenes in the mineralized zone will pose a separation problem. Their specific gravity is similar to that of britholite, thereby making clean separation difficult.

The magnetic separation study gave the best results from the sample. The britholite is paramagnetic and unbound britholite particles can be cleanly separated from the accompanying silicates. The best concentrate made from the sample is 44% britholite.

Further Work

Chemical analysis and metallurgical study was completed on a sample. The preliminary sample gave a bench-scale britholite concentrate. A chemical analysis of a bulk sample of approximately 1000 kg is needed to determine if there is any chemical variability in the britholite. A bulk sample will also be required to determine the proper procedures for separating the finer britholite from the middlings and fines and to calculate the optimum grain size for liberating the britholite particles.

Commercial rare earth oxide concentrates are generally quoted as 80% CeO. To produce a concentrate to those specifications from the Eden Lake mineralization, a chemical digestion of the britholite and a leaching of the rare earth oxides would be required. The leach tests could be completed on the concentrates from the preliminary sample; however, more representative results would be obtained from a test on concentrates obtained from the bulk sample.

Acquisition of a bulk sample will require outcrop stripping and trenching of an area to the east of the mineralized outcrop. Diamond drilling of the mineralized area will also be required. A rare earth oxide deposit should have a minimum of one million tonnes contained mineralization before it becomes commercially viable (Harben and Bates, 1990).

MARKETS

Cerium oxide is an internationally traded commodity used in optical glass, largely for CRT screens. The majority of the world production originates in the People's Republic of China (Harben and Bates, 1990). The price for cerium oxide is U.S. $1.05 per pound contained rare earth from a 70% rare earth oxide leached bastnaesite concentrate (Industrial Minerals Magazine, August 1995).

The remaining rare earth oxides within the britholite concentrate have smaller volume markets. A bulk sample of the mineralization will have to be chemically analyzed and further tests performed extraction before the recovery of the remaining rare earth oxides can be calculated. When these values are known, the markets will be investigated to determine if the minor oxides can be produced economically.

GEOCHEMICAL SURVEYS

Vegetation geochemical studies undertaken in 1993 and 1994 (Fedikow *et al.,* 1993, 1994) were supplemented this year with the collection of 24 B-horizon soil samples (Fig. GS-2-2). Sample sites were selected to correspond to alder (*Alnus rugosa*) twig sample sites in which high contrast La, Ce, Cs and ∑REE anomalies had been defined (Fedikow and Dunn, 1994). Alder twigs had been identified as the most effective vegetation tissue type for acquisition and storage of REE in the Eden Lake environment (Fedikow *et al.*, 1994). Analysis of the soil samples will document geochemical response of the REE mineralization in mineral specific phases within B-horizon soil samples using the enzyme leach (Clarke, 1993). The results will be used to compare the geochemical response of the two sample types and assess their relative merits for application to exploration for this deposit type. Sampling error and reproducibility of the enzyme leach analyses will be assessed by the analysis of six soil samples from a single site within an area of 9 m^2. Upon completion of the analytical phase of this study data will be released as a Manitoba Energy and Mines economic geology report.

GROUND SCINTILLOMETER SURVEY

Continued interest in the REE potential of the Eden Lake aegirine-augite monzosyenite prompted the need to complete reconnaissance ground scintillometer surveys over the intrusion south of Kwaskwaypichikun Bay (McRitchie, 1989). Accordingly, a ground traverse was conducted over outcrops in the southern sector of the monzosyenite (Fig. GS-2-3) using a Scintrex broadband gamma-ray scintillometer model BGS-1SL (with a 1.5" x 1.5" thallium-activated sodium iodide crystal).

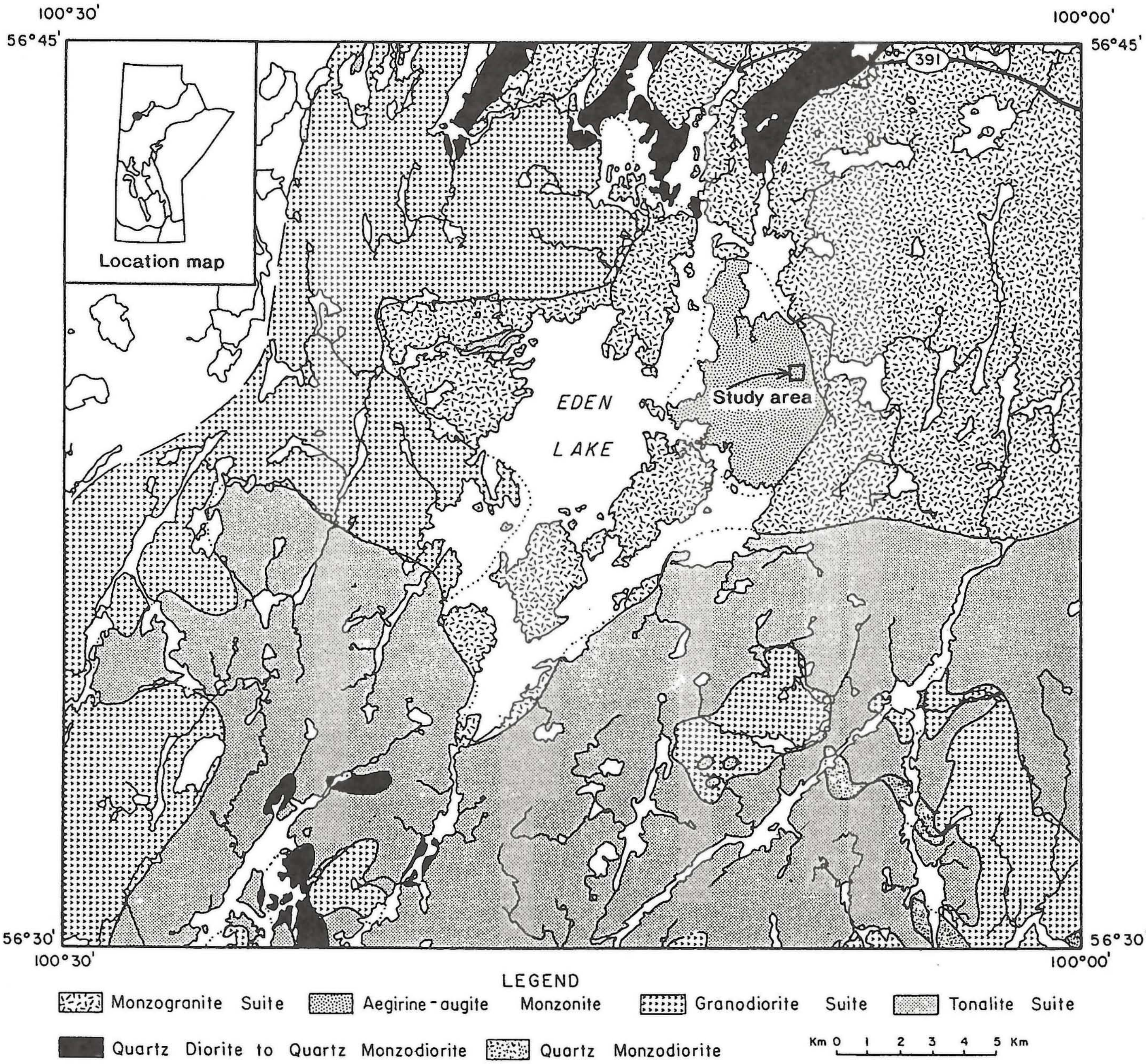

Figure GS-2-1: Location map and regional geological setting for the Eden Lake survey area. Geology after Cameron (1988).

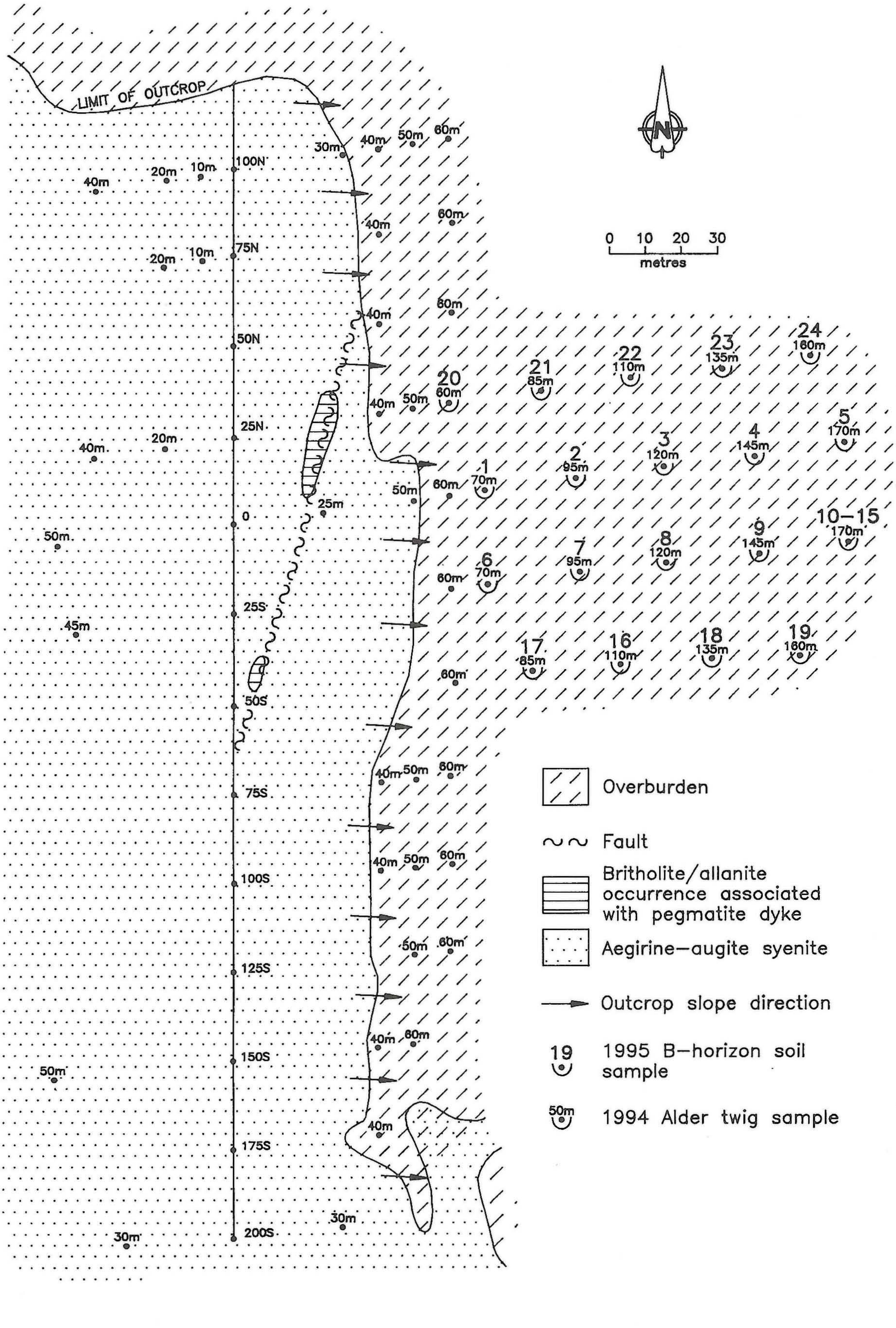

Figure GS-2-2: B-horizon soil and alder (Alnus rugosa) sampling sites, Eden Lake rare earth element occurrence.

Background readings were taken over water at the commencement and end of the traverse. The scintillometer was run continuously (at waist height) during the 7.25 km traverse (Table GS-2-1). Eighty readings were taken at regularly spaced stations, with additional sweeps in areas of good outcrop. Background readings over outcrop ranged between 120 and 250 counts per second (cps); nine extremely localized "hot spots" gave responses between 1000 and 4000 cps. All areas of increased radioactivity were sampled and submitted for mineralogical analysis. No zones of extensive mineralization were located, all "hot spots" being related to small mineral aggregates associated with minor millimetre-thick shears in the monzonitic host rock.

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Table GS-2-1
Ground Scintillometer Survey 1995
Eden Lake - Southern Sector

Station/ Turning Point*	Ft.	CPS	Notes
1	0	50	Alder bog
	+ 200	60	Alder bog
	+ 400	90	Alder bog
	+ 600	90	Spruce and moss
	+ 800	170	1-2 m boulders
	+1000	100	1-2 m boulders
	+1200	90	Swamp
	+1400	90	Swamp
	+1600	120	1 m boulders
	+1800	130	Boulder
	+2000	150	Massive blocks
	+2200	150	Outcrop .
	+2400	150	Outcrop
2	-0		Outcrop, fine grained pink leucomonzonite Local "hot spot" 800, 950, 1000 and 2400 cps.
	+ 200	130	
	+ 400	160	
3	-0	140	
	+ 200	150	1-2 m boulders at base of ridge
	+ 400	140	
	+ 600	100	
	+ 800	140	
4	-	50	Black spruce bog
5	-	140	Fine grained leucosyenite
	+ 140		2700 cps "hot spot", minor fracture next to pegmatite
	+ 200	200	
	+ 400	200	
	+ 600	170	
	+ 800	180	
6	-	200	Local "hot spot" 670 cps
7	-	160	"Hot spot" 300 cps. fine grained leucomonzonite
	+ 200	200	
	+ 400	100	Black spruce bog
	+ 600	190	Outcrop
	+ 800	150	Boulders
	+1000	180	
	+1200	180	
8	-	200	Fine grained leucomonzonite. Local "hot spot" 1500 cps.

Table GS-2-1
Ground Scintillometer Survey 1995
Eden Lake - Southern Sector

Station/ Turning Point*	Ft.	CPS	Notes
9	-	180	Outcrop - fine grained leucomonzonite
	+ 200	140	Fined grained leucomonzonite
	+ 400	200	Leucomonzonite - planar flaggy parting
	+ 600	160	Leucomonzonite
	+ 800	220	Leucomonzonite
10A	+ 100	200	Leucomonzonite
	+ 200	120	Leucomonzonite
10B	+ 200	180	
	+ 400	200	Outcrop
	+ 600	200	Outcrop
11A	-	200	Massive fine grained leucomonzonite. "Hot spot" 1000 cps. 5 cm x 1.5 cm lens of red crystals 2000 cps and 4000 cps.
	+ 200	160	
	+ 400	170	
12	-	170	
	+ 200	160	Outcrop
	+ 400	400	Outcrop
	+ 600	190	Outcrop
13	-	200	
11B	-		
	+ 200	150	
11B+	-		
	+ 400	150	
14	-	200	
	+ 200	140	Black spruce bog
	+ 400	140	
	+ 600	120	
	+ 800	140	
15	-	280	Vertical cliff leucosyenite with patches of coarse grained aegirine-augite monzonite. Carbonate-bearing miarolitic patches. 200 cps.
	+ 200	110	Black spruce bog
	+ 400	70	Swamp
	+ 600	100	
16	-	150	
	+ 200	110	
	+ 400	120	
	+ 600	120	
17	-	210	Monzonite, 25 m cliff
	+ 200	190	
	+ 400	120	Black spruce bog
	+ 600	120	Gully
	+ 800	210	Boulders
	+1000	180	Outcrop
	+1200	150	Average 150-200 cps. over 180 m to south
18	-	190	
	+ 200	250	Leucomonzonite outcrop
19	-	200	Leucomonzonite outcrop
20	-	200	1-2 m boulders pink monzosyenite
21	-	130	Local highs of 200 cps - leucosyenite

*See Figure GS-2-3 for traverse lines, turning points, and local "hot spots".

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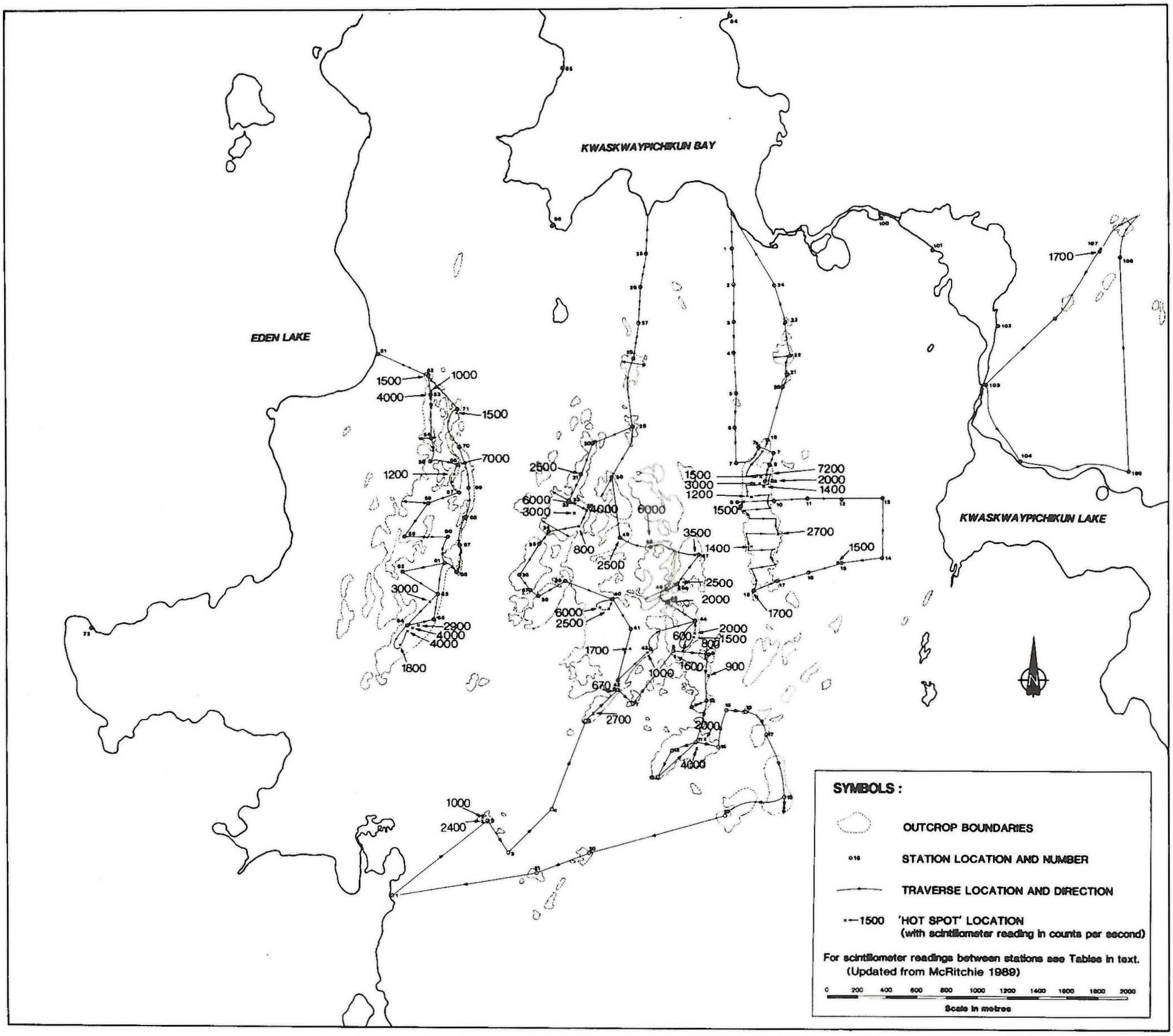

Figure GS-2-3: Ground scintillometer survey lines, north and south sectors.

GS-3 PARTRIDGE BREAST LAKE SUITE VOLCANIC AND VOLCANICLASTIC DERIVED GNEISSIC ROCKS IN THE PUKATAWAGAN BAY AREA OF SOUTHERN INDIAN LAKE

by M.T. Corkery

Corkery, M.T., 1995: Partridge Breast Lake Suite volcanic and volcaniclastic derived gneissic rocks in the Pukatawagan Bay area of Southern Indian Lake; **in** Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 17-18.

SUMMARY

A reconnaissance program was initiated to sample metabasalt and associated layered amphibolite in the Pukatawagan Bay to Long Point area of Southern Indian Lake and to identify units that would indicate whether these volcanic rocks represent a westward extension of the Partridge Breast Lake Suite. This program stems from mapping in the Partridge Breast Lake area, where the Partridge Breast Lake Suite forms a lithologic sequence between the Long Point Suite and the Arkosic Suite. In the Southern Indian Lake region to the west, the supracrustal belt is dominated by Long Point Suite and Arkosic Suite; Partridge Breast Lake Suite rocks were not identified. However, metagabbro, quartz diorite and calc-silicate rocks commonly associated with the Partridge Breast Lake Suite were reported in the Southern Indian Lake belt and an isolated area of mafic volcanic rocks, included in the Long Point Suite, was reported in the Pukatawagan Bay area.

GENERAL GEOLOGY

In the Partridge Breast Lake area metavolcanic rocks of the Partridge Breast Lake Suite are interpreted to overlie Long Point Suite metasediments (Lenton and Corkery, 1981). The Partridge Breast Lake Suite is composed chiefly of tuffs, or reworked tuffs, that are hornblende phyric and/or biotite clot bearing (Corkery, 1993a, 1993b). Composition varies from basaltic to andesitic with minor interbeds of quartz-feldspar phyric rhyodacite and rare pillowed basalts. These are, in turn, unconformably overlain by meta-conglomerates and sandstones of the Arkosic Suite. However, in the Southern Indian Lake region to the west, the supracrustal belt is dominated by greywacke-derived gneisses of the Long Point Suite and feldspathic sandstone and conglomerate derived gneisses of the Arkosic Suite (Cranstone, 1972) Partridge Breast Lake Suite rocks were not identified in previous mapping programs. However, Frohlinger (1972) mapped mafic volcanic rocks in the Pukatawagan Bay area and included them in the Long Point Suite.

The Partridge Breast Lake Suite was successfully traced westward into the area south of Missi Falls on Southern Indian Lake (Corkery, 1993a) by tracing the distinctive hornblende phyric units and the associated metagabbro, quartz diorite and calc-silicate rocks.

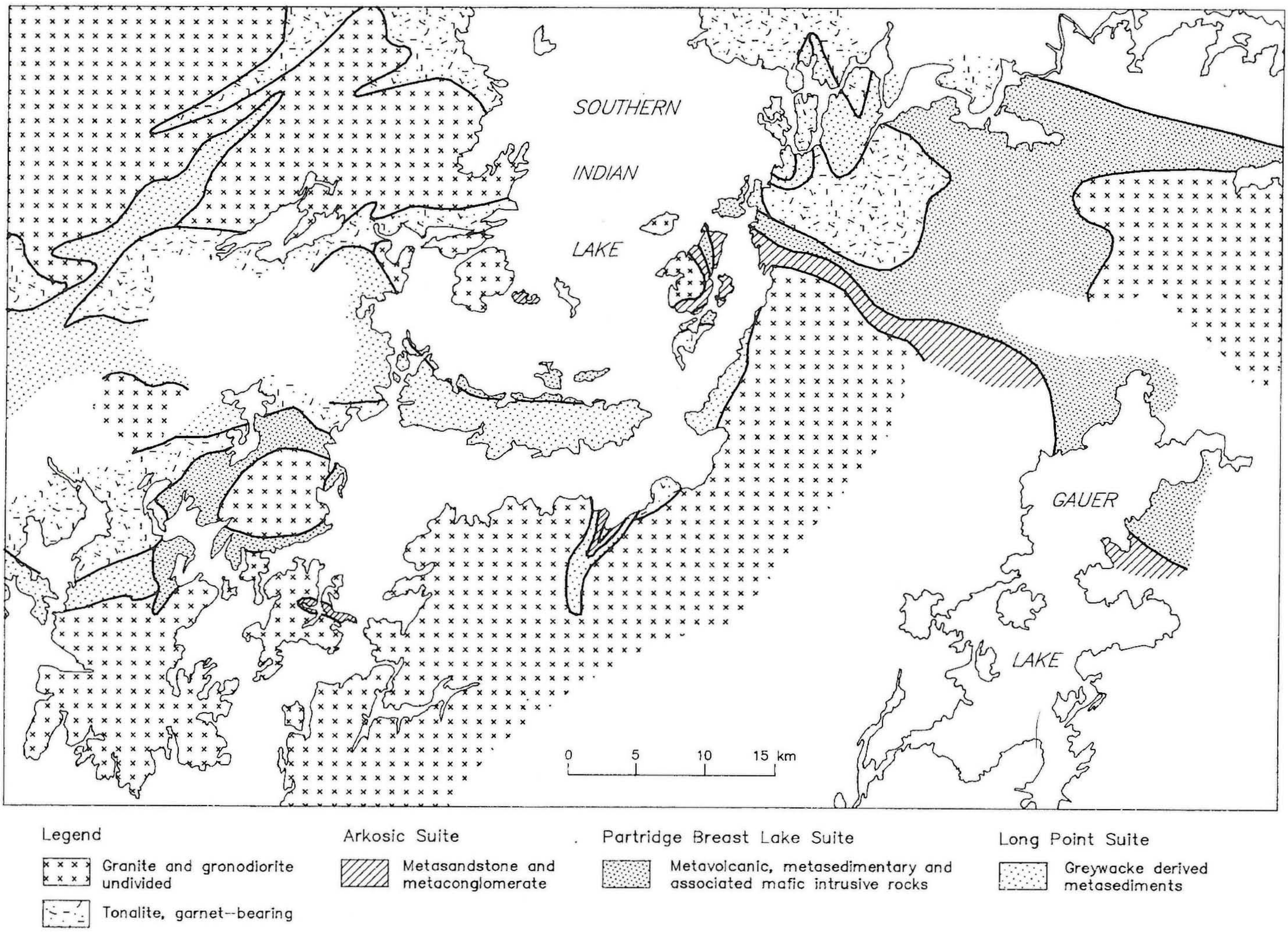

Figure GS-3-1: Regional distribution of Partridge Breast Lake Group and associated mafic and ultramafic rocks.

RESULTS

The objectives of the 1995 program were to 1) trace pillowed metabasalt and derived amphibolites from the Pukatawagan Bay area northeast to Long Point; 2) identify associated hornblende phyric gneisses that may represent the extension of the Partridge Breast Lake Suite; and 3) sample the metabasalts for geochemical analysis.

Well preserved pillowed basalts occur only in the Pukatawagan Bay area. These are the least deformed and altered rocks in the region and may represent an enclave of lower metamorphic grade similar in nature to the Partridge Breast Lake area (Lenton and Corkery, 1981). A small ultramafic body, with numerous pyrrhotite-bearing rusty weathering zones along the east margin, is intrusive into the basalts. To the northwest the volcanics are truncated by a granitic intrusion and to the southeast by Long Point Suite greywacke derived migmatites (Fig. GS-3-1).

Reconnaissance mapping and sampling traced the extent of the metabasalt to the northwest from Pukatawagan Bay. Outcrops of highly flattened pillow basalts (Fig. GS-3-2) and basalt-derived amphibolite occur as a discontinuous horizon within the greywacke gneisses along the west shore of Southern Indian Lake (Fig. GS-3-1) and on to the north shore of Long Point. Hornblende phyric gneisses, which form the major lithologies in the Partridge Breast Lake area, and gabbro intrusions are typically associated with these amphibolites.

The broad association of Partridge Breast Lake Suite and associated mafic intrusive phases was traced as a discontinuous chain westward as far as Pukatawagan Bay. This chain is flanked to the north by tonalitic intrusions and to the south generally by greywacke-derived gneisses. No other occurrences of similar rocks have been reported to the west between Pukatawagan Bay and Magrath Lake in the Barrington Lake area. However, in the Magrath Lake area, Gilbert (1980) describes volcanogenic sediments that include significant hornblende phyric units in association with mafic volcanics and a late gabbro. This sequence is markedly similar to the Partridge Breast Lake Suite and may indicate an original continuity with the Lynn Lake belt into the Partridge Breast Lake Suite in the Southern Indian Lake area.

Figure GS-3-2: Deformed pillow basalt in the Pukatawagan Bay area.

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GS-4 GEOLOGY OF THE DOW LAKE AREA (PARTS OF NTS 63K/15 AND 63N/2)

by H.V. Zwanzig

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SUMMARY

At Dow Lake a major high-strain zone that cuts north across the Flin Flon-Snow Lake volcanic belt joins the northwest-trending structures on the margin of the Kisseynew gneiss belt (Fig. GS-4-1). The high-strain zone lies east of the Gants Lake batholith within the steeply dipping Amisk collage and extends from Reed Lake north across North Star Lake (Syme *et al.*, GS-10, this volume). At Dow Lake it becomes parallel to shallow northeast-dipping foliation in the structural footwall of the Loonhead Lake fault. This fault is a major thrust (Connors, in press) that separates Amisk collage from younger metasedimentary rocks in the Kisseynew belt (Burntwood and Missi suites). Both structures were involved in large-scale late-metamorphic folding at Dow Lake. An upper panel of Burntwood Suite is overlain by the highest structural slice of Amisk collage along the newly assumed Fairwind Lake fault. The Batty Lake shear zone forms the contact with the overlying Batty Lake intrusive complex.

A compilation of existing data and limited new mapping suggests that these structures separate rocks formed in different tectonic and metallogenic environments. In the Dow Lake area the footwall of the Reed-North Star high-strain zone is intruded by augen gneiss, which features potassic alteration and gold mineralization west of Martell Lake (Ostry, 1987). The structural footwall of the Loonhead Lake fault is intruded by Josland Lake gabbro (Bailes, 1980), which contains subeconomic gold occurrences elsewhere on the south flank of the Kisseynew gneiss belt (Zwanzig, 1994a). The upper structural package of Amisk felsic gneiss features hydrothermal alteration products, elsewhere associated with base metal deposits.

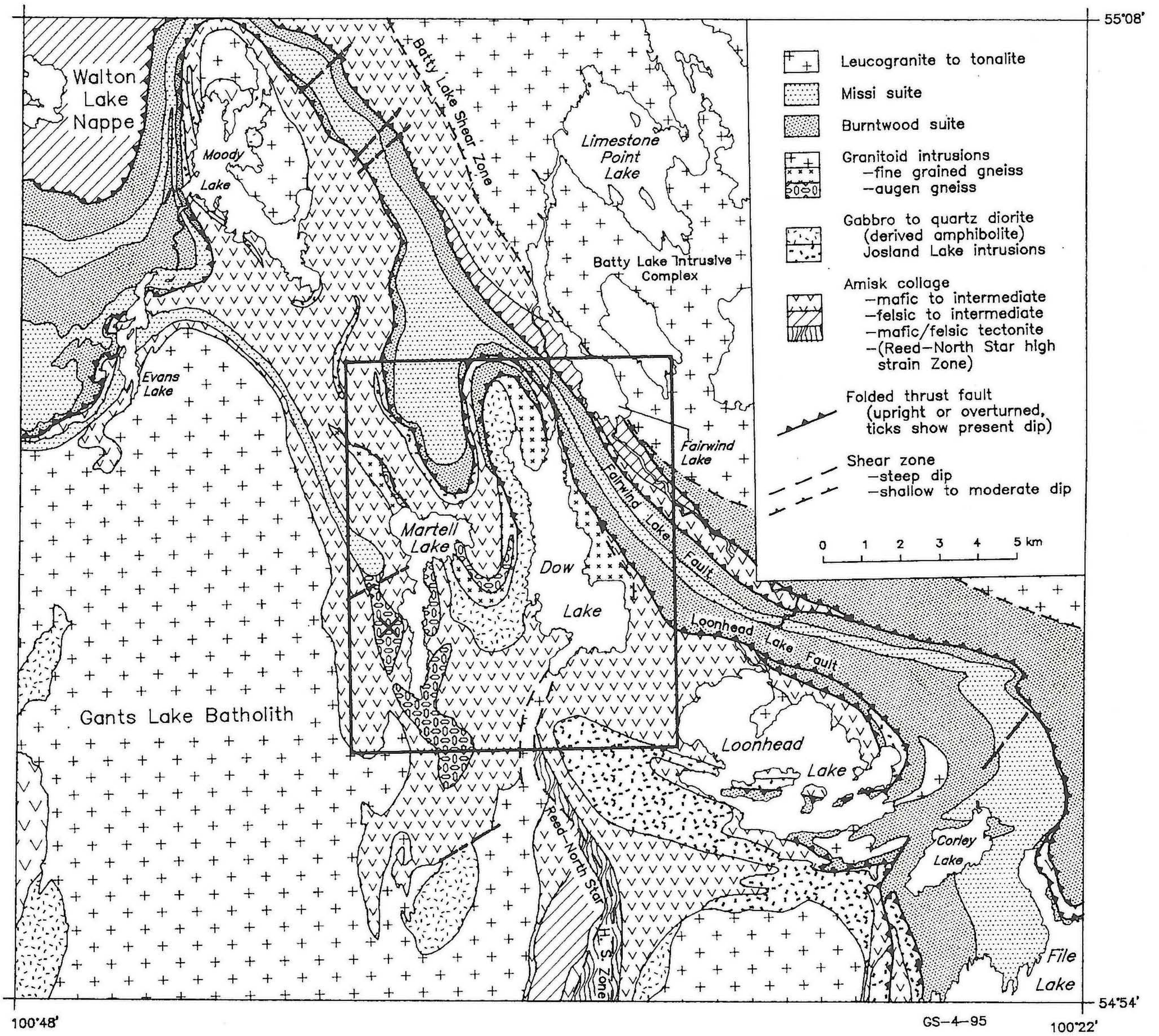

Figure GS-4-1: Simplified geology and structural interpretation of the Flin Flon belt-Kisseynew belt transition zone between Moody Lake and File Lake. Also shown are the location of the Dow Lake map area and the Martell Lake gold occurrence (X).

INTRODUCTION

Existing field data (Zwanzig and Lenton, 1987), figures (Ostry, 1987) and maps (McGlynn, 1959; Whalen, 1993) were compiled at 1:15 800 scale and seven new traverses were carried out during this summer in the east half of the Dow Lake area to upgrade and extend detailed geologic mapping under NATMAP. Important regional relationships were also examined along Kississing Lake and north of Kisseynew Lake. The aims of the work were (1) to trace out major units and structures in the area of the Kisseynew belt-Flin Flon belt boundary, between previously mapped areas at Moody Lake (Zwanzig, 1992), File Lake (Bailes, 1980; Connors, in press) and North Star Lake (Norquay *et al*., 1993); (2) to sample the amphibolite and test if it can be correlated with the adjacent metabasalts by trace element chemistry; (3) to establish the structural setting for the gold showing at Martell Lake and to trace the regional extent of the Josland Lake intrusion in the Kisseynew belt. This report reviews the lithologies and structures at Dow Lake based on compiled data (Zwanzig and Schledewitz, 1992), regional tectonics (Lucas *et al*., in press) and results of the 1995 mapping.

In parts of the Dow Lake area the outcrops are small and widely spaced. Bedrock is either moss- and lichen-covered in mature bush or nearly inaccessible among piles of fallen trees and thick regrowth in areas that were burnt at least 20 years ago. The interpretation of the geology relies on the regional compilation (Zwanzig and Schledewitz, 1992). Preliminary Map 1995K-2 (Zwanzig, 1995) relies locally on airphoto interpretation because magnetic maps are little help where dips are very shallow.

LITHOSTRATIGRAPHY

The map units at Dow Lake are determined by mineral composition, grain size, secondary structures and field relationships. Their protolith is generally not recognized directly because the rocks are in the upper amphibolite facies, and primary structures are rarely preserved. However, most units grade into recognizable lithologies in adjacent areas. Some volcanic units are known to extend through the area because rocks with the same distinctive geochemical fingerprint occur to the east and west (Zwanzig, in press). Tectonic and stratigraphic relationships, and unit numbers given in this report, apply to the whole Kisseynew-Flin Flon boundary region (Zwanzig, in prep.)

Several units are recognized as Amisk collage (Lucas *et al*., in press). Each has a metavolcanic and a meta-intrusive component. In this report *Amisk collage* is used for rocks that may belong to the Flin Flon or Snow Lake segments of the volcanic belt, and for coarse grained gneisses in the Kisseynew belt with volcanic affinity of similar age. These rocks include (i) amphibolites of basaltic composition, regionally mapped as units 2a-3b, (ii) intermediate to mixed rocks (units 4d-4e), and (iii) felsic to intermediate rocks (units 5b-7). A younger sequence, dominated by metasedimentary rocks, comprises the Burntwood Suite (unit 9) and Missi Suite (units 11-14). The Missi Suite lies unconformably on plutons and Amisk collage, but is conformable with the Burntwood Suite. The younger rocks are generally intruded only by late pegmatite (unit 20b). The local ages of intrusive units 15-19e are unknown, but these units are generally older than the sedimentary rocks.

The rocks at Dow Lake occupy folded structural packages, which are in the order of 500 m thick. Packages contain two or three units and are separated by tectonic contacts. Earlier interpretations of these rocks as sequences (Zwanzig and Schledewitz, 1992; Zwanzig, 1992, 1994b) did not recognize all the major faults (Zwanzig, in press). Primary and early kinematic structures and grain size were highly modified during high-temperature recrystallization and strain. The origins assigned to map units in the field are based only on apparent composition and are preliminary.

Amisk collage

Fine grained amphibolite (unit 2a)

Dark grey-green to black weathering amphibolite with fine grained, granular hornblende and plagioclase ± garnet forms the footwall of the Loonhead Lake fault. The unit is 200 m thick at Martell Lake and widens toward the northwest and southeast. Grey quartz-garnet-magnetite-bearing amphibolite occurs locally. The rocks have weak compositional layering with plagioclase-rich veins and local, thin diopside-bearing lenses. Layering is planar and has a metamorphic or tectonic origin. The unit is similar to Evans Lake amphibolite, which is correlated with basalt at Moody Lake and File Lake (Zwanzig, in press).

Porphyritic metabasalt (unit 2b)

Dark grey amphibolite and deformed pillow basalt has <20% plagioclase phenocrysts (2-10 mm) and fewer mafic phenocrysts (2-6 mm). The rock contains 2 to 3 cm thick, elongate calc-silicate lenses. Pillows are locally transposed into layering and some phenocrysts are deformed to porphyroclasts. The unit lies below undivided amphibolite. It is 240 m thick in the south, but is lost in the schistose rocks on Dow Lake.

Porphyroclastic amphibolite, tectonite (unit 2c)

Finely schistose amphibolite contains <20% lens-shaped plagioclase porphyroclasts (<8 mm). The rock is interlayered with uniform amphibolite and weakly layered amphibolite ± garnet ± diopside. It appears to be highly strained and probably contains recrystallized mylonite. The porphyroclastic component is interpreted to be derived from unit 2b. It was recognized only along the south shore of Dow Lake and is apparently truncated to the north in the Reed-North Star high-strain zone.

Undivided amphibolite (unit 3b)

Dark grey fine- and medium-grained amphibolite is locally uniform and recognized as gabbro and microdiorite, but weakly layered members were probably derived from flows. The principal outcrop area of unit 3b is southwest of the northern extension of the Reed-North Star high-strain zone where the amphibolite is intruded by augen gneiss. East of the high-strain zone, the unit occurs in a synform, but this may be a variety of unit 2a with a high proportion of mafic intrusions.

Felsic gneiss and amphibolite, tectonite (unit 4d)

Fine grained felsic gneiss with sheets of finely layered amphibolite ± garnet is interpreted as a "straight gneiss" or recrystallized tectonite. The felsic component is similar to Dow Lake gneiss (unit 18g) and is interpreted to be mainly intrusive. The unit is 80 to 150 m thick. It forms the sheared inner mantle of the Batty Lake intrusive complex and occurs locally between structural packages at Dow Lake.

Intermediate to mafic gneiss (unit 4e)

Medium- to fine-grained, dark grey amphibolite is interpreted as a quartz-dioritic to gabbroic intrusive suite, but a supracrustal origin for much of the rock is not ruled out. The composition generally changes over a distance of metres or tens of metres. Individual members are homogeneous and moderately foliated. The most common variety contains about 15% quartz and 35% hornblende grains (<1 mm) in <5 mm aggregates. Garnet, biotite and magnetite are widespread lesser constituents. The grain size suggests that the rocks formed a dyke complex, probably during Amisk volcanism. Weakly layered fine grained amphibolite members may be screens of metabasalt. Grey quartz-rich members may be fine grained tonalite.

Felsic biotite-garnet gneiss (unit 5b)

Greenish- to brownish-grey weathering quartzofeldspathic gneiss and migmatite contains <10 mm garnet porphyroblasts ± dark green amphibole porphyroblasts. Rusty weathered layers occur locally. The unit is <120 m thick southwests of Fairwind Lake. Similar gneiss in the Walton Lake area is interpreted to have formed by regional alteration of felsic volcanic rocks (Zwanzig, 1992).

Garnet-biotite gneiss (unit 5c)

A schistose variety of felsic gneiss, containing more biotite than unit 5b, constitutes a few outcrops along the File River. It was probably derived by high strain from unit 5b and felsic intrusions.

Orthoamphibole-biotite-garnet gneiss (unit 6)

Garnet gneiss with orthoamphibole rosettes is interpreted to be metamorphosed alteration rock. Exposures <3 m wide occur on outcrops, which are 100 m apart, parallel to the southwest shore of Fairwind Lake.

Layered felsic gneiss, calc-silicate and amphibolite (unit 7a)

Layered gneiss, 120 m thick at Fairwind Lake, is generally plagioclase rich and contains variable amounts of amphibole and garnet. Diopside, calcite and K-feldspar occur in calc-silicate layers. The Walton Lake nappe, 20 km along strike, contains similar rocks that grade into a felsic volcanic gneiss (Zwanzig, 1992). In both areas the unit is in assumed fault contact (Fairwind Lake fault) with the underlying Burntwood Suite.

Burntwood Suite

Garnet-biotite gneiss (unit 9)

Gneiss derived from greywacke weathers grey to reddish brown and is generally strongly cleaved with <10% veins of quartz-feldspar leucosome. Garnet porphyroblasts (<12%) are 1-7 mm in diameter. The unit is ~130 m thick. It occurs in the hanging wall of the Loonhead Lake fault and in the footwall of the Fairwind Lake fault.

Missi Suite

Units 11 to 14

The Missi Suite includes basal conglomerate (unit 11), which is 50 m thick in the hinge of the syncline west of Martell Lake. It lies with distinct angular unconformity on amphibolite (unit 3b) and augen gneiss (unit 19e). It grades stratigraphically up into quartzofeldspathic gneiss derived from sandstone (unit 12).

About 260 m of unit 12, overlain by 50 m of porphyritic amphibolite (mafic tuff, unit 13), occur in the syncline north of Martell Lake. Fine grained granular pink felsic gneiss interpreted as tuffaceous sandstone and possible felsic tuff (unit 14) occurs within unit 12. This suite overlies Burntwood paragneiss.

Intrusive Rocks

Ultramafic rock (unit 15)

A medium grained ultramafic rock containing pale green amphibole, clinopyroxene, <40% serpentinized olivine, magnetite and spinel occurs on a small island in Dow Lake. The rock is interpreted to be a tectonic lens in or near the Reed-North Star high-strain zone. Layered mafic to ultramafic tectonite occurs in the main part of the high-strain zone. Another small body of ultramafic rock occurs in the hanging wall of the Fairwind Lake fault.

Metapyroxenitic gabbro (15a)

A dark green weathering, hornblende-rich amphibolite, derived from pyroxenitic gabbro occupies part of a large synform southeast of Dow Lake. The margin of the intrusion contains gabbro and ultramafic rock. The rock lies along strike of and may be part of a Josland Lake intrusion (Bailes, 1980).

Differentiated mafic sills (unit 16a)

Sills consisting of metagabbro and tonalite intrude the structural top of unit 2a. These sills are generally composite and interpreted to be differentiated Josland Lake intrusions. No gradational contacts between mafic and felsic phases are exposed in the Dow Lake area, but igneous layering occurs along strike at Moody Lake.

Gants Lake tonalite to quartz-diorite gneiss (unit 17c)

The Gants Lake batholith was mapped by Whalen (1993). One intrusive phase (unit 17c) extends along the east margin of the batholith into the Dow Lake area. It is described as grey, medium- to coarse-grained biotite-hornblende, tonalitic to quartz-dioritic gneiss, with abundant rafts of layered tonalitic and mafic gneiss.

Batty Lake tonalite gneiss (unit 18d)

Light grey weathering quartz-rich tonalitic gneiss exposed northeast of Fairwind Lake is one of the main phases of the Batty Lake complex (Zwanzig and Schledewitz, 1992). This orthogneiss is commonly garnetiferous and contains buff weathering veins of mobilizate. It has a straight, sheared southwest contact, which is parallel to the underlying supracrustal packages.

Granodiorite to tonalite gneiss (unit 18e)

Light grey to buff weathering, massive to strongly foliated granitoid rock forms an elongate body (<400 m thick) in the Reed-North Star high-strain zone south of Dow Lake. The rock contains a variety of xenoliths and possible tectonic inclusions. It grades into unit 19e south of the map area (Whalen, 1993).

Dow Lake felsic rock (unit 18g)

Fine grained quartzofeldspathic rock occupies much of the belt interpreted as the folded extension of the Reed-North Star high-strain zone. Elongate lenses of the rock, <180 m thick and <8 km long, extend across the Dow Lake area at the top of the structural package containing units 3b and 4e, and at the structural base of unit 2a. The rock is uniformly light grey or layered light to medium grey. Quartz and plagioclase with small amounts of garnet and magnetite form 0.1-1 mm grains. Fine grained biotite or thin aggregates of biotite ± hornblende (<5 mm long) make up 5-10% of the rock. Some biotite is locally concentrated in a spaced cleavage.

The rock was interpreted as a paragneiss because of its high quartz content (Zwanzig and Schledewitz, 1992), but an intrusive origin is indicated by outcrops that contain mafic inclusions. The presence of a thin sheet of the gneiss, interpreted as a dyke in the surrounding amphibolite, supports this conclusion. The Dow Lake felsite may have been a fine grained quartz-rich tonalite. Locally, aggregates (5-30 mm long) contain granular K-feldspar interpreted as annealed porphyroclasts. Most of the rock shows no evidence of high strain; elongate inclusions and tectonic layering are rare.

Augen gneiss (unit 19e)

Light grey to pink weathering tonalitic to granitic augen gneiss forms elongate bodies 400 m thick in unit 3b. Sill-like lenses, <5 km long and <80 m thick, are at the upper contact of Dow Lake felsite. The sills are structurally overlain by units 2a and 3b amphibolite and 4d tectonite in the extension of the Reed-North Star high-stain zone. Augen are 5-15 mm long aggregates of K-feldspar and plagioclase. The best preserved igneous texture is in the Martell Lake area where 30-40% pink or grey feldspar is locally prismatic. At Dow Lake the gneiss contains garnet; feldspar porphyroclasts are fewer (0-20%), smaller (<10 mm) and more rounded. South of the map area the rock comprises equigranular to K-feldspar phyric granodiorite gneiss (Whalen, 1993).

Leucotonalite to leucogranite and pegmatite (units 20 and 20b)

Sheets of pegmatite (unit 20b) are abundant in the sheared rocks east and west of Dow Lake.

STRUCTURE AND METAMORPHISM

Early structures divide the area between the Gants Lake batholith and the Batty Lake intrusive complex into four lithotectonic packages, which are 300 m to >2000 m thick and dip 20° to 40° east to northeast. Internal strain increases and thickness and dip decrease upwards and to the northeast. Successive packages are separated, from base to top, by the Reed-North Star high-strain zone, Loonhead Lake fault, Fairwind Lake fault and Batty Lake shear zone. Regional correlation and preliminary trace element geochemistry (Zwanzig, in prep.) suggest that successive packages have distinctive oceanic arc to ocean floor compositions. The Burntwood and Missi suites represent a sedimentary successor basin, and the Batty Lake complex comprises successor arc plutons (Lucas *et al.*, in press). Each supracrustal package contains a different set of early intrusions.

Evidence for an extended history of metamorphism and polyphase deformation at Dow Lake includes shallowly dipping mid-crustal structures (F_2 and F_3) overprinted on early, steeply dipping upper crustal structures and on the F_1 faults. F_3 and F_4 folds deform the early high-strain zone, the F_1 folds and faults, and the main foliation (S_2). S_3 is parallel to S_2 and represents continued flattening on the fold limbs. A spaced east-dipping S_3 foliation with parallel granitoid veins cuts S_2 in a fold hinge. The latest deformation (F_4) has produced upright east-northeast trending domes, but no new fabrics.

The structural history of the Dow Lake area is consistent with the following scenario: (i) early structures resulted from intermittent terrain fragment assembly; (ii) F_2 structures resulted from tectonic burial and overturning of the Flin Flon belt margin beneath the Kisseynew belt during continental collision; (iii) F_3-F_4 structures formed during uplift and continued convergence.

Reed-North Star high-strain zone

A "straight belt" of fine grained schistose rocks trends north-south within the Amisk collage and plutonic rocks at North Star Lake (Norquay *et al.*, 1993). It extends south to Reed Lake as one of the main structural features between the Flin Flon and Snow Lake arc segments of the volcanic belt (Syme *et al.*, GS-10, this volume). It is called the *Reed-North Star high-strain zone* in this report. At Dow Lake the north end of the high-strain zone becomes shallow-dipping and merges with the strong regional fabric. The zone is folded in large F_3 structures and refolded around east-northeast trending F_4 domes.

The foliation in augen gneiss and rare mylonite is parallel to, and generally not distinguished from, the main S_2 foliation. Apparently, the fine grained tectonites were annealed at high metamorphic grade, consistent with an early age for the shearing.

Loonhead Lake fault (F_1)

The boundary between the Kisseynew gneiss belt and the Flin Flon volcanic belt lies along the Loonhead Lake fault and related faults that separate Amisk collage volcanic rocks from structural slices of younger, predominantly sedimentary rocks belonging to the Burntwood and Missi suites. The faults have been traced in a zone extending from Wekusko Lake, north beyond Snow Lake, and northwest into the Kisseynew gneiss belt. At Dow Lake the fault is inferred to lie along the unexposed contact between metavolcanic rocks and the sediment-derived gneisses. The fault appears to splay at Dow Lake, where a slice of garnet-biotite gneiss of possible sedimentary origin extends into the present footwall. The main fault and the splay fault were warped into a large S-shaped, late-metamorphic F_3 fold.

Evidence from areas west of Dow Lake suggests that the Loonhead Lake fault may have been overturned during the F_2-F_3 deformation and that the present footwall was once the hanging wall (Zwanzig, in press). This history is consistent with the steep southerly and westerly dips of the fault in rocks with primary structures at File Lake (Bailes, 1980; Connors, in press), and with the shallow northeast dip of the fault in rocks at Dow Lake, which were highly strained and recumbently folded during F_2-F_3. Josland Lake gabbro occurs along parts of the fault and may have acted a as competent member in controlling flats in the thrust system.

Fairwind Lake fault (F_1 -F_2)

The contact between the Burntwood Suite and the overlying Amisk collage at Fairwind Lake is not exposed. It is assumed to be a fault because the adjacent rocks represent widely different tectonic environments and there is a variety of gneisses, including an occurrence of ultramafic amphibolite, in the hanging wall. The contact is interpreted as an F_1 fault, folded about the F_2 Walton Lake nappe in areas to the northwest (Zwanzig, 1994b). Connors (in press) interprets a fault at the inverted upper contact of the Missi Suite. The relative age, exact position and vergence of the early faults remain uncertain.

Early major folds (F_1 -F_2)

The metasedimentary rocks bounded by the early faults occupy an F_1 syncline that probably formed in the original hanging wall of one of the faults. The syncline extends 60 km northwest from File Lake. Its southwest limb was refolded near Dow Lake during F_3. A pelite member in the upper part of the Burntwood Suite is symmetrically disposed about the Missi Suite near Corley Lake and helps define the syncline (Bailes, 1980). Gradational contacts at the base of the Missi Suite (Zwanzig, 1994b) help to define the western part as a syncline rather than a fault slice.

West of Martell Lake the Missi Suite occupies another syncline, as indicated by metasandstone with inward-facing basal conglomerate near Evans Lake. This fold may be F_1 or F_2.

Regional foliation (S_2)

The regional foliation is defined by shallow east-northeast or southeast dipping metamorphic and tectonic layering, and transposed primary layering with parallel aligned biotite and hornblende. The peak-metamorphic assemblage garnet-cordierite-sillimanite occurs in selvages around veins of leucosome in S_2 migmatitic layering in pelites (Zwanzig and Shwetz, 1994). Pillows, conglomerate clasts and local tectonic lamination show high strain, whereas quartz, feldspar and hornblende grains are equant or only slightly elongate with smooth boundaries that indicate annealing. Individual minerals are fine grained (<1 mm) in most rock types. Flattened and sutured grains are restricted to the coarse orthogneiss units (18d and 19e) deficient in hydrous minerals. Consequently, the S_2 fabric is interpreted to be the result of protracted ductile deformation (flow) at high temperature under mid-crustal conditions.

A strong L_2 lineation is developed where S_2 appears to be overprinted on early planar structures south of Dow Lake. The only rocks with primary structures (*i.e.*, pillows and phenocrysts) and early foliation (S_S) occur in the pressure shadow of the pyroxenitic gabbro. S_S foliation trends east-northeast and has a steep dip in this low-strain domain. The shallow southeast-dipping S_2 intersects S_S in the gently east-northeast-plunging L_2 direction. Steeply dipping foliation is typical in the low grade parts of the Flin Flon belt where it generally represents upper crustal structures. Shallow east-northeast-dipping lineation marks the transition from steep to shallow structures along much of the north margin of the Flin Flon belt (Zwanzig and Schledewitz, 1992). The relationship at Dow Lake indicates that the steep upper crustal structures were overprinted by the shallow S_2 foliation in the mid crust.

Batty Lake shear zone (S_1 -S_3)

Shearing occurred repeatedly along the planar northeast-dipping contact of the Batty Lake complex. A structural sliver of sheared Burntwood Suite suggests F_1 faulting. S_2 is defined near the contact by highly flattened grains, and foliated late pegmatite indicates continued deformation during F_3.

Dow Lake structure (F_3)

The large S-shaped antiform-synform pair north and west of Dow Lake deforms foliation (S_2), the Loonhead Lake fault, and the Reed-North Star high-strain zone. The folds are highly asymmetric; long limbs dip 20° northeast and an overturned common limb dips ~55° east-northeast. Plunge is 10° north. The southwest vergence of the F_3 fold pair is consistent with tectonic transport of the upper structural layers (*i.e.*, upper package of Amisk collage and Batty Lake complex) towards WSW. The large southeast-plunging synform that contains unit 15a in its core south of Dow Lake may be the southerly tilted continuation of the synform west of Dow Lake.

The foliation in the common limb of the Dow Lake structure shows local evidence of F_3 shearing and probable faulting. The resulting complex structures have not been mapped. Late pegmatite in this zone ranges from undeformed to sheared. A spaced S_3 foliation with leucogranite veins is developed in part of the hinge zone of an F_3 fold.

Late dome structure (F_4)

On the south end of Dow Lake the large F_3 folds interfere with an open east-northeast trending F_4 arch producing a gentle dome in the lake and a saddle structure to the southwest. The dome is *en echelon* with another dome at Loonhead Lake and with the tighter structures of the same age at Corley Lake (Bailes, 1980; Connors, in press). The arch may be a local hinge zone of southerly tilting in the Flin Flon belt during uplift of the Kisseynew belt. The regional culmination near the south margin of the Kisseynew belt is imaged on LITHOPROBE seismic profiles (Lucas *et al.*, 1994).

Regional structure

Reconnaissance in previously mapped areas on the south flank of the Kisseynew belt and trace element chemistry suggest a remarkable continuity of the structural package that is rooted southwest of the Loonhead Lake fault and extends northwest into the Kississing Lake area. For example, at Lobstick Narrows, 55 km west of Dow Lake, the Burntwood Suite continues to be in sharp (fault) contact with amphibolite, identified as differentiated Josland Lake melagabbro to ferrogabbro, overlain by a narrow sill of ferrotonalite to leucotonalite gneiss. These rocks intruded the Amisk collage (fine grained amphibolite) overlain by basal Missi conglomerate. Fine grained amphibolite at Loonhead Lake, Moody Lake and Evans Lake has a unique geochemical signature similar to the basalt at File Lake, intruded by Josland Lake gabbro southwest of the Loonhead Lake fault (Zwanzig, in press). This structural package tapers towards the northwest and apparently was thrust far into the Kisseynew belt.

REGIONAL IMPLICATIONS FOR MINERAL DEPOSITS

Structural packages that are exposed at Dow Lake on the margin of the Flin Flon volcanic belt extend northwest across the south flank of the Kisseynew gneiss belt. Their diverse tectonic origins and variable mineral potential control the distribution of known deposits and showings.

The lowest structural package of unit 3b contains the Martell Lake (Wood Lake) gold occurrence associated with "arsenopyrite-galena-sphalerite-pyrite-chalcopyrite mineralization" (Ostry, 1987). The host rock is augen gneiss (unit 19e) that has been altered to quartzofeldspathic gneiss containing white mica ± garnet, locally with a high content of K-feldspar. Ostry (1987) reported 1-2% disseminated arsenopyrite associated with the potassic alteration and quartz veins. The early shearing and the unequal distribution of potassium feldspar in the augen gneiss across the Dow Lake area may have been related to the mineralizing event.

In the Kisseynew belt widely separated gold showings and a small gold deposit (Nokomis Lake) occur in gneisses equivalent to Josland Lake intrusions. The mineralization (Ostry and Trembath, 1992) is mainly in mottled gneiss (ferrotonalite) above various types of amphibolites (differentiated melagabbro to ferrogabbro) (Zwanzig, 1994). These sills intruded Evans Lake amphibolite that is recognized as Amisk collage lying stratigraphically below the Missi Suite and in fault contact with the Burntwood Suite (Zwanzig, in press). The same assemblage of rocks occurs at the Lobstick Narrows gold showing, 55 km west of Dow Lake. It is interpreted to occupy an attenuated fault slice (F_1 thrust nappe) that also extends throughout the Kississing Lake area. The fault packages of Amisk collage intruded by Josland Lake gabbro at File Lake, Dow Lake and Moody Lake are interpreted to be the root zone for the nappe that contains the gold mineralization.

Northeast of Dow Lake, the upper structural package of Amisk felsic gneiss was affected by local hydrothermal alteration. The root zone of this slice is the Walton Lake nappe, which contains base metal mineralization in similar rocks. Thin, discontinuous mineralized units of felsic gneiss extending to Yakushavitch Island on Kississing Lake may also represent equivalent structural slices.

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GS-5 DETAILED GEOLOGY AND STRUCTURE OF THE COLLINS POINT AND YAKUSHAVICH ISLAND AREA, KISSISSING LAKE; IMPLICATIONS FOR TRACING THE EXTENT OF MINERALIZATION (NTS 63N/3NW AND 63N/6SW)

by D.C.P. Schledewitz

Schledewitz,D.C.P.,1995: Detailed geology and structure of the Collins Point and Yakushavich Island area of Kississing Lake and implications for tracing the extent of mineralization (NTS 63N/3NW and 6SW); **in** Manitoba Energy and Mines, Minerals Division, Report of Activities,1995, p. 24-29 .

SUMMARY

Highly foliated gneisses and variably foliated igneous rocks on Collins Point and Yakushavich Island are folded into large recumbent folds which have been refolded. The fold geometry is based on the orientation of S_1 metamorphic layering and foliations. The evidence for recumbent folding comes from mapping the gneisses on Yakushavich Island. Three major rock types, a suite of garnet-biotite gneisses, a suite of amphibolites and a suite of quartzofeldspathic gneisses, are isoclinally folded about a shallow northwest-dipping axial plane. Mineral deposits comprising chalcopyrite and sphalerite occur consistently within the suite of garnet-biotite gneisses. The characteristics of the mineral deposits fit a volcanogenic massive sulphide model. Volcanogenic massive sulphide style mineralization has been interpreted to be part of the Flin Flon belt infrastructure as exposed in the Kisseynew south flank (Zwanzig and Schledewitz, 1992). Establishing which lithologies are part of a Flin Flon belt infrastructure remains a problem in the area of Kississing Lake. Resolution of this question is fundamental to mineral exploration in the Kisseynew south flank.

INTRODUCTION

A detailed mapping (1:20 000, with selected areas at 1:10 000) project was undertaken in 1995 in an area that covers Collins Point and Yakushavich Island. Regional scale mapping (1:50 000, with selected areas at 1:20 000) was carried out at the north end of Kississing Lake (Fig. GS-5-1). The objective of the program is to provide an improved geological data base and to contribute to a better understanding of the structural geology. This area was chosen because of the renewed mineral exploration activity focused on Collins Point and Yakushavich Island.

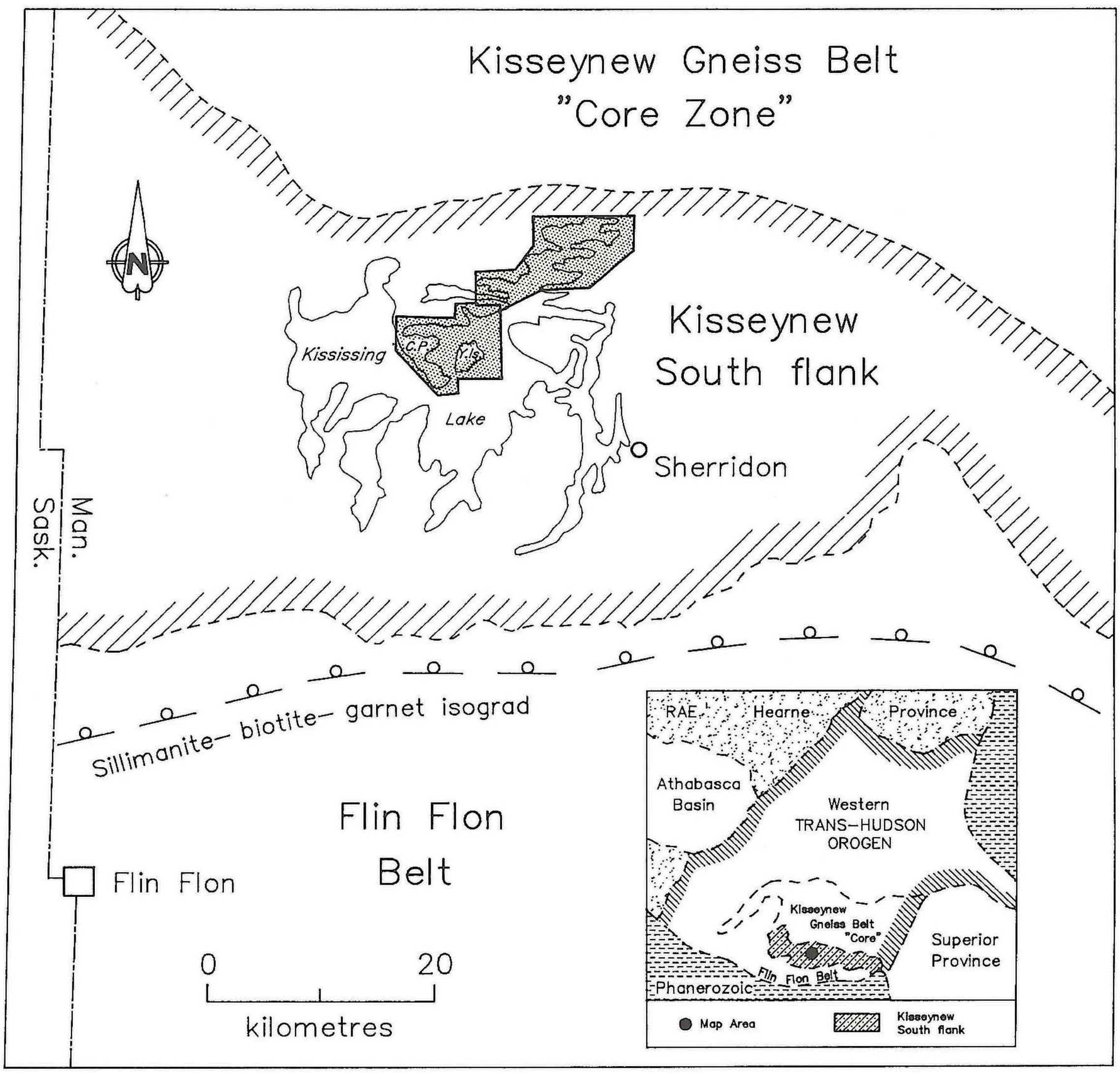

Figure GS-5-1: Location of the Collins Point (labelled C.P.) and Yakushavich Island (labelled Y.I.) map area and the area of regional mapping at the north end of Kississing Lake.

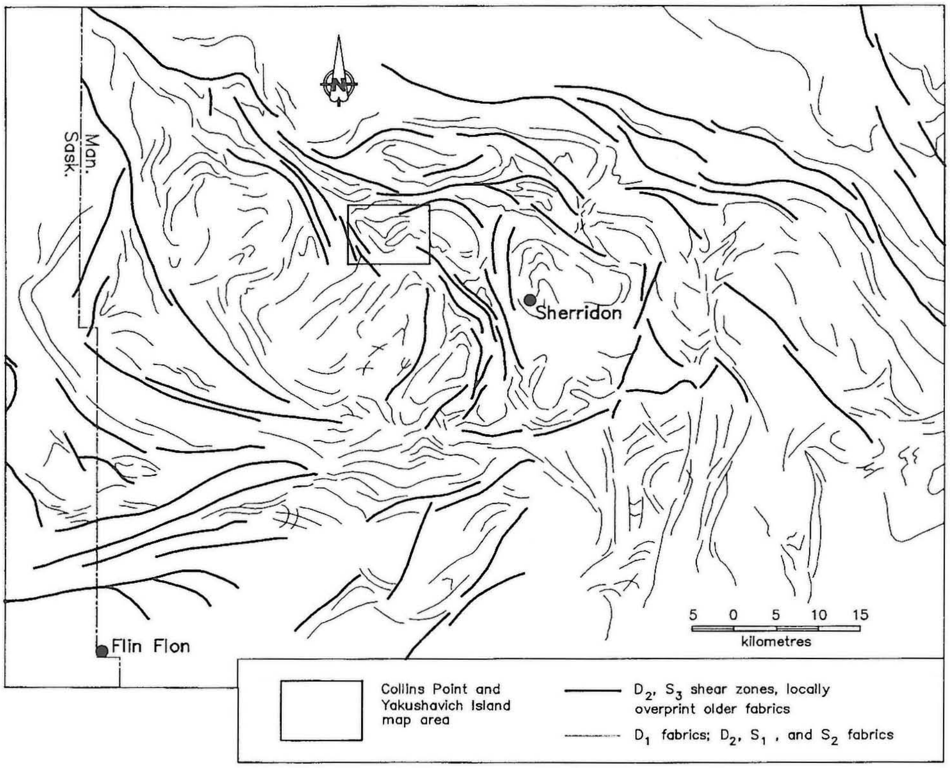

Figure GS-5-2: Regional structural trends in the Kisseynew gneiss belt and northern margin of the Flin Flon belt.

REGIONAL GEOLOGICAL SETTING

The project area lies within the southern flank of the Kisseynew gneiss belt which is a subdivision of the Trans-Hudson Orogen, a Paleoproterozoic orogenic belt between the Archean Superior Province to the east and the Rae and Hearne Provinces to the west (Fig. GS-5-1). Previously, the two main subdivisions of the orogen were thought to be the Kisseynew gneiss belt, characterized by amphibolite- to granulite facies gneisses, and the Flin Flon volcanic belt, a volcanic and intrusive terrane exhibiting mineral assemblages of the sub-greenschist to almandine amphibolite facies of metamorphism.

Recent geological mapping in conjunction with geochronological, geochemical and geophysical studies have greatly enhanced geological understanding of the Flin Flon belt (Lucas *et al.*, 1993; Lucas *et al.*, in prep.). The belt is a collage of ocean floor and island arc terranes welded by plutons. Large-scale tectonic zones have been identified and related to this early period of multi-staged inter-arc accretion (D_1). Arc accretion was followed by deposition of turbidites of the File Lake Formation and fluvial sediments of the Missi Suite, plutonism and localized volcanic flows. Deposition of turbidites of the File Lake Formation, which began earlier than deposition of the Missi Suite, chronologically overlaps the Missi Suite (David and Bailes, in prep.). Subsequent thin-skin tectonics involved large-scale overthrusting and resultant interleaving and local inversion of the File Lake Formation, Missi Suite and older volcanic rocks (D_2, S_1, F_1).

The Kisseynew gneiss belt has been subdivided into the Kisseynew belt 'Core Zone' and the Kisseynew south flank (Fig. GS-5-1) (Zwanzig and Schledewitz, 1992). The 'Core Zone' is predominantly 1.86-1.84 Ga (Ansdell and Norman, 1994; David *et al.*, 1993) garnet-biotite gneisses and migmatites (Burntwood Suite) derived from turbidites equivalent to the File Lake Formation. The Kisseynew south flank differs from the core zone since it contains highly strained, metamorphically high grade gneissic equivalents of the rocks of the Flin Flon belt. These rocks are structurally interleaved with the Burntwood Suite (D_2, F_2).

The second stage of tectonic interleaving, which took place during continental collision, is characterized by shallowly dipping structures and ductile deformation (D_2, F_2). This process involved transport of the gneissic and migmatitic Kisseynew core zone rocks in a thick-skin style of deformation. The metamorphosed stratigraphy was overturned into large-scale nappes (D_2, F_2) with imbrication or delamination of deep levels of the collage of island arcs, ocean floor and plutonic terrane of the Flin Flon belt. The second stage of overturning was superimposed on the earlier phase of post-Missi deformation (D_2, F_1), which produced the first stage of interleaving and local inversion of Missi Suite, File Lake and older volcanic rocks.

Late collisional sinistral transpression modified the already complex structures (Fig. GS-5-2) along conjugate shears and related passive folds (D_2, S_3, F_3). A system of late brittle faults crosscut and locally overprinted early structures (D_3, S_4).

STRUCTURAL GEOLOGY

The highly foliated gneisses and variably foliated igneous rocks on Collins Point and Yakushavich Island are folded into large recumbent folds (D_2, F_2), which have been refolded (D_2, F_3) (Fig. GS-5-3). The fold geometry is based on the orientation of S_1 metamorphic layering and foliations. These fabrics parallel the trend of the contacts between large scale and continuous lithological units. Contacts are rarely exposed, but where observed, the foliation and metamorphic layering (S_1) are parallel.

The evidence for the interpretation of recumbent F_2 structures comes from mapping the gneisses on Yakushavich Island. A layered sequence of three major rock types, a suite of garnet-biotite gneisses, a suite of amphibolites and a suite of quartzofeldspathic gneisses (Table GS-5-1), are isoclinally folded. The dip of the axial plane is shallow to the northwest (Fig. GS-5-4). A variably magnetiferous and hornblende-bearing quartzofeldspathic suite of gneisses occupies the core of the structure. The amphibolite suite overlies and underlies the quartzofeldspathic rocks. The amphibolite outlines a very tight F_2 Z-fold in the underlimb of the recumbent fold in the northeast corner of Yakushavich Island. The axial plane of the F_2 Z-fold trends northerly and has a shallow dip to the north-northwest. The amphibolite also outlines a large fold closure at the south end of Yakushavich Island (Fig. GS-5-3). The orientation of the metamorphic layering within the

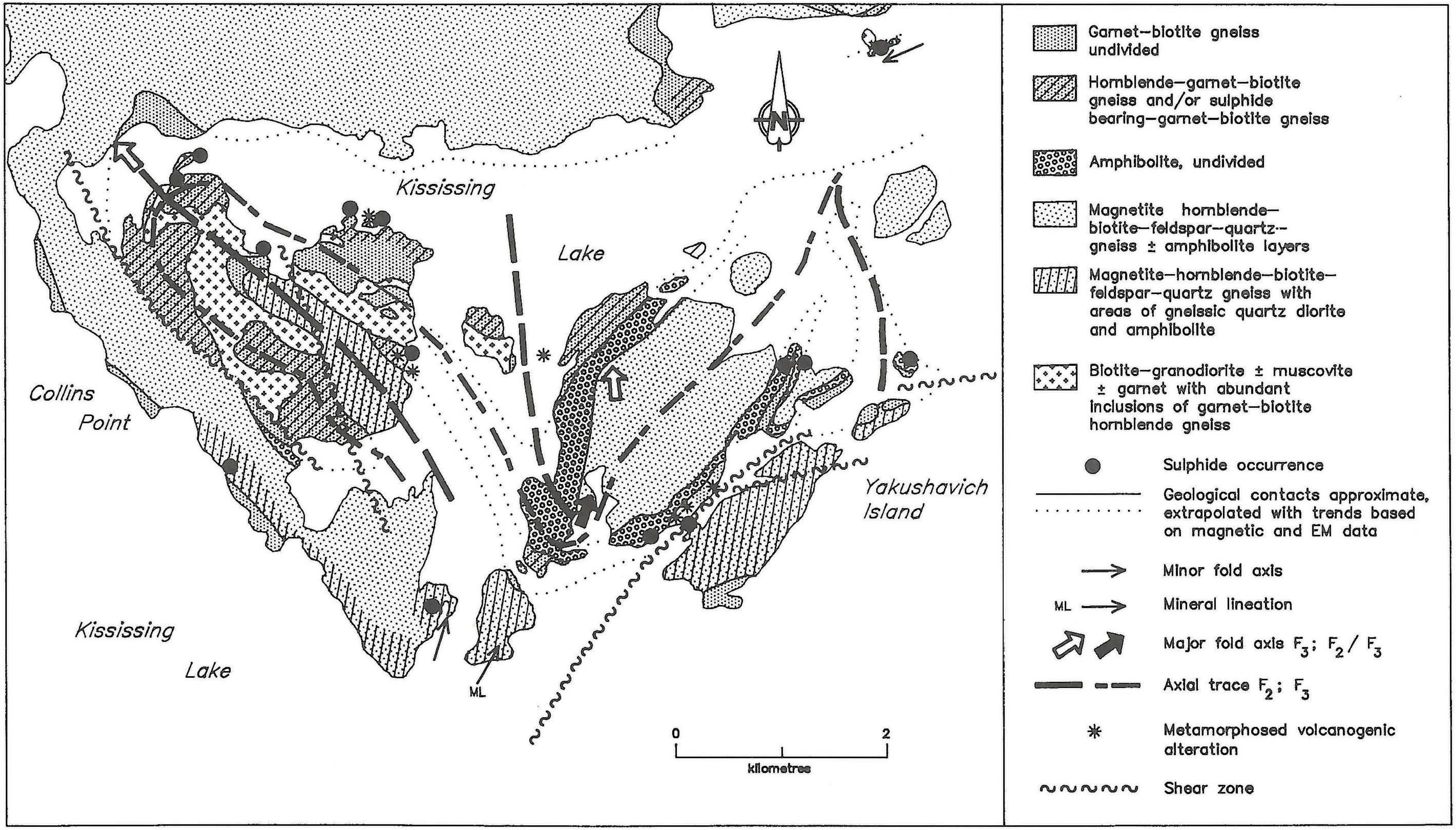

Figure GS-5-3: Simplified geology and mineral occurrences in the Collins Point and Yakushavich Island areas.

Table GS-5-1
Table of Lithologies

Unit	Subunit
Garnet-biotite-feldspar-quartz gneiss suite	- Hornblende (8%)-garnet (red)- biotite-plagioclase-quartz gneiss - Rusty pyritic garnet-biotite-plagioclase-quartz gneiss - Coarse grained garnet (10-25%)-sillimanite-orthoamphibole-cordierite; marginal to bodies of massive sulphide (metamorphosed volcanogenic mineral deposit related alteration) - Felsic gneiss, underlies the alteration on the east side of Yakushavich Island
Amphibolite suite	- Layered garnetiferous amphibolite, layers (5 mm - 2 cm) thick) of (i) garnet-amphibole (60%)-biotite-plagioclase-quartz (ii) garnet-amphibole (20-45%)-biotite-plagioclase-quartz (iii) white plagioclase-quartz *lits* - Medium grained amphibolite, diopside, plagioclase+epidote+sulphides - Coarse grained amphibolite+sulphides
Quartzofeldspathic gneiss suite	- Hornblende (25-40%)-magnetite- biotite-plagioclase-quartz-gneiss - Hornblende (5-8%)-biotite-feldspar-quartz+magnetite - Biotite-feldspar-quartz gneiss+magnetite - Amphibolite, 1-4 m thick

amphibolites around this closure defines an overturned synform that plunges 17°/018° with a shallow north-dipping axial plane. The amphibolites are overlain and underlain by the suite of garnet-biotite gneisses. The F_2 axial trace of the recumbent fold can be extrapolated from the south tip of Yakushavich Island northwesterly to Collins Point. This interpretation is based on the trend of the metamorphic layering in the garnet-biotite gneiss. The axial plane of the F_2 recumbent fold is assumed to lie within the garnet-biotite suite of gneisses. The layer of amphibolites appears to close out in the nose of the fold before reaching Collins Point. The fold closure lies under Kississing Lake and its orientation is unknown.

This recumbent structure has been refolded about north- to northwest-trending F_3 axial planes (Fig. GS-5-3). The degree of closure and the azimuths of consistently shallow plunges are variable. The orientation of the axial planes and plunge of the F_3 structure appear to rotate counterclockwise corresponding to the increasing tightness of the F_3 fold closures.

A large F_3 synformal cross fold, with a core of the garnet-biotite gneisses, lies on the west side of Yakushavich Island (Fig. GS-5-3). The more open part of the synformal crossfold has an interlimb angle of 90°, shallow dips and a shallow plunge to the northeast. In the tighter part of the fold the eastern limb of the structure is steep and the plunge of the large scale synform is more northerly (Fig. GS-5-3). The axial plane of this F_2 recumbent fold, which lies within the garnet-biotite gneisses on Collins Point, is folded isoclinally about a northwest-trending axial plane with a shallow northeast dip. This is the tightest F_3 crossfold and it has a shallow plunge to the northwest. The interpretation of an F_3 fold closure is based on the folded S_1 metamorphic layering and foliation.

The underlimb of the recumbent fold on Yakushavich Island was also folded during the F_3 cross fold event. The amphibolite layer in the northeast corner of Yakushavich Island is folded about a shallow northwest-plunging F_3 fold axis and a northwest-trending axial plane. The large F_2 Z-fold, outlined by the amphibolite, was tightened and the limbs of the fold were attenuated during the cross folding event. The axial plane of the F_2 Z-fold trends north-northeast. This fold geometry is characteristic of minor folds along the underlimb of the recumbent fold, an indication of significant layer-parallel slip.

IMPLICATIONS

Mineralization that occurs in the suite of garnet-biotite gneisses and within the suite of amphibolites can be traced around the entire recumbent fold structure on Yakushavich Island and Collins Point. The mineralization occurs most consistently within areas of a graphite-hornblende(3-8%)-garnet-biotite gneiss on the west side of Yakushavich Island and Collins Point. Pyrite-bearing, variably garnetiferous, biotite-plagioclase-quartz gneiss and a coarse grained quartz-rich aluminous orthoamphibole-garnet(10-15%)-bearing granoblastite occur in areas of mineralization on both limbs of the recumbent fold on Yakushavich Island. These two rock types, interpreted as alteration related to the mineralizing process, are more restricted in volume than the hornblende-garnet-biotite gneiss. The presence of these altered rock types provides a more positive indication of potential mineralization. Mineralization comprises disseminated and near solid chalcopyrite-sphalerite; solid and disseminated pyrite; and variably magnetic, solid and disseminated pyrrhotite. In drill core the zones of mineralization are associated with micaceous garnet-biotite ± orthoamphibole ± cordierite.

Refolding of the F_2 recumbent fold produced a highly tectonically thickened section of the potentially mineralized zone that occurs within the garnet-biotite gneiss. This highly thickened section occurs in the F_3 synformal cross fold on the west side of Yakushavich Island. Conversely, the underlimb of the recumbent fold on the east side of Yakushavich Island was attenuated during the F_3 folding event.

The large volume of the hornblende-garnet-biotite gneiss and interlayered garnet-biotite gneiss exposed on Collins Point is due to the refolding of the F_2 recumbent fold. The folded axial trace of the F_2 recumbent fold lies within these rock types. The F_3 folding event, while effectively producing a four-fold repetition of these rock types, was accompanied by tectonic thinning. A large body and numerous sills of leucocratic muscovite-bearing granodiorite (Fig. GS-5-3) are interpreted as synkinematic and related to extensional domains developed during the F_3 fold event. Mineralized zones on Collins Point were deformed during the F_3 folding event and intruded by the leucocratic synkinematic granodiorite.

DISCUSSION

The interpretation of the large-scale fold geometry based on S_1 fabrics and large-scale lithologic units is useful in tracing the trend of the lithologies that may host mineral occurrences. However, the organization of the subunits within each of the large scale units and the primary controls for mineralization are less clearly defined and more poorly constrained. The characteristics of the mineral deposits fit a volcanogenic massive sulphide model. But predictability requires resolution of stratigraphic relationships and establishing the age and geological setting of the mineralizing volcanic and igneous activity.

Volcanogenic massive sulphide style mineralization and alteration has been interpreted to be part of the Flin Flon belt infrastructure as exposed in the Kisseynew south flank (Zwanzig and Schledewitz, 1992). This inference is based on the comparison of mineral deposit types and metamorphosed volcanogenic alteration documented in the Snow Lake area (Bailes and Galley, 1989, 1991). Defining the boundaries for areas of Flin Flon belt infrastructure is a problem when mapping in the Kisseynew south flank, since interpretation is based entirely on lithostratigraphy. Lithologies of uncertain age have been identified in the most recent compilation of the geology of the Kisseynew south flank and the north margin of the Flin Flon belt (Zwanzig *et al.*, 1995). The garnet-biotite gneiss suite on Collins Point and Yakushavich Island contains rocks of uncertain affinity. The association with areas of mineralization and alteration requires that these rocks be distinguished from the garnet-biotite gneisses of the Burntwood Suite. Rocks of the Burntwood Suite postdate rocks of the Flin Flon belt collage. Establishing which lithologies are part of a Flin Flon belt infrastructure remains a problem in the area of Collins Point and Yakushavich Island. The resolution of this question is fundamental to mineral exploration in the Kisseynew south flank.

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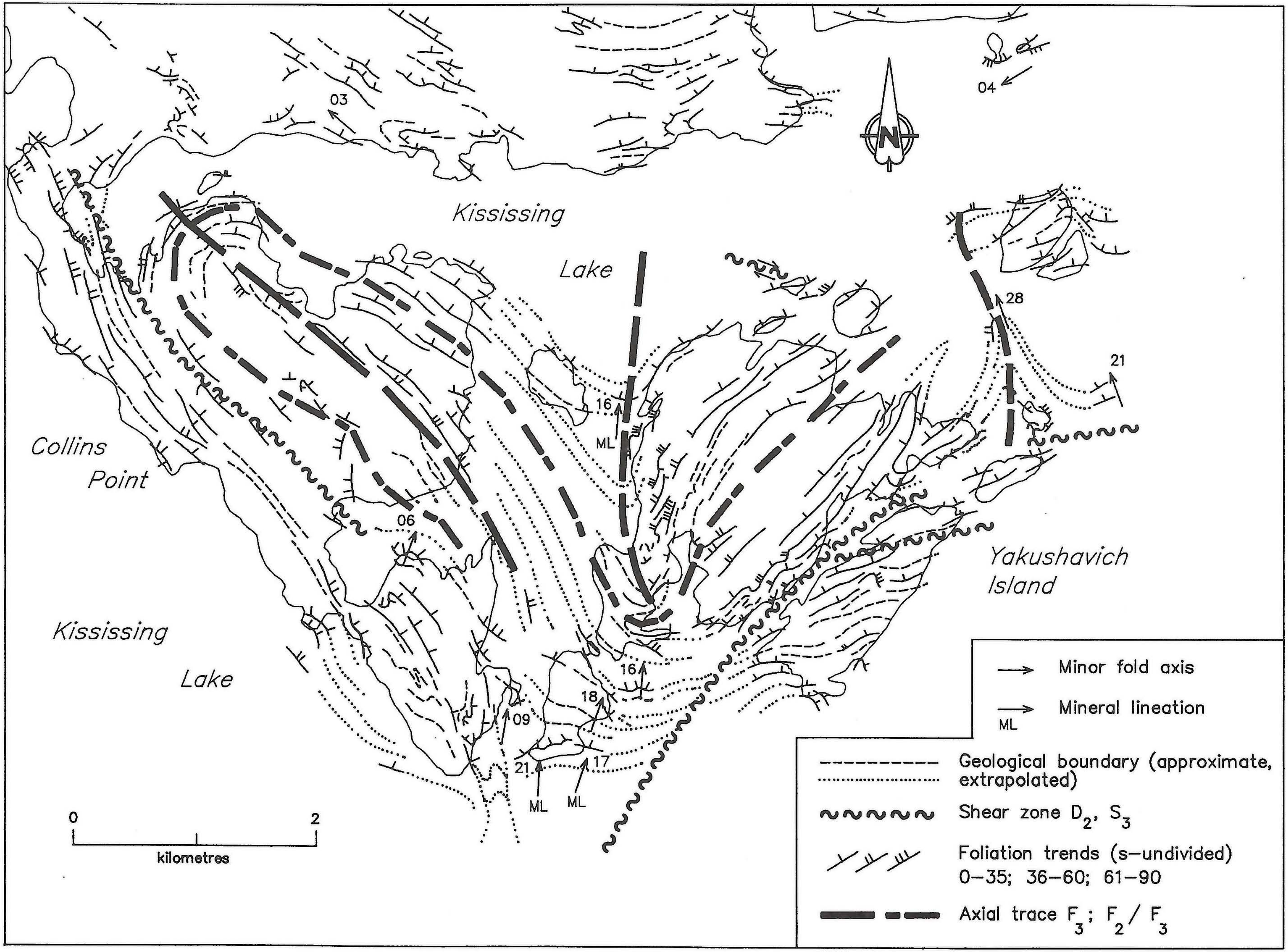

Figure: GS-5-4: Structural trends in the Collins Point and Yakushavich Island area.

GS-6 THE BAKER PATTON FELSIC COMPLEX (PARTS OF 63K/12 AND 63K/13)

by G.H. Gale and L.B. Dabek

Gale, G.H., Dabek, L.B., 1995: The Baker Patton felsic complex (Parts of 63K/12 and 63K/13); in Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 30-33 .

SUMMARY

Detailed mapping within the Baker Patton Felsic Complex (BPC) at 1:5 000 scale was extended to include a previously unmapped area north of Amulet Lake. Several areas in the vicinity of known mineral deposits were remapped in detail to refine the local stratigraphy and structure. Drill core from the vicinity of the North Star and Don Jon mines provided new insights into the geological settings of these deposits; the Don Jon deposit is situated within a small fault block and rocks equivalent to its host rocks have not been recognized elsewhere within the map area. Preliminary interpretation of the geochemical data indicates that the base metal deposits are located within a predominantly calc-alkaline volcanic sequence.

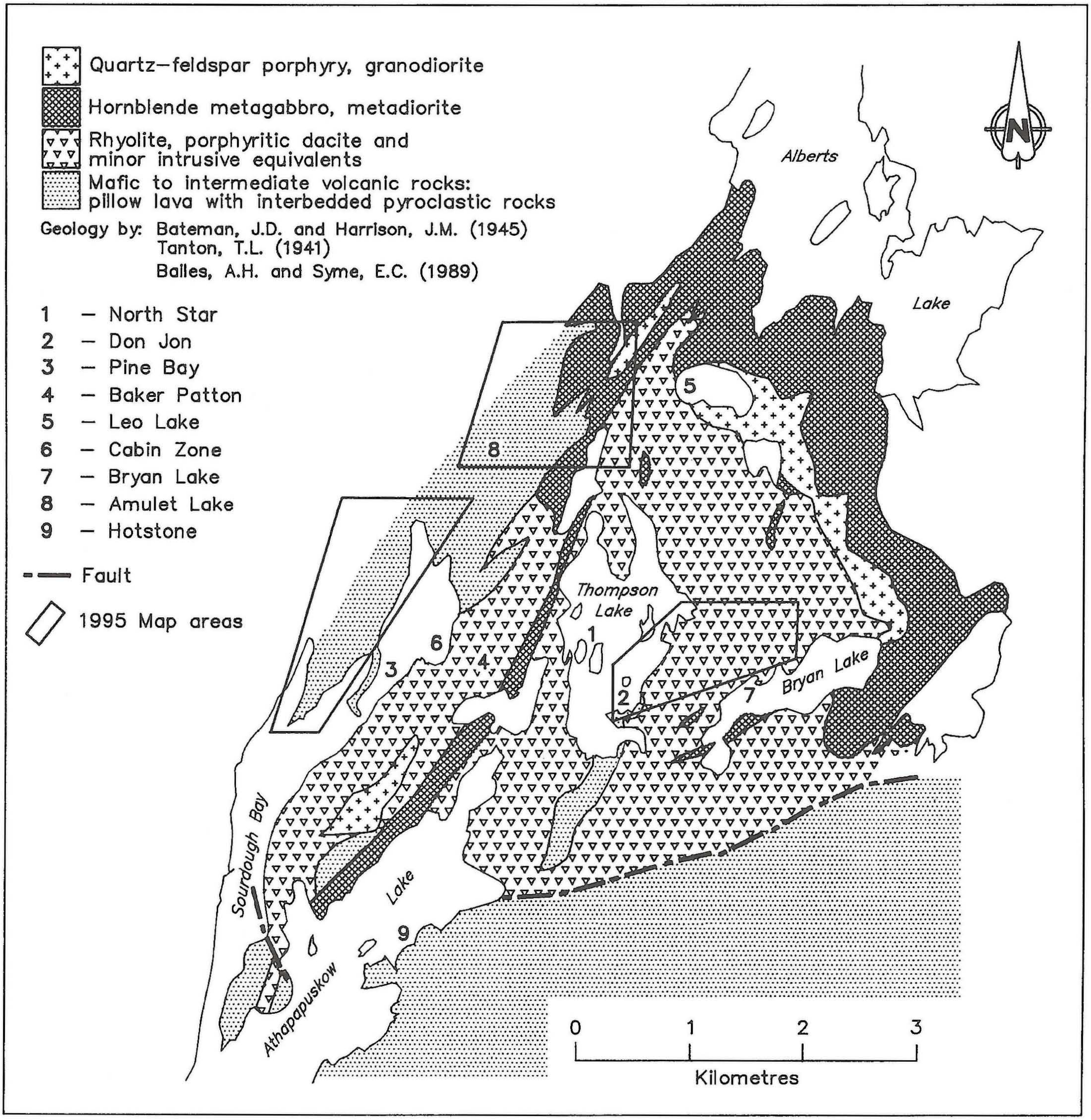

Figure GS-6-1: General geology of the Baker Patton Felsic Complex.

INTRODUCTION

Geological mapping of the Baker Patton Felsic Complex (BPC) (NTS 63K/12 and 63K/13) was continued north of the Amulet Lake area (Fig. GS-6-1; Gale *et al.*, 1994) to include the northward extension of felsic volcanic rocks exposed in the Amulet Lake area. Selected areas of the BPC were remapped to refine stratigraphic units and investigate structural problems identified from previous studies. Drill cores from the vicinities of the Don Jon and North Star mines were logged. Selective rock units were sampled and analysed in order to enhance the geochemical database.

AMULET LAKE-FLINTOBA LAKE AREA

The area between Amulet and Flintoba lakes is underlain predominantly by aphyric rhyolitic and minor basaltic rocks that have been intruded by quartz phyric rhyolite and fine- to medium-grained gabbroic rocks (Gale *et al.*, 1994). These rock units continue northward into the northernmost parts of the map area (Fig. GS-6-2). In addition, units of quartz phyric rhyolitic tuff and tuff breccia ± flows and quartz (1%)-feldspar (2-5%)-pyroxene (1-2%) bearing pyroclastic rocks are exposed in the northwestern part of the map area (Fig. GS-6-2).

The current mapping indicates that the extrusive felsic rocks of the BPC extend beyond the northern limits of the map area, but stratigraphic continuity is suspect due to the dissection of the units by gabbroic intrusions and several events of brittle deformation.

A zone of ductile deformation, characterized by a 50 to 75 m wide zone of schistose rhyolitic rocks, has been traced through Amulet Lake and across the map area (Fig. GS-6-2). This zone of deformation parallels and is probably related to the development of the regional schistosity; it is cut by late faults.

A rusty weathered, pyrite-bearing andesitic/dacitic unit occurs immediately north of Amulet Lake. The alteration is pervasive throughout this unit. In contrast, the mineralization that occurs along the west shore of Amulet Lake is terminated on the west by a fault and represents mobilization of chalcopyrite and pyrite along the fault zone. This mineralization and the mineralization underlying Amulet Lake (A.F. 91540) are separated from the pyrite-bearing andesitic/dacitic rock to the north by a massive aphyric rhyolite that is probably a late intrusion.

PINE BAY MINE AREA

The peninsula west of the Pine Bay Mine is underlain by a 750 m thick section of basalt and rhyolite flows, breccia and volcaniclastic sedimentary rocks (Gale *et al.*, 1994). Remapping of a portion of this area revealed that a regional fault occurs along the eastern boundary of a quartz-feldspar porphyritic felsic rock. The quartz-feldspar porphyry, which locally occurs along the eastern margin of a distinctive quartz phyric rhyolite flow, is generally massive. Locally, this unit contains variable concentrations of feldspar and in one outcrop near the powerline contains mafic fragments or biotitic domains that are several mm by several cm in size. This unit is probably an intrusion, but an extrusive origin cannot be ruled out on the basis of the existing data.

The distinctive quartz phyric rhyolite flow, with up to 1 cm quartz crystals, does not extend to the southwestern tip of the peninsula (Gale *et al.*, 1994); it is overlain by aphyric and quartz phyric rhyolite tuff, lapilli tuff and tuff breccia.

The mafic heterolithic and monolithic breccia and basaltic flows that form the westernmost portion of the Pine Bay peninsula extend northwards to the northern extremity of the map area (Fig. GS-6-2).Top determinations indicate the western sequence is right way up

DON JON MINE AREA

The Don Jon Mine area has been shown to be structurally complex (Gale *et al.*, 1994). The mineralization is bound on both sides by faults. It is hosted by layered felsic rocks that are partly, if not entirely, reworked clastic rhyolite. Layer attitudes indicate that the host rocks are part of the northeasterly-striking sequence that is exposed on the mainland east of the Don Jon deposit rather than the northwesterly-striking sequence that contains the North Star deposit. A northeast-trending zone of alteration that contains abundant quartz-talc and sericite (?) veins, but sparse sulphides, was intersected in drill cores and is exposed in outcrop along strike to the east. This alteration does not appear to be related to the sulphide mineralization and alteration associated with the Don Jon copper deposit.

STRUCTURE

The BPC is characterized by a paucity of sedimentary units and reliable top indicators. For example, the area is dominated by subaqueous pyroclastic rhyolitic flows. Some of the thicker flow units have small lobes distributed throughout the stratigraphically upper portions of the flows, but other units are characterized by the presence of massive rhyolite lobes in the basal portions of the flows/domes. In addition, an abundance of late brittle deformation features characterized by north-south and east-west oriented fault systems have dissected the area into a number of blocks and removed portions of individual flow units; correlation across the block boundaries and determination of displacements along the brittle structures is rarely possible.

The distribution of lithologies and top determinations suggest the presence of a regional, southwestward facing, open to tight early fold with an overall northeast-trending axial plane. This fold has been modified slightly by younger fold events and extensively by brittle deformations. The presence of earlier tight to isoclinal southeast-plunging parasitic folds in westward topping cherts and andesites south of the Don Jon deposit suggest the presence of an early isoclinal fold. There are insufficient top criteria to confirm the presence of a regional isoclinal fold within the map area.

GEOCHEMISTRY

A large geochemical database has been assembled during the course of this mapping project. This database is being used to refine the volcanic stratigraphy and document both the geochemical changes within the magma during the development of the complex and the effects of the various alterations associated with the mineralization. Major element data plot in the fields of both tholeiitic and calc-alkaline rocks (Fig. GS-6-3); however, the basalts and basaltic andesites plot predominantly within the field of calc-alkaline basalts (Fig. GS-6-4), which is consistent with the observations of Stern *etal.*, 1995 for rocks of the Bakers Narrows area that occur immediately south of the BPC (Bailes and Syme, 1989). The REE rock/chondrite plots for the BPC basalts show slightly enriched light REE ratios similar to those of the Bakers Narrows suite (Stern *etal.*,1995), but have higher heavy REE ratios (Fig. GS-6-5).

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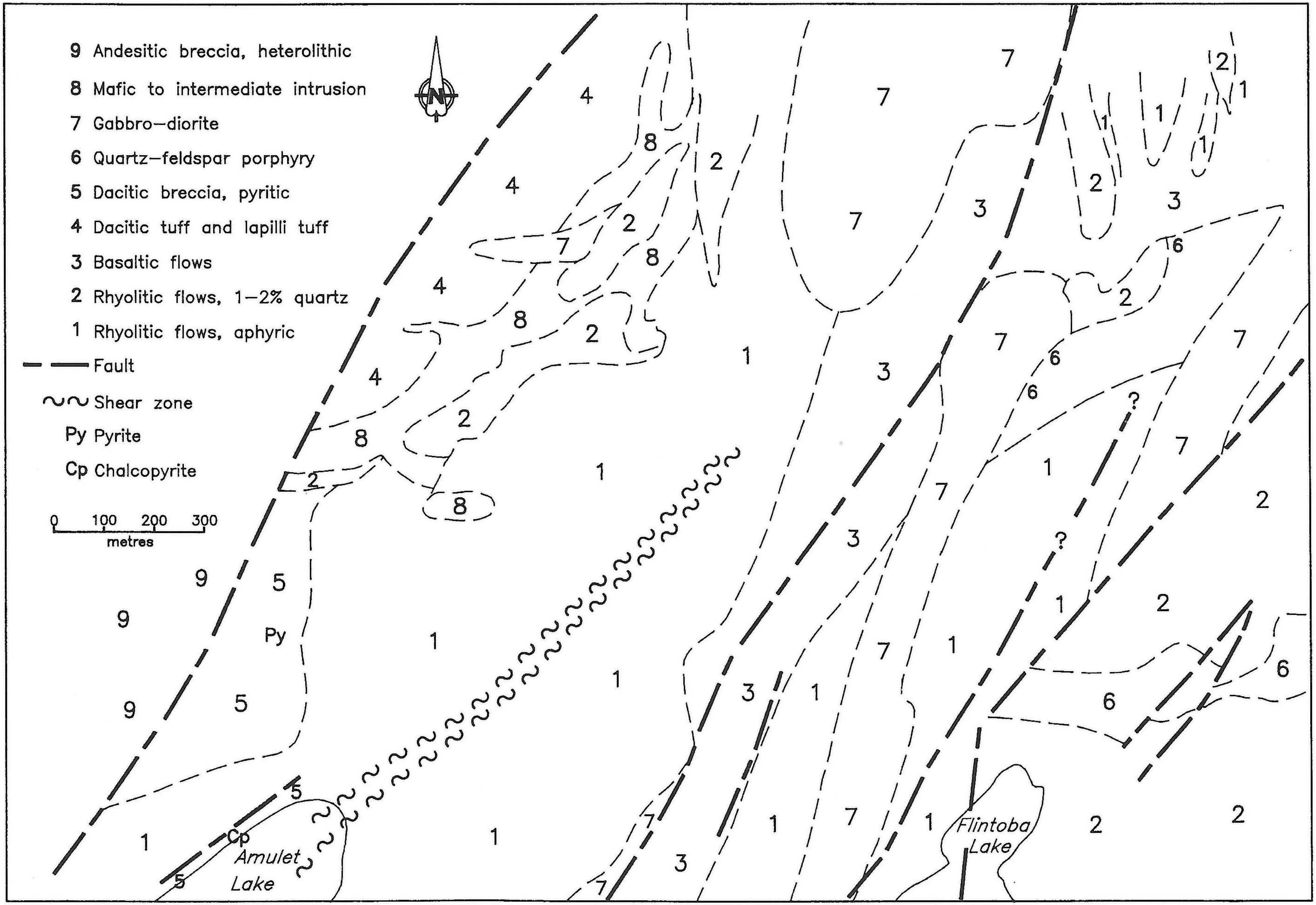

Figure GS-6-2: Geology of the Amulet Lake-Flintoba Lake area.

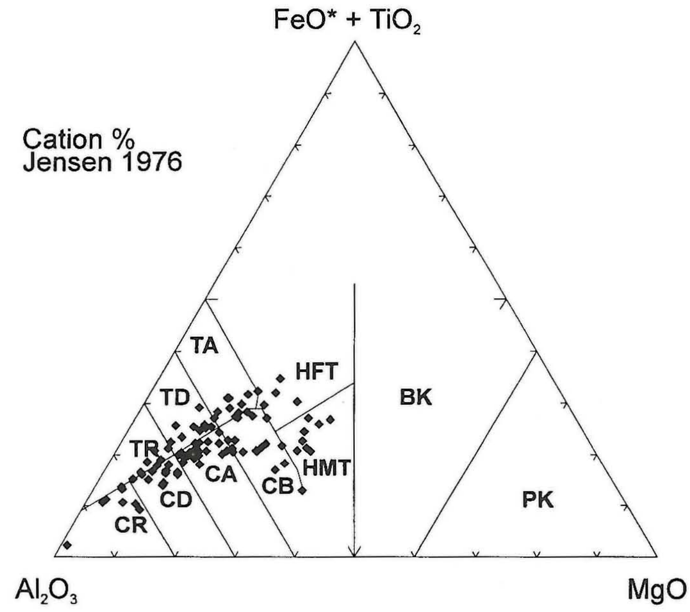

Figure GS-6-3: Cation plot of volcanic rocks from the Baker Patton Complex (fields after Jensen, 1976).

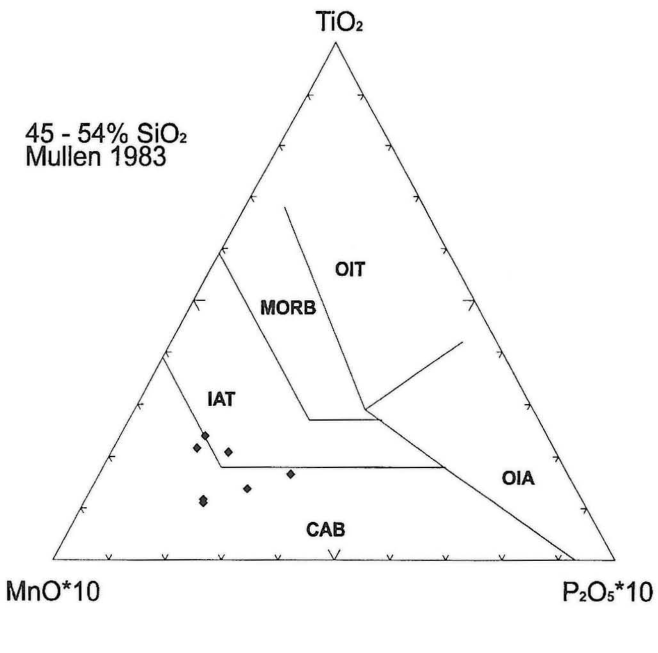

Figure GS-6-4: Discrimination diagrams for basaltic rocks from the Baker Patton Felsic Complex (after Pearce, 1968).

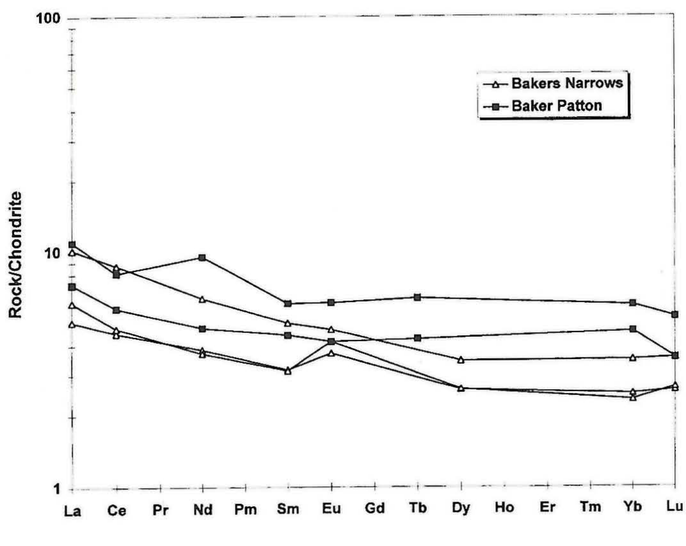

Figure GS-6-5: Rare earth element plots of basaltic rocks from the Baker Patton Felsic Complex.

GS-7 THE HOTSTONE-CLEAVER LAKE PROJECT, NORTH ARM, LAKE ATHAPAPUSKOW (NTS 63K/12)

by D.E. Prouse

Prouse, D.E., 1995: The Hotstone-Cleaver Lake project, North Arm, Lake Athapapuskow (NTS 63K/12); **in** Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 34-37 .

SUMMARY

The map area is underlain dominantly by a thick bimodal sequence of mafic and felsic volcanic flows and synvolcanic dykes. Detailed mapping has outlined a number of previously undocumented rhyolite units. Gabbro/diorite intrudes the volcanic sequence in the northeast and central portion of the map area. Granitic rocks, which include granitic quartz porphyry, intrude the predominantly mafic volcanic rocks in the central and eastern portions of the map area.

The volcanic rocks include northeast- to east-trending flows that are overprinted by a north-northeast trending schistosity. Mineralized north trending shears and faults associated with the North Arm Fault are abundant along the east shore of Thompson Bay.

INTRODUCTION

Geological mapping in 1995 continued east of Thompson Bay at the North Arm of Lake Athapapuskow. Preliminary mapping (Gale *et al.*, 1994) in the area east of the Hotstone mineral occurrence (Gale and Eccles, 1992) outlined the presence of felsic volcanic rocks in a previously undifferentiated sequence (Buckham, 1944).

The program is designed primarily to delineate lithologic units and structures at 1:5 000 scale and ultimately produce a 1:10 000 scale geological map. A portion of the project area will be mapped using cut grid lines and outcrop outline maps provided by Placer Dome Inc. The balance of the area will be mapped using 1:5 000 scale airphotos.

The project area constitutes a portion of the Bakers Narrows Block (Bailes and Syme, 1989). The project area is bounded to the west by the North Arm Fault; to the north by the fault bounding the southern margin of the Baker Patton Complex; and to the east by the granitic intrusion at Cleaver Lake and Pothook Lake (Fig. GS-7-1).

VOLCANIC ROCKS

Basalt-Andesite

Mafic flows constitute approximately 70% of the supracrustal rocks in the project area. A large proportion of the mafic rocks exposed along the east shore of Thompson Bay are composed of volcaniclastic breccia and tuff. Pillowed and massive flows constitute a small proportion by volume. Further east in the vicinity of the intrusions, massive mafic rocks are more common, but these rocks have undergone silicification and recrystallization that have partially obliterated primary textures.

Massive Flows

Massive mafic flows have a medium green to light brown weathered surface and a medium to dark green fresh surface. Typically massive flows contain 1 to 2% 1 mm vesicles that are up to 3 to 4 mm in places. Quartz, carbonate and local alkali feldspar, and rare epidote-filled amygdules together constitute 2 to 4% of the rock. Rare gas-charged flow tops 1 to 2 m thick contain 20 to 25% quartz- and quartz-carbonate filled amygdules. Massive flows are aphyric in the northern portion of the map area (Gale *et al.*, 1994) and aphyric to weakly plagioclase or pyroxene phyric in the south. Massive flows consist of an aphanitic aggregate of plagioclase, pyroxene ± amphibole, chlorite, and trace to 2% pyrite. The basaltic mafic flows usually contain a higher proportion of chlorite and amphibole than the andesitic flows.

Pillowed Flows

Well preserved pillowed flow units are sparsely exposed throughout most of the project area. Well exposed pillowed flows are usually about 5 to 20 m thick. Pillows range from 0.5 to 3.0 m long with weak to moderately amygdular cores. One exception is a highly vesicular pillowed flow unit west of "Lake 1" (Fig. GS-7-2) that contains pillows up to 3 m and vesicles up to 2 cm diameter. Pillows are usually irregular oval and less commonly pear shaped. Top indications from pillows are unreliable especially in the north and eastern portions of the map area. However, preliminary indications are that tops are towards the southeast in the central area and towards the south in the south part of the map area. Thin andesitic pillowed flows exposed just north of "Lake 1" appear to have tops towards the west.

Breccia

Breccia comprise a large proportion of the exposed volcanic rocks in the western portion of the map area. Breccia textures vary from angular and amoeboid blocks to tuff-breccia. Fragment composition is variable and tends to be restricted to dacite-andesite.

Blocky breccia weathers a medium to buff brown and contains subangular fragments up to 1 m long with smaller fragments interstitial to the larger blocks. The unit is primarily fragment supported to very weakly matrix supported. Fragments and matrix are moderately vesicular with some highly vesicular and/or amygdular zones. Amygdules range from 2 to 8 mm in diameter with quartz-carbonate and K-feldspar fillings. Blocky fragments are devitrified and commonly contain 1 to 2% magnetite and are rimmed by chlorite. The matrix to the fragments contains abundant hyaloclastite tuff and a higher percentage of amphibole and chlorite than the blocks. Blocky breccia are typically monolithic. However, the mafic fragments commonly exhibit varying textures. These breccia are considered to be products of mass wasting.

Other breccia (including amoeboid, pillow fragment, etc.) weather buff-brown to dark grey and contain subangular to subrounded fragments <1 cm to 10's of cm in diameter. The breccia are matrix supported and rarely fragment supported. The fragments contain <1 to 5% quartz ± feldspar phenocrysts. Amygdules are filled with variable amounts of quartz, carbonate, and epidote. The matrix to the fragments varies from medium green to green-black and is composed of mixture of hyaloclastite lapilli, tuff and quartz phenocrysts in a fine grained plagioclase, pyroxene and amphibole ± chlorite groundmass. Macroscopically, the matrix commonly exhibits a moderate foliation which is not visible in the fragments. These breccia are interpreted to be flow breccia.

Mafic Tuff

Mafic tuff consists of lapilli tuff and ash tuff deposits. Lapilli tuff is commonly associated with flow breccia and may occur as discrete layers with massive mafic flows. Lapilli tuff consists of a medium green matrix with subangular to subrounded buff to light green fragments. Fragments are usually 1-2% quartz or feldspar phyric.

Finer grained ash tuffs weather a buff to dark grey with a gritty texture and commonly are thinly laminated. Ash tuffs consist of an aphanitic groundmass of plagioclase with silica-carbonate cement ± interstitial amphibole.

INTERMEDIATE VOLCANICLASTIC ROCKS

Dacitic volcaniclastic rocks consisting of tuff-breccia and tuff comprise thin layers within and between mafic and felsic flow sequences. Dacite tuff varies from aphyric to 5% subrounded quartz phenocrysts set in a fine grained groundmass of plagioclase, K-feldspar and minor pyroxene. Most fine grained tuffs are thinly laminated. A dacite tuff unit on the east shore of "Lake 2" (Fig. GS-7-2) contains subrounded pumiceous fragments. This gritty, well laminated tuff contains 2 to 3% fine grained disseminated pyrite in a siliceous groundmass with biotite-rich laminae. Dacite tuff-breccia is rare. A poorly exposed section near the Thompson Bay shore exhibits subangular lapilli fragments in a beige-brown weakly vesicular intermediate matrix. This grades eastward into a flow breccia with lighter coloured subangular fragments up to 60 cm diameter in a dacitic matrix.

RHYOLITE

Relatively thick (200-300 m) units of felsic volcanic rocks are exposed along the east shore of Thompson Bay and in the area east of "Lake 1". These rhyolitic rocks consist of massive flows, lobes and hyaloclastite tuff and tuff-breccia.

Well exposed outcrops of rhyolite lobes and hyaloclastite are located on the mainland shore southeast of "Island 1". Rhyolite lobes at this location are up to 2.5 m long, subround to lenticular and contain up to 2% quartz phenocrysts. The lobes are surrounded by a green-brown hyaloclastite tuff, which is moderately to strongly amygdular and contains up to 4% black-green chlorite clots. At some locations rhyolite lobes grade into coarse breccia consisting of 75% subrounded fragments and 25% amoeboid fragments. The lobes are massive with a localized north-northwest trending fracture cleavage which is not macroscopically evident in the matrix. The hyaloclastite has a moderate to well developed north-northeast-trending schistosity.

A well exposed outcrop of massive rhyolite on the mainland 500 m southwest of "Island 1" (Fig. GS-7-2) is light beige to light green and contains <1% quartz phenocrysts. The massive flow grades laterally into rhyolite lobes and hyaloclastite.

Rhyolites east of "Lake 1" are composed of tuff, breccia and minor massive flows. The rhyolite breccia includes *in situ* breccia (phreatomagmatic ?) with 2-3 cm subangular felsic and chloritic fragments, as well as tuff breccia with rare angular lighter coloured blocks up to 50 cm. Lapilli-tuff units east of "Lake 1" consist of <2 cm fragments in a tuff matrix with 1-3% K-feldspar and <1% quartz phe-

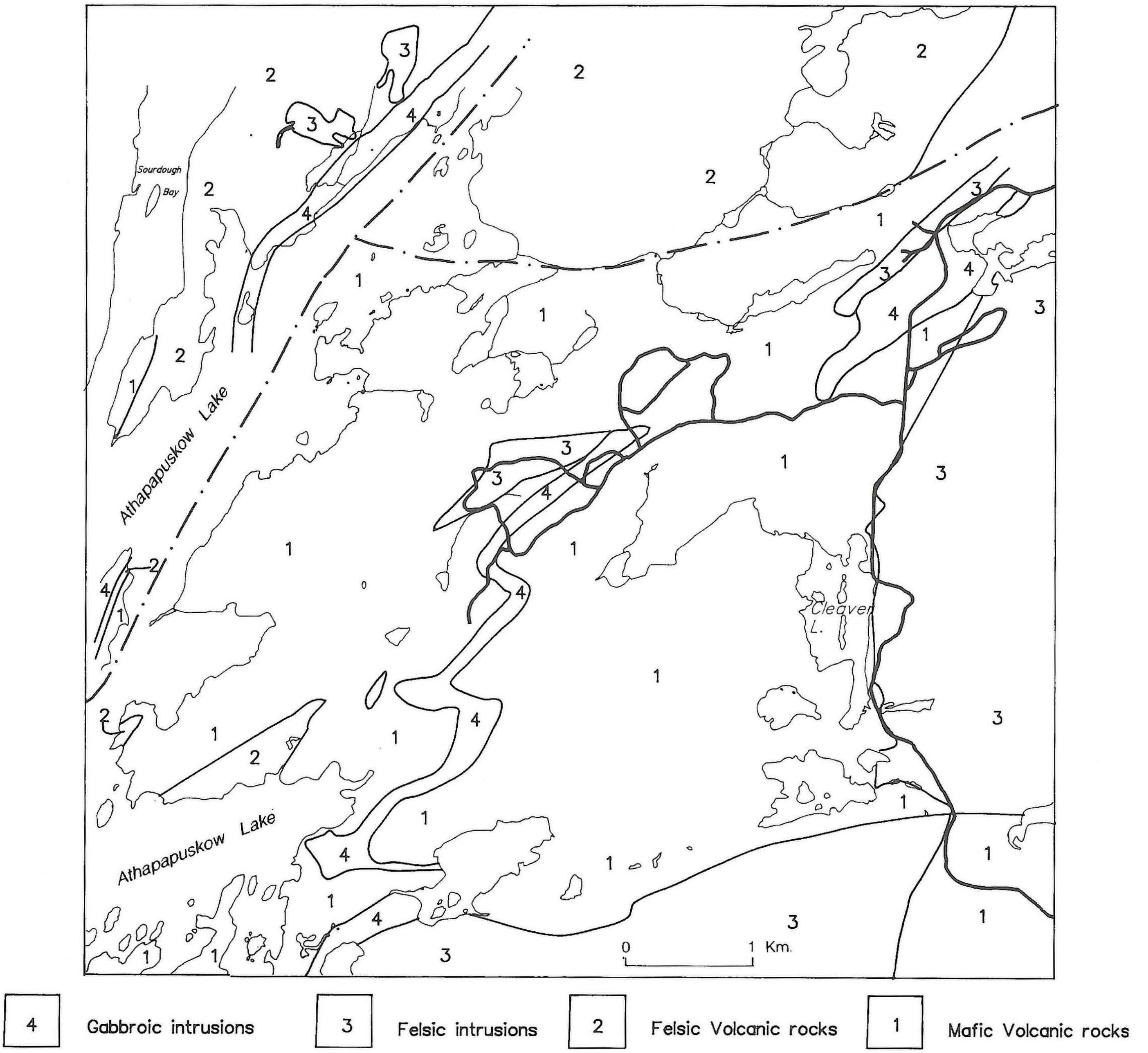

Figure GS-7-1: Location map and general geology of the Hotstone -Cleaver Lake project area.

nocrysts. A zone of altered rhyolite tuff-breccia approximately 100 m east of "Lake 1" contains discontinuous chlorite stringers (Fig. GS-7-3). Massive mafic dykes(?) with a northeast trend intrude these rhyolite units for about 500 m east of "Lake 1".

Rhyolites north of Wright Bay consist of massive flows and tuff. Massive quartz and feldspar phyric rhyolite has been intensely sheared at one well exposed outcrop. The sheared massive rhyolite contains 0.5 mm wide beige sericite streaks filling spaced cleavage planes. The north boundary is in contact (fault ?) with a highly amygdaloidal pillowed mafic flow. South of the massive and sheared rhyolite there is a distinctive white weathered tuffaceous rhyolite with 3 to 4% 1-2 mm subrounded quartz phenocrysts. This unit contains carbonate filled microfractures.

Rhyolites exposed south of "Lake 3" consist of relatively thin (10-20 m) zones of 1-2% quartz phyric massive rhyolite and rhyolite breccia. Approximately 300 m south of "Lake 3" (Fig. GS-7-2), massive rhyolite is underlain by a 40 m thick *in situ* brecciated rhyolite with a chloritized matrix. An exposure 500 m south of "Lake 3" contains a 5-10 m thick rhyolite flow breccia that grades into tuff/breccia which is underlain on its north side by massive rhyolite.

Rhyolites east of "Lake 3" consist of massive, quartz (1%) phyric dykes 0.5 to 10 m thick, which intrude massive andesite flows.

INTRUSIVE ROCKS

North and northeast of "Lake 3", fine grained gabbro and diorite intrude basaltic-andesite and quartz-feldspar phyric rhyolite dykes 1 to 5 m thick. The fine grained gabbroic intrusions are composed of plagioclase, pyroxene, amphibole plus minor K-feldspar, quartz, magnetite and pyrite. The mafic volcanic rocks contain lenticular epidote cores and stringers. Numerous rusty weathering layers with 2-3% disseminated pyrite are associated with the rhyolite dykes.

South of "Lake 2", quartz porphyritic granite-granodiorite intrudes mafic volcanic flows and diorite. This quartz porphyry unit has an orange-beige weathered surface and contains 5-20% 4-6 mm

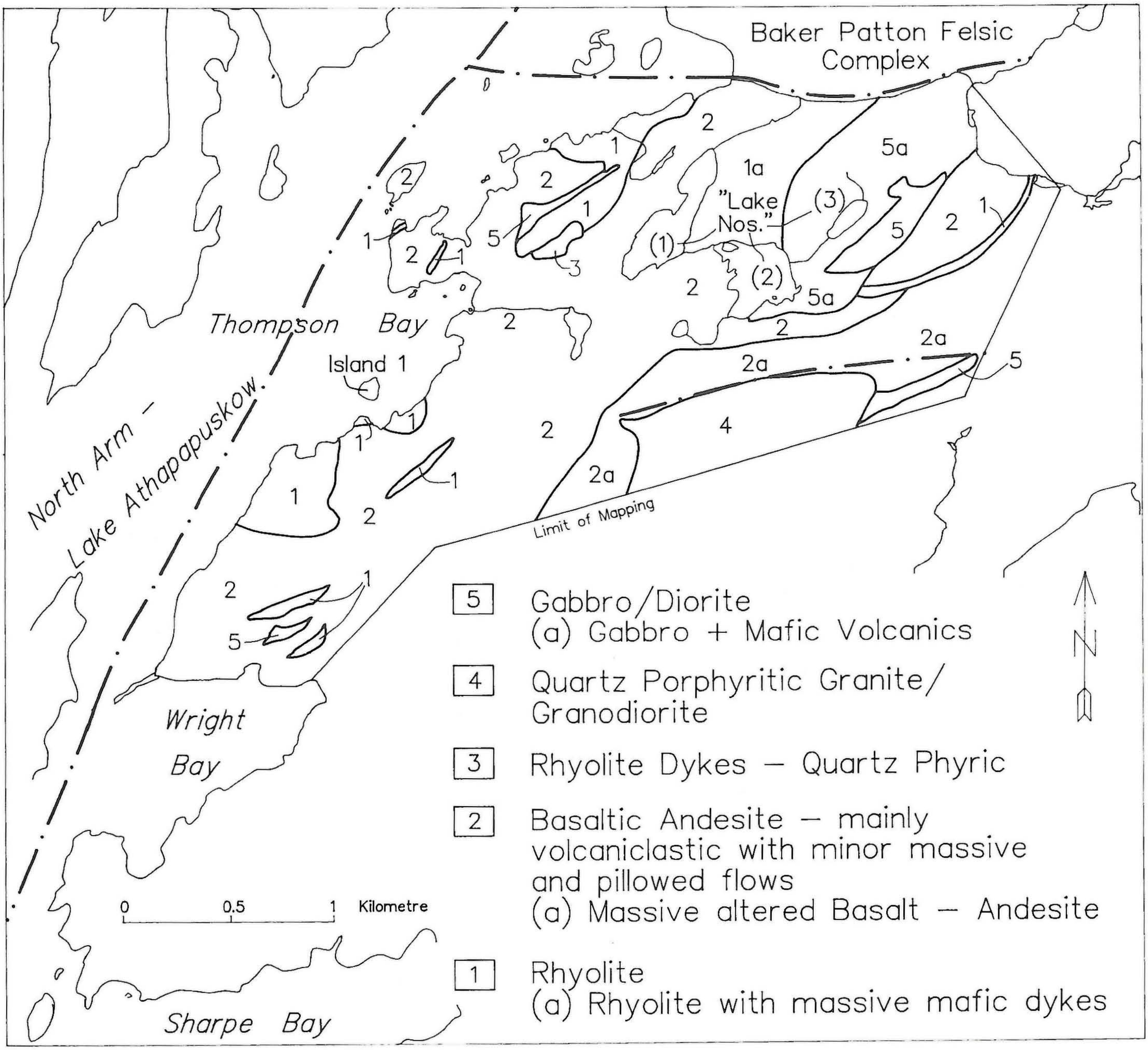

Figure GS-7-2: Simplified geology of the Hotstone-Cleaver Lake project area.

quartz phenocrysts in a medium grained groundmass of approximately 50% quartz, 20% K-feldspar, 15% plagioclase and 15% hornblende. The unit contains up to metre-size angular to subrounded xenoliths of diorite on its eastern margin, and xenoliths of mafic volcanic rocks near its fault-bounded northern boundary (Fig GS-7-2). The fault bounding the northern margin of this unit strikes almost east-west. A poorly exposed mafic flow just north of the swamp-covered fault zone exhibits a vague blocky tectonic fabric. The faulted extension of this unit is believed to be exposed in a thin linear mass that strikes northeast from the east side of Pothook Lake (Gale *et al.*, 1994)

ALTERATION AND MINERALIZATION

Rusty weathered zones associated with pyrite-mineralized shears and faults are abundant along the shore of Thompson Bay, especially in the Hotstone area. Barren sulphide lenses at or near contacts of mafic and felsic volcanic rocks or within sheared and altered rhyolitic rocks are numerous in the northern part of the map area.

A large gossan zone (approx. 130 x 25 m) 800 m southeast of "Lake 3" partially subcrops. This gossan is hosted by sheared silicified andesite with quartz veinlets. Sulphide mineralization consists of 2-4% and locally up to 10% pyrite.

An iron-magnesium alteration zone approximately 20 x 5 m occurs in an *in situ* rhyolite breccia 600 m southwest and along strike of the Hotstone occurrence. The alteration zone contains angular to subangular rhyolite fragments in a chlorite-rich matrix with a patchy quartz vein network. Chlorite alteration veins and quartz veins also occur within massive andesite and minor andesite breccia just east of Hotstone.

Chlorite patches and stringers within an altered rhyolite tuff-breccia are exposed 100 m east of "Lake 1". Approximately 50 m to the south and overlying this chlorite altered zone is a poorly exposed sulphide layer that contains 2-3% pyrite.

North of Wright Bay, massive rhyolite is strongly sheared and exhibits a narrow (0.5 cm) spaced cleavage with thin sericite stringers. Rusty weathered zones occur within the sheared rhyolite and at the contacts of highly amygdaloidal andesite. Unsheared massive rhyolite to the east contains 2-3% 1-2 mm chlorite grains in an aphanitic felsic matrix.

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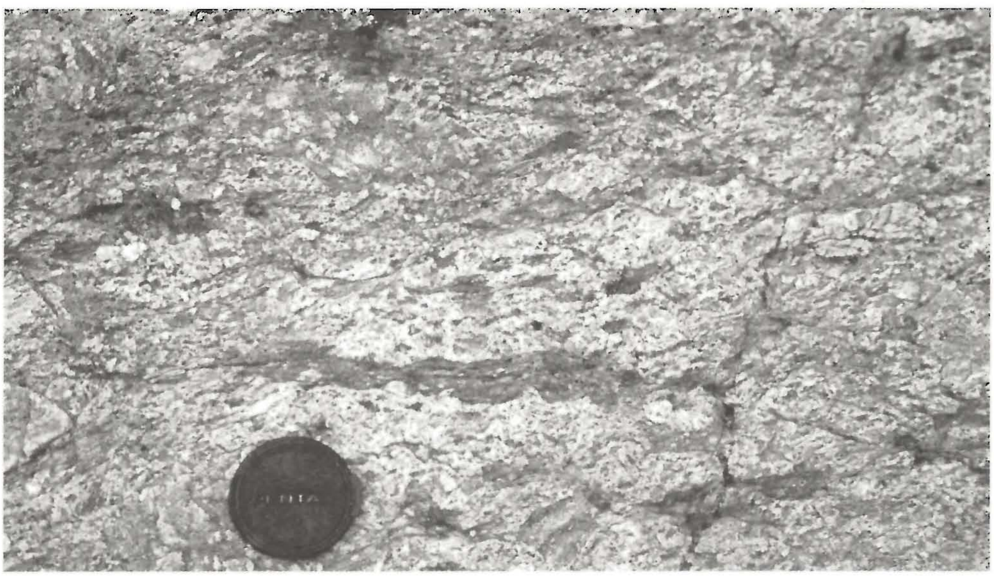

Figure GS-7-3: Discontinuous chlorite alteration veins within rhyolite tuff-breccia, 100 m east of "Lake 1".

GS-8 CALLINAN MINE PROJECT (NTS 63K/13)

by T.H. Heine, L.I. Norquay and G. Gale

Heine, T.H., Norquay, L.I., and Gale, G., 1995: Callinan mine project (NTS 63K/13); **in** Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 38.

The Callinan project, a joint investigation of the Callinan deposit by Manitoba Energy and Mines (MEM), Hudson Bay Mining and Smelting Company Ltd. (HBMS), and Hudson Bay Exploration and Development Company Ltd. (HBED), continued during this year. The goals of this investigation are to develop an understanding of the stratigraphic positions of the Callinan and Flin Flon Cu-Zn deposits and their geochemical and structural characteristics.

The digital base and geological maps for this project have been completed by HBED. Digital maps of adjacent areas mapped by Dave Thomas and supplied by Saskatchewan Energy and Mines have also been incorporated into the geological data base. After a review of this information, several areas were mapped in detail northwest of the Flin Flon smelter complex and in the vicinity of the South Main shaft. This information has been integrated with drillhole results obtained by HBED.

Several underground headings have been mapped in detail in the Callinan deposit to define the stratigraphic assemblage associated with, and to delineate structural influences on, the ore lenses. Geological information obtained from the back and rib faces has been extended by information in delineation holes drilled by HBMS.

Work is in progress to extend the structural data from the underground investigations to surface exposures. Field investigations by MEM and HBED have concentrated on the Hidden Lake mafic volcanic sequence north-northeast of the smelter complex, and the overlying Missi Group.

Future activities include completion of work in progress, additional detailed underground and surface mapping, drill core examination and integration of this information into the stratigraphic and structural framework of the area. Petrographic studies of the stratigraphic sequence associated with the deposit and geochemical investigations will be conducted when the surface and underground mapping is competed.

GS-9 GEOLOGICAL INVESTIGATIONS IN THE DION LAKE AREA (63J/13SE, 63/J14SW)

by H.P. Gilbert

Gilbert, H.P., 1995: Geological investigations in the Dion Lake area (63J/13SE, 63/J14SW); **in** Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 39-41.

SUMMARY REPORT

A two week reconnaissance mapping project investigated the stratigraphy and structure of metamorphosed volcanic and sedimentary rocks in the vicinity of Dion Lake (Gilbert, 1995). Results of this mapping are described in Manitoba Energy and Mines Open File Report OF95-7. The map area is located 34 km east-southeast of the town of Snow Lake, close to the east end of the Flin Flon-Snow Lake volcanic belt. The rocks are characterized by a medium to high grade of metamorphism and a predominantly northeast structural fabric that reflect proximity of the map area to the contact between the Flin Flon-Snow Lake volcanic belt and the Thompson Nickel Belt (Fig. GS-9-1).

The aims of the project are as follows:

(a) to determine the age and geochemical affinity of a predominantly mafic volcanic rock unit 2 km southwest of Dion Lake;
(b) to investigate the origin and age of quartzofeldspathic gneisses that are the predominant rock type in the map area;
(c) to investigate the structural geology;
(d) to investigate all mineralized localities;
(e) to assess the potential for further mapping.

Field work was conducted with the very capable assistance of D. Lobreau, who made a significant contribution to the collection and evaluation of field data. The main results of the field mapping are as follows:

(a) A southeast-trending enclave of predominantly mafic volcanic rocks southwest of Dion Lake (unit 1, Fig. GS-9-2) is lithologically similar to basalts in the Snow Lake volcanic arc assemblage; geochemical analysis is underway to investigate the affinity and possible age of these rocks.
(b) Quartzofeldspathic and quartzitic gneisses (unit 3) north, west and south of Dion Lake are derived from arkose, subordinate pebbly arkose and conglomerate. Current mapping agrees with previous reports (Cerny *et al.*, 1981; Bailes, 1985) that these rocks are part of the Missi Group.
(c) Major folds, faults and S_1 regional foliation trend mainly northeast to north-northeast. The northeast-trending sillimanite isograd within arkosic paragneisses intersects the west part of Dion Lake; regional metamorphic grade increases toward the southeast. Arkosic paragneiss and conglomerate north of Dion Lake are deformed in major east-northeast to northeast-trending F_2 folds.
(d) Base metal mineralization in quartzofeldspathic paragneisses (unit 3) at Dion Lake occurs in 1 to 10 m wide zones that are locally fault controlled. Mineralization in the basaltic enclave southwest of Dion Lake is characterized by relatively higher values of Cu and Zn (± Au and traces of Ag, Pb, Ni, and Cd) than in the paragneisses at Dion Lake. Southwest of Dion Lake the mineralization occurs in a 150-300 m wide zone that extends southeast for 2.5 km (Lee Claims Mineral Zone, LCMZ).
(e) Future mapping may profitably investigate the significance of the southeast-trending LCMZ, and investigate any geophysical anomalies that may occur where this zone is intersected by major faults. The most promising mineralization is associated with fine grained quartzofeldspathic gneiss (2a), which may be derived

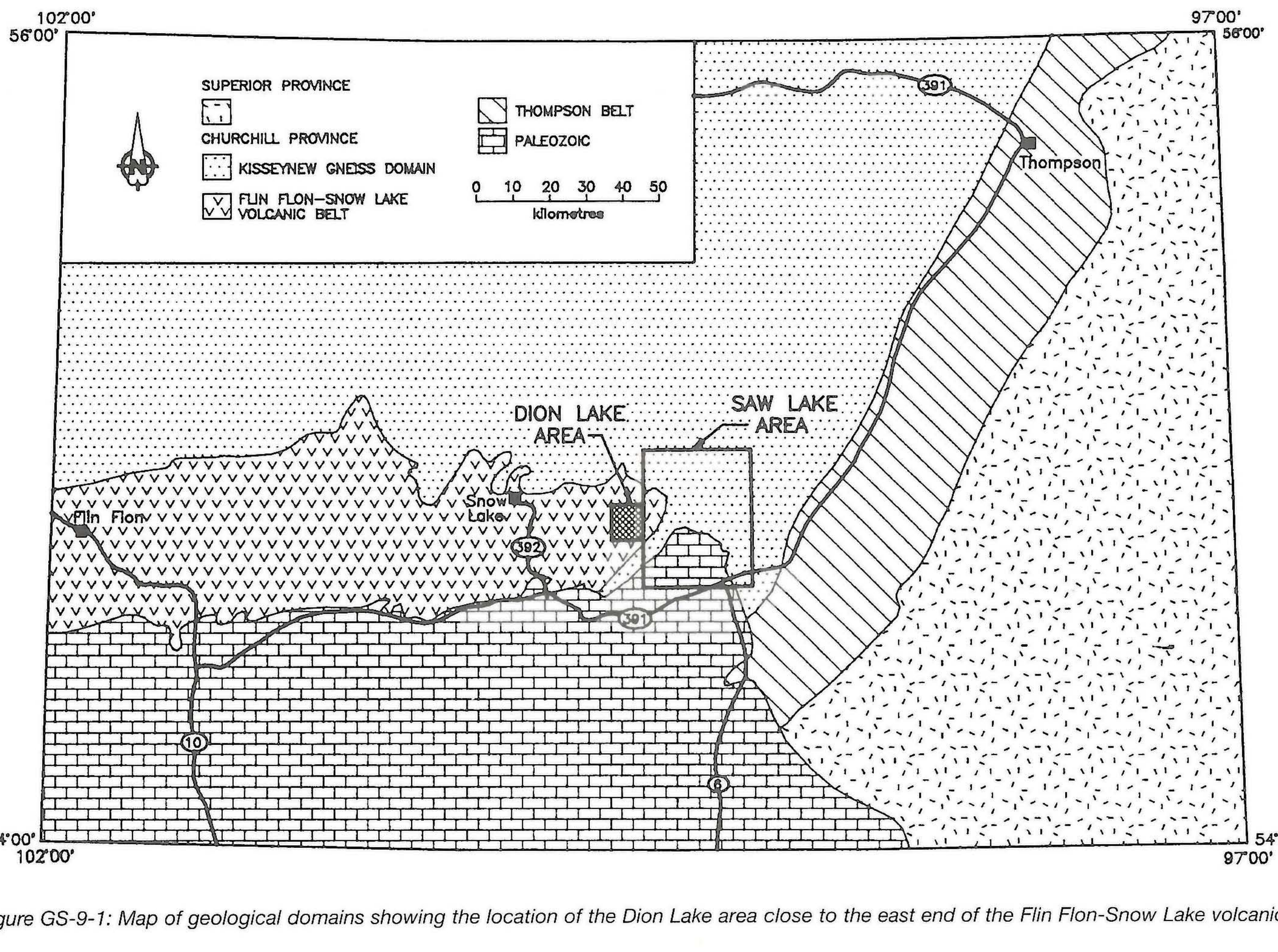

Figure GS-9-1: Map of geological domains showing the location of the Dion Lake area close to the east end of the Flin Flon-Snow Lake volcanic belt.

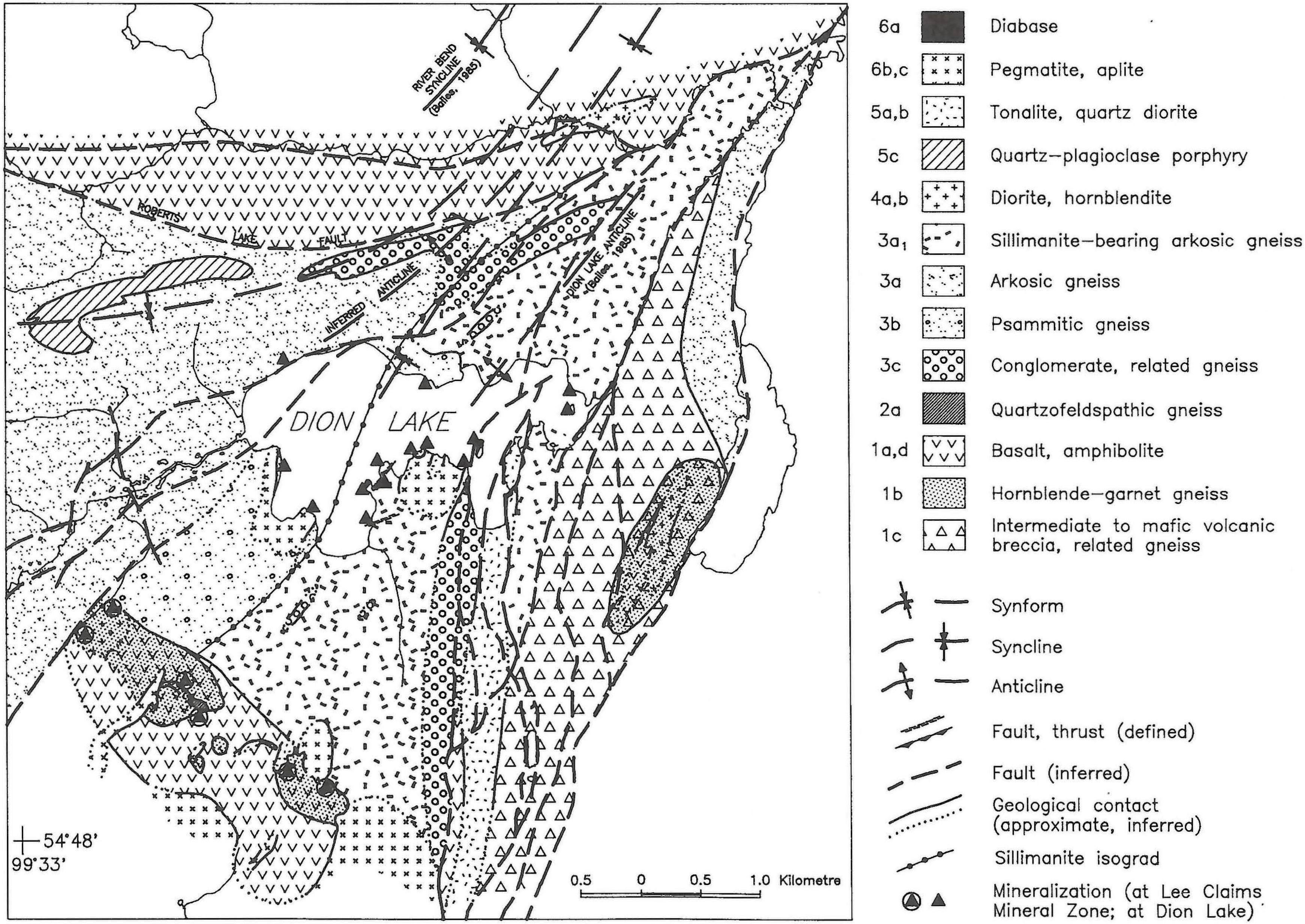

Figure GS-9-2: Generalized geological map of the Dion Lake area. Geologic unit numbers correspond to those in Map OF95-7-1.

from felsic volcanic rocks, and coarse grained hornblende-garnet ± biotite gneiss (1b) of possible alteration zone origin, which occurs in the LCMZ and in a north-northeast trending unit east of Dion Lake.

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Gilbert, H.P.
1995: Dion Lake (Part of NTS 63J/13 and 14); Manitoba Energy and Mines, Open File OF95-7-1, 1: 20 000.

GS-10 GEOLOGY OF THE REED LAKE AREA (PARTS OF 63K/9 AND 63K/10)

by E.C. Syme[1], A.H. Bailes[1] and S.B. Lucas[2]

Syme, E.C., Bailes, A.H. and Lucas, S.B., 1995: Geology of the Reed Lake area (Parts of 63K/9 and 10); in Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 42-60.

SUMMARY

A collaborative Manitoba - GSC mapping project in the Reed Lake-Tramping Lake area produced significant new information that necessitates a re-interpretation of the geology in this critical part of the Paleoproterozoic Flin Flon belt. A major (kilometres wide), regionally extensive tectonite belt exposed on western Reed Lake (West Reed-North Star shear zone) juxtaposes rocks of oceanic affinity on the west (Reed Lake mafic-ultramafic complex) with rocks of arc affinity on west-central Reed Lake (Fourmile Island assemblage). It thus marks the eastern termination of a broad belt of volcanic and plutonic rocks of ocean floor character (Elbow-Athapap assemblage). Further, the Reed Lake map area is split into two domains by the Morton Lake fault zone, defining the leading edge of Kisseynew allochthons. The Morton Lake fault zone juxtaposes a footwall (autochthonous) domain, comprising the Fourmile Island assemblage, West Reed-North Star shear zone and Reed Lake mafic-ultramafic complex, and a hanging wall (allochthonous) domain, consisting of the oceanic-affinity Northeast Reed assemblage, the composite Reed Lake pluton, and the Snow Lake arc assemblage. The fault zone itself includes a slice of File Lake Formation greywacke turbidites. These relations are significant in that they suggest that the Snow Lake arc assemblage is contained in a southwest-verging allochthon emplaced after deposition (*ca.* 1.84 Ga) of the File Lake Formation. This structural interpretation is consistent with earlier suggestions (based on lithologic, geochemical and isotopic criteria) that the Snow Lake and Flin Flon VMS camps are unrelated and represent remnants of different and distinct volcanic arcs that have been structurally juxtaposed.

INTRODUCTION

The central part of the Flin Flon Belt, Manitoba and Saskatchewan, is a collage composed of 1.92-1.88 Ga tectonostratigraphic assemblages juxtaposed during a period of 1.88-1.87 Ga intraoceanic accretion (Lucas and Stern, 1994; Stern and Lucas, 1994; Lucas *et al.*, in press). The NATMAP Shield Margin Project working group has termed this the 'Amisk collage', replacing existing stratigraphic terminology for the metavolcanic rocks in the Flin Flon belt (*e.g.*, Lucas *et al.*, in press). Tectonostratigraphic assemblages within the Amisk collage include juvenile arc, juvenile ocean floor, ocean plateau/ocean island basalt, evolved arc, and Archean crustal slices (Syme and Bailes, 1993; Reilly *et al.*, 1994; Stern *et al.*, 1995a, 1995b; David and Syme, 1995; Lucas *et al.*, in press; Fig. GS-10-1). The Amisk collage formed the basement during 1.87-1.83 Ga post-accretion magmatism, expressed as voluminous calc-alkaline plutons and rarely preserved calc-alkaline to alkaline volcanic rocks (Lucas *et al.*, in press).

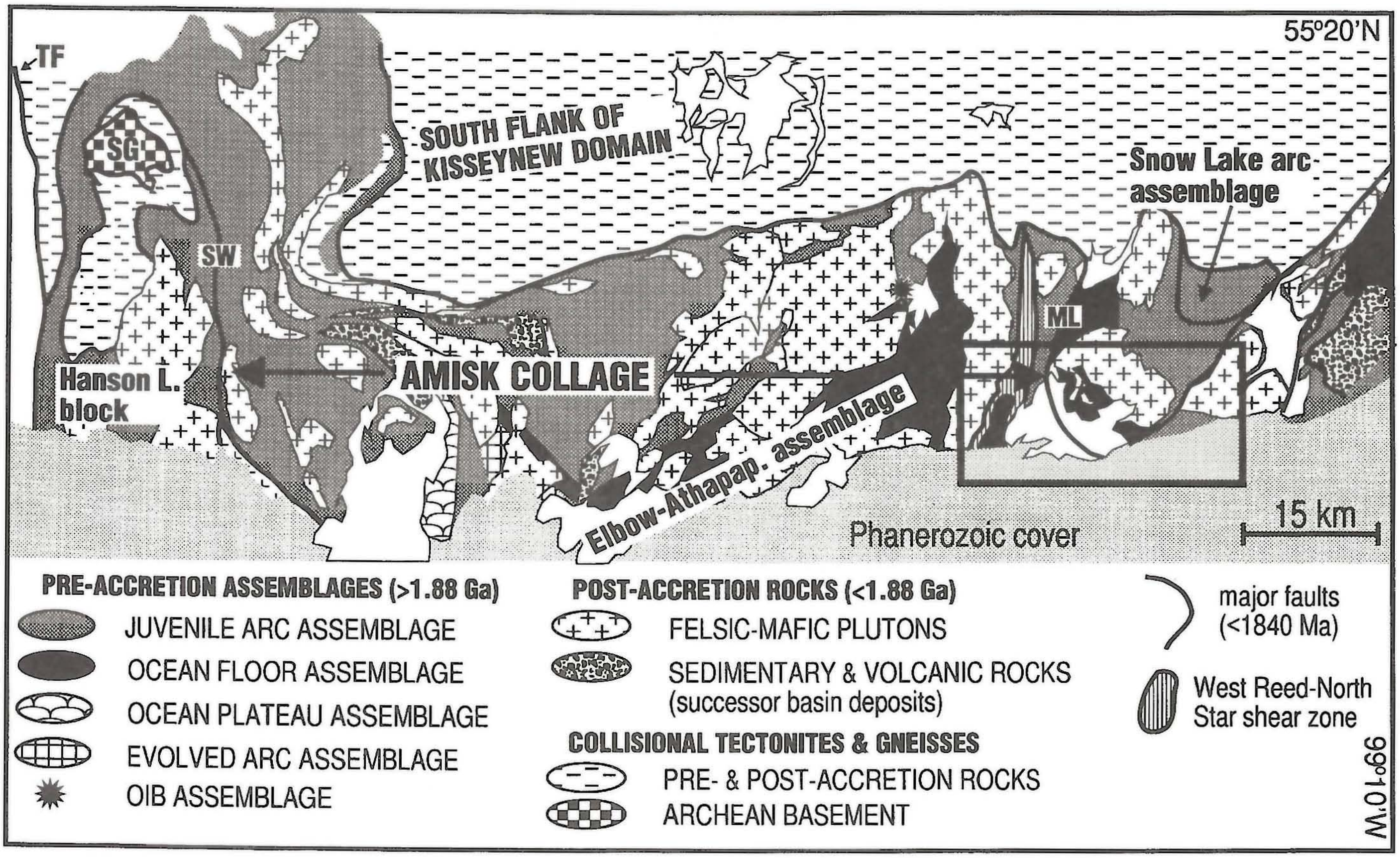

Figure GS-10-1: Map of the Flin Flon belt showing major tectonostratigraphic assemblages and plutons. The Flin Flon belt is structurally sandwiched between the overriding south flank of the Kisseynew domain and Snow Lake arc assemblage and the underlying Hanson Lake block. The location of the Amisk collage and location of the Reed Lake area (Preliminary Map 1995F-1; heavy rectangle) are indicated. ML: Morton Lake fault; SW: Sturgeon-Weir shear zone; TF: Tabbernor fault.

[1] Manitoba Energy and Mines, Geological Services Branch

[2] Geological Survey of Canada

Younger sedimentary and subordinate volcaniclastic and volcanic rocks (1.85-1.83 Ga; *e.g.,* Missi Suite, File Lake Formation) may represent depositional basins that formed contemporaneous with post-accretion ('successor') arc magmatism and deformation (Lucas *et al.*, in press; Ansdell *et al.*, in press).

A fundamental problem in the eastern part of the Flin Flon belt has been the relation between the Amisk collage, which includes the Flin Flon arc assemblage and contained VMS deposits, and the arc-type metavolcanic rocks at Snow Lake (Fig. GS-10-1). An extensive tract of ocean floor (MORB-like) basalts and associated mafic and ultramafic rocks lies between the Flin Flon and Snow Lake segments of the belt (Elbow-Athapap assemblage, Fig. GS-10-1), and is interpreted as having a back-arc basin origin (Stern *et al.*, 1995b; Lucas *et al.*, in press; Syme, in press). Significant stratigraphic, geochemical and isotopic differences between the arc rocks at Flin Flon and those at Snow Lake (Stern *et al.*, 1995a) suggest that these segments may represent the remnants of unrelated arcs (Lucas *et al.*, in press). In order to understand the nature of the 'contact' between the Amisk collage *sensu stricto* and the Snow Lake segment, a four-week reconnaissance study in the critical Reed Lake portion of the Flin Flon belt (NTS 63K/9 and 63K/10E; Fig. GS-10-1) was conducted as a joint Manitoba Geological Services Branch-Geological Survey of Canada study.

Preliminary Map 1995F-1 (Syme *et al.*, 1995) is a compilation of existing maps and information obtained this season. The geology of the supracrustal rocks is based on Rousell (1970) and Stanton (1945), but was extensively modified as a result of this project, when the extensive shoreline outcrop on Reed Lake was re-mapped during unusually low water conditions. Morrison and Whalen (1995) reported on mapping of the granitoid rocks in 63K/10; a simplified version of their map is included in Preliminary Map 1995F-1.

SUPRACRUSTAL ROCKS

Prior to re-mapping in 1995 the supracrustal rocks on Reed Lake were simply subdivided into mafic volcanic, volcaniclastic and sedimentary lithologies (Stanton, 1945; Rousell, 1970). Our work has identified tectonostratigraphic packages (Fig. GS-10-2) similar to those in the Snow Lake area and the Amisk collage to the west: (1) a succession of mafic, intermediate and felsic flows and volcaniclastic rocks in western Reed Lake, termed the Fourmile Island assemblage and interpreted to have a juvenile arc affinity; (2) a sequence of monotonous pillow basalts in northern and eastern Reed Lake, termed the Northeast Reed assemblage and interpreted to have a juvenile ocean floor basalt affinity; and (3) a narrow package of greywacke turbidites that separates the two volcanic assemblages and represents the strike-equivalent of the File Lake Formation (Bailes, 1980) mapped to the north on Morton Lake. In the following sections, the field characteristics of these stratigraphic packages will be described, as well as the basis for preliminary interpretation of their tectonic affinity.

Fourmile Island assemblage

Metavolcanic rocks of the Fourmile Island assemblage occur on western Reed Lake (Fig. GS-10-2). They are separated from the Reed Lake mafic-ultramafic complex by a wide zone of heterogeneous tectonite (West Reed-North Star shear zone), and are bounded on the east by the Morton Lake fault zone, containing a slice of File Lake Formation turbidites. The Fourmile Island assemblage includes at least 5.5 km of subaqueous volcanic stratigraphy in west-central Reed Lake, comprising six lithologic units (A-F, Fig. GS-10-3). The upper and lower contacts of the assemblage are faults/shear zones, which are discussed below (*Structure).* The metavolcanic rocks are intruded by a thick (975-1585 m), compositionally zoned Josland Lake sill (see below). The lithologic characteristics of the six principal stratigraphic components of the Fourmile Island assemblage are summarized here in ascending stratigraphic order. In the area northwest of Fourmile Island (Fig. GS-10-2), the younging direction throughout the sequence is to the north. The rocks contain lower-middle greenschist facies regional metamorphic mineral assemblages.

Unit 'A' (>350 m thick) comprises poorly exposed pillowed and massive, grey-green aphyric mafic flows with pervasive epidote alteration.

Unit 'B' (150 m) is a heterolithologic breccia dominated by aphyric and plagioclase phyric, subrounded, amygdaloidal, intermediate to mafic clasts (2-40 cm). The breccia also contains sporadic angular quartz-feldspar phyric rhyolite cobbles and boulders up to 1 m across. The unit is poorly sorted, thick bedded, contains rare fine grained (sandy) interbeds and thin intermediate-mafic pillowed flows, and is interpreted as a sequence of proximal subaqueous debris flows.

Unit 'C' (365 m) is a highly heterogeneous unit dominated by thin, pillowed, aphyric and plagioclase phyric, buff-brown weathering, intermediate-mafic flows and related amoeboid pillow breccia. The flows are cut by synvolcanic (locally pillowed) dykes of similar composition, and are intercalated with rare interbeds of chert-hematite iron formation. The sequence includes a thick (150 m) unit of coarsely quartz-feldspar phyric rhyolite interpreted as an exogenous felsic dome, on the basis of its low strike-length to thickness ratio and fragmental nature. The rhyolite was sampled for U-Pb zircon geochronology in order to determine the age of the Fourmile Island assemblage felsic volcanism.

Unit 'D' (550 m) is also heterogeneous but is dominated by intermediate-felsic fragmental rocks. The contact with the underlying unit ('C') is gradational. The base of this sequence at least locally is a quartz-feldspar phyric rhyolite flow or dome that grades upward into a well defined felsic breccia. The basal part of unit 'D' also contains thin pillowed flows of mafic-intermediate composition. The proportion of rhyolite clasts decreases up section, with an increasing abundance of plagioclase phyric andesite clasts. Felsic (rhyolite-dacite) clasts are only about 10% of the uppermost part of the volcaniclastic section. The top of the sequence contains thin-bedded tuffs with pebble to sand grain size. The heterogeneous suite of intermediate clasts that dominate the breccias in the main part of the unit are granule-size to 40 cm, and vary from rounded to angular (Fig. GS-10-4). The breccias are matrix-supported and thick-bedded, suggesting that they were deposited from subaqueous debris flows, possibly shed from a subaerial volcanic centre into an adjacent basin.

Unit 'E' (700 m) is composed of grey-green to green weathering, aphyric, pillowed and massive mafic flows. Unlike the gradational contact between units 'C' and 'D', unit 'E' flows abruptly overlie unit 'D' and contain no intercalated andesitic volcaniclastic rocks. The 'D'-'E' contact therefore signals an abrupt change in volcanic style and composition. Flows in the sequence are commonly characterized by large (metre-scale) pillows and carbonate-filled amygdales. Massive flows have amoeboid pillow breccia flow tops (Fig. GS-10-5). Rhyolite dykes up to 100 m wide cut the mafic sequence at a high angle, presumably as feeders to (unexposed) felsic volcanic rocks higher in the sequence. Pillowed flows in the western part of the unit are pervasively epidotized and weather in positive relief relative to recessive (carbonate-rich?) interpillow material. Elsewhere, some of the flows in unit 'E' display selective silicification of pillow margins. The top of unit 'E' is defined arbitrarily as the base of the overlying, concordant Josland Lake sill.

Unit 'F' (>3350 m) occurs on the northeast side of the Josland Lake sill and may represent a continuation of unit 'E'-type mafic volcanic rocks, although the sill and general lack of exposure render the correlation difficult. It is composed of pillowed and subordinate massive mafic flows, and is cut by fine grained diabase dykes. The flows are aphyric to plagioclase phyric, with varying amounts of quartz-, epidote- or carbonate-filled amygdales. In the upper part of the section many flows are variably silicified, with silicification concentrated in pillow margins, flow tops and amoeboid pillows.

South of Fourmile Island, a northwest-trending, northeast-younging sequence can be approximately correlated with units defined in the more continuous stratigraphy described above (Fig. GS-10-3). The section is truncated to the north and south by faults or plutons, and has not been observed in stratigraphic continuity with the volcanic rocks to the north and west of Fourmile Island. The stratigraphic sequence consists of >900 m of intermediate-mafic volcaniclastic rocks (mainly aphyric and plagioclase phyric amoeboid pillow breccia; possibly equivalent to unit 'B' above), 700 m of pillowed mafic flows (unit 'C'?), and 500 m of felsic breccia and presumably cogenetic quartz-feldspar porphyry dikes and sills (unit 'D'?). Whereas there are gross similarities to the 'type' Fourmile Island assemblage stratigraphic succession documented above, there are sufficient differences to

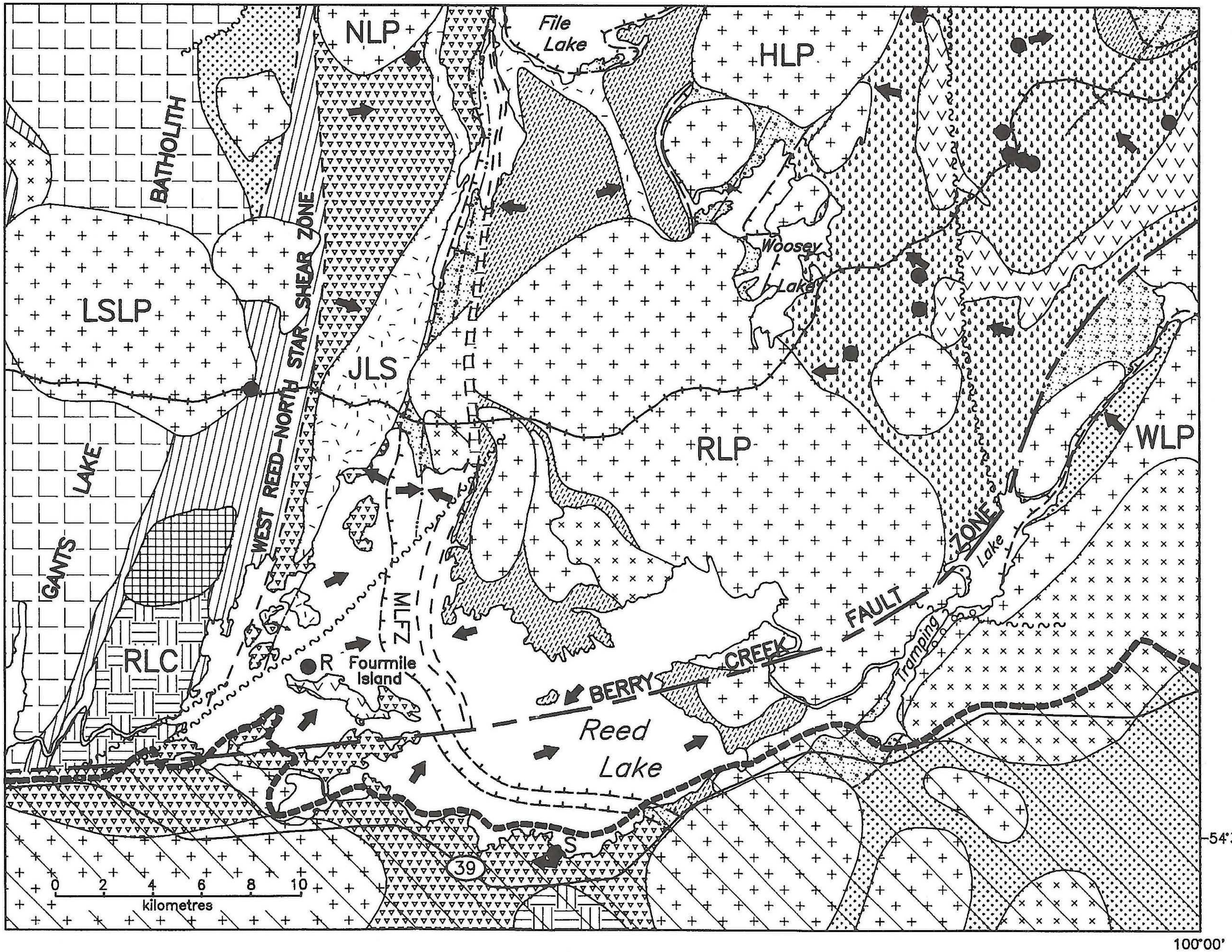

Figure GS-10-2: Generalized geology of the Reed Lake-Morton Lake-Tramping Lake area, modified from Stanton (1945), Rousell (1970), Bailes et al. (1994) and Morrison and Whalen (1995). Intrusive rocks: RLC: Reed Lake mafic-ultramafic complex; JLS: Josland Lake sills; LSLP: Little Swan Lake pluton; NLP: Norris Lake pluton; RLP: Reed Lake pluton; HLP: Ham Lake pluton; WLP: Wekusko Lake pluton. MLFZ: Morton Lake fault zone. Sub-Phanerozoic geology modified from Manitoba Energy and Mines (1992). S: Spruce Point Cu-Zn deposit; R: Reed Lake Cu deposit.

LEGEND

INTRUSIVE ROCKS

<1.84 Ga granite, granodiorite and tonalite
RLP: Reed Lake pluton
HLP: Ham Lake pluton
WLP: Wekusko Lake pluton
LSLP: Little Swan Lake pluton
NLP: Norris Lake pluton

<1.84 Ga gabbro, diorite and quartz diorite

<1.85–1.84 Ga layered gabbro sills
JLS: Josland Lake sill

<1.86 Ga granite, granodiorite and tonalite

TECTONITE

D2 shear zones
MLFZ: Morton Lake Fault Zone

D1–D3a West Reed–North Star shear zone

POST ACCRETION SEDIMENTARY ROCKS

Missi suite fluvial–alluvial sandstone and conglomerate (ca.1.85–1.84 Ga)

File Lake Formation turbidites (ca. 1.85–1.84 Ga)

ARC ASSEMBLAGES

Subvolcanic tonalite plutons (ca. 1.89 Ga)

Fourmile Island assemblage

Snow Lake assemblage (ca. 1.89 Ga)

Other arc assemblages

OCEAN FLOOR ASSEMBLAGES

Reed Lake mafic–ultramafic complex; layered series, massive gabbro

Northeast Reed assemblage basalt

SUB–PHANEROZOIC ROCKS

Felsic plutonic rocks

Intermediate to mafic plutonic rocks

Ultramafic rocks

File Lake Formation turbidites

Metavolcanic rocks

SYMBOLS

Facing direction

VHMS base metal deposits
R: Reed Lake
S: Spruce Point

North limit of Phanerozoic rocks

Discrete D5 fault

Ductile–brittle D3–D5 shear zone

D2 fault

Boundary of shear/tectonite zone

Folds (unknown age, F2, F3)

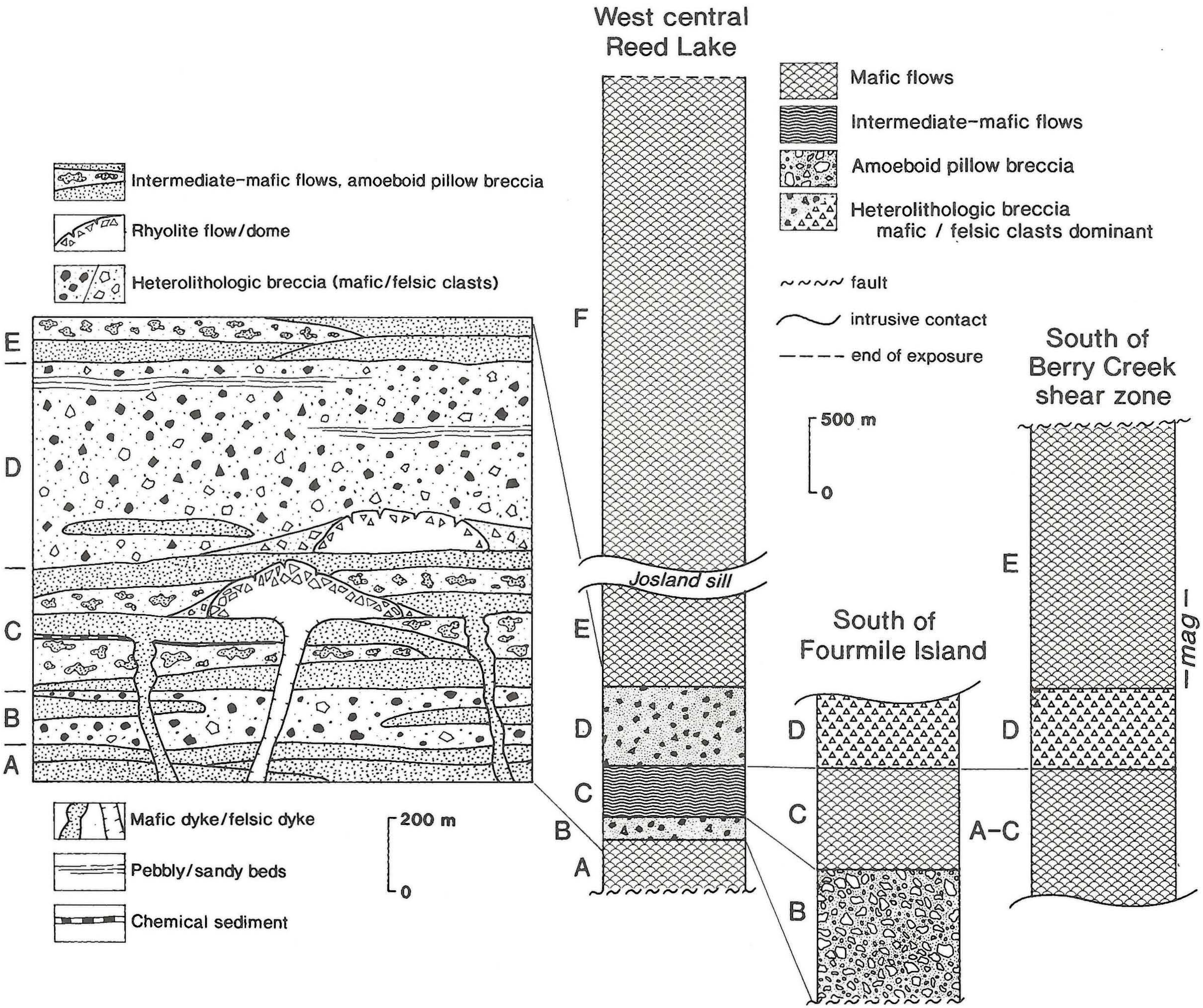

Figure GS-10-3: Stratigraphic sections through the Fourmile Island assemblage, western Reed Lake. The west-central section is separated by a fault from the sequence south of Fourmile Island. The Fourmile Island section is in turn transected by the dextral Berry Creek shear zone (BCSZ); the illustrated section south of the BCSZ is exposed on and south of Bartlett Point. Mafic flows with a high magnetic response are designated 'mag' (see text for discussion). A schematic facies representation of the volcanic and volcaniclastic rocks in units 'B', 'C', and 'D' on west-central Reed Lake demonstrates the complex relations in this part of the arc assemblage.

make direct correlation impossible. For example, unit 'D' south of Fourmile Island is felsic in composition and includes both breccias and dykes, whereas unit 'D' volcaniclastic rocks northwest of Fourmile Island contains mainly intermediate-mafic clasts. Nevertheless, we have interpreted this package as belonging to the Fourmile Island assemblage.

Volcanic stratigraphy south of the Berry Creek shear zone can be related in a general sense to that to the north (Fig. GS-10-3). South of the shear zone, the stratigraphic sequence trends northwest and tops to the northeast, as it does to the north. The sequence consists of (from oldest to youngest) >900 m of mafic flows (possibly equivalent to units 'A'-'C' above), 550 m of felsic breccia and synvolcanic felsic dykes (unit 'D'?), and >1800 m of massive and pillowed mafic flows (units 'E'-'F'?). Direct correlation of units across the Berry Creek zone is hampered by poor exposure and high strain. Massive flows correlated with the base of unit 'E'-'F' display a distinctive high magnetic signature on a vertical gradient map (Geological Survey of Canada, 1983). In outcrop, this 600-700 m thick magnetic zone corresponds with a sequence of grey-green- to green-weathering, thick, aphyric, massive basalt flows with strongly amygdaloidal flow tops and prominent flow-top amoeboid pillow breccias. This unit of magnetically anomalous, massive basalts has no direct equivalent north of the Berry Creek shear zone. A test of the correlation depicted in Figure GS-10-3 is whether the geochemical characteristics of members in the three stratigraphic sections are similar; these analyses are in progress.

The volcanic stratigraphy of the Fourmile Island assemblage is similar to that of the juvenile arc assemblages in the Flin Flon Belt (*e.g.*, West Amisk, Flin Flon, Snow Lake assemblages; Syme and Bailes, 1993; Syme *et al.*, 1993; Reilly *et al.*, 1994; Bailes and Galley, in prep.; Lucas *et al.*, in press). Geochemical study of the mafic volcanic rocks is required to establish the tectonic affinity of the assemblage; reconnaissance geochemical analysis of some of the Fourmile Island assemblage has indicated an arc signature (Williamson, 1994). In detail, the Fourmile Island assemblage bears no direct correlation with arc stratigraphy at Flin Flon (*e.g.,* Bailes and Syme, 1989; Syme, 1990) or Snow Lake (*e.g.,* Bailes and Galley, in prep.). However, the presence of widespread silicification of mafic flows in units 'E' and 'F' bears some similarities with the widespread stratiform silicification at Snow Lake (Bailes, 1987).

The Fourmile Island assemblage stratigraphy is interpreted as a relatively proximal subaqueous arc succession (*cf.* Williams and McBirney, 1979), dominated by thick mafic flows and synvolcanic dykes. Felsic-intermediate volcaniclastic units 'B', 'C', and 'D' are interpreted as calc-alkaline intra-arc basinal deposits. However, these units also appear to have been deposited proximal to volcanic centres, as suggested by the presence of synvolcanic feeder dykes, lava flows and felsic exogenous domes within the dominantly fragmental sequence.

Northeast Reed assemblage

An areally extensive sequence of well exposed pillowed basalt was mapped on northern to eastern Reed Lake. This mafic volcanic sequence, distinguished by its lithological homogeneity, has been termed the Northeast Reed assemblage (Fig. GS-10-2). It is similar in field character to basalt sequences of the Elbow-Athapap ocean floor assemblage (Syme, 1994, in press; Stern *et al.*, 1995b; Fig. GS-10-1), and on this basis is tentatively interpreted as having an ocean floor affinity. Sampling was undertaken for a detailed geochemical assessment of the Northeast Reed basalts.

The sequence of pillowed basalt is approximately 4.3 km thick; neither the base nor the top of the section is exposed. On north-central Reed Lake the basalts trend north to northwest and young to the west. More than 90% of the exposed flows are pillowed; massive flows are rare, volcaniclastic rocks are absent, and the basalts are intruded by rare diabase dykes or sills. Flows weather dark grey-green and are composed of generally small- to medium-sized, round, irregular or bun-shaped pillows. The pillows are marked by narrow dark green selvages, few amygdales, and thin epidote-replaced interpillow hyaloclastites (Fig. GS-10-6). Interpillow chert, radial pipe vesicles, and stacked pillow drainouts do occur but are not common. Most of the flows are aphyric, but there are some interlayered plagioclase phyric flows that are in sharp contact with the aphyric ones. The basalts contain a lower-middle greenschist facies regional metamorphic mineral assemblage, and an older, middle greenschist-lower amphibolite facies assemblage in a thermal aureole around the Reed Lake pluton.

North of the Reed Lake pluton, similar aphyric pillowed to massive basalt is exposed between Morton, File and Woosey lakes (Fig. GS-10-2). We interpret this sequence to be correlative with the Northeast Reed assemblage; this correlation, and the overall interpretation that the sequence has a ocean floor tectonostratigraphic affinity, is being tested through a regional basalt geochemistry study.

Reed Lake mafic-ultramafic complex

The Reed Lake complex is a 4x10 km, compositionally zoned, mafic-ultramafic plutonic body (*Reed Lake pluton:* Young and Ayres, 1985; Ayres and Young, 1989; Young, 1992) that occurs west of Reed Lake (Fig. GS-10-2). It may be correlative with lithologically similar massive and layered gabbro-ultramafic complexes exposed on Elbow Lake, Claw Lake, Iskwasum Lake and Athapapuskow Lake (Syme, 1991, 1992, 1994; Syme and Morrison, 1994), and associated with the Elbow-Athapap ocean floor assemblage (Stern *et al.*, 1995b). The latter, kilometre-scale bodies are interpreted as dismembered synvolcanic plutonic complexes (Stern *et al.*, 1995b), overlapping in age (1901 Ma) and geochemically related to basalts of the ocean floor assemblage (1904 Ma; Stern *et al.*, 1995b). The Reed Lake mafic-ultramafic complex has also been interpreted to be synvolcanic (Young and Ayres, 1985; Ayres and Young, 1989), but there are no U-Pb zircon age

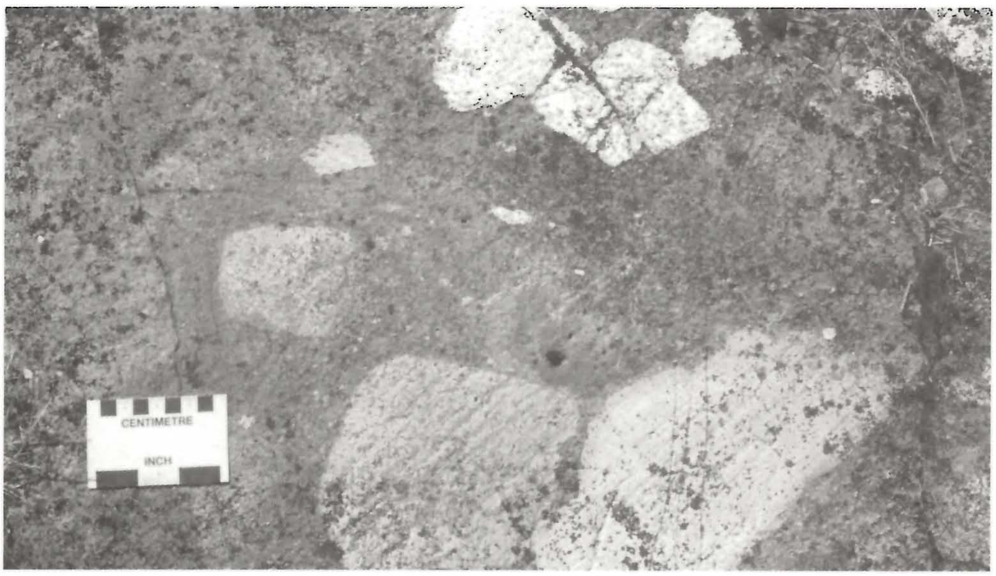

Figure GS-10-4: Heterolithologic volcanic breccia containing plagioclase phyric intermediate and quartz phyric rhyolite clasts, unit 'D', Fourmile Island assemblage, west-central Reed Lake.

determinations available. Close lithologic similarities with the superbly exposed Claw Lake mafic-ultramafic complex (Syme, 1992), dated at 1901 Ma (Stern *et al.*, 1995b), form the basis for suggesting that the Reed Lake pluton may be similar in age.

Interpretation of the tectonic significance of the Reed Lake mafic-ultramafic complex is crucial for understanding the assembly of the central Flin Flon belt. The complex is not well exposed, obscured by moss and lichen, and was not examined in any detail during this study except along its eastern tectonic boundary. Accordingly, the following description relies heavily on studies by Young (1992), Williamson (1992, 1993), and Williamson and Ekstrand (this volume).

The Reed Lake mafic-ultramafic complex has a near vertical orientation and has consistently tops to the west as indicated by cumulate layering/differentiation relationships (Young, 1992). As the east and west contacts of the complex are tectonic, its primary stratigraphic relationships with adjacent volcanic rocks are unknown. The eastern and western contacts are marked by an increase in strain and a transition into heterogeneous tectonites (West Reed-North Star shear zone) described below (*Structure*).

The pluton has been subdivided into three groups: Lower Mafic Group (100-300 m thick), Mafic-Ultramafic Group (335-700 m), and Upper Mafic Group (3200 m) (Young and Ayres, 1985). The Lower Mafic Group consists of modally layered gabbro and minor pyroxenite; the Mafic-Ultramafic Group consists of modally layered pyroxenite, olivine pyroxenite, orthopyroxene-bearing pyroxenite, peridotite, melagabbro, gabbro, leucogabbro and rare anorthosite; the Upper Mafic Group comprises leucogabbro, gabbro, melagabbro and minor anorthosite, olivine-bearing gabbro and magnetiferous gabbro (Young, 1992). The ultramafic layers in the Mafic-Ultramafic Group crystallized from a subalkaline tholeiitic magma that had undergone some fractionation prior to emplacement (Young, 1992). Discontinuities in mineralogy and mineral chemistry suggest that the complex formed from multiple magma batches (Young, 1992).

The complex is characterized by three north-trending aeromagnetic anomalies (Geological Survey of Canada, 1983) produced by areas of increased magnetite abundance. The eastern (stratigraphically lowermost) anomaly corresponds to the Mafic-Ultramafic Group (Young, 1992). The western (stratigraphically uppermost) anomaly correlates with a mafic melagabbro containing sporadic minor disseminated sulphide, underlain by leucogabbro and overlain by quartz-bearing gabbro and anorthositic gabbro (Williamson, 1992). The lithology responsible for the middle aeromagnetic anomaly is not known, but presumably is also a melanocratic variety. The magnetic anomalies terminate in the northern part of the body, in a manner suggesting that they are truncated by a younger intrusive mass. However, a gravity survey across the northern part of the pluton confirmed strike continuity of a previously recognised 15 mgal anomaly measured across the complex to the south (Williamson, 1993). One interpretation of the gravity and aeromagnetic data is that the layered gabbro-ultramafic sequence is intruded in the north by a related, but nonlayered, more homogeneous gabbro; similar relations have been documented in the Claw Lake mafic-ultramafic complex (Syme, 1992).

File Lake Formation

The File Lake Formation consists of interbedded greywacke, siltstone and mudstone deposited by turbidity currents in a submarine fan environment (Bailes, 1980). These sedimentary rocks are important because they can be traced directly into metasedimentary gneisses of the Kisseynew belt, providing a stratigraphic link between the Flin Flon and Kisseynew belts. Although originally interpreted to be derived by mass wasting of *ca.* 1.89 Ga Flin Flon arc volcanoes into adjacent submarine basins (Bailes, 1980), recent U-Pb dating of detrital zircons (David *et al.*, in prep.; Machado, 1995) indicates that the sediments are 40-50 Ma younger than the adjacent arc volcanic rocks of the Flin Flon Belt and are thus contemporaneous with *ca.* 1.84 Ga fluvial-alluvial sediments of the Missi Suite (Ansdell *et al.*, in press; see below).

The File Lake Formation is everywhere in fault contact with adjacent volcanic rocks throughout the File Lake-Snow Lake-Wekusko Lake area (Fig. GS-10-1; Bailes, 1993; Connors and Ansdell, in prep.; Connors, in press). Recent work demonstrates that the File Lake Formation was initially imbricated with slices of the older volcanic assemblages of the Flin Flon belt (Bailes, 1993; Connors and Ansdell, in prep.; Kraus and Williams, 1994). On Reed Lake, the File Lake Formation forms a fault-bound slice interpreted as a thrust imbricate separating the Fourmile Island assemblage to the west from the Northeast Reed basalts to the east (*Structure*).

Exposures of the File Lake Formation on northern Reed Lake consist of interbedded lithic-feldspathic greywacke, siltstone and mudstone that display normal size grading, scour channels, ripups, and load structures. They are identical to exposures of File Lake Formation 6 km to the north on Morton Lake, where a southerly increase in the sandstone to mudstone ratio, grain size and bed thickness has been documented (Bailes, 1980). This coarsening trend continues south to Reed Lake, where mudstone beds are rare and the sequence is dominated by thick (>2 m), coarse to very coarse, A- or AE-type beds, including rare pebble- and cobble-dominated beds.

Clasts in pebble- and cobble-bearing greywacke are instructive with regard to the provenance of these sediments. The cobbles are typically well rounded, consistent with subaerial (fluvial) transport. In addition to the dominant volcanic lithologies, they include plutonic cobbles, vein quartz pebbles, and intraformational greywacke clasts (Fig. GS-10-7). Some of the plutonic clasts are foliated. Whereas the Kisseynew belt turbidites as a whole are most likely derived from uplifted terranes across the Reindeer Zone (Ansdell *et al.*, in press; David *et al.*, in prep.; Machado, 1995), the proximal nature of the deposits at Reed Lake, even relative to those at File Lake or Snow Lake, suggests

Figure GS-10-5: Amoeboid pillow flow-top breccia, unit 'E', Fourmile Island assemblage, west-central Reed Lake. Large amoeboid pillows are partially silicified, and are enclosed in a matrix of blocky fragments.

Figure GS-10-6: Well preserved pillowed basalt of the Northeast Reed assemblage. These basalts are characterized by medium- to small-sized pillows, narrow selvages, thin interpillow filling, and low amygdale abundance. Note the amygdales in these pillows are concentrated at pillow margins.

that they may have been derived from erosion of the Amisk collage post-accretion arc and basement.

Missi Suite (Tramping Lake)

During the course of the reconnaissance mapping on Reed Lake, Missi Suite metasedimentary rocks on Tramping Lake (Stanton, 1945) were briefly investigated to determine their relationship to File Lake Formation rocks. Within the Flin Flon belt, the Missi Suite consists of >2 km thick packages of sandstone and conglomerate deposited in alluvial and fluvial environments (*e.g.,* Bailes and Syme, 1989; Syme, 1988; Stauffer, 1990). U-Pb analysis of detrital zircons (Ansdell *et al.*, 1992; Ansdell, 1993) and crosscutting intrusions (Heaman *et al.*, 1992) has bracketed sedimentation to *ca.* 1845 Ma at Flin Flon and Athapapuskow Lake. At Wekusko Lake, Missi-type sedimentation ranges in age from *ca.* 1845 Ma ('eastern package') to 1835 Ma ('western package') (Connors and Ansdell, 1994b; Ansdell *et al.*, in press).

Missi fluvial-alluvial sedimentary rocks have been interpreted as the lateral facies equivalents of File Lake turbidites (Harrison, 1951; Ansdell *et al.*, in press). Important new observations regarding both the Missi Suite and File Lake Formation were made on Tramping Lake (Fig. GS-10-2), where greywacke turbidites are spatially associated with Missi Suite units. Although the Missi units are dominated by fluvial-alluvial sandstone and polymictic conglomerate, the presence of thin units of graded sandstone-siltstone with turbidite bedforms near the apparent stratigraphic top of the Missi section (see below) suggests that the facies transition between the Missi Suite and the File Lake Formation rocks is preserved on Tramping Lake. If correct, this represents the only location discovered thus far in the Flin Flon belt where the transition between nonmarine and marine facies in the young (*ca.* 1.85-1.83 Ga) sedimentary sequences is preserved.

On Tramping Lake, the Missi Suite is dominated by a sequence of sandstone and polymictic conglomerate. Multiple truncation surfaces (scours) are common in the light grey-weathering fluvial conglomeratic facies, with gravel-sand channel fills and pebble-cobble lag deposits (Fig. GS-10-8). Conglomerates contain abundant pebble- to cobble-sized, rounded, felsic volcanic and intermediate (trachyandesite?) clasts, as well as granitoid, felsic porphyry, vein quartz, mudstone, epidosite and rare mylonite clasts. The felsic and intermediate clasts may well have been derived from coeval 1835-1845 Ma continental arc volcanoes (*cf.* Connors and Ansdell, 1994a, in prep.), since delicate spherulitic and porphyritic textures are preserved.

There is a continuum from crossbedded (high energy, fluvial) to plane-bedded (deltaic?) to graded-bedded (turbidite) sedimentary structures preserved within the Missi section. The planar-bedded facies consists of alternating conglomeratic and pebbly sandstone beds 2-5 m thick, with no crossbedding or scour surfaces. Planar epidosite bands 10-30 cm thick in which the matrix sandstone is epidote-rich are developed in both the sandstone and conglomerate. The significance of the epidote-rich bands is unclear, but epidote is absent in the Missi basins at Flin Flon, Athapapuskow Lake and Wekusko Lake and may reflect marine diagenesis, preserved in these rocks due to their low (greenschist facies) metamorphic grade. A massive, pinkish-weathering sandy facies is associated with the planar-bedded sandstones, and is marked by isolated pebble- to cobble-sized felsic volcanic and vein quartz clasts. This bedform, with plane-laminated bed tops, is rare in the fluvial facies of the Missi and may represent a deltaic facies or an overbank deposit.

A distinctive facies of the Missi Suite on Tramping Lake is a greenish-buff weathering sequence of thin (2-30 cm) graded sandstone beds. The beds have turbidite bedforms, locally with shaley ripups and rare isolated felsic pebbles. Like the planar-bedded facies above, these sandstones have an epidote-rich mineralogy quite unlike that in the subaerial fluvial sandstones. We interpret these beds as Bouma sequence A-E division couplets, and infer a submarine, below wave base depositional environment. On the northwest shore of Tramping Lake, less than 500 m from this unit, 'classic' File Lake Formation greywacke turbidites outcrop. However, at least one northeast-trending fault separates the two sedimentary units. Despite this, we believe that the stratigraphic transition observed within the continuous, northwest-facing Missi section demonstrates that the Missi sedimentary facies overlap with those of the coeval File Lake Formation, and suggest that Tramping Lake section effectively demonstrates stratigraphic continuity between the Missi and File Lake sedimentary packages. As both packages are intruded by plutons along the Tramping Lake corridor (Fig. GS-10-2; Stanton, 1945) and are amenable to detrital zircon U-Pb geochronological study, it will be possible to closely bracket their depositional ages and thereby further test this stratigraphic model.

PLUTONIC ROCKS

Fourmile Island tonalite

The Fourmile Island tonalite pluton is an elongate (1x4 km) body emplaced in Fourmile Island assemblage volcanic rocks in central Reed Lake (Fig. GS-10-2). Most of the pluton is highly deformed and altered, with a penetrative foliation, ductile shear zones, brittle fracture sets and abundant quartz veins. The northwest end of the pluton is crosscut by a west-northwest-trending mylonite zone that has affected the tonalite over a width of approximately 50 m. No evidence of the quartz crystal tuff and metasedimentary units identified by Heine (1993) was observed on this part of the island.

Reconnaissance examination indicates that the pluton is compositionally and texturally variable. The two main phases are (1) a pale grey to white, fine to medium grained equigranular to weakly quartz phyric leucotonalite, outcropping mainly on the north side of the island; and (2) a pale pink to grey, medium grained massive tonalite to granodiorite, observed on the south side of the island. The pluton has

Figure GS-10-7: Intraformational boulder in File Lake Formation greywacke, Reed Lake. The clast is typical File Lake Formation, and contains thin, graded greywacke beds. The rock from which this clast was derived was lithified and veined with quartz prior to its incorporation in the sediment density flow that now encloses it. This relation demonstrates that lithification, deformation, and fluid flow in (proximal?) File Lake Formation was coeval with active sedimentation.

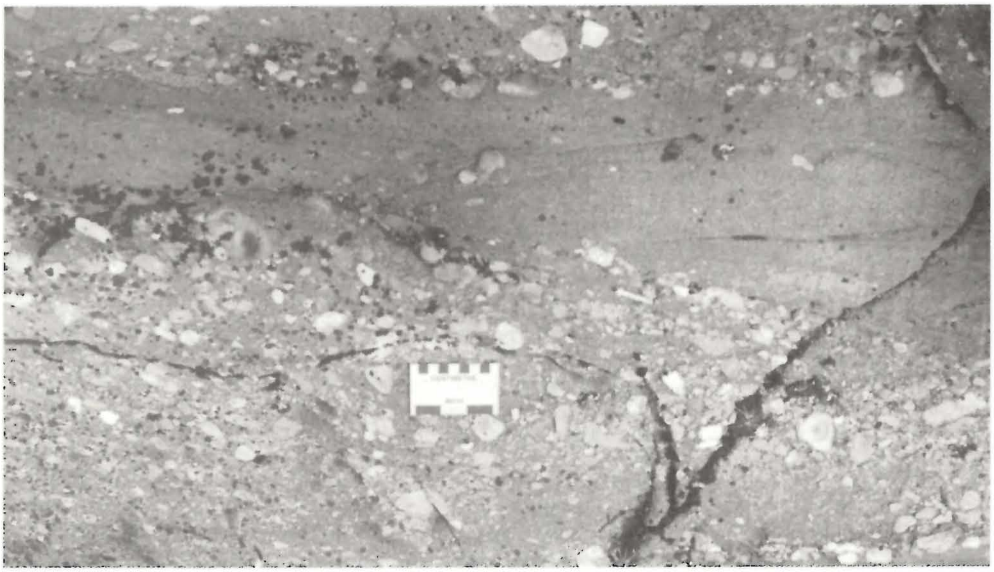

Figure GS-10-8: Bedforms in Missi Suite conglomerate and sandstone, Tramping Lake. Clasts in the conglomerate are dominantly volcanic in origin (but also include plutonic rocks and vein quartz) and have been rounded in a subaerial fluvial environment, demonstrated by low-angle bed truncations (scour channels), cross lamination and pebble lags.

chilled contacts with the surrounding volcanic rocks and locally contains xenoliths, including older phases of the tonalite as well as the country rocks. Although individual phases were not mapped out, at least some of the variation in the pluton is likely due to the presence of multiple intrusions.

The high degree of deformation of the Fourmile Island pluton suggests that it was likely intruded early in the deformation history of the Reed Lake area. Although this pluton has been included on compilation maps as a potential synvolcanic intrusion, no definitive evidence for emplacement synchronous with Fourmile Island assemblage volcanism was discovered (*cf.* Galley *et al.*, 1993). A sample for U-Pb zircon geochronology was collected.

Josland Lake sills

The Josland Lake intrusions are a distinctive suite of zoned, strongly fractionated, tholeiitic, gabbroic sills displaying extreme iron enrichment (Bailes, 1980). They occupy an interesting and unique position in the tectonic history of the File Lake-Snow Lake area: (1) they appear to predate the File Lake Formation, as they have not been observed to intrude it (Connors and Ansdell, 1994a); (2) they may be emplaced synchronous with deformation (folding) in the equivalent of the Fourmile Island assemblage volcanic rocks at File Lake (Bailes, 1980); and (3) they intrude both the Fourmile Island and Northeast Reed assemblage, suggesting that they postdate juxtaposition of these assemblages with the File Lake Formation imbricate (Fig. GS-10-2).

In the Reed Lake area, there are four zoned Josland Lake sills, varying in width from 200 to 1700 m (Fig. GS-10-2). These laterally continuous, fractionated intrusions typically have a lower gabbro zone, a middle ferrogabbro zone, and an upper granophyric to porphyritic quartz ferrodiorite and tonalite zone. The central ferrogabbro zone of the three sills in the Fourmile Island assemblage displays a positive aeromagnetic anomaly that allows lateral extrapolation of unit boundaries. The largest sill, located east of Sewell Lake, is 1700 m thick, with a 750 m thick lower gabbro zone, a 400 m thick ferrogabbro zone, and a 550 m thick upper quartz ferrodiorite zone. This intrusion represents the along-strike extension of the >17 km long Josland Lake sill mapped by Bailes (1980) in the File Lake-Morton Lake area.

Reed Lake pluton

The Reed Lake pluton is a large (22x12 km), ovoid, polyphase granitoid body located directly northeast of Reed Lake (Fig. GS-10-2;

Stanton, 1945). The entire pluton was not re-mapped during this project. Instead, a cross-section through the centre of the pluton was constructed by examining all outcrops along the abandoned Chisel Lake railway line. In addition, we mapped in detail that part of the pluton exposed in the large eastern bay of Reed Lake. Correlation of mapped lithologies with their aeromagnetic characteristics (Geological Survey of Canada, 1984) allowed extrapolation of unit boundaries. These reconnaissance investigations revealed that the Reed Lake pluton is a composite body that consists of a variety of older, gneissic granitoid phases intruded by smaller, oval, relatively undeformed phases, locally with septa of supracrustal rocks. Thus, the pluton does not appear to represent a single magmatic body, but contains a variety of intrusive phases consistent with a long history of magmatism and deformation. None of the phases of the pluton have been dated, but it is younger than the File Lake Formation (*i.e.*, <1.84 Ga; David *et al.*, in prep.) and is most likely part of the 1.84-1.83 Ga plutonic suite that occurs in the File Lake-Snow Lake-Wekusko Lake area (Gordon *et al.*, 1990; Ansdell *et al.*, in press; David *et al.*, in prep.; Machado, 1995). Samples of the various phases were collected for U-Pb geochronology.

Two gneissic phases of the Reed Lake pluton, totalling 8.5 km in map width, occupy the boundary between Snow Lake arc assemblage metavolcanic rocks and the Northeast Reed basalts (Fig. GS-10-2). The eastern gneissic phase is 3.5 km wide, composed of pink- to grey-weathering, heterogeneous, foliated to gneissic, coarse grained, equigranular to plagioclase phyric granodiorite, and medium grained granodiorite gneiss with locally abundant, highly flattened mafic inclusions. Centimetre-scale compositional banding in the gneiss is defined by biotite selvages and layer-parallel pink pegmatite veins. The western gneissic phase is 5 km wide, comprising a heterogeneous, fine grained, grey-weathering, variably gneissic tonalite with amphibolite xenoliths (Fig. GS-10-9). Along the abandoned railway line, this phase is thinly banded, with alternating grey amphibolitic layers (derived from highly flattened mafic xenoliths) and white tonalitic layers. The gneissic banding is complexly folded and contorted. This gneissic material is veined, brecciated and intruded by larger masses of fine grained tonalite that do not contain the gneissic banding. Intrusion breccias associated with this younger tonalite phases contain amphibolite and tonalite gneiss inclusions and rafts that are misoriented, indicating deformation prior to incorporation into the tonalite. In the eastern bay of Reed Lake, the heterogeneous tonalite gneiss contains amphibolite enclaves that range from cm-scale xenoliths to km-scale screens. Xenoliths in least-deformed members of this suite include amphibolite derived from the Northeast Reed assemblage, File Lake Formation metagreywacke, calc-silicates derived from concretions in the greywacke, and various gneissic tonalites.

File Lake Formation garnet-biotite gneisses occur in a 2x2.5 km enclave within the gneissic tonalite, in the eastern bay of Reed Lake. These shallow dipping, recumbently folded rocks are intruded by both the tonalite and a younger granodiorite phase. The greywacke gneisses contain recognizable calc-silicate concretions and locally display normal grain size gradation. One to five centimetre thick granitic *lit* are ubiquitous in the gneiss, formed by partial melting of the greywacke and injection of granitic material.

Younger phases in the Reed Lake composite pluton are weakly foliated to unfoliated, and form elongate to oval bodies that are readily identifiable on 1:50 000 aeromagnetic maps, in that they truncate the magnetic fabric in the older granitoid gneisses. Two significant younger plutons have been identified. The westernmost is an elongate 2x5 km pluton that intrudes the Northeast Reed basalt sequence and has a positive magnetic anomaly at its margin. It is composed of a fine grained, weakly foliated biotite-hornblende tonalite to quartz diorite with abundant, variably assimilated amphibolite xenoliths. East of Reed Lake, an oval, 5 km diameter quartz diorite pluton is emplaced in the tonalite gneiss.

STRUCTURE

The Reed Lake area is a polydeformed, low grade part of the Flin Flon belt that marks the transition in both regional and outcrop-scale structure between the style of deformation observed in the Amisk collage (*e.g.,* Elbow-Iskwasum lakes area: Syme, 1992, 1994; Morrison and Whalen, 1995; Ryan and Williams, 1994, in press) and that observed along the south flank of the Kisseynew Domain in the File-Snow-Wekusko lakes area (Bailes, 1980; Connors, in press; Connors and Ansdell, 1994a, in prep.; Kraus and Williams, 1994). Preliminary structural analysis of the area, undertaken in concert with the reconnaissance mapping, has enabled a synoptic deformation history to be proposed (Table GS-10-1). Further field and laboratory study of the Reed Lake area structures, as well as targeted U-Pb geochronology, is required to verify this scheme as well as to correlate structures and deformation events between tectonostratigraphic domains. The five principal deformation events outlined in Table GS-10-1 (D_1-D_5) are based largely on crosscutting relations both within and between tectonostratigraphic domains (*e.g.,* Fourmile Island and Northeast Reed assemblages). An important exception to this is the relation between D_1 and D_2 events, which are mutually exclusive in the distribution of outcrop- and map-scale structures in the overall western Reed Lake area. The principal argument for distinguishing D_1 and D_2 as temporally and tectonically distinct events is that the development of S_1 appears to be synmagmatic, which by comparison with the Elbow-Iskwasum corridor to the west, probably reflects deformation within the 1.88-1.84 Ga post-accretion arc system (Lucas *et al.*, in press; Ryan and Williams, in press). A maximum age for the D_2 event is provided by the 1842 Ma age of the youngest detrital zircon in the File Lake Formation turbidites (Machado, 1995). A lower bracket on the age of the $S_{3a\ sz}$ deformation along the West Reed-North Star shear zone (Table GS-10-1) should be given by the apparent crosscutting relation

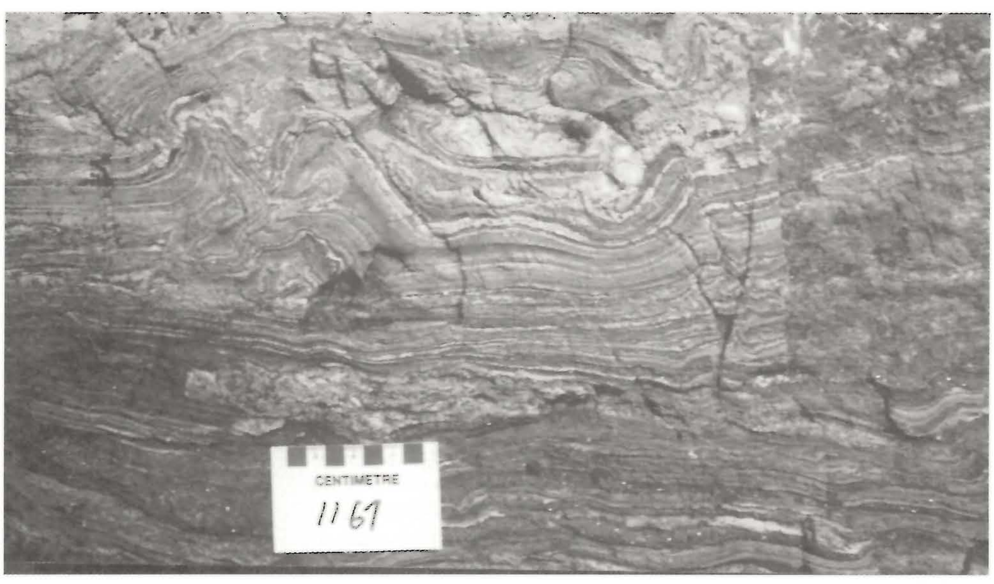

Figure GS-10-9: Thinly layered tonalitic gneiss phase of the Reed Lake pluton, eastern Reed Lake. Most of the Reed Lake pluton is composed of gneissic granitoid material containing flattened amphibolite and plutonic inclusions.

with the Rail Lake pluton (Fig. GS-10-2).

In the following sections, the principal field observations regarding outcrop and regional-scale structures associated with the D_1-D_5 events are described, along with broader considerations of their age and tectonic significance.

D_1: Early deformation along the West Reed-North Star shear zone

The Fourmile Island volcanic assemblage is separated from the Reed Lake mafic-ultramafic complex by the West Reed-North Star shear zone. The shear zone is approximately 5.5 km wide and has been traced along strike for over 25 km, extending from the North Star Lake area to the Phanerozoic cover in the south (Figs. GS-10-1, -2). It has been mapped and studied in detail in the North Star Lake area by Norquay and Halden (1992; see also Norquay *et al.*, 1992, 1993). The north-trending shear zone as outlined on Preliminary Map 1995F-1 is a D_{3a} structure that deforms an older shear zone foliation (S_1). In general, the extent of the younger D_{3a} shear zone appears to correlate well with that of the D_1 zone, as indicated by the extent of D_1-deformed, mafic-felsic intrusive sheets emplaced in mafic rocks presumably derived from basalts (see below). This suggests that the strong anisotropy developed as a result of D_1 shear zone deformation served to localize subsequent D_{3a} strain, in a manner similar to that observed along the long-lived Elbow Lake shear zone (Ryan and Williams, 1994, in press; Syme, 1991, 1992).

The S_1 foliation is defined by a penetrative grain-scale fabric that is parallel to centimetre- to metre-scale compositional layering. Mesoscopically ductile deformation prevailed along the shear corridor, and S_1 mylonites have been recognized, although in general, the overprinting $S_{3a\,sz}$ strain obscures much of the D_1/S_1 structure. The layering is defined by transposed primary lithologic units and by abundant, metre-scale mafic to felsic intrusive sheets (Figs. GS-10-10, -11). One distinctive intrusion type is a grey-green weathering, quartz-plagioclase phyric intermediate-felsic rock. The general restriction of the intrusive sheets to the shear corridor, coupled with their layer-parallel orientation regardless of bulk strain, suggest syntectonic emplacement of the intrusive sheets during D_1 (*cf.* Lucas *et al.*, in press). The D_1 shear zone appears to have developed largely within mafic supracrustal rocks, at least in part derived from basalts of the Fourmile Island assemblage, but does not extend into the core of the Reed Lake mafic-ultramafic complex. In one key outcrop at the western margin of the shear zone, layered gabbroic rocks of the Reed Lake complex contain a penetrative S_1 foliation and are cut by mafic and felsic (hornblende tonalite) dykes that themselves contain the S_1 foliation (*i.e.*, syn-D_1 emplacement). Such dykes do not characterize the Reed Lake complex as a whole, but are localized on the sheared margin.

It is not possible to confidently determine either the orientation, geometry or kinematics of the D_1/S_1 shear zone. However, the enveloping surface to F_{3a} minor folds within the shear zone is steeply dipping, suggesting that the S_1 foliation was steep prior to D_{3a} deformation. Norquay and Halden (1992) report a very similar early (D_1) history for the West Reed-North Star shear zone in the North Star Lake area, but indicate that the equivalent of our F_{3a} structures (their F_2) in general have moderate plunges.

D_2: Collisional deformation and development of the Morton Lake fault zone

The most significant map-scale structure in the Reed Lake area is the Morton Lake fault zone, which is ascribed to D_2 (Table GS-10-1). We propose that two subparallel faults juxtapose imbricates of File Lake Formation turbidites and Northeast Reed assemblage basalts on volcanic rocks of the Fourmile Island assemblage. Evidence for bedding-parallel faults bounding the turbidites includes (1) truncation of both Fourmile Island assemblage and Northeast Reed stratigraphy against the contacts with the turbidites (Fig. GS-10-2); (2) tectonostratigraphic juxtaposition of *ca.* 1.84 Ga turbidites against *ca.* 1.9 Ga volcanic assemblages that, in general, have Missi Suite fluvial-alluvial sandstones forming the *ca.* 1.84 Ga cover sequence, and (3) the strike-continuity of the turbidite package with thrust imbricates in the Morton-File lakes area (Connors, in prep.). Based on the linkage of the Morton Lake fault zone with well documented southwest-verging thrust faults on File Lake to the north, we suggest that the two D_2 faults on Reed Lake are also southwest-verging thrusts. The apparent southerly increase in Fourmile Island assemblage section beneath the Morton Lake fault zone suggests a north-dipping footwall ramp, consistent with the proposed thrusting direction. The faults and stratigraphy all dip steeply, but when traced along strike to the File Lake area, they flatten dramatically to moderate-shallow northward dips (Bailes, 1980; Connors, in prep.). We follow Connors (in prep.) and suggest that the D_2 faults initially had low to moderate, presumably northeast dips and were steepened during and/or subsequent to thrusting.

The oldest structures in the File Lake Formation turbidites include isoclinal folds (F_{2a}) and a variably developed bedding-parallel foliation (S_{2a}). A map-scale syncline in the turbidite imbricate is suggested by a reversal in facing directions (northern Reed Lake, Fig. GS-10-2), but there are too few observations to enable us to confidently distinguish between a regional isoclinal fold (recumbent?) and minor isoclinal folds within a homoclinal thrust slice. A north-trending fold of bedding in western Fourmile Island assemblage (Fig. GS-10-2) may be an F_{2a} (or F_{2b}?) structure as it is transected by the west-trending regional S_3 foliation. A north-trending, pre-D_3 cleavage is locally mapped in the Fourmile Island rocks and may be axial planar to the fold. However, as these structures are isolated from the main zone of D_2 deformation, it is difficult to determine their relation to the thrusting event, or their relation to the D_1 event.

A penetrative regional foliation (S_{2b}) developed following F_{2a}/S_{2a} deformation in the File Lake Formation and the hanging wall Morton Lake fault zone. The foliation appears to have formed at peak metamorphic conditions, and thus correlates with similar metamorphic foliations in the File Lake (Connors, in prep.) and Snow Lake areas (Kraus and Williams, 1994). The greenschist-facies S_{2b} foliation cuts across both limbs of the F_{2a} isoclines in the File Lake turbidites but generally forms at a low angle to bedding. The S_{2b} foliation is mapped throughout the Northeast Reed basalt assemblage and older Reed Lake pluton phases, where it is manifested in part as a gneissosity. A zone of File Lake Formation xenoliths occurs in a gneissic phase of the pluton (see above) and separates, at the regional scale, the Northeast Reed assemblage from the Snow Lake arc assemblage. These relations suggest that the main (older) phases of the Reed Lake pluton were emplaced following D_{2a} thrusting and prior to S_{2b} foliation development, similar to the Ham and Woosey plutons to the north (Fig. GS-10-2; Connors, in prep.). The younger phases of the Reed Lake pluton only contain a weak S_{2b} foliation, suggesting that they may have been emplaced during S_{2b}. This hypothesis will be tested by U-Pb geochronology on a sample of one of these late monzogranite phases, given that the age of peak metamorphism is well constrained in the area (1820-1805 Ma; David *et al.*, in prep.).

It is not clear whether the regional S_{2b} foliation was developed in the Fourmile Island assemblage. Two possibilities exist: (1) the north-trending foliation mentioned above may be S_{2b} as opposed to S_{2a} as suggested above; or (2) the regional flattening foliation in the Fourmile Island assemblage (interpreted as S_{3a}) is, in fact, S_{2b}. As a prominent west-trending foliation is also present in the File Lake Formation in central Reed Lake and appears to be contiguous with the regional foliation in the Fourmile Island rocks, we reject the second suggestion. Study of the grain-scale relation between foliations and metamorphic minerals is required to further address this question.

No map-scale D_{2b} structures have been identified in the Reed Lake area with the exception of the proposed shear zone that places Northeast Reed basalts on File Lake Formation turbidites. We suggest that this may be a D_{2b} thrust, based on analogy to the McLeod Road fault at Snow Lake (Kraus and Williams, 1994) and the Beltz Lake fault north of File Lake (Connors, in prep.). This structure has been termed the 'Dummy Bay' shear zone by Bailes (1980) based on work in the File-Morton lakes area, and is delineated on vertical gradient aeromagnetic anomaly maps (Geological Survey of Canada, 1984) as a narrow high that can be traced from File Lake through Morton Lake into

Table GS-10-1
Summary of deformational events, Reed Lake area

Event	Fabrics	Regional structures	Associated magmatic rocks	Meta-morphism	Age	Tectonic significance
D_1	S_1	West Reed-North Star shear zone	mafic-felsic intrusive sheets	greenschist	1.87-1.84 Ga	Intra-arc (successor)
D_2	S_{2a} (File) F_{2a} folds	Morton Lake fault zone	?	?	<1.842, >1.840 Ga	Contraction of Kisseynew basin/collision
			Reed Lake pluton			
	S_{2b} (strain localized in File imbricate and hanging wall in general, plus folds in Fourmile Island assemblage)	Morton Lake fault zone (out-of-sequence thrusts?)	? late phases of Reed pluton	greenschist-lower amphibolite (peak)	<1.83 (1.820-1.805) Ga	Collision with 'exotic' Archean block (Ansdell *et al.*, 1995)
D_3	S_{3a} (regional NE foliation/crenulation) F_{3a} (N- to NE-trending folds)	F_{3a} folds (Threehouse-type?)	?	greenschist	<1.81 Ga	Collision with Superior craton
	S_{3a} sz ($L_{3a\ sz}$) F_{3a} sz (isoclinal folds parallel to $L_{3a\ sz}$)	West Reed-North Star shear zone	?	greenschist	?	
	S_{3b} (crenulations associated with F_{3b} minor folds)	Early Berry Creek shear along E-W limb of F_{3b} fold? Crenulation of BCSZ fabric		retrograde (chlorite-carbonate)		
D_4	S_4	F_4 NW crenulation cleavage		retrograde	1.8-1.7 Ga	Post-collisional incremental transpression
D_5	brittle/ductile shears and faults	Berry Creek fault zone (brittle/ductile)		carbonate		

Figure GS-10-10: Heterogeneous tectonite in the West Reed-North Star shear zone, west shore of Reed Lake. The tectonite is composed of foliated to mylonitic, felsic-mafic intrusive sheets. Some of the sheets contain a well-developed tectonic lamination.

Figure GS-10-11: Heterogeneous tectonite in the West Reed-North Star shear zone, Grass River west of Flag Lake. Felsic intrusive sheets (white) and mafic layers (dark) are strongly foliated to mylonitic. In lower strain rocks to the west the felsic sheets are medium grained granodiorite and tonalite; these mylonitic equivalents are very fine grained and laminated. Figures GS-10-10 and 11 are from the east and west sides, respectively, of the Reed Lake mafic-ultramafic complex.

the centre of Reed Lake, where it is truncated by the Berry Creek fault zone (see below).

D_3: Post-collisional folding and shear zone development

The D_3 event in the Reed Lake map area is characterized by regional folds and ductile shear zones as well as several generations of foliation. The significance of the D_3 event is that it effectively 'stitches' all map units together, including the File Lake Formation and the voluminous Reed Lake pluton. In addition, it is marked by classic 'Flin Flon'-type post-metamorphic structures in the western part of the lake (transcurrent shear zones; Lucas *et al.*, in press; Ryan and Williams, in press) and classic 'Snow Lake'-type post-metamorphic structures in the central and eastern parts of the lake (northeast-trending folds and foliations; Bailes, 1993; Kraus and Williams, 1994; Connors, in prep.). The most obvious D_3 structure is the regional-scale east-northeast-plunging synform that folds the Morton Lake fault zone (F_{3a}; Fig. GS-10-2). This structure appears to be similar in geometry and relative age (*i.e.*, post-peak metamorphism) to the Threehouse synform at Snow Lake (Fig. GS-10-2; Bailes, 1993; Kraus and Williams, 1994) and the File Lake synform at File Lake (Connors, in prep.). An east-northeast-trending axial planar foliation (S_{3a}) is variably developed throughout the area and cuts across the Morton Lake fault zone and S_{2b} foliation at a high angle in the central part of Reed Lake. S_{3a} is pervasive throughout the Fourmile Island assemblage and forms the principal flattening fabric, demarcated by deformed primary features such as clasts, pillow tubes and vesicles. It is associated with a moderately to steeply plunging lineation that is defined by oriented inequidimensional minerals, elongated primary features and the intersection of S_{3a} and $S_0/S_1/S_2$. F_{3a} minor fold axes plunge to the northeast to east-northeast, parallel to lineation and consistent with D_3 structural relations throughout the File Lake-Snow Lake area (Connors, in prep.; Kraus and Williams, 1994). No consistent sense of F_{3a} minor fold asymmetry was noted in the western part of Reed Lake, perhaps in part because much of the area is the broad hinge region of the map-scale F_{3a} fold.

The West Reed-North Star shear zone was reactivated during D_{3a} deformation (Table GS-10-1). The east-northeast-trending S_{3a} foliation can be traced westward in the Fourmile Island assemblage to within about 1 km of the north-northeast-trending shear zone, where it is deflected anti clockwise into the shear zone trend. The north-north-east-trending shear zone foliation is termed $S_{3a\ sz}$, as we have not observed it overprinting the S_{3a} foliation at any point in the transition zone (*i.e.*, strain gradient) into the shear zone. The change in orientation of the foliation with increasing strain indicates an apparent sinistral sense of motion on the shear zone. The eastern margin of the shear zone is marked by intense deformation of basalts of the Fourmile Island assemblage. Local Z-folds deform quartz and minor mafic veins and are axial planar to the shear zone foliation axial planar to them, suggesting that they are F_{3a} structures. To the west, the D_{3a} shear zone encounters S_1 tectonites and mylonites developed during D_1 movement along the West Reed-North Star zone. These laminated mafic-felsic tectonites are isoclinally folded on outcrop scale and have a well developed axial planar foliation (S_{3a}), which itself becomes a mylonitic fabric. The $S_{3a\,sz}$ foliation appears to have formed at lower greenschist-facies conditions, as chlorite ± actinolite is a common assemblage in the fabric. Within the Reed Lake map area, this pattern of D_{3a} shear deformation can be traced to the margin of the Reed Lake intrusive complex, where the S_1 foliation is similarly folded and cut by S_{3a} -F_{3a} fold axes are steeply plunging in general, parallel to extension and mineral lineations in the zone. The isoclinal folds of S_1 do not display a consistent sense of asymmetry, although Z-folds are more common than S-folds.

The D_{3a} structures observed in the shear zone on Reed Lake are similar to those described as D_2 structures in the North Star Lake area (Norquay and Halden, 1992). In total, D_{3a} deformation appears to be recording northwest-southeast shortening resulting in northeast to east-northeast-trending folds and foliations and sinistral transpression along north-northeast-trending West Reed-North Star zone. The transition from D_2 southwesterly thrusting to D_3 northwest-southeast shortening has been attributed to the collision of the Reindeer Zone with the Superior Province at *ca.* 1.81 Ga (Connors, in prep.; Kraus and Williams, 1994; Connors and Ansdell, in prep.). Sinistral shear along the West Reed-North Star zone during D_{3a} may be coeval with development of the S_5 Elbow Lake shear zone to the west, which is associated with sinistral transpression (Ryan and Williams, 1994, 1995, in press).

The D_{3a} structures, including the West Reed-North Star shear zone, appear to be reoriented into an east-west orientation just north of the Shield margin in western Reed Lake. Here, all fabrics are overprinted by a west-trending penetrative shear foliation associated with the Berry Creek shear zone (Fig. GS-10-2), although the full significance of ductile deformation along the Berry Creek zone remains a major unresolved question. Both ductile and brittle deformation fabrics along the Berry Creek zone are characterized by distinctive carbonate-chlorite assemblages and veins. It is not clear whether the D_{3a} foliations are (1) dragged westward (dextrally) into the Berry Creek trend, as appears to be the case at Iskwasum Lake to the west (Syme, 1994; Ryan and Williams, this report); or (2) folded by large-scale, northeast-trending Z-folds with a long, east-west limb near the shield margin that resolves dextral shear during Berry Creek ductile deformation. An alternate view of the D_3 structures in western Reed Lake would be that the West Reed-North Star zone and the Berry Creek zone are conjugate shear zones developed on the limbs of the large F_{3a} synform and accommodating sinistral and dextral shear (respectively). Further fieldwork and extensive thin section study is required to resolve the complex D_3 history of western Reed Lake.

All D_{3a} structures and the Berry Creek ductile fabrics are overprinted by a regional northeast-trending crenulation cleavage (S_{3b}). The S_{3b} crenulation cleavage is in general associated with mm- to m-scale Z-asymmetric folds that plunge moderately to steeply to the northeast. The exception to this occurs along the north-northeast-trending West Reed-North Star zone, where S_{3b} is associated with small-scale S-folds.

D_4-D_5: Berry Creek fault zone and late deformation of the Reed Lake area

A northwest-trending foliation (S_4) forms the sole crenulation fabric in the northern part of the Reed Lake but is only sporadically developed in the southwest part of the lake, overprinting $S_{3a/b}$ foliations. It is associated with rare F_4 minor folds that plunge moderately to steeply northwest and have a Z-asymmetry. A similar west- to northwest-trending late foliation has been noted by Connors (in prep.) north of File Lake, and is associated with the development of map-scale F_4 cross-folds (see also Kraus and Williams, 1994). The upright F_4 structures contribute to the regional dome-and-basin fold interference pattern that deforms the D_2 imbricate stack in the File Lake-Snow Lake-Wekusko Lake area.

A series of late brittle-ductile shear zones and discrete brittle faults deform the D_1-D_4 structures in the map area. Northeast-trending steep faults offset lithological and structural features in west-central Reed Lake and have dextral map separations. A north-trending fault that cuts all D_1-D_4 structures extends from northeastern Tramping Lake to the east side of the Ham Lake pluton (Fig. GS-10-2). It displays sinistral map separations, but clearly has an important dip-slip displacement component.

The most important zone of late faulting in the area is the Berry Creek structure. This enigmatic structure (*cf.* Syme, 1993, 1994; Kraus and Williams, 1994; Ryan and Williams, 1995) is reasonably well exposed on Reed Lake and, importantly, Precambrian bedrock exposures continue far enough south to allow the southern wall rocks of the zone to be mapped (Fig. GS-10-2). Although associated with a prominent linear anomaly in the vertical gradient of the aeromagnetic field (Geological Survey of Canada, 1983, 1984), the map pattern on Reed Lake demonstrates that the Berry Creek fault does not significantly offset lithological units in the Fourmile Island assemblage. On eastern Reed Lake, however, the Berry Creek shear zone separates a homoclinal, broadly *west*-facing sequence of Northeast Reed assemblage basalts north of the shear zone from a homoclinal, *east*-facing sequence of pillow basalts south of the shear zone. Both sequences are kilometres (4-5 km) thick. West of Tramping Lake the Berry Creek shear zone clearly truncates the gneissic phases of the Reed Lake pluton, and juxtaposes them against a granodiorite with a different magnetic character (Geological Survey of Canada, 1984).

The Berry Creek zone appears to be a long-lived zone of localized ductile to brittle deformation. The fault zone on Reed Lake is approximately 1 km wide, with the bulk of it comprising phyllonite and finely laminated tectonites marked by layer-parallel, deformed carbonate and quartz-carbonate veins. As discussed above, ductile deformation along the Berry Creek zone initiated during D_3. In addition to the F_{3b} minor Z-folds that deform the earliest ductile foliation, there are locally zones of S-folding of the Berry Creek foliation about similar east-northeast- to northeast-trending axes. Ryan and Williams (1995) describe S-folding of Berry Creek foliation at Iskwasum Lake and attribute it to an interval of sinistral shear along the zone, postdating the period of principal dextral shear.

Structures attributed to the D_5 event vary from the finely laminated phyllonite to cataclasite seams, brittle fractures (dilational and nondilational) and pseudotachylite bands. Overprinting relations between these structures indicate a temporal ductile to brittle transition along the Berry Creek fault zone. All of these features are associated with carbonate mineralization (ankerite?), with carbonate forming the matrix in some of the cataclasite seams. In general, both brittle and ductile structures maintain the east-northeast trend of the Berry Creek zone, although the brittle fracture arrays describe a Riedel fault system. Detailed study of the brittle and brittle-ductile structures should allow their kinematic framework to be resolved. We suggest that the Berry Creek fault zone was successively reactivated during post-collisional deformation and regional cooling and exhumation (1.8-1.7 Ga; Fedorowich *et al.*, 1995) in the eastern Trans-Hudson Orogen. Reactivation of segments of the Berry Creek fault zone may have continued into the Phanerozoic, as topographic relief currently exists between high-standing Ordovician carbonates and lower Precambrian rocks in areas such as southwestern Reed Lake.

ECONOMIC GEOLOGY

Spruce Point Cu-Zn deposit

The past-producing Spruce Point Cu-Zn mine, operated by Hudson Bay Mining and Smelting Co. Ltd., is located on the south shore of Reed Lake in an area covered by 3 m of Paleozoic carbonates (Fig. GS-10-2). To the end of 1988 the deposit had produced 1,364,000 tonnes averaging 2.36% Cu, 2.8% Zn, 2.0 g/t Au and 25.0 g/t Ag from a series of Cu- and Zn-rich sulphide lenses hosted by rhyolite breccia (Fedikow and Lebedynski, 1990).

The following description of the deposit is summarized from the work of Fedikow and Lebedynski (1990). The stratigraphic sequence that hosts the deposit is overturned: it trends northeast, youngs to the northwest and dips steeply to the southeast. The rocks are foliated and contain a well-developed stretching lineation that plunges 40-55° south, parallel to the plunge of the sulphide lenses (36° south). The sulphides are underlain by a strongly and variably altered sequence of rhyolitic rocks, including fine grained tuff, aphyric breccia and flows. Footwall alteration consists of a sericite-chlorite-sulphide assemblage, developed most strongly in the matrix of rhyolite breccia. The wall rock-sulphide contact is marked by intense sericitization and locally abundant chlorite. Disseminated sulphides and narrow (4-5 cm) solid sulphide layers occur up to 15-20 m stratigraphically below the ore-body. The deposit (averaging 9 m wide) is overlain by fine grained felsic rocks (tuff?) and aphyric rhyolitic fragmental rocks possibly representing flow breccias. Alteration in the stratigraphic hanging wall extends at least 5 m above the deposit, but is most intense immediately adjacent to it. An argillite unit with pyrrhotite and graphite occurs in the hanging wall sequence and contains erratic gold values associated with arsenopyrite. Fine- to medium-grained mafic intrusions intrude the felsic rocks, and truncate the alteration observed in hanging wall fragmental rhyolite. These intrusions are not altered and are not mineralized.

Extrapolation of geology from Reed Lake to the north suggests that the Spruce Point deposit is hosted by Fourmile Island assemblage rocks that appear to have an intraoceanic arc tectonostratigraphic affinity, a tectonostratigraphic setting common to all other economic VMS deposits in the Flin Flon belt (Syme and Bailes, 1993; Syme *et al.*, 1995). The Spruce Point deposit lies south of the Berry Creek fault, and its larger scale stratigraphic relations are not known. However, this work has demonstrated the possible stratigraphic correlation between rocks on the north and south sides of the Berry Creek fault, suggesting that stratigraphic equivalents of the Spruce Point mineralized zone may be found in the Fourmile Island assemblage volcanic rocks on western Reed Lake.

Reed Lake Cu deposit

The Reed Lake deposit occurs a few hundred metres north of the western part of Fourmile Island in Reed Lake (Fig. GS-10-2). It is reported to contain 1.36 million tonnes containing 2.09% Cu (diluted 10%) to 549 m, and is open at depth (Bamburak, 1990). The copper- and minor zinc-sulphide mineralization is hosted by felsic volcanic rocks that do not outcrop on surface (Manitoba Mineral Inventory File No. 736). Rocks exposed on islands surrounding the deposit are gabbro and ferrogabbro, possibly a Josland sill. To the south, on Fourmile Island, are strongly epidotized basalts intruded by the Fourmile Island tonalite. The deposit probably occurs within the Fourmile Island assemblage, but limited exposure and structural complexity preclude unqualified correlation with any of the units ('A'-'F') described above. The most reasonable interpretation is that the volcanic rocks in the vicinity of the Reed Lake deposit are either unit 'E' or 'F'.

Gold occurrences

Gold occurrences on Reed Lake are few, and are mainly associated with quartz veins in sheared and altered metavolcanic and metaplutonic rocks. The structural controls on the vein systems have not been studied in detail; however, most are spatially associated with the Berry Creek fault and its immediate wall rocks. None of the occurrences contain significant quantities of gold.

Four gold occurrences on Fourmile Island have been located and described by Stanton (1945), Rousell (1970), Stewart (1977) and Heine (1993; listed as 1a-1d). The occurrences are hosted by quartz-ankerite veins trending north-northwest to north-northeast in altered tonalite. The veins contain pyrite (trace to 10%), chalcopyrite (trace), chlorite inclusions, and chloritized and carbonatized fragments of wall rock (Heine, 1993). Stanton (1945) also reports free gold and sphalerite, but free gold was not observed by either Heine (1993) or Rousell (1970). Tonalite adjacent to the gold occurrences is commonly extensively ankeritized. Fourmile Island is transected by a northwest-trending mylonite zone, and major northeast- to east-trending faults occur north of the island (Preliminary Map 1995F-1). The gold-bearing veins hosted by tonalite are conceivably higher-order structures related to the mapped faults and shear zones, but detailed structural study is required to resolve their geometry, age and relation to regional structures.

Gold occurrences on Bartlett Point, south of Fourmile Island, may be controlled by proximity to the Berry Creek shear zone. A trench at one occurrence (number 5 in Heine, 1994) exposes sheared quartz phyric tonalite (a dyke?) and chlorite schist. A single 20 cm thick quartz vein and several irregular quartz masses occur in the schist. Both the vein and the country rocks contain ankerite. Disseminated pyrite (<1%) occurs in chloritic inclusions within the quartz vein, but no assays are reported (Heine, 1994). This occurrence is 150 m south of the Berry Creek shear zone, and lies 300 m north of a quartz phyric tonalite pluton occupying the southwest bay of Reed Lake.

A gold occurrence located approximately 300 m north of occurrence 5 (above), on the shore of Reed Lake, lies within the Berry Creek shear zone. It is exposed in stripped and washed outcrop, and core from several diamond drill holes is piled nearby. On the shoreline exposure the shear zone consists of mafic tectonite with deformed felsic intrusive sheets and boudinaged, folded quartz-carbonate-chlorite-pyrite) veins up to 50 cm thick.

Platinum group elements

Grab samples from the Reed Lake mafic-ultramafic complex indicate weakly enriched levels of PGE, mainly from the lowermost (eastern) part of the complex (Williamson, 1993). In a population of 124 samples, 24 contain >20 ppb Pt, 32 contain >20 ppb Pd, and 5 contain >100 ppb Pt+Pd; the highest levels of PGE occur in two samples with 117 ppb Pt, 134 ppb Pd and 89 ppb Pt, 176 ppb Pd (Williamson, 1993).

DISCUSSION AND SYNTHESIS

The Reed Lake map area forms a critical bridge between the Flin Flon and Snow Lake areas in terms of tectonostratigraphy, structure, magmatism and mineral deposits. It also represents, as discussed below, a segment of the south flank of the Kisseynew Domain (*cf.* Zwanzig, 1990; Bailes, 1980; Ansdell *et al.*, in press). Given the complexity of the area and its pivotal role in regional tectonics, we will outline here a broad synthesis of its tectonic history and a number of testable hypotheses as to the significance of the area in terms of tectonostratigraphy and metallogeny.

Three principal questions associated with the tectonic setting of the Reed Lake area arose during the course of the reconnaissance mapping. (1) What is the tectonic significance of the West Reed-North Star shear zone, and did it play a role in linking the Amisk collage to the Snow Lake arc assemblage prior to 1.84 Ga (Fig. GS-10-1)? (2) What is the relation between the File Lake Formation, the Amisk collage and Snow Lake arc assemblage at the leading edge of the File/Kisseynew allochthons (Fig. GS-10-1)? (3) What is the relation between the 'autochthonous' Missi Suite fluvial-alluvial sedimentary rocks and the low grade, proximal File Lake Formation allochthons (*cf.* Bailes, 1980, 1993; Ansdell *et al.*, in press)? These questions are discussed separately below.

West Reed-North Star shear zone

The West Reed-North Star shear zone separates, at the regional scale, the Amisk collage from the Fourmile Island volcanic assemblage (and the Northeast Reed and Snow Lake assemblages to the east). However, imbrication of these packages with File Lake Formation turbidites along the Morton Lake fault zone (see below) does not permit first order correlation, from west to east, of either volcanic assemblages or pre-File Lake Formation (*i.e.*, pre-1.84 Ga) structures. As a result, we will restrict our discussion of the West Reed-North Star shear zone to its most direct consequence: juxtaposition of the Reed Lake mafic-ultramafic complex with the Fourmile Island assemblage.

The shear zone juxtaposes oceanic-affinity rocks (Reed Lake complex) with arc affinity rocks (Fourmile Island assemblage) and thus marks the eastern termination of a broad belt of volcanic and plutonic rocks of ocean floor character. This belt, collectively termed the Elbow-Athapap assemblage (Fig. GS-10-1), is best interpreted as the remnants of a back-arc basin, dated at *ca.* 1.9 Ga (Stern *et al.*, 1995b; Syme, 1994, in press; Lucas *et al.*, in press). Given the extent of the

Elbow-Athapap assemblage, it seems plausible that it records the trace of a suture between arc fragments/accretionary complexes. Taken in this light, the West Reed-North Star shear zone may well be a bounding structure (at map scale) to the collapsed Elbow-Athapap back-arc basin.

Preliminary study of the West Reed-North Star shear zone highlights two important facets of its character: (1) polyphase deformation history, culminating in S_1 tectonites/mylonites (see Table GS-10-1); (2) syn-magmatic nature of at least the S_1 'event', demonstrated by mafic-felsic, layer-parallel intrusive sheets in the shear zone corridor. These characteristics are remarkably similar to those found along the major inter- and intra-assemblage deformation corridors in the Amisk collage (*e.g.,* Elbow Lake shear zone: Syme, 1991, 1992; Ryan and Williams, 1994, 1995; Northeast Arm shear zone: Lucas, 1993; Meridian-West Arm shear zone: Lucas *et al.*, in press). The tectonic history of these zones, as constrained by structural studies and age relations, is marked by early assembly of tectonostratigraphic packages (1.88-1.87 Ga) to form the Amisk collage, and subsequent deformation of the collage synchronous with post-accretion ('successor') arc magmatism (1.87-1.84 Ga; Lucas *et al.*, in press; Stern and Lucas, 1994). Our field data suggest that the West Reed-North Star shear zone bears similarities with the post-accretion intra-arc structures, rather than the accretion-related structures *sensu stricto*.

The age of the shear zone, other than being broadly bracketed as post-Reed Lake complex and pre-D_3, is not constrained at present but will represent a focus of geochronological study at the Geological Survey of Canada in 1996. A sample of a syntectonic intrusive sheet from the West Reed-North Star zone was collected for U-Pb geochronology, and should provide a syntectonic age for the D_1/S_1 event and an upper bracket for the $D_3/S_{3a\ sz}$ event. As illustrated in Figure GS-10-2 (see also Preliminary Map 1995F-1), the D_1 shear zone is cut by a pluton at the latitude of the abandoned Chisel Lake railway line. This effectively undeformed pluton may be a late phase of the File Lake-Snow Lake-Wekusko Lake calc-alkaline suite (*ca.* 1860-1840 Ma). It is similar in composition, size and timing to the Little Swan Lake pluton (U-Pb titanite age: 1828 ± 6 Ma; Whalen and Hunt, 1994) that cuts the Gants Lake batholith and related shear zones to the west (Whalen, 1992; Morrison and Whalen, 1995). The relation between the $D_1/S_1/F_1$ deformation along the shear zone and D_2 initiation and subsequent shear along the Morton Lake fault zone could not be resolved during the course of the field work.

We suggest that the D_1 West Reed-North Star shear zone is a relatively early structure that developed within the Amisk collage, possibly coeval with early movement on the Elbow Lake shear zone-Centre Lake tectonite (*ca.* 1.87-1.86 Ga; Ryan and Williams, in press; K. Ansdell, pers. comm., 1995). As mentioned above, it may separate the extensive Elbow-Athapap ocean floor assemblage from a separate arc terrane to the east, based on the reasonable assumption that the Fourmile Island volcanic assemblage is indeed an arc package. However, linkages between the Fourmile Island assemblage and the Snow Lake assemblage cannot be directly made, as a result of imbrication along the Morton Lake fault zone. Geochronologic, Nd-isotopic and detailed geochemical studies will be required to establish any possible connections between these arc packages, as well as the relation between the Northeast Reed basalt assemblage and the Elbow-Athapap assemblage. Such information should permit the pre-D_2 extent of the Amisk collage to be established, as well as the location of the Snow Lake assemblage relative to the Flin Flon assemblage prior to 1840 Ma.

Morton Lake fault and File Lake Formation-volcanic assemblage relations

Discovery of the Morton Lake fault zone requires a revision of the location of the leading edge of the south flank of the Kisseynew Domain, as defined by the fault contact between allochthonous File Lake Formation turbidites and autochthonous Amisk collage rocks (Harrison, 1951; Connors, in prep.). The Reed Lake map area is split into two domains by the Morton Lake fault zone (Fig. GS-10-2): (1) the footwall (autochthonous) domain, comprising the Fourmile Island assemblage, West Reed-North Star shear zone and Reed Lake mafic-ultramafic complex, and (2) the hanging wall (allochthonous) domain, consisting of the Northeast Reed assemblage, Reed Lake pluton and Snow Lake arc assemblage. The fault zone itself includes the File Lake Formation imbricate on Reed and Morton lakes, and if our extrapolation is correct, both File and Missi rocks on Tramping Lake. Older gneissic phases and younger massive phases of the Reed Lake pluton may postdate D_{2a} imbrication but predate D_{2b} regional foliation development (S_{2b}) and growth of peak metamorphic mineral assemblages. This relation is suggested by the presence of screens of File Lake Formation within the gneissic phases of the Reed Lake pluton. It is possible that the Reed Lake and Ham Lake plutons (Fig. GS-10-1, -2) intruded and effectively masked another D_2 imbricate zone, separating the Northeast Reed basalt assemblage from the Snow Lake arc assemblage.

The present, steeply dipping geometry of the Morton Lake fault zone is consistent with the geometry of D_2 structures observed on south File and Morton lakes (Bailes, 1980; Connors, in prep.), but contrasts with the more typical, shallowly dipping, Kisseynew south flank geometries (*e.g.,* Kraus and Williams, 1994; Connors, in prep.; Zwanzig *et al.*, in prep.). Connors (in prep.) examined this structural transition (shallow to steep structures) in the File Lake area and concluded that southward steepening of all structural elements was due to thrusting of File Lake allochthons over north-dipping thrust ramps at the edge of the ancestral Kisseynew basin. In addition, a phase of back-folding was proposed to have accompanied development of the regional metamorphic cleavage (*i.e.,* S_{2b}) and contributed to the southward steepening of structures. The outcrop database for the File Lake Formation on Reed Lake is too limited to be able to adequately constrain the structural history and determine if Connors' (in prep.) model for File Lake is adequate to explain the observed geometries and overprinting structural relations. However, we do infer that interleaving of File Lake Formation turbidites and older volcanic assemblages occurred along low-angle thrust systems. Evidence for this is the apparent truncation of Fourmile Island stratigraphy against the Morton Lake fault zone from south to north on Reed Lake, and possible elimination of Northeast Reed assemblage stratigraphy against the fault from northwest to southeast (Tramping Lake) (Fig. GS-10-2), although this relation is obscured by the Reed Lake pluton. The regional transport direction for the thrust faults is top-to-the-southwest (Connors, in prep.; Norman *et al.*, in press; Zwanzig, 1990).

Two important questions remain concerning the Morton Lake fault zone. First, what is the significance of the Josland sills, which intrude both hanging wall and footwall volcanic assemblage rocks but apparently not the File Lake Formation? Does this relation 'stitch' the Fourmile Island and Northeast Reed assemblages together prior to imbrication with the File Lake Formation, or is it just fortuitous that similar intrusive bodies are found on both sides of the fault zone? U-Pb zircon geochronology of the Josland sills has yielded an imprecise age of *ca.* 1.855 Ga (K. Ansdell, unpublished). Resolution of the age and significance of Josland sills in both hanging wall and footwall of the Morton Lake fault zone should permit the stacking order of D_{2a} (and D_{2b}?) thrusts to be established. The field relations suggest that the fault juxtaposing Northeast Reed basalts on File Lake turbidites may be an out-of-sequence thrust (late D_{2a} or D_{2b}), similar to the McLeod Road fault at Snow Lake (Kraus and Williams, 1994) or the Beltz Lake fault at File Lake (Connors, in prep.). Second, how 'allochthonous' is the File Lake Formation with respect to older volcanic assemblages in the Reed Lake area? Its relatively proximal nature and stratigraphic transition with Missi Suite sandstones on Tramping Lake both suggest that it may not necessarily be far traveled with respect to the older volcanic assemblages in the hanging wall and footwall. The key to this question is the relation between Missi Suite transitional marine facies on Tramping Lake and the File Lake Formation turbidites, given that Missi Suite sandstones are parautochthonous with respect to the older basement (Connors and Ansdell, 1994a; in prep.). Detailed study of the stratigraphic relations between these sedimentary packages, as well as U-Pb analysis of detrital zircon populations in a number of File Lake Formation and Missi Suite samples, is required to establish if the File turbidites at this latitude are also parautochthonous with respect to the Amisk collage footwall.

Relations between the File Lake Formation and Missi Suite

Reconnaissance examination of outcrops on southern Tramping Lake has revealed the possibility that a stratigraphic transition between the Missi Suite continental sedimentary rocks and the File Lake Formation turbidites is preserved within the Flin Flon belt. As outlined above, the geochronological database from U-Pb analyses of both Missi Suite and File Lake Formation detrital zircons is consistent with coeval marine and nonmarine sedimentation at about 1.84-1.85 Ga (Ansdell *et al.*, 1992; Ansdell, 1993; David *et al.*, in prep.). The presence of younger non-marine sandstone packages in the east Wekusko area (*ca.* 1.835 Ga; Ansdell, 1994; Connors and Ansdell, 1994b, in prep.) complicates the field interpretation of Missi Suite rocks in the Tramping Lake area. Without geochronological constraints, the Missi rocks could be *ca.* 1.84-1.85 Ga deposits, effectively lateral equivalents of the extensive Kisseynew turbidites, or *ca.* 1.835 Ga foreland basin sediments deposited during D_{2a} thrusting (Connors and Ansdell, 1994a, in prep.). We speculate that the Missi Suite sandstones along Tramping Lake are probably equivalent in age to the *ca.* 1.845 Ga package at Flin Flon or the older (eastern) package in the eastern Wekusko Lake area.

The Missi Suite facies with turbidite bedforms on Tramping Lake, if indeed autochthonous with respect to the older volcanic-plutonic basement, is fundamentally important because it could provide the first direct evidence for drowning and submergence of the Amisk collage at *ca.* 1.85 Ga. Uplift, emergence and deep erosion of the collage is documented in the Flin Flon area, where ~10 km of uplift and erosion of the collage and its successor arc cover took place between *ca.* 1.86 and 1.845 Ga (Ansdell, 1993; Lucas *et al.*, in press). Ansdell *et al.* (1995) have suggested that the Kisseynew/File Lake Formation turbidites were deposited in a back-arc basin built on Amisk collage and other Reindeer zone terranes at *ca.* 1.85 Ga. A prediction of this model is that the stratigraphic transition from emergent post-accretion arc to subsiding back-arc basin should be preserved in the *ca.* 1.85-1.84 Ga sedimentary record. Sedimentological and geochronological study of both Missi and File Lake sedimentary rocks on Tramping Lake is urgently required to further constrain this key tectonic relationship.

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GS-11 A SUMMARY OF NEW CONTRIBUTIONS ON THE REED LAKE MAFIC COMPLEX*

by B.L. Williamson[1] and O.R. Eckstrand[1]

Williamson, B.L., and Eckstrand, O.R., 1995: A summary of new contributions on the Reed Lake mafic complex; **in** Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 61-70.

SUMMARY

The Reed Lake Mafic Complex (RLMC) is a layered gabbroic complex that has been intruded into arc assemblage volcanic rocks of the Flin Flon belt (Churchill Province) at the west end of Reed Lake. A summary of significant findings from recent studies is presented here.

The term Reed Lake Mafic Complex is proposed to refer to the intrusion, with subdivision into Lower, Middle and Upper zones. The Lower Zone correlates roughly with the Lower Gabbro and Ultramafic-Mafic groups of Young and Ayres (1985). The Lower Zone has distinct magnetic signature, layer orientation, proportion of lithological and chemical types and PGE content compared to the Middle and Upper zones, and likely represents a separate intrusive phase.

Three north-striking aeromagnetic anomalies coincide with mafic rock along the study cross section. The linear anomalies indicated by a vertical gradiometer aeromagnetic survey indicate different orientations in the Lower Zone compared to the Middle and Upper zones: the eastern (Lower Zone) anomaly consists, in detail, of a series of *en echelon* lenticular anomalies that strike obliquely to its main trend and to the trend of the other anomalies. The contacts of igneous layers exhibit this same discrepancy in orientation between the two domains. The aeromagnetic pattern also suggests that the intrusion may not be as extensive to the north and northwest as originally mapped by Rousell (1970). A gravity survey indicates a 15 mGal positive anomaly centred on the RLMC is probably a result of ultramafic rock within the complex; it is truncated at the south end (probably by the Berry Creek Fault) and the RLMC does not extend south under Paleozoic cover rocks.

All rocks have been metamorphosed, and little of their original mineralogy remains. Lithologies range from rare peridotite, through pyroxenite, gabbro, anorthosite and tonalite. Intrusive breccia has been newly identified. The appearance of mafic minerals reflect whole rock geochemistry, regardless of lithology: geochemically primitive rocks (Mg# >0.6 and TiO_2 <0.30) weather grey, are colourless and non-pleochroic in thin section; geochemically evolved rocks (all others) weather black, are moderately to intensely coloured and strongly pleochroic. Geochemically, the intrusion is tholeiitic.

Sulphide and oxide minerals are present in minor disseminated amounts. Enrichment of platinum group elements is reported within the Lower Zone, but most of the complex contains insignificant levels. Negative correlation of Pt, Pd and Ni with sulphur suggests that the conditions needed for partitioning of these elements into an immiscible sulphide phase did not occur; hence, within the limitations of this study, the RLMC may have limited potential to host a PGE or Ni deposit.

INTRODUCTION

The term "Reed Lake Mafic Complex (RLMC)" is used here to describe a suite of mafic plutonic rocks occurring at the west end of Reed Lake that were intruded as a sequence of magma batches in a complex manner. The RLMC is a large gabbroic layered intrusion that represents a potential host for Ni-Cu-PGE mineralization. A reconnaissance study by Ayres and Young (1989) identified some of the fundamental aspects of the intrusion, and they suggested it had the best potential of several intrusions studied in the Flin Flon-Snow Lake greenstone belt to host PGE mineralization. Based on these results, the present study was undertaken in an attempt to document the extent and nature of layering in the intrusion, supplement the stratigraphy proposed by Ayres and Young (1989), document chemical trends through the stratigraphic column, and to further assess the potential for PGE or Fe-V-Ti oxide mineralization. The study area is a cross section through the south end of the intrusion along the Grass River. This report is a summary of the significant results that are reported along with extensive chemical data in a Geological Survey of Canada Open File (Williamson and Eckstrand, in press).

The RLMC has been subject to four previous studies, in addition to early reconnaissance studies. Rousell (1970) recognized two gabbroic bodies within his map area. Young and Ayres (1985) and Ayres and Young (1989) recognized north-trending, subvertical and west-facing layering in the intrusion concordant with bedding planes in the host tuffs, and proposed a three-fold subdivision of the intrusion into: 1) Lower Gabbro Group (100-300 m); 2) Ultramafic-Mafic Group (335-700 m); and 3) Upper Gabbro Group (3200 m). Mineral exploration for PGE was undertaken during 1986-88 by International Platinum Corporation that included a reconnaissance geological survey (Gittings, 1986) and a detailed helicopter-borne geophysical survey (Konings, 1988). The geological report describes PGE analyses up to 134 ppb Pt and 228 ppb Pd. Young (1992) detailed the lithological and mineralogical form and composition of the Ultramafic-Mafic Group and defined 15 cycles, each consisting of a lower ultramafic zone and an upper mafic zone. He also reported more than 1200 clinopyroxene compositions that show limited compositional variation ($Wo_{43.8}$ $En_{48.2}$ $Fs_{8.0}$ to $Wo_{42.3}$ $En_{43.8}$ $Fs_{13.9}$).

GEOPHYSICAL CHARACTERISTICS

The RLMC has distinctive aeromagnetic and gravity signatures. A gravity survey (Thomas *et al.*, 1993; Broome *et al.*, 1993) consisted of three east-west profiles across layering and one north-south profile across the southern edge of the intrusion. An aeromagnetic survey was performed during mineral exploration by International Platinum Corporation (Konings, 1988).

Total field aeromagnetic results (Fig. GS-11-1) indicate three strongly magnetic zones in the centre and near the east and west margins of the intrusion, essentially oriented parallel to the intrusion margins described by Rousell (1970). Although the total field anomalies are grossly similar, vertical gradiometer results (Fig. GS-11-2) indicate that their form and orientation differ significantly in detail.

The central and western anomalies are oriented at a strike of 014°. The western anomaly is a moderately intense, narrow and sharply defined magnetic high. The calculated vertical gradiometer plot (Fig. GS-11-2) indicates a principal anomaly and parallel minor discontinuous anomalies, suggesting magnetically layered rocks. The central anomaly is the largest and most intense and turns abruptly to the east at its southern end, which may reflect drag associated with the east-striking Berry Creek Fault. The vertical gradiometer plot (Fig. GS-11-2) indicates a massive, but irregularly shaped form.

In contrast, the eastern anomaly in gross form (Fig. GS-11-1) consists of a complex, northerly-trending anomaly. In detail (enhanced on the vertical gradiometer plot, Fig. GS-11-2), it contains a parallel set of smaller linear anomalies that individually are oriented at a strike of 355° (*i.e.*, oblique to the main trend, the other principal anomalies and the intrusion margins). This is unique to the eastern anomaly. It implies a distinct structural and lithological character for the associated rocks, apparently a series of layered magnetic and nonmagnetic rocks that developed at a different orientation to that of the western half of the intrusion. Possible interpretations are that the rocks underlying the eastern magnetic anomaly formed as a separate intrusion, or as an early stage of the intrusion followed by tilting and development of later intrusive stages at a different orientation.

The magnetic pattern in the northern portion of the intrusion is different from the layered pattern in the south. In the north, the total field plot (Fig. GS-11-1) exhibits a relatively flat magnetic relief, and the vertical gradiometer plot (Fig. GS-11-2) displays a random burled pattern similar to that of the host volcanic rocks. This suggests that the intrusion may not be as extensive northward as was originally mapped by Rousell (1970).

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[1] Geological Survey of Canada, Mineral Resources Division

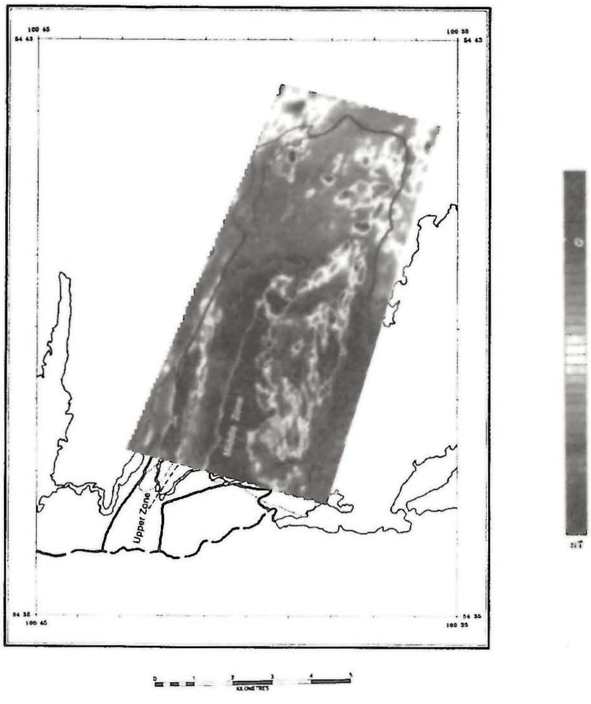

Figure GS-11-1: Total field aeromagnetic map of part of the Reed Lake Mafic Complex. Heavy solid line indicates the extent of the Reed Lake Mafic Complex, and heavy dashed line, the northern limit of Paleozoic cover rocks (after Rousell, 1970). Light dotted lines indicate the extension of aeromagnetic anomalies (from Geological Survey of Canada Map C20, 341G); light dashed lines indicate stratigraphic subdivisions of the present study.

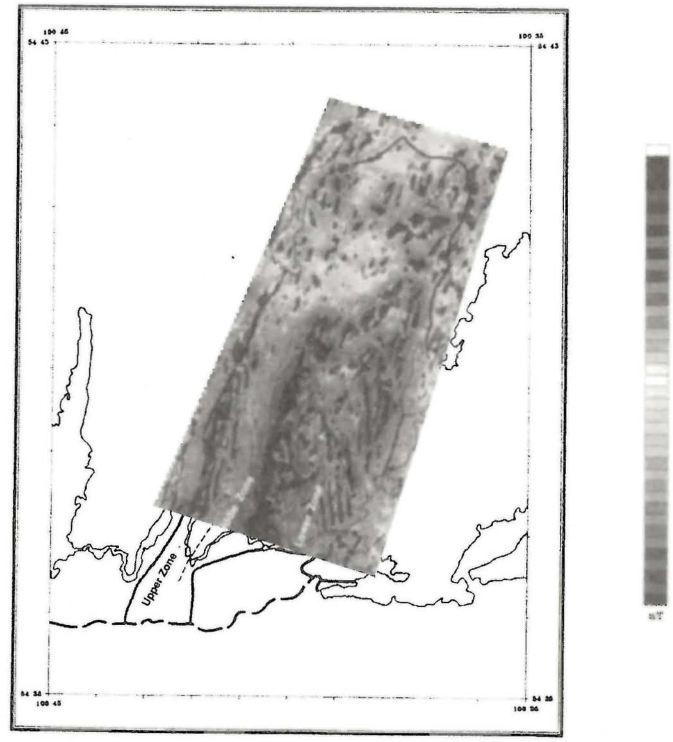

Figure GS-11-2: Calculated vertical gradiometer aeromagnetic map of part of the Reed Lake Mafic Complex. Line symbols as in Figure GS-11-1.

Bouguer gravity results (Fig. GS-11-3) indicate a 14 mGal positive anomaly centred on the intrusion, suggesting the presence of denser ultramafic rock. The apparent continuity of the anomaly to the northern limits of the intrusion is in contrast to the aeromagnetic results, a paradox that cannot be resolved with current data. The profile across the southern edge of the intrusion indicates an abrupt termination, probably as a result of truncation by the Berry Creek Fault. The very flat nature of the gravity profile along Highway 39 (a relief of only a few milligals over tens of kilometres) indicates that the intrusion does not extend under the Paleozoic cover.

STRATIGRAPHIC SUBDIVISION

In the present study, the intrusion was subdivided into 3 zones: Lower, Middle and Upper. The Lower Zone extends from the eastern (basal) contact of the intrusion to the eastern edge of the central magnetic anomaly (incorporating the eastern zone of magnetic lenses near its base). The Middle Zone incorporates the central magnetic anomaly at its base, and extends from its eastern (stratigraphically lowermost) edge to the eastern edge of the western magnetic anomaly. The Upper Zone incorporates the western magnetic anomaly at its base, and extends from its eastern (stratigraphically lowermost) edge to the western (upper) contact of the intrusion.

The new subdivision in this study is based on three lines of evidence:

1. the presence of the three principal aeromagnetic anomalies, interpreted to represent ultramafic rock forming the base of three major cyclic units. This interpretation is substantiated by the correlation of the magnetic anomalies with more mafic rocks (melagabbro, pyroxenite and rare peridotite) which have a magnetic character (*i.e.*, attract a swing magnet).
2. the contrasting form and attitude of the eastern magnetic anomaly compared to the central and western magnetic anomalies, as described above. The contrasting attitudes of magnetic anomalies are also reflected in the contrasting attitude of igneous layering in the Lower Zone compared to layering in the Middle and Upper Zones (described below).
3. the repetition on a gross scale of three successions of more mafic rocks (melagabbro, pyroxenite or rare peridotite) at the base of each zone, that are overlain in each case by less mafic rocks (gabbro, anorthosite or quartz-bearing rocks). This is interpreted to reflect a typical magmatic differentiation trend from more mafic to more felsic rocks within each zone.

This stratigraphic subdivision is in contrast to that proposed by Young and Ayres (1985), and correlation between the two schemes is not obvious. The magnetic anomaly portion of the Lower Zone (present study) appears to correlate with the Ultramafic-Mafic group of Young and Ayres (1985), and their Lower Gabbro Group with the Lower Zone gabbros (present study), which underlie the magnetic anomaly. The Lower Zone (present study) extends upward into the basal part of Young and Ayres' Upper Gabbro Group. The absence of distinguishing features in Young and Ayres' Upper Gabbro Group does not permit ready correlation with the Middle and Upper zones of the present study.

This subdivision is based on aeromagnetic anomalies (which only extend through the southern two-thirds of the intrusion as outlined by Rousell, 1970) in conjunction with geological observations restricted to a cross section at the south end of the intrusion, along the Grass River. More extensive investigations in the future may require revision of this subdivision.

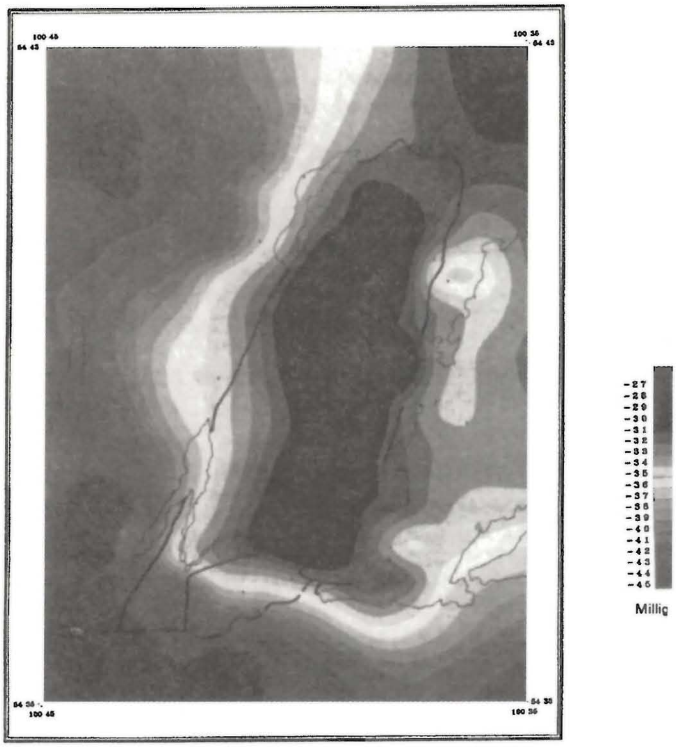

Figure GS-11-3: Bouguer gravity map of the Reed Lake Mafic Complex. Heavy solid line indicates the extent of the Reed Lake Mafic Complex, and heavy dashed line, the northern limit of Paleozoic cover rocks (after Rousell, 1970). Dots indicate individual gravity stations.

IGNEOUS LAYERING

Igneous layering is on the order of several metres or tens of metres thick. Layering is commonly represented by a succession of outcrops of differing lithology, each outcrop representing successive different homogeneous layers. Internal layering at finer scales is more commonly observed, with layering distinguished by minor variation in modal composition. Lithologic contacts are poorly exposed.

The attitude of contacts of igneous layers within the Lower Zone differs from those within the Upper and Middle zones (Fig. GS-11-4). The layers in the Lower Zone (n=30) strike at an average 350° and dip steeply (85.4°) to the southwest. This is oblique to the lower contact of the intrusion (015°). The layers in the Middle and Upper zones (n=4) strike at an average 026° and dip vertically. These divergent attitudes of the observed contacts of layers are essentially the same as the divergent orientations of magnetic anomalies in the two domains.

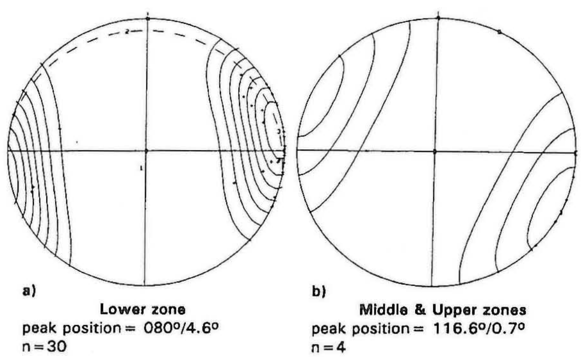

Figure GS-11-4: Stereonet plots of poles to measured igneous layer contacts in (a) the Lower Zone and (b) the Middle and Upper Zones of the Reed Lake Mafic Complex. Poles to individual measured contacts are plotted as crosses (+).

LITHOLOGICAL CHARACTERISTICS

The rocks are metamorphosed. In most cases well preserved relict textures and mineral grains partly or completely pseudomorphed by alteration assemblages allow determination of the original rock type. The rocks are meta-anorthosite, metagabbro (including leuco- and melagabbro) and metapyroxenite. Metaperidotite is rare; quartz-bearing rocks also occur. In the Lower Zone, pyroxenite and gabbro dominate; in the Middle Zone, gabbro dominates; the Upper Zone is principally gabbro, but it also contains some quartz-bearing rocks. Several lithological features correlate with geochemically primitive and evolved suites (described later in the geochemistry section).

In the Lower Zone, chemically primitive melagabbro and pyroxenite contain mafic minerals that weather medium green, commonly with light brown iron staining; in evolved rocks, mafic minerals weather dark green to black. In thin section of primative melagabbro mafic minerals, chiefly tremolite (?) and chlorite are colourless and non-pleochroic, whereas mafic minerals in evolved melagabbro, hornblende (?) and chlorite, are intensely coloured and usually strongly pleochroic. In addition, preservation of original mineralogy and textures is better in primitive rocks, which commonly contain relict pyroxene, and which preserve original pyroxene shapes and the crystallographic orientation of twin planes and suspected pigeonite exsolution lamellae in the pseudomorphing alteration products. Evolved rocks are thoroughly recrystallized, and relict minerals and textures are nonexistent. In pyroxenite, the pyroxene grain outlines are in some cases enhanced by rims of opaque minerals, likely magnetite formed by alteration reactions,. Evolved melagabbro usually contains minor apatite, reflecting an enriched P_2O_5 content.

In the Middle Zone, the chemically primitive suite is sparsely represented by gabbro and melagabbro, which appear similar to primitive rocks from the Lower Zone (lighter weathering mafic minerals, pale and weakly pleochroic in thin section; feldspar extensively altered to zoisite; textures moderately well preserved). The chemically evolved suite is well represented, but the consistently dark weathering mafic minerals that distinguish evolved rocks in the Lower Zone are not as apparent here. Mafic minerals in evolved anorthosite, leucogabbro and gabbro weather medium green to black, commonly with brown staining, and are pale and weakly pleochroic to distinctly coloured and strongly pleochroic. Feldspar has been largely altered to zoisite and textural preservation is poor. Apatite occurs as a significant minor phase in one sample. Evolved melagabbro and pyroxenite are comparable to evolved rocks of the Lower Zone, and they contain the typical dark weathering, intensely coloured and moderately to strongly pleochroic mafic minerals. Feldspar has generally been partially or completely altered to zoisite ± carbonate, although a few samples contain abundant fresh feldspar. Textures range from poorly preserved to thoroughly recrystallized. Several melagabbro samples contain significant minor apatite; one pyroxenite sample is a texturally well preserved rock that contains abundant fresh feldspar.

Rocks in the Upper Zone are of the geochemically evolved suite, and comprise pyroxenite, gabbro, melagabbro and quartz-bearing rocks. They weather black, hornblende and chlorite are pleochroic, and feldspar has been 50-100% altered to zoisite. Primary textures are not well preserved. Quartz-bearing rocks within the Upper Zone are described below.

Quartz-bearing rocks (*i.e.*, those that contain significant modal quartz visible on the weathered surface with the naked eye or with a hand lens) occur in all three zones. Poor exposure obscures the field relationships, but for the most part, outcrop exposures are as extensive as for any other layered unit of the complex. The rock types represented include quartz gabbro, quartz melagabbro and tonalite, all of evolved chemical type. Mafic minerals show the black weathering, intense colouring and strong pleochroism characteristic of the evolved suite. Feldspar is in some cases slightly to completely altered to zoisite, although in two rare specimens from nearest to the upper contact of the intrusion it has been altered to sericite. Quartz weathers milky white to purplish. Locally, apatite is a significant accessory mineral.

Figure GS-11-5 (a): Lower Zone breccia of predominantly melagabbro blocks cut by a dense stockwork of leucogabbro. Knife is 16 cm in length.

Figure GS-11-5 (b): Lower Zone breccia of predominantly leucogabbro matrix enclosing melagabbro blocks. Knife is 16 cm in length.

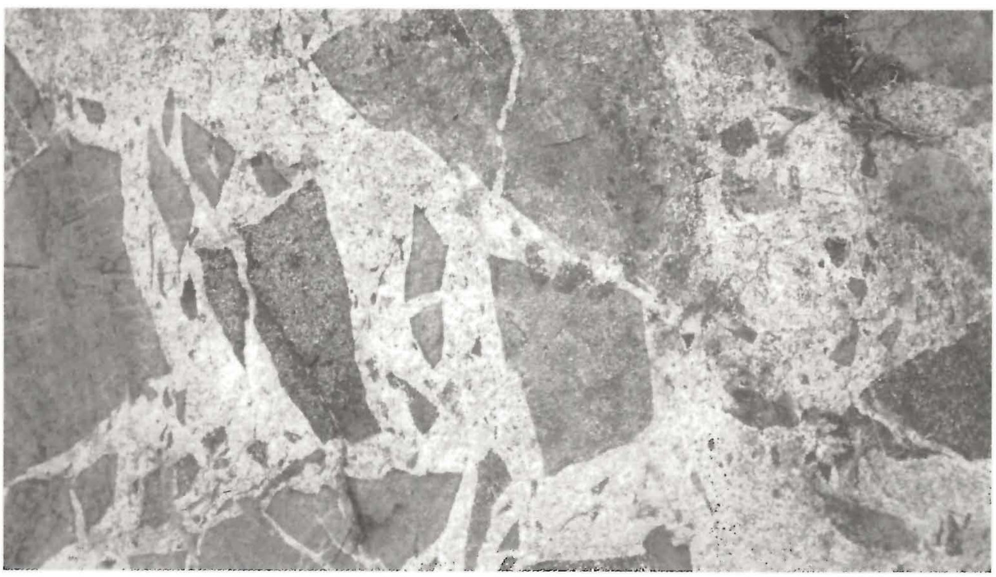

Figure GS-11- 5(c): Middle Zone breccia displaying extremely angular fragments of various lithologies in a quartz-bearing gabbro/anorthosite matrix. Notebook is 11 cm wide.

Breccia

Intrusive breccia has not been reported by previous workers. It occurs at 3 locations in the RLMC: basal breccias comprising a vague zone of 6 scattered outcrops along a strike length of about 1 km occur within the lowermost 200-300 m of the intrusion; within the Middle Zone, 3 outcrops that define an area 150x100 m; and within the Upper Zone, a small area exposed on part of a single outcrop.

Intrusive breccia consists of blocks of more mafic rock in a matrix of more felsic material, commonly pyroxenite or melagabbro blocks in a gabbroic to anorthositic matrix. Quartz is a matrix constituent in some localities. Fragment to matrix proportions can range from matrix veining the primary rock in a concentrated stockwork (Fig. GS-11-5a) to a matrix-supported melange with 25-50% fragmented blocks (Fig. GS-11-5b). In the Middle Zone breccia, the blocks consist of a variety of lithologies that encompass pyroxenite, melagabbro and gabbro (Fig. GS-11-5c).

Chemical analyses indicate that both geochemical suites are represented in fragments and matrix.

GEOCHEMISTRY

All samples collected during field studies were analyzed for the normal suite of whole rock major elements and numerous trace elements, including the complete REE suite for more than half the samples. A summary of the significant features are presented here; full analytical results are presented in Williamson and Eckstrand (in press).

The intrusion has a tholeiitic composition (Fig. GS-11-6). Differentiation trends reflect principally Fe-Mg variation and for the most part do not involve any significant alkali enrichment. Figure GS-11-6 also shows ferromagnesian differentiation upsection throughout the stratigraphic column on a gross scale. The Lower Zone contains magnesium-rich rocks that plot in a cluster and represent the most primitive compositions found, as well as rocks that grade continuously through intermediate and iron-rich compositions. The Middle Zone contains only intermediate to iron-rich rocks; the Upper Zone contains exclusively iron-rich rocks.

A plot of Mg# against TiO_2 (Fig. GS-11-7a) depicts a refinement of this differentiation. Two chemical suites are distinguished: primitive and evolved, based on Mg# and TiO_2. The primitive suite consists of the sample subset with Mg#> 0.60 and TiO_2< 0.3%, and the evolved suite consists of samples outside these boundaries. The compositions of the two types are also reflected in P_2O_5, Ni and Cr contents (Figs. 7b, 7c, 7d; Table GS-11-1). The primitive suite samples are tightly clustered at the extremities of the differentiation trends (*i.e.*, Mg#) on the various chemical variation diagrams, whereas the evolved suite samples have a much wider range of compositions. Vanadium shows a different trend from TiO_2, P_2O_5, Ni or Cr, peaking in the midrange at about Mg#=0.4 (Fig. GS-11-8). Yttrium, Zr and Nb concentrations are generally so low that analyses for only a few samples were above detection limits.

Table GS-11-1
Chemical characteristics of primitive and evolved suites

	Primitive			Evolved	
	criterion	range	average	range	average
Mg#	> 0.60	0.60-0.84		0.08-0.59	
TiO_2	<0.30	0.03-0.29%	0.13%	0.16-3.42%	1.14%
P_2O_5		0.01-0.08%	0.017%	0.01-2.12%	0.31%
Ni		21-680 ppm	177 ppm	<10-160 ppm	26 ppm
Cr		17-6300 ppm	928 ppm	<10-390 ppm	32 ppm

Chemical types are independent of lithology: gabbro, melagabbro and pyroxenite are represented in both chemical suites. Anorthosite and leucogabbro occur only in the primitive suite; melagabbro is predominantly of evolved type. Chemical types do not seem to be consistently distributed with regard to field relationships: in some cases dykes of evolved chemical type have cut host rocks of primitive chemical type, but in other cases chemically primitive gabbro has invaded and formed the matrix of a brecciated evolved pyroxenite.

Chemical types are related in a general way to stratigraphic height; chemically primitive rocks are more abundant near the base and chemically evolved rocks predominate towards the roof. Lower Zone rocks are predominantly of primitive chemical type (82 of 108 samples), whereas Middle Zone rocks are predominantly of evolved chemical type (38 of 43 samples), and Upper Zone rocks are exclusively of evolved chemical type (8 samples). This stratigraphic distribution of the two chemical types suggests that early pulses of magma were primitive in composition and were differentiated significantly (from primitive to evolved) in many cycles, and that successive pulses of magma were progressively less primitive. Another explanation is that the intrusion formed from two magmas (primitive and evolved), with pulses of primitive magma type predominant in producing rocks of the Lower Zone and increasing proportions of evolved magma type intruding to form the rocks of the Middle and Upper zones.

Chondrite normalized REE plots for layered rocks are presented in Figure GS-11-9. They show two fundamental aspects: overall REE concentrations, which differ between chemical types (independent of stratigraphic zone); and the shape of the chondrite normalized REE plot, which varies by stratigraphic zone (independent of chemical type). In addition, most of the layered rocks have a positive Eu anomaly; few have a negative Eu anomaly, and a flat profile is rare.

The distinction between primitive and evolved chemical suites

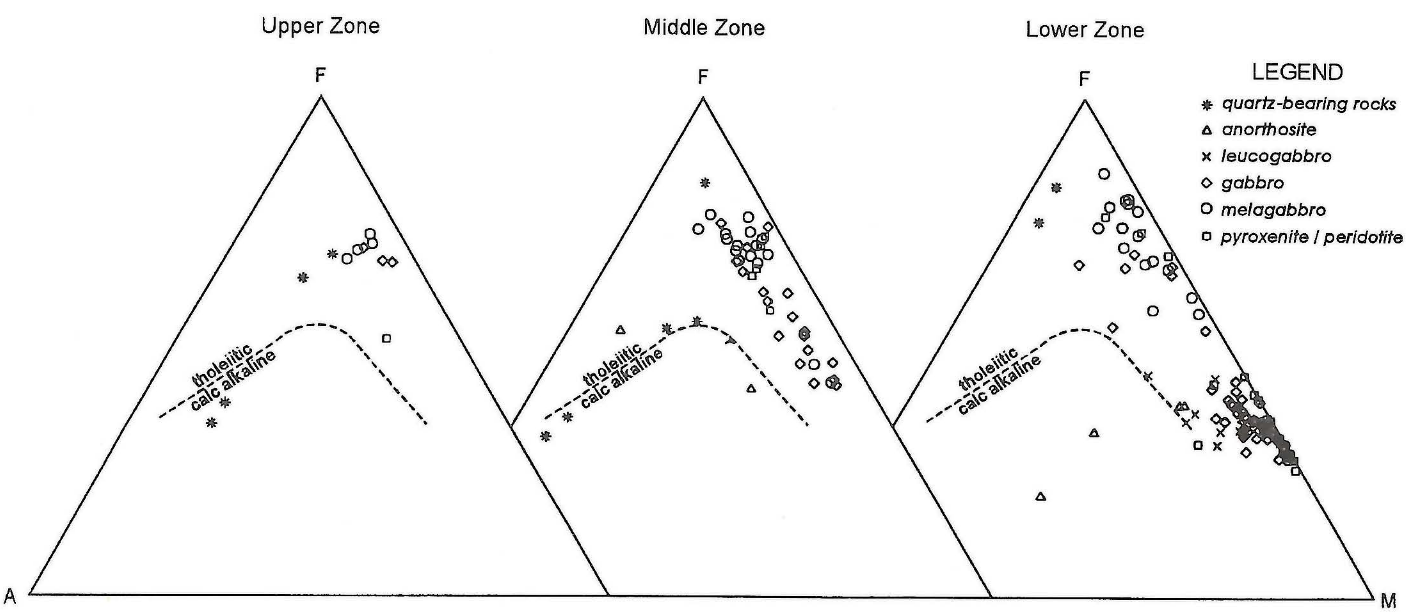

Figure GS-11-6: AFM plot of samples from the Lower, Middle and Upper zones of the Reed Lake Mafic Complex. A=Na_2O+K_2O, F=total iron reported as FeO, M=MgO; all in weight %. The tholeiite/calc-alkaline discriminant line is from Irvine and Baragar (1971).

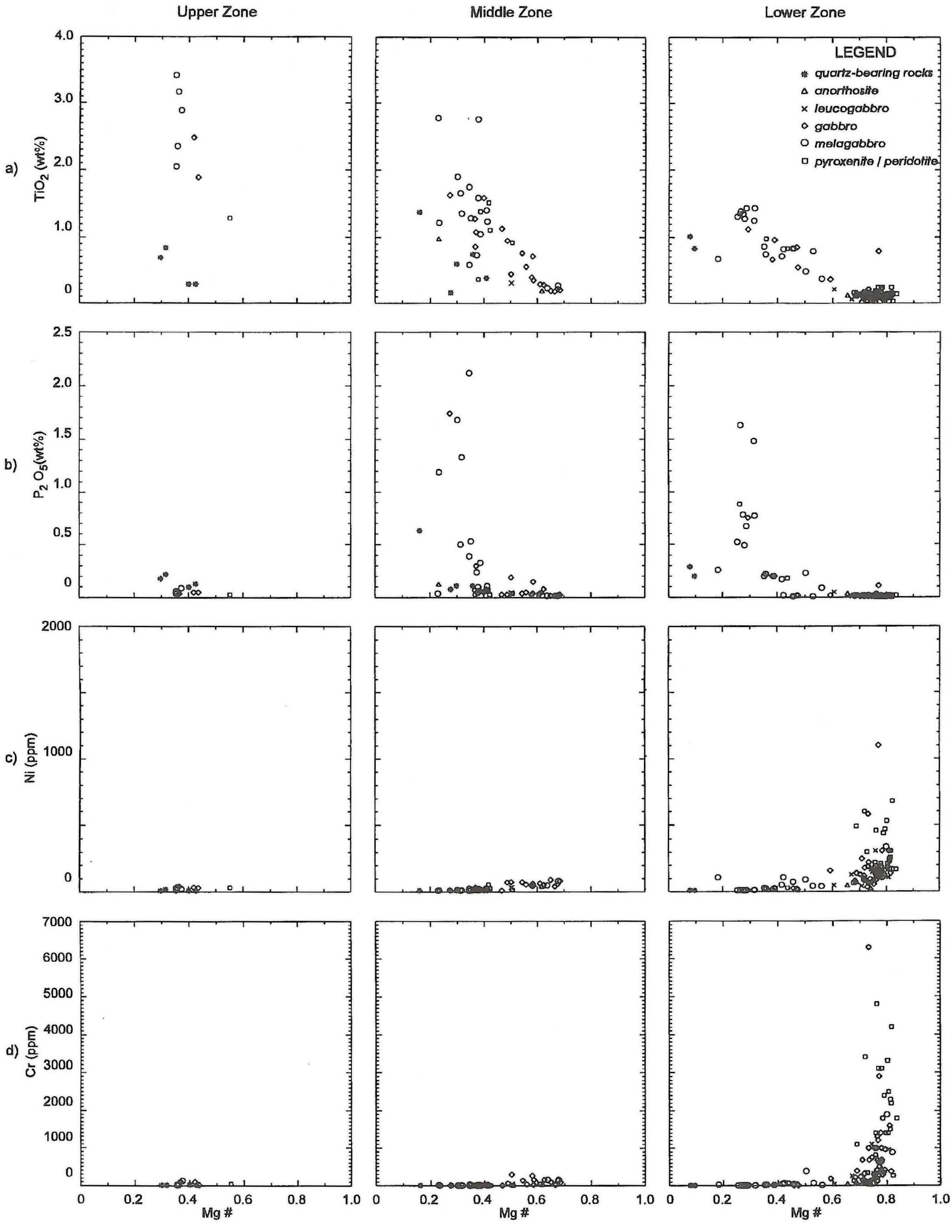

Figure GS-11-7: Plots of a) TiO_2, b) P_2O_5, c) Ni and d) Cr vs. Mg# for samples from the Lower, Middle and Upper zones of the Reed Lake Mafic Complex.

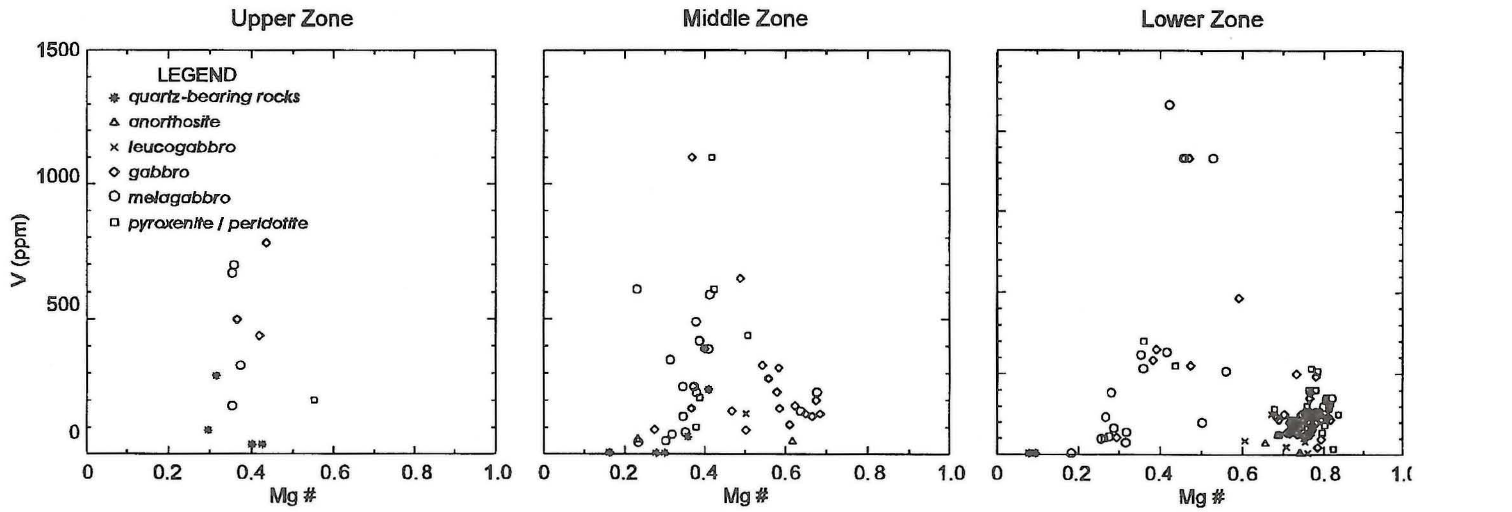

Figure GS-11-8: Plot of V vs. Mg# for samples from the Lower, Middle and Upper zones of the Reed Lake Mafic Complex.

is maintained in the overall level of REE: rocks of the primitive suite generally have lower REE values (5x chondrite) than rocks of the evolved suite (1- 20x chondrite). This distinction is maintained independent of both lithology and stratigraphic zone.

The shapes of the REE curves correlate with stratigraphic zone (independent of either lithology or chemical type), and the curves have unique features within each zone. The Lower Zone is distinguished by a flat to weakly negative slope. The Eu anomaly is variable: it is generally positive (for most rock types, of both primitive and evolved chemistry), rarely flat, and occasionally negative (for chemically primitive ultramafic rocks). The rocks of the Middle Zone generally have more complex REE profiles (with a variable slope for the LREE and a flat slope for the HREE) and overall flat to very slightly positive slopes (La:Lu ratio). The Europium generally displays a positive anomaly, rarely flat or negative. The REE profiles for the Upper Zone display two divergent shapes, dependent on the presence or absence of quartz. Rocks that do not contain quartz have a positive slope and a positive Eu anomaly; quartz-bearing rocks have a weak but distinctly negative slope and a negative Eu anomaly. Amongst the quartz-bearing samples, tonalites, which are stratigraphically highest and exhibit distinctive sericite alteration of feldspar, have the highest REE levels and the strongest Eu depletion of all samples.

Arc assembly volcanic rocks in the area (Williamson, 1994) do not compare in chemistry to either chemical suite of the Reed Lake Mafic Complex.

DYKES

Numerous dykes were observed to crosscut igneous layering at all levels of the intrusion, and could represent feeder dykes to stratigraphically higher units of the RLMC, feeders to overlying volcanic rocks, or much later features unrelated to magmatic activity within the RLMC or Amisk Group. Most dykes are fine grained, massive mafic rocks (melagabbro or gabbro). All fine grained dykes display a fine diabasic texture, both macroscopically and microscopically; a few from the Middle and Upper zones exhibit a fine grained porphyritic texture of 1-2 mm black weathering hornblende (?) in a finer grained, diabasic groundmass. Medium- to coarse-grained rocks of gabbro to leucogabbro compositions are similar in appearance to other gabbros of the intrusion, but only are rarely distinguishable from layered gabbro by field relationships.

The chemistry of the dykes does not reflect the primitive/evolved suite subdivisions of the layered rocks. Although dyke rocks can be classified by the primitive/evolved parameters, such a classification is not reflected in their appearance or in their trace element chemistry, as is the case with layered rocks. As well, dyke rocks are distinguished from layered rocks by their REE contents and patterns: layered rocks generally exhibit a Eu anomaly, usually positive (Fig. GS-11-9), whereas dyke rocks generally do not (Fig. GS-11-10).

Three distinct patterns of chondrite normalized REE emerge for the dykes. Type I has a pattern which is essentially flat at levels 3 to 10 times chondrite (Type 1a with overall slightly negative slope and more enriched REE content, Type 1b with a slightly positive slope and less enriched REE content). Type II displays a pattern that is comparatively depleted in all REE except Eu, giving a positive Eu anomaly similar to layered rocks. Type III has a pattern that is strongly differentiated, giving steeply dipping slopes (Type IIIa LREE enriched with a negative slope, Type IIIb LREE depleted with a positive slope).

GEOCHRONOLOGICAL STUDIES

Two samples were collected in order to attempt radiometric dating of the RLMC. The sites were chosen to sample material containing zircon amenable to U-Pb techniques. No zircons were recovered. Heavy minerals that were recovered included apatite and pyroxene, but further analytical work on the samples was not pursued.

ECONOMIC GEOLOGY AND MINERAL POTENTIAL

Oxide layers that would explain the cause of the aeromagnetic anomalies were not observed during field investigations. Although there is a general correlation of aeromagnetic anomalies with more mafic rocks (peridotite, pyroxenite and melagabbro) that generally have a distinctly magnetic characteristic (*i.e.*, would attract a swing magnet), only disseminated magnetite was observed, and this commonly appeared to be an alteration product. This corroborates observations made by another worker (J. Young, pers. comm.). Magnetic lenses in the Lower Zone appear to correlate with altered ultramafic rock, but in many cases are difficult to locate on the ground. For future work, a ground magnetometer survey would be helpful to accurately locate the magnetic anomalies and thus help locate any potential related oxide concentration or ultramafic rock.

Significant sulphide concentrations were not found, although several samples contain trace to a few per cent sulphide minerals (pyrrhotite). All samples were analyzed for Pt, Pd, Rh and Au. PGE levels generally are low; the greatest values are from the Lower Zone, and the Middle and Upper zones generally contain very low levels. Rh was below the detection limit (5 ppm) for all samples. The ranges of values for each zone are summarized in Table GS-11-2. The three best values obtained (Pd > 100 ppb, and significant associated Pt) are listed in Table GS-11-3.

These PGE results compare with data presented by Gittings (1986): only 8 of 88 of his samples contained Pt or Pd significantly above the detection limit, and 3 contained >100 ppb (two clearly located within the Lower Zone, and one near the projection of the Lower Zone-Middle Zone boundary).

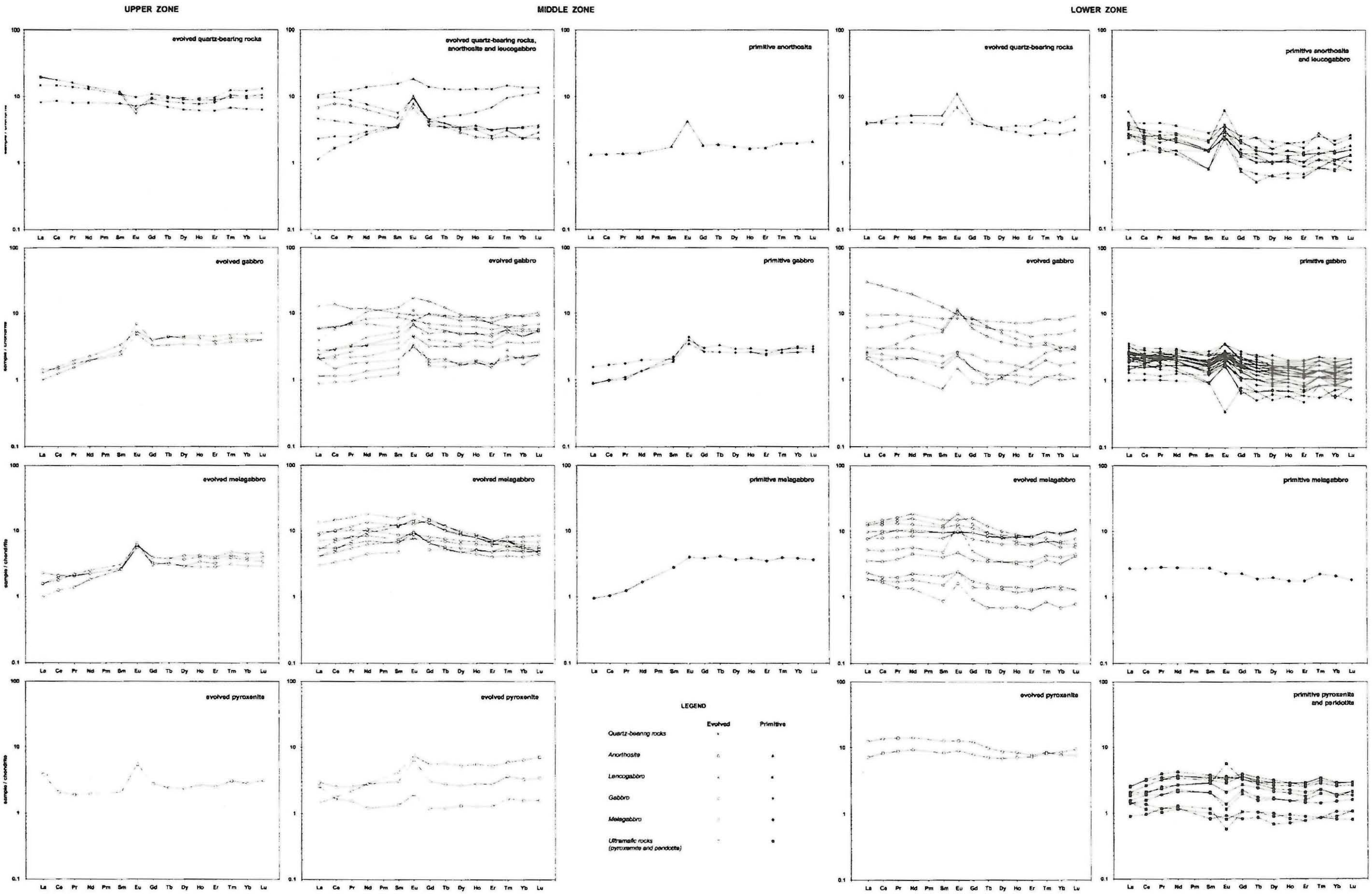

Figure GS-11-9: Chondrite normalized REE plots of samples from the layered rocks of the Lower, Middle, and Upper zones of the Reed Lake Mafic Complex, plotted by lithology and geochemical suite. Normalizing values are from Taylor and McLennan (1985).

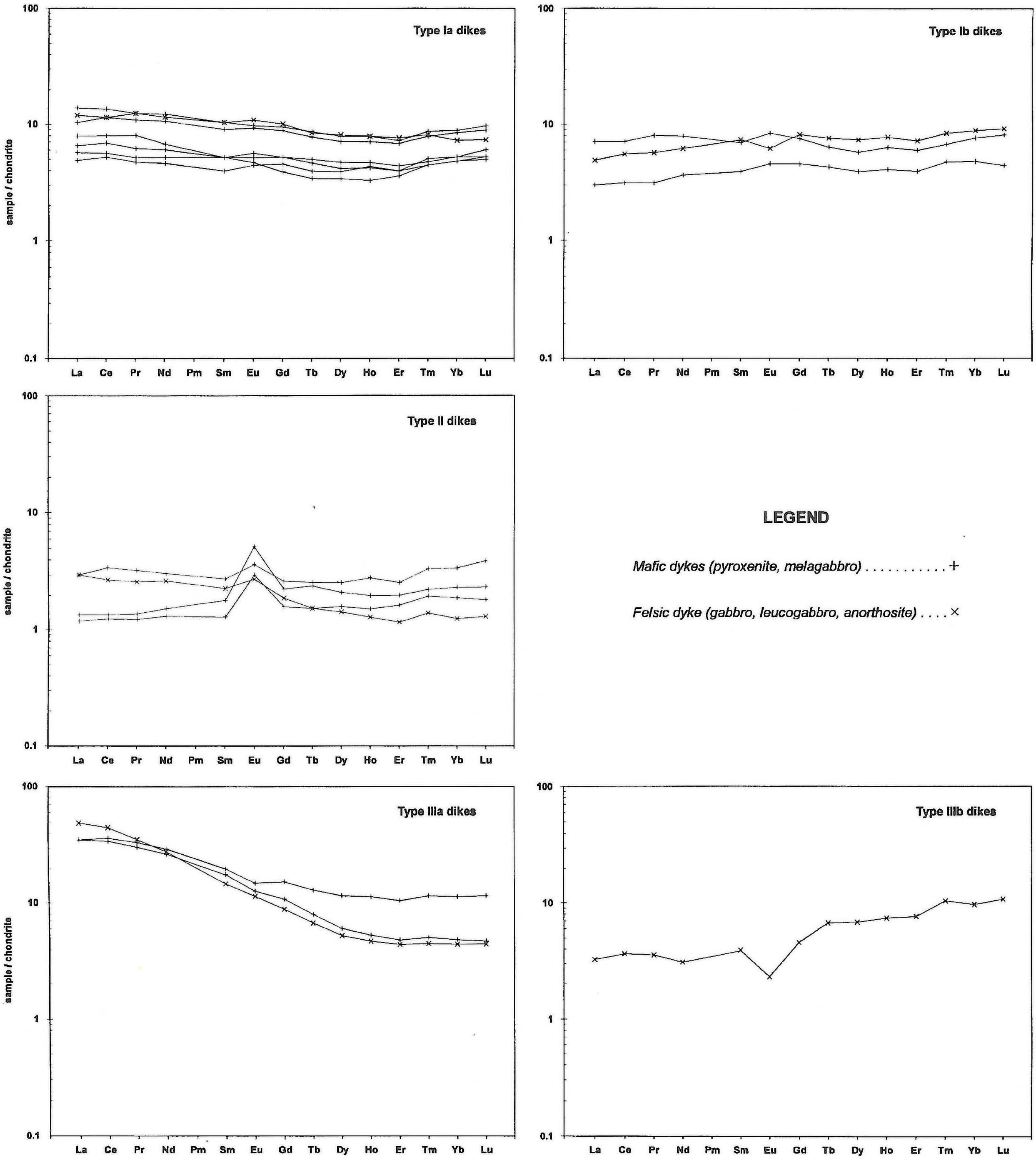

Figure GS-11-10: Chondrite normalized REE plots of samples from dikes that cut the Reed Lake Mafic Complex. Normalizing values are from Taylor and McLennan (1985).

Table GS-11-3
Greatest reported PGE levels

Sample	Pt (ppb)	Pd (ppb)
WY92-033	117	134
WY92-056	89	134
WY92-011	57	110

PGE contents do not correlate with lithology: Lower Zone samples that contain >20 ppb Pt+Pd include pyroxenite, gabbros and anorthosite. Samples that contain <20 ppb Pt+Pd (from all zones) include all rock types represented, including one peridotite and several pyroxenite samples that contain less than detectable amounts. The amounts of PGE also do not correlate with sulphur contents (Table GS-11-4); many of the PGE enriched samples contain minimal sulphur and many sulphur-rich samples contain low PGE. For the degrees of freedom resulting from this sample set, a Pearson correlation coefficient of about 0.2 is significant. Four correlations stand out as significant from Table GS-11-4: a very strong correlation of Pt with Pd; a lesser but still significant correlation of Pt and Pd with Ni; a weak but significant inverse correlation of Ni, Pt and Pd with S; and a significant correlation of Cu and S. The common model invoked to explain PGE mineralization is by PGE partitioning into an immiscible sulphide phase. The lack of correlation of PGE and Ni with sulphur gives no indication that this process has taken place; however, the low levels of PGE could also be the result of an earlier partitioning of PGE into an immiscible sulphide phase formed in a lower, hidden facies of the intrusive complex. The low levels of PGE present suggest that the RLMC may not be a good host for PGE mineralization; further investigations should be conducted before decisively dismissing the RLMC as an unfavorable host for a PGE deposit.

Table GS-11-4
Pearson correlation coefficients
(n=172)

	S	Pt	Pd	Ni	Cu
S	1.000				
Pt	- 0.212	1.000			
Pd	- 0.200	0.839	1.000		
Ni	- 0.237	0.258	0.216	1.000	
Cu	0.380	0.041	- 0.098	- 0.005	1.000

ACKNOWLEDGMENTS

Many people have contributed in large or small part to the work that eventually produced this report. We would like to thank Steven Bond and Nalini Mohan for field assistance; International Platinum Corporation for allowing access to the digital form of proprietary geophysical data from which the aeromagnetic maps were produced; Ken Anderson of the Aeromagnetic Section, Geophysics Division (GSC) for the data manipulation that produced the aeromagnetic plots included in this report; the Geophysical Data Centre, Geophysics Division (GSC) for producing the gravity plot from their national database; Subhas Tella, Continental Geoscience Division (GSC) for assistance in interpretation and plotting of the layer attitudes; Phil O'Regan and Rachelle Lacroix, Cartographic Unit (GICD, GSC) for redrafting some diagrams; the staff of the Analytical Chemistry Section (MRD, GSC) for the extensive set of chemical analyses. We would like to thank Ralph Thorpe (MRD, GSC) for critical review of the manuscript. This work was funded under the Canada-Manitoba Partnership Agreement on Mineral Development.

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GS-12 STRUCTURAL MAPPING IN THE ELBOW-CRANBERRY-ISKWASUM LAKES AREA, FLIN FLON BELT, MANITOBA (PARTS OF NTS 63K/10, 11 AND 15)

by J.J. Ryan[1] and P.F. Williams[1]

Ryan, J.J., and Williams, P.F., 1995: Structural mapping in the Elbow-Cranberry-Iskwasum lakes area, Flin Flon belt, Manitoba (Parts of NTS 63K/10, 11 and 15); **in** Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 71-73.

SUMMARY

An S_5 strand of the Elbow Lake Shear Zone (ELSZ) can be traced with confidence from 3 km north of Elbow Lake to Cranberry Portage 50 km to the southwest. An S_3 strand of the ELSZ trends southeast through Iskwasum Lake, and was shortened and folded during sinistral transpression along the S_5 strand of the ELSZ. Locally preserved, shallowly plunging, upright isoclinal F_2 folds of bedding in the Long Bay area may indicate that D_2 deformation was responsible for steepening stratigraphy.

INTRODUCTION

The 1995 field season concluded three summers of field work in the Elbow Lake area, part of the first author's Ph.D. program at the University of New Brunswick. This report is a brief summary of this summer's mapping; a more complete synopsis will appear as a contribution in the Geological Survey of Canada Current Research volume. In addition to the completion of mapping at Elbow Lake, two weeks were spent in the Cranberry Lakes area and one week was spent at Iskwasum Lake, following up on the work of Syme (1993, 1994). The expansion of the mapping area was an attempt to extrapolate the tectonometamorphic history interpreted at Elbow Lake to the southern extremity of the exposed Flin Flon belt. Ryan and Williams (in press) described the development of six generations of structures (F_1-F_6) during four deformation episodes (D_1-D_4) and two episodes of metamorphism (M_1-M_2). Previous work at Elbow Lake is summarized by Ryan and Williams (1993, 1994a, 1994b) and Syme (1992). Previous mapping in the Cranberry Lakes and Iskwasum Lake areas is summarized by Syme (1993, 1994). For geographic reference refer to Syme and Whalen (1992), Syme (1993), and Syme and Morrison (1994). Highlights of the field season are as follows:

1. The nature of the major tectonostratigraphic contacts in the northwest part of the Elbow Lake area;
2. The extent and development of S_2 regional foliation;
3 The trace of the ELSZ to the north;
4. The extension of ELSZ structures through the Cranberry Lakes and Iskwasum Lake areas;
5. The relative timing of mineralization and structural development.

TECTONOSTRATIGRAPHIC CONTACTS AT ELBOW LAKE

Supracrustal rocks at Elbow Lake have been differentiated into ocean floor, arc, and ocean island tectonostratigraphic assemblages (Stern *et al.*, 1995a, 1995b). Syme (in press) concluded that the various assemblages are structurally bound. The ocean floor-ocean island assemblage boundary and the ocean island-arc assemblage boundary were investigated this summer in the northwest portion of the Elbow Lake area. The contacts are not exposed, but are likely structural and predate the development of regional foliation (S_2). This is consistent with the presence of early shear zones in the southern Elbow Lake area, which predate 1.86 Ga tonalites likely and were active during early accretionary tectonism within the Flin Flon collage.

The boundary between the Webb Island felsic breccia and the Webb Island basalt of the arc assemblage is exposed on Webb Island. It is a high strain contact, but consistency in younging criteria across the boundary indicates that it is likely stratigraphic rather than structural in nature.

Local occurrences of chert and rhyolite were mapped in the Long Bay formation, illustrating that this unit is more lithologically diverse than noted by Syme (1991). A lithologically similar mafic conglomerate was mapped along the northern extension of the ELSZ along Moen Creek, indicating that the Long Bay formation may be more extensive. Geochemical analysis of mafic clasts will hopefully resolve this problem.

REGIONAL FOLIATION AT ELBOW LAKE

The regional foliation (S_2) is intensely developed in eastern and northwestern parts of the Elbow Lake area, and weakly developed in the southwest part. It trends north and north-northwest in the southern and eastern portions of the map area, and sweeps west in the northwest part of the area. Detailed mapping of the Long Bay formation and the Webb Island basalt illustrates km-scale isoclinal F_2 folds with axial planer S_2. The F_2 folds are refolded at km-scale by tight to open F_5 folds. At one locality north of Long Bay, large (10's of metres) F_2 folds plunge at a shallow angle (≈10°), the shallowest macroscopic folds recorded in this portion of the Flin Flon belt. Most F_2 folds are steep to vertically plunging, but are interpreted to have been steepened during F_5 deformation. The shallow F_2 folds are interpreted to preserve the original orientation, and indicate that F_2 folding was responsible for the steepening of stratigraphy. Stratigraphy was upright prior to F_4 and F_5 transcurrent movements along the Elbow Lake and Claw Bay shear zones.

NORTHERN EXTENSION OF THE ELSZ

The northern extension of the ELSZ occurs in poorly exposed outcrops in valleys. This summer, it was traced for 3 km along Moen Creek; its boundaries vary only slightly from those of Syme and Whalen (1992). The ELSZ diverges about 2 km north of Moen Bay; the two strands coincide with high strain zones mapped by Schledewitz (1993) west of Sexton Lake. Poor exposure and the presence of abundant plutonic rocks obscure the trace of the ELSZ farther north (D.C.P. Schledewitz, pers. comm.).

Cranberry Lakes

Reconnaissance scale mapping through the Cranberry Lakes area was restricted to low-lying shoreline exposures, and afforded only local modification of geologic boundaries of Syme (1993). The most prominent fabrics in the Cranberry Lakes area are the Cranberry shear zone (CSZ) and S_2 foliation. S_2 trends generally between north and north-northeast in the Cranberry Lakes area, and as at Elbow Lake, is more intensely developed around the margins of plutons. The CSZ appears to be similar in character and age to the S_5 manifestation of the ELSZ, and is interpreted here to be the same structure. Like the ELSZ, the CSZ also contains both sinistral and dextral kinematic indicators. The location of the CSZ through the inlet of the Grass River is obscured by a late shear zone deformation manifested as the Grass River fault (GRF) of Syme (1992). The GRF appears brittle-ductile, with more abundant carbonate brecciation than in the CSZ-ELSZ. The GRF obliterates the CSZ along most of the Grass River, then swings westward, and runs along the west side of the Cranberry Lakes as a very narrow structure. The CSZ is well preserved through the centre of the lakes.

S_2 is intensely developed in the southern portion of First Cranberry Lake. The prominent rock type is a locally gneissic well layered/laminated mafic tectonite (Syme, 1993). The intense layering in this rock is likely derived from transposition of an already layered rock (*e.g.,* a mafic turbidite). Extensive units of mafic turbidite have not been previously described in this part of the Flin Flon belt. These rocks are intensely folded with a roughly east-west axial planar fabric, apparently associated with deformation along the Berry Creek shear zone farther south.

[1] Centre for Deformation Studies in the Earth Sciences, Department of Geology, University of New Brunswick, P.O. Box 4400, Fredericton, New Brunswick E3B 5A3

Iskwasum Lake

Syme (1994) mapped a southeast extension of the ELSZ through Iskwasum Lake. Mapping this summer was concentrated along the well exposed shoreline of Iskwasum Lake because of exceptionally low water conditions this summer and a heavy veneer of lichen, moss and forest inland. Orientation and geometry of structures and fabrics were consistent with those reported by Syme (1994); their relative timing and tectonic implications differ. This strand of the ELSZ is interpreted here to be the extension of the S_3 manifestation of the ELSZ documented at Elbow Lake (Ryan and Williams, in press). S_3 postdates the 1864 Ma Elbow Lake tonalite (Whalen and Hunt, 1994), and appears syn- to post-peak regional metamorphism.

S_3 is folded with a northeast-trending axial plane crenulation cleavage (Syme, 1994). The crenulation cleavage is interpreted as an S_5 fabric, related to S_5 movement along the ELSZ to the north and west. As S_5 sinistral transpression occurred through the Elbow-Cranberry lakes area, the S_3 ELSZ in the Iskwasum Lake area was oriented in a shortening direction, and simply folded. Along the southern part of Iskwasum Lake, S_3 and S_2 are dragged into an east-west orientation by the Berry Creek shear zone (BCSZ) in a dextral sense. The BCSZ appears to have been reactivated in sinistral shear, folding the reoriented fabric.

A polymictic mafic conglomerate, which is similar to Missi conglomerate in character, outcrops in a couple locations along the ELSZ in the northern part of Iskwasum Lake. Clasts vary in composition from ultramafic to felsic, with a large proportion composed of quartz-porphyritic tonalite, similar in appearance to the Elbow Lake tonalite (1864 Ma). The conglomerate contains the S_3, S_5 and S_6 fabrics. If the clasts are related to the Elbow Lake tonalite, this strand of the ELSZ must have been active after 1864 Ma. It also means that the shear zone was active after 1864 Ma tonalites were exposed at the surface (more likely ~1845 Ma). The matrix of the conglomerate is overgrown by amphibole. The conglomerate is fault bounded, and lies within ultramafic rocks. If the conglomerate is related to Missi sedimentation, it is the only recorded occurrence in this portion of the Flin Flon belt. The unit may represent a downdropped block of Missi conglomerate that was deposited on, or was thrust over, this portion of the Flin Flon belt. Alternatively, the unit may be associated with minor Missi age basins related to strike-slip deformation within the Flin Flon belt.

ECONOMIC GEOLOGY

Some implications of the structural geology mapped at Elbow Lake include the timing and setting of mineralization associated with some known gold occurrences. As reported by Stockwell (1935) and McGlynn (1959), most gold occurrences at Elbow Lake are structurally controlled, but a few occurrences are associated with banded iron formation. Most gold occurrences are hosted by quartz-carbonate veins emplaced in competent bodies that behaved brittly during ductile deformation associated with shear zones. Mapping over the past three summers indicates that mineralized veins were emplaced episodically, throughout a protracted deformational and metamorphic history. Some veins predate the regional foliation (S_2). Other veins are associated with the intersection of the S_3 and S_4 shear zones. Later mineralization appears to be associated with a major sinistral transpressional episode (S_5) that postdates regional metamorphism. A more rigorous account of specific examples of structurally controlled mineralization will be documented in the Ph.D. dissertation of the first author.

The excellent bedrock exposure afforded by the 1989 fire in the Elbow Lake area (Syme, 1990) is rapidly deteriorating. Most areas that were not intensely burned are now covered by severe blow down, generally between 1.2 and 2.4 m deep. Most of these blown-down trees still have most of their branches intact, making traversing very difficult. Almost all areas, regardless of the intensity of burn, are covered by thickly regenerated hardwoods between 1.8 and 3.0 m high. Areas of intense burn are still free of moss and lichen, but are covered by minor blow down, which is generally free of branches. Traversing these areas is still relatively easy. The combination of blow down and new forest growth makes outcrop location difficult. It is recommended that future prospecting and surface exploration be carried out within the next couple years to take advantage of this maximum bedrock exposure.

The Cranberry Lakes area does not host the numerous porphyritic felsic to intermediate composition dykes that are heavily veined and mineralized at Elbow Lake. Diabase and minor rhyolite intrusions host abundant quartz veins that exhibit evidence of extensive prospecting in past years. The Cranberry Lakes area has endured a similar tectonic and metamorphic history as Elbow Lake, and is just as prospective for gold mineralization.

Iskwasum Lake lacks the large scale F_5 shear zone deformation and associated quartz-carbonate veins prevalent at Elbow Lake and the Cranberry Lakes. Iskwasum Lake has evaded the extensive surface prospecting and exploration prevalent to the north and east. The Iskwasum Lake area hosts similar rock types to the Elbow and the Cranberry lakes areas, with a similar deformation and metamorphic history, and is just as viable an exploration target.

CONCLUSIONS

An S_5 strand of the ELSZ can be traced with confidence from 3 km north of Elbow Lake to Cranberry Portage 50 km to the southwest. The GRF, coincident with the ELSZ in the Grass River, is a later brittle-ductile shear zone that runs along the western shore of First and Second Cranberry Lakes. An S_3 strand of the ELSZ trends southeast through Iskwasum Lake, and was shortened and folded during sinistral transpression along the S_5 strand of the ELSZ.

Locally preserved, shallowly plunging, upright isoclinal F_2 folds of bedding in the Long Bay area may indicate that D_2 deformation was responsible for steepening stratigraphy. The axial planar S_2 foliation is intensely developed throughout the eastern and northwestern portions of the map area, and less well developed along the southwestern side of Elbow Lake. The S_2 foliation appears similar in character, orientation and timing to regional foliation developed as far west as Flin Flon (S.B. Lucas, pers. comm.), and as far east as Reed Lake (E.C. Syme, pers. comm.).

Most planar fabrics and lithologic units in the First Cranberry Lake and south Iskwasum Lake areas sweep into the east-west Berry Creek shear zone in a dextral sense. The foliation is overprinted by sinistral shear, and by later brittle-ductile deformation which may be dip-slip in nature.

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GS-13 GEOLOGY AND OXIDE MINERAL OCCURRENCES OF THE CENTRAL AND EASTERN PORTIONS OF THE PIPESTONE LAKE ANORTHOSITE COMPLEX (PARTS OF NTS 63I/5 AND I/12)

by L.S. Jobin-Bevans[1], D.C. Peck, H.D.M. Cameron and J.P. McDonald[2]

Jobin-Bevans, L.S., Peck, D.C., Cameron, H.D.M. and McDonald, J.P., 1995: Geology and oxide mineral occurrences of the central and eastern portions of the Pipestone Lake anorthosite complex; in Manitoba Energy and Mines, Mineral Resources Division, Report of Activities, 1995, p. 74-83.

SUMMARY

The Late Archean Pipestone Lake anorthosite complex (PLAC) is a sill-like, layered intrusion that is currently being explored for Ti, V and Fe. The PLAC is located on the south shore of Pipestone Lake in the Cross Lake region of central Manitoba (Figs. GS-13-1, -2). It averages 800 m in width (maximum of 1.5 km) and is approximately 17 km long (Fig. GS-13-2).

The present field study was initiated to complement previous geological mapping of the PLAC (Cameron, 1992; Peck *et al.*, 1994a, 1994b). Mapping (1:2500 scale) covered the central and eastern portions of the complex. Field observations, coupled with diamond-drill core data, indicate that the type lithostratigraphy developed for the western PLAC (Peck *et al.*, 1994a), including zones of oxide enrichment, extends through the central and eastern portions of the complex. In the central PLAC, where at least two additional subunits are developed, the stratigraphy thickens.

Disseminated, semi-massive and massive oxides form four laterally extensive layers or layered sequences. The South zone (the most southerly mineralized zone) contains disseminated to semi-massive ilmenite + magnetite hosted by interlayered leucogabbro, gabbro and melagabbro. The Main Central zone (centrally located within the PLAC) ranges from <1 m to >20 m in thickness and comprises one or more semi-massive to massive oxide layers that interdigitate with oxide-bearing gabbro and melagabbro layers. The Disseminated zone, directly overlying the Main Central zone, is the thickest of the mineralized zones. It represents a homogeneous melagabbro layer that displays a uniform ilmenite abundance (~10%). The lower part of the Disseminated zone is magnetite-bearing, and magnetite abundances display a systematic upward decline. The North Contact zone, the most northerly of the mineralized zones, is the oxide-enriched part of a garnetiferous layered sequence comprising melagabbro, gabbro and lesser leucogabbro and pyroxenite. The North Contact zone is characterized by more variable and higher ilmenite abundances (typically 10 to 20%) than the underlying Disseminated zone. Rare, late-stage semi-massive and massive ilmenite veins occur locally in the Disseminated and North Contact zones.

Although the present interpretation for the origin of the Fe-Ti-V mineralization is magmatic (Peck *et al.*, 1994a), current field evidence suggests that a number of the massive ilmenite-magnetite stringers, bands and veins may have developed as a result of secondary processes. Ongoing mineralogical, petrological and geochemical investigations will focus on addressing the origins of the mineralization and the petrogenesis of the PLAC.

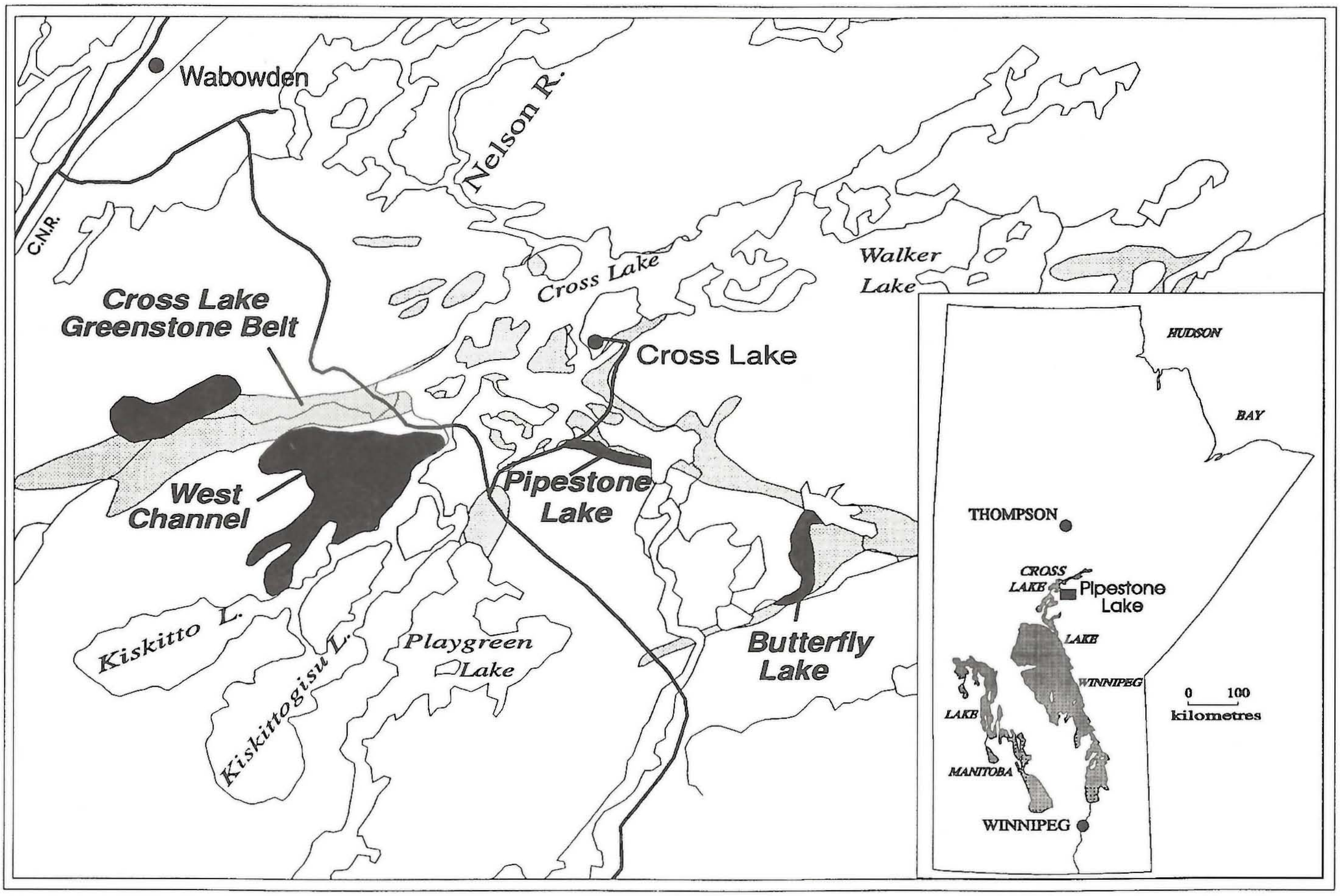

Figure GS-13-1: Location of anorthosite bodies in the Cross Lake region and the Pipestone Lake study area.

[1] University of Manitoba, Dept. of Geological Sciences
[2] Laurentian University, Dept. of Geology

INTRODUCTION

The PLAC is one of several anorthosite bodies that occur in, or proximal, to the Cross Lake greenstone belt (Fig. GS-13-1). Two of these bodies (PLAC and West Channel anorthosite; see Fig. GS-13-1 and Cameron and Peck, GS-14, this volume) are currently being explored for Fe-Ti-V oxide mineralization. This report describes the results of a three-month mapping project that focussed on the central and eastern portions of the Pipestone Lake anorthosite complex (PLAC). These investigations represent the preliminary stages of two related M.Sc. thesis projects that were initiated in May of the current year. One of these projects will describe the geology, lithostratigraphy and petrogenesis of the PLAC. The other will examine the mineralogy, petrology, geochemistry and genesis of the massive and disseminated Fe-Ti-V oxide mineralization within the PLAC. Both studies were initiated to address the need for improved geological and geochemical control on the distribution and intensity of the oxide mineralization. The results will aid in ongoing exploration for Ti, V and Fe in the Cross Lake area, currently being done by Gossan Resources Ltd., Cross Lake Mineral Exploration Inc. and several independent prospectors.

The current study of the Pipestone Lake anorthosite complex represents the continuation of 1:2500 scale geological mapping and lithogeochemical sampling initiated last year (Peck *et al.*, 1994a, 1994b). This work builds on existing detailed mapping for the central and eastern portions of the complex (Cameron, 1992). Mapping on the 10.2 km x 1 km exploration grid established by joint venture partners Gossan Resources Ltd. and Cross Lake Mineral Exploration Inc. was completed during the 1995 field season. The mapping results will be integrated with diamond-drill hole and ground magnetometer survey data provided by the joint-venture partners. Extensive sampling of outcrops and drill core has provided an excellent resource for the planned mineralogical and geochemical studies. Four areas of outcrop, which provide partial to complete cross sections through the PLAC stratigraphy, have been cleared and washed in preparation for detailed mapping (1:100 scale) to be completed during the 1996 field season (see stripped outcrop locations on Fig. GS-14-2).

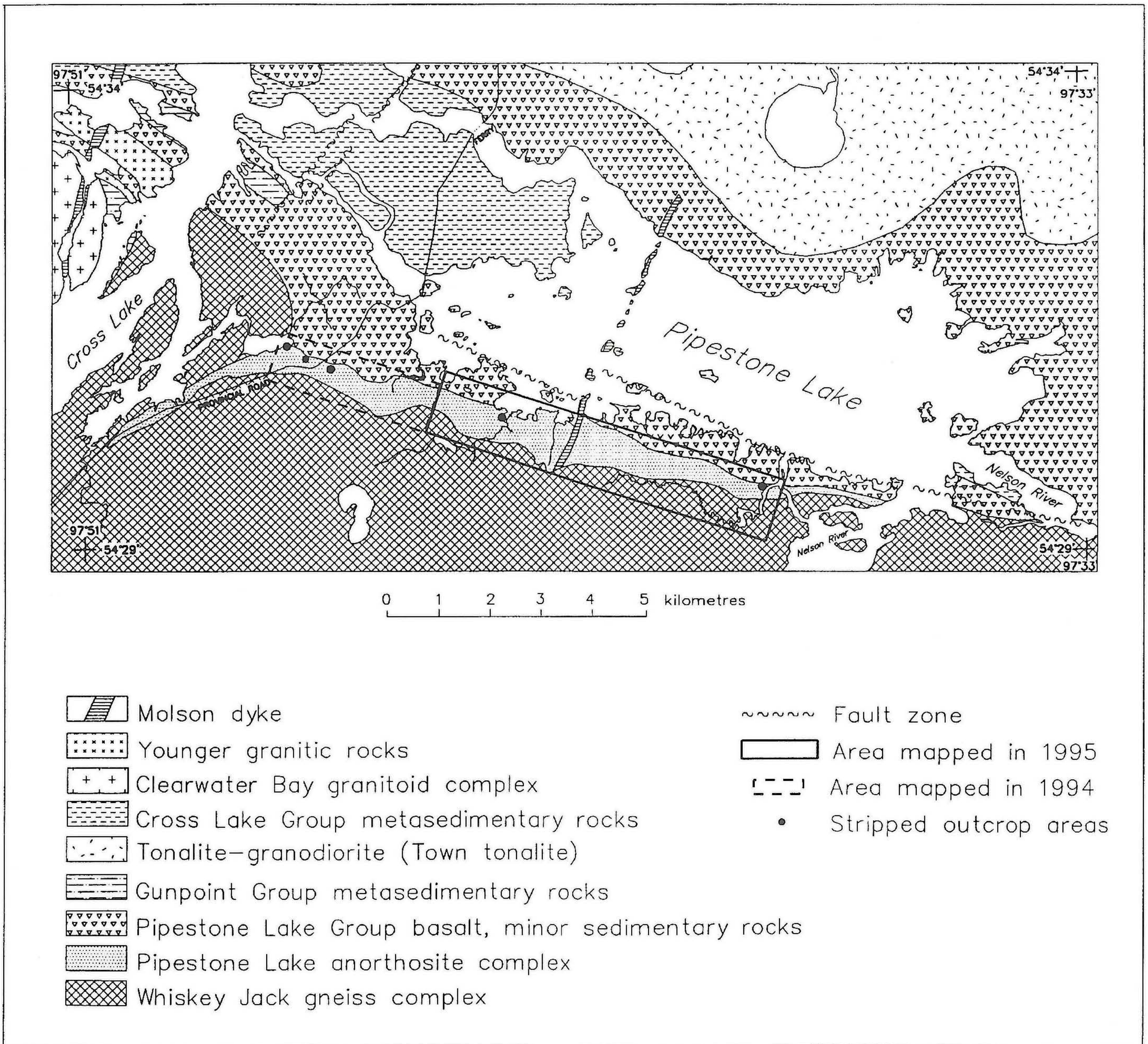

Figure GS-13-2: General geology of the Pipestone Lake area (modified after Cameron, 1992).

GEOLOGY

The geology of the Cross Lake area is described by Corkery *et al.* (1992; and references cited therein). The PLAC is a Late Archean (2758 ± 3 Ma; U-Pb zircon age determination, Corkery *et al.*, 1992) layered mafic intrusion that has a sill-like morphology (Fig. GS-13-2). Detailed accounts of the geology and oxide mineralization within the PLAC are given by Cameron (1992) and Peck *et al.* (1994a). According to Ashwal (1993), the PLAC is an excellent example of a group of petrologically distinctive intrusions referred to as Archean megacrystic anorthosites.

The geology of the study area (Fig. GS-13-2) incorporates layered anorthositic, gabbroic and pyroxenitic cumulates that have been subjected to greenschist to lower amphibolite facies metamorphism (Corkery *et al.*, 1992). In keeping with previous studies of the PLAC, igneous nomenclature (LeMaitre, 1989) based on visual estimation of the relative proportions of primary, igneous minerals has been adopted (Peck *et al.*, 1994a). Note that the term pyroxene, as used in this report, refers to primary pyroxene that has been pseudomorphically replaced by amphibole.

The northern margin of the PLAC is in contact with basalts that belong to the Pipestone Lake Group, and its southern boundary is intruded by tonalite veins that emanate from the Whiskey Jack gneiss complex (Fig. GS-13-2). Based on cryptic chemical variations (Gossan Resources Ltd., confidential drilling results) and an implied genetic relationship with some of the basalts, the PLAC is believed to be north-facing. The maximum observed width of the PLAC within the area mapped is 1.2 km (Fig. GS-13-2). Although minor folds are a common feature within the numerous east-trending shear zones developed in the study area, no large scale folds have been recognized, and the observed stratigraphy (see below) is ascribed to magmatic rather than tectonic processes.

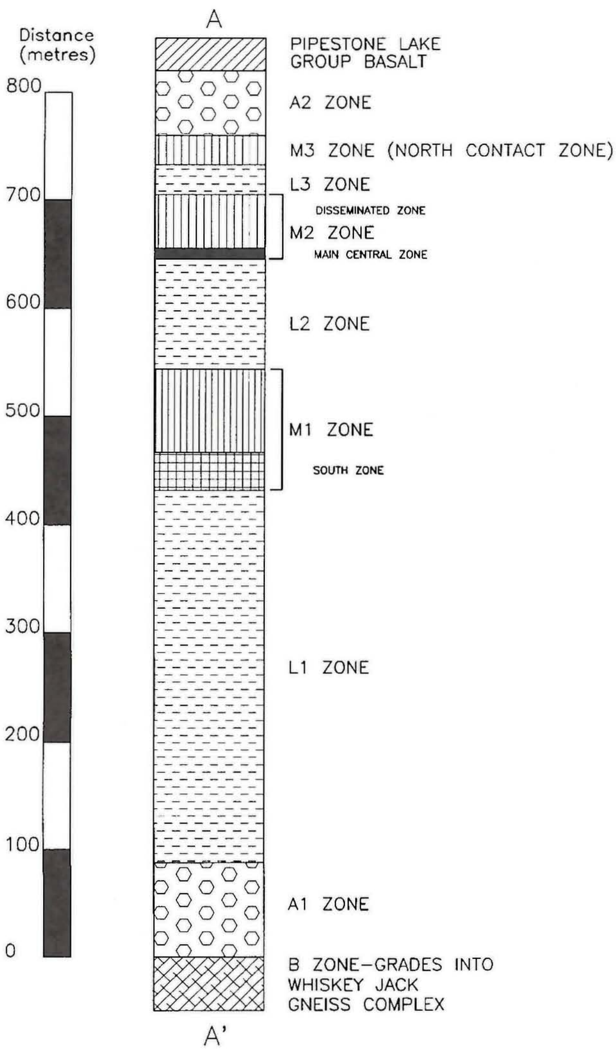

Figure GS-13-3: Type lithostratigraphic section for the central and eastern portions of the Pipe Lake anorthosite complex (modified after Peck et al., 1994a). Section is based on mapping and integrated drillhole information along section line A-A' (Figure GS-13-4). See text for a description of the zones.

A type section for the central and eastern portions of the PLAC, based on surface mapping and integrated drillhole information along section line A-A' (Fig. GS-13-4), is given in Fig. GS-13-3. This section is very similar to the type section proposed for the western PLAC (Peck *et al.*, 1994a), the main differences being (1) the transitional unit (Transition zone, Peck *et al.*, 1994a) between the top of the PLAC and the base of the Pipestone Lake Group, is not observed in the central and eastern parts of the PLAC; and (2) the L1 zone (see below) is much thicker in the central parts of the complex. A simplified version of the geological map produced during the current study (Jobin-Bevans *et al.*, 1995) is given in Figure GS-13-4. Most of the major lithostratigraphic units have been correlated across the 10.3 km section of the PLAC that is covered by the exploration grid (Fig. GS-13-4; Peck *et al.*, 1994b). Although drilling results suggest vertical continuity of these units to a minimum depth of 300 m, individual layers within these major stratigraphic divisions commonly display significant petrologic and/or thickness variations, making detailed correlations between outcrops or drillholes difficult. Correlation of lithostratigraphic units was further impeded by the presence of easterly trending shear zones and northerly-trending late brittle faults (Cameron, 1992; Jobin-Bevans *et al.*, 1995). Ongoing mineralogic and geochemical studies may enable more detailed lithostratigraphic interpretations.

The principal lithologic types recognized in the central and eastern portions of the PLAC are (in order of decreasing abundance) anorthosite, leucogabbro, melagabbro, gabbro and pyroxenite. Unique combinations of these rock types define the nine major lithostratigraphic zones that are observed in the study area (Figs. GS-13-3, -4). Igneous layering is conspicuous in many of these zones, and is typically developed on a metre-scale (decimetre and centimetre scale-layering also occur). Layering is generally defined by variations in plagioclase and pyroxene abundance, and less commonly by total oxide abundances and magnetite:ilmenite ratios. Textural layering, defined by distinct grain size variations, is locally developed. Layering generally strikes parallel to the upper and lower contacts of the PLAC (~280-290°) and generally dips sub-vertically to vertically. Modally graded and grain size graded layers are rare.

The following descriptions for the major lithostratigraphic units are based on field observations and drill core examination. The principal characteristics of each of the zones are summarized in Table GS-13-1.

B (Breccia) Zone

The B zone comprises a heterogeneous intrusive breccia that represents the contact between the Whiskey Jack Gneiss Complex (WJGC) and the PLAC (Fig. GS-13-4). The breccia consists of variable proportions of megacrystic anorthosite and megacrystic gabbro fragments (derived from the A1 zone) and tonalite, granodiorite and amphibolite veins (correlative with the Whiskey Jack Gneiss Complex). Peck *et al.* (1994a) subdivided the B Zone into fragment-rich and vein-rich subunits. These subdivisions could not be made with certainty in the current study, although the general southerly increase in the amount of vein material described by Peck *et al.* (1994) was noted.

The B zone reaches a maximum width of ~215 m (Fig. GS-13-4 and Jobin-Bevans *et al.*, 1995). Sharp contacts between the WJGC veins and fragments of megacrystic gabbro (Fig. GS-13-5) suggest that the veins were emplaced following consolidation of the lower part of the PLAC. As such, the veins cannot represent partial melts of an older component of the WJGC, as proposed by Peck *et al.* (1994a). The contact between the B zone and the A1 zone is gradational.

A1 (Anorthosite 1) Zone

The A1 zone forms the base of the PLAC. It ranges in width from <20 m in the east to ~140 m in the central part of the complex and pri-

Table GS-13-1
Principle features of the major lithostratigraphic units in the Pipestone Lake anorthosite complex

Zone	Principal Lithologies/Mineralization	Total Oxides*	Max. Width	Layering
A2	massive to poikilitic leucogabbro and massive to megacrystic anorthosite	trace to <10%	75 m	modal, textural m-scale
M3	medium grained melagabbro, gabbro and leucogabbro **North Contact Zone**	<10% to >40%	40 m	modal cm/m-scale
L3	medium- to coarse-grained poikilitic and massive leucogabbro and anorthosite	<5% to 15%	50 m	modal m-scale
M2	medium grained melagabbro and gabbro **Main Central and Disseminated Zones**	<5 to 90%	100 m	modal, cryptic cm/m-scale
L2	medium- to coarse-grained massive to poikilitic leucogabbro and massive to megacrystic anorthosite	<5% to 10%	100 m	modal, textural cm/m-scale
M1	medium grained melagabbro, gabbro and leucogabbro **South Zone**	20% to 50%	100 m	modal cm/m-scale
L1	medium- to coarse-grained, massive to poikilitic leucogabbro, anorthosite	trace to 1%	550 m	modal, rhythmic cm/m-scale
A1	megacrystic anorthosite	trace to 1%	140 m	crude banding m-scale
B	intrusive breccia; tonalite matrix and anorthosite fragments	trace	215 m	none observed

*ilmenite and magnetite

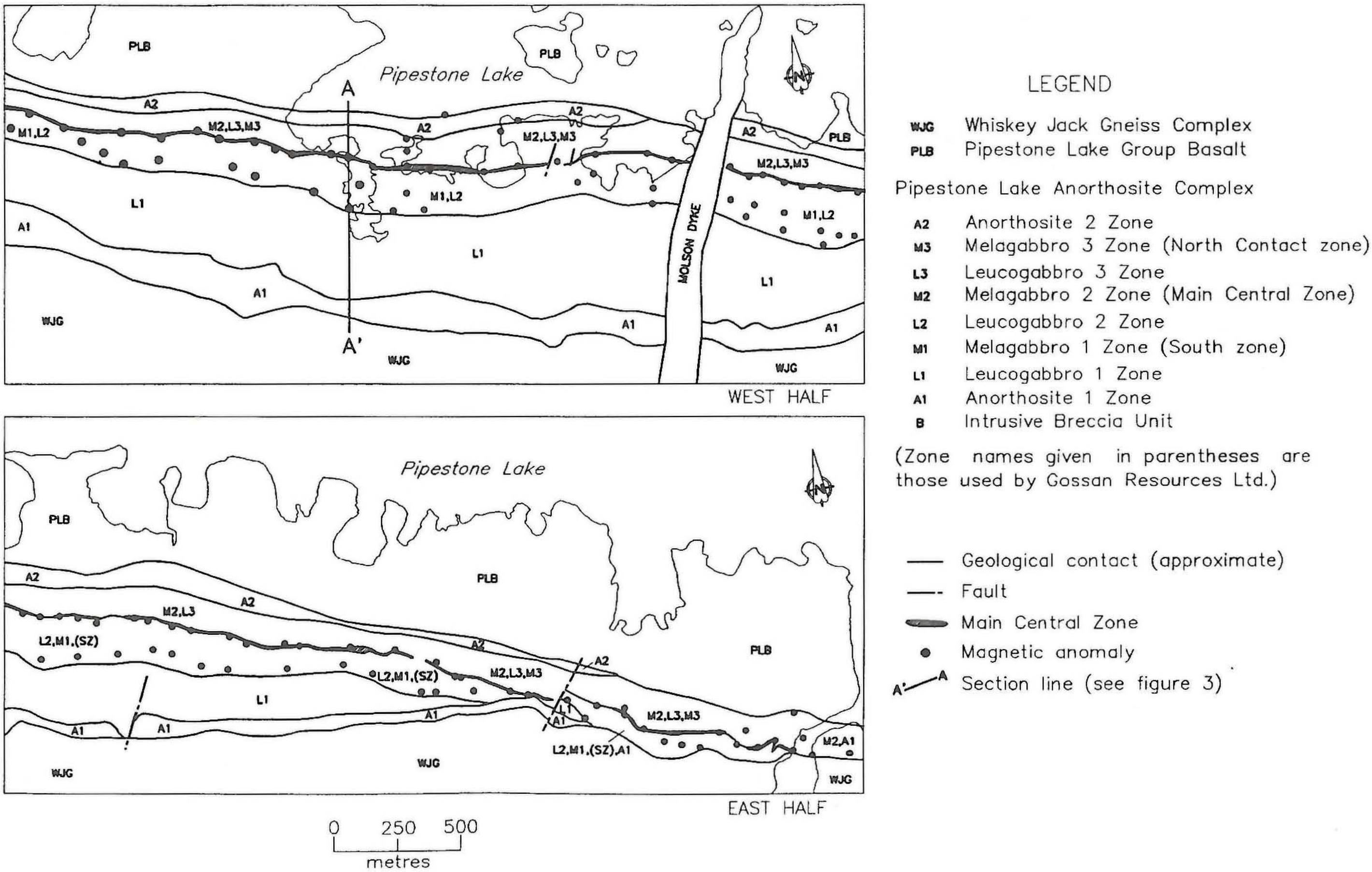

Figure GS-13-4: Simplified geology of the central and eastern portions of the Pipestone Lake anorthosite complex (modified from Jobin-Bevans et al., 1995).

marily consists of megacrystic anorthosite, typically containing >85% plagioclase megacrysts (>2 cm in length) and <15% interstitial pyroxene ± magnetite and ilmenite. Megacrysts locally display concentric zoning, Carlsbad and polysynthetic twinning, and labradorescence. Rare size grading of megacrysts within crudely defined layers is developed. Poorly defined layering within thick (tens of metres) megacrystic anorthosite units is defined by irregular variations in matrix abundance that result in alternating massive anorthosite, megacrystic anorthosite and coarse grained leucogabbro 'bands'. This irregular distribution of mafic to ultramafic matrix is attributed to compaction of megacrysts and subsequent convection of mafic intercumulus liquids. Rare tonalite dykes (<3 m wide) also occur within this zone. The maximum observed grain size for the megacrysts is 34 cm (within 'football' anorthosite; Fig. GS-13-6).

Subordinate rock types within the A1 zone include massive anorthosite, leucogabbro, megacrystic gabbro and megacrystic pyroxenite. Megacrystic gabbro forms a 20 m thick subunit at the base of the A1 zone in the central part of the PLAC and represents a previously unrecognized subunit within the complex. It comprises up to 20% plagioclase megacrysts, 2 to 7 cm long, within a medium- to coarse-grained gabbroic matrix (Fig. GS-13-7). Thin (20-40 cm) layers of megacrystic pyroxenite are gradational into the megacrystic gabbro unit at the base of the A1 zone. A 4 m thick layer of megacrystic pyroxenite occurs within megacrystic to massive anorthosite in the upper A1 zone. The megacrystic pyroxenite contains 1 to 5% plagioclase megacrysts, up to 13 cm long, 2 to 3% medium- to coarse-grained plagioclase, and >90% coarse grained to pegmatitic pyroxene. Most of the megacrysts are broken, display evidence of abrasion and resorption, and commonly display albitized rims.

The contact between the A1 zone and the L1 zone is gradational, and characterized by an upward increase in the abundance of pyroxene, a corresponding decrease in grain size, and enhanced layering.

L1 (Leucogabbro 1) Zone

The L1 zone is the thickest lithostratigraphic unit. It attains a maximum thickness of 550 m in the central portion of the complex, and pinches out at the eastern end of the PLAC (Fig. GS-13-4). It consists primarily of medium- to coarse-grained, massive to poikilitic leucogabbro that contains 10 to 35% net-textured pyroxene oikocrysts that partially to completely enclose fine- to medium-grained, subidiomorphic to idiomorphic (laths) plagioclase chadocrysts. Oikocrysts vary from <1 cm to 15 cm in length, but are commonly 2 to 6 cm long. The plagioclase chadocryst content within individual pyroxene oikocrysts typically varies from 40% to 70%. The L1 zone is moderately well layered (modal) on a scale of several centimetres to several metres. Layer contacts are typically diffuse. Rhythmic layering is sporadically developed and involves decimetre- to metre-scale massive to poikilitic anorthosite, and massive to poikilitic leucogabbro. On a larger scale, there is a general increase in plagioclase abundance towards the north of the L1 zone.

Subordinate rock types in the L1 zone include medium- to coarse-grained gabbro, massive 'spotted' anorthosite, megacrystic to massive anorthosite, and poikilitic 'spotted' leucogabbro. Gabbro forms thin to thick modal layers (>10 cm to 20 m). The massive spotted anorthosite is medium- to coarse-grained and characterized by the presence of subequant to equant interstitial pyroxene. At one locality where the pyroxene abundance systematically increases to the north over a 2 m interval the rocks form a modally graded spotted anorthosite + plagioclase-bearing pyroxenite unit. Assuming that the pyroxene represents a cumulus mineral, then the observed modal vari-

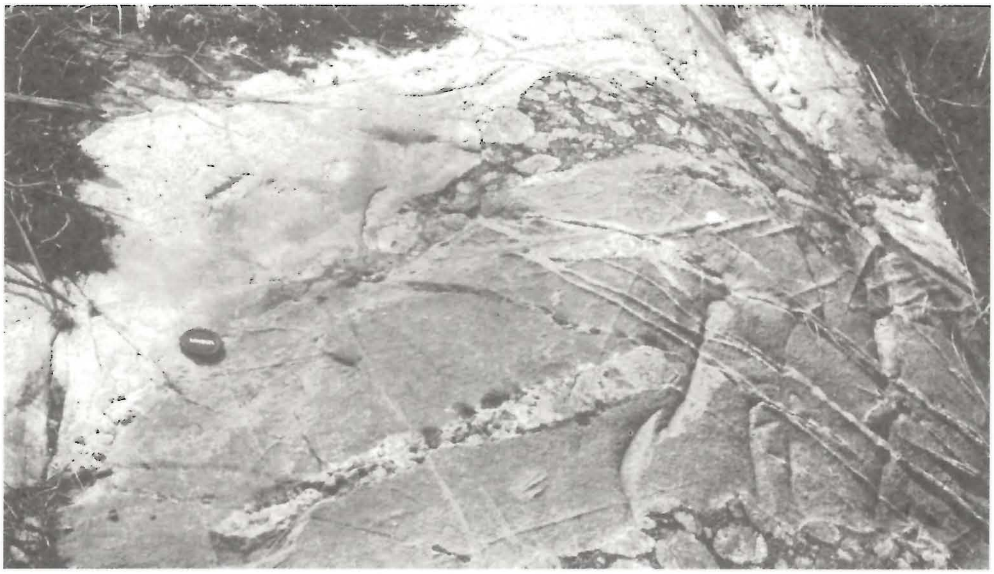

Figure GS-13-5: Tonalite and amphibolite dykes of the Whiskey Jack gneiss complex in sharp contact with megacrystic gabbro. From the B zone, Pipestone Lake anorthosite complex.

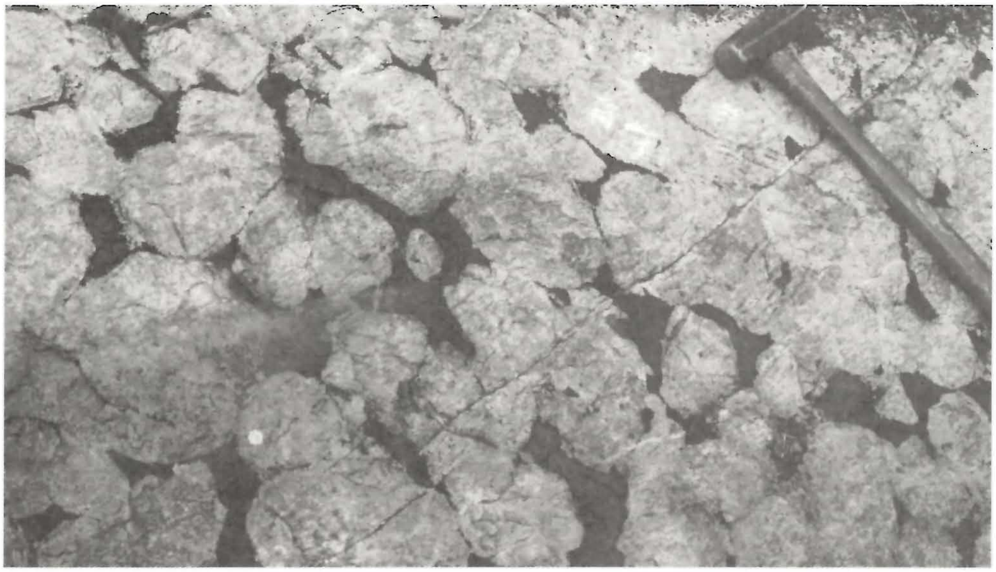

Figure GS-13-6: "Football" anorthosite from the most southerly part of the A1 zone, Pipestone Lake anorthosite complex.

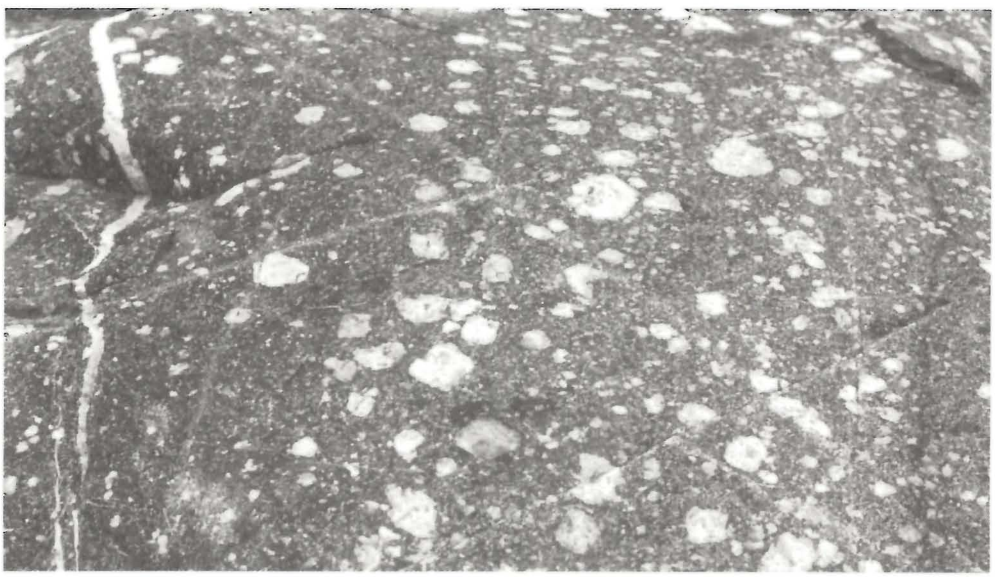

Figure GS-13-7: Megacrystic gabbro from the basal portion of the A1 zone, Pipestone Lake anorthosite complex. Note the presence of younger tonalite dykes that belong to the Whiskey Jack gneiss complex.

ation suggests that the stratigraphy is south facing in this location. Poikilitic 'spotted' leucogabbro contains variable proportions of subequant to equant pyroxene ('spots'; 25-75% of total pyroxene) and net-textured pyroxene. These proportions locally vary systematically and possibly reflect changes in crystal growth rates. Alternatively, the presence of two textural varieties of pyroxene reflects crystallization of both ortho- and clinopyroxene.

The contact between the L1 zone and the overlying M1 zone is gradational.

M1 (Melagabbro 1) Zone

The M1 zone is distinguished from underlying zones by the first appearance of melagabbro and oxide-rich layers (including leucogabbro, gabbro, melagabbro and pyroxenite) and by the absence of anorthosite and paucity of poikilitic textures. The thickness of the zone varies from <5 m in the east to >100 m in the central part of the study area. Maximum thickness is attained immediately to the east and west of the large Molson dyke shown on Fig. GS-13-4. Diffuse modal layering is developed on a scale of decimetres to metres. Layer contacts are typically sheared and planar. Melagabbro, most abundant in the upper portion of the zone, consists of >65% pyroxene and forms layers that range from several cm to 60 m thick. Some layers are modally graded and incorporate both gabbro and melagabbro. Coarse grained to pegmatitic pyroxenite is locally developed as layers and irregular veins that are generally <25 cm wide. In the upper part of the M1 zone, melagabbro is interlayered with massive, oxide-rich gabbro and subordinate leucogabbro and pyroxenite. In the lower part, leucogabbro and gabbro are the principal rock types, but minor melagabbro and pyroxenite also occur. Oxide abundance is highest in the lower part of the zone (generally >20% and up to 50% oxides); the oxide-enriched portion of the M1 zone is referred to as the South zone (see below).

Where observed, the upper part of the M1 zone is gradational into gabbro and poikilitic to massive anorthosite from the overlying L2 zone.

L2 (Leucogabbro 2) Zone

The L2 zone principally comprises massive to poikilitic leucogabbro and massive to megacrystic anorthosite. The zone displays significant variation in thickness along strike (<10 m in the east, reaching a maximum thickness of 100 m in the central portion) and is absent in several areas (Fig. GS-13-4). Subordinate rock types include medium- to coarse-grained gabbro, poikilitic anorthosite (typically magnetite-bearing) and rare pyroxenite. Grain sizes are highly variable, and textural layering is commonly developed. Metre-scale modal layering is well developed, particularly in areas that contain abundant leucogabbro.

Oxide mineral abundances are typically <5%, and magnetite and ilmenite occur as fine grained disseminations. At one locality, massive anorthosite is intruded by a plagioclase phyric diabase dyke (maximum width ~7 m) that is discordant to layering within the zone.

A layered megacrystic anorthosite unit (up to 45 m thick) is exposed in the lower part of the zone within the thick, central part of the PLAC. The unit has been traced laterally for 425 m. It typically contains <10% interstitial pyroxene, but locally contains up to 35% pyroxene. Layers are typically tens of cm to several m thick and are defined on the basis of megacryst size and content. Most of the layers are well sorted, but a few are poorly sorted and some of these display a crude size grading. Coarse grained oxides (ilmenite and/or magnetite) locally occur within the matrix where they sporadically form 3 to 5 cm long stringers. Coarse grained garnetiferous pyroxenite with up to 5% plagioclase megacrysts forms <1 m thick layers that have sharp contacts with megacrystic anorthosite. Garnet porphyroblasts, 2 to 3 cm in diameter, account for 15 to 20% of the mode. A single layer of coarse grained megacrystic pyroxenite that contains 5 to 10% plagioclase megacrysts, is developed in the upper part of the megacrystic anorthosite, and has sharp planar contacts with the surrounding anorthosite.

Thin bands (<5 cm) of chlorite-amphibole-magnetite schist that contain up to 10% disseminated and blebby oxides (magnetite with subordinate ilmenite) rarely occur in the upper part of the L2 zone. These bands may represent strongly sheared and recrystallized pyroxenite layers.

The contact between the L2 and M2 zones is abrupt and is commonly sheared.

M2 (Melagabbro 2) Zone

The base of the M2 zone is defined by the first appearance of massive oxide layers and stringers, in addition to abundant garnet-rich melagabbro to leucogabbro layers. A <1 m to 25 m thick oxide-rich section at the base of the M2 zone is referred to as the Main Central zone (see below). Oxides form semi-massive (~50-80% oxides) to massive layers (>80% oxides) up to 3 m thick (typically 0.5-1 m thick), and are separated by oxide-bearing (<20% oxides) leucogabbro, gabbro, melagabbro and subordinate pyroxenite. Massive oxide layers are commonly mantled by thin layers (commonly <3 cm) of pyroxenite or chlorite-amphibole schist (possibly derived from pyroxenite). In the east end of the map area, a single megacrystic pyroxenite layer, <1 m thick, is developed between two massive oxide layers.

Layer contacts within the Main Central zone are gradational to abrupt and layering is typically defined by large modal variations in the total oxide abundance and plagioclase:pyroxene ratio. Massive oxide layers are massive to strongly foliated and comprise fine- to medium-grained magnetite and lesser ilmenite and fine- to medium-grained, pale-green chlorite and dark-green amphibole. The number of oxide layers ranges from 1 to 8 across the map area. The oxide-rich layers are generally poorly exposed; detailed mapping of the Main Central zone at two well-exposed localities along the south shoreline of Pipestone Lake was conducted by Cameron (1992). Additional detailed mapping of this zone will be completed in the 1996 field season.

The uppermost massive oxide layer within the Main Central zone is in sharp contact with a relatively homogeneous, medium grained, oxide-bearing melagabbro layer that is referred to as the Disseminated zone. The melagabbro layer ranges from <20 m to 75 m thick, and can be subdivided into magnetite-bearing melagabbro at the base (typically <10 m thick) that grades upward into ilmenite-rich melagabbro. The gradational contact represents a cryptic and systematic upward decrease in the abundance of magnetite from ~10% at the base of the layer to <1% at the top. Whereas magnetite abundance decreases up section, ilmenite abundance within the melagabbro layer is consistently in the range 8 to 12%. Within the Disseminated zone, gradational modal variations on a metre scale occur locally (pyroxene abundance ranges from 60 to 90%), such that some gabbro, in addition to melagabbro, is present. Ilmenite-bearing melagabbro contains rare, irregular massive ilmenite veins less than 2 cm wide.

The M2 zone is overlain by either the L3 or M3 zones, and displays abrupt contacts with both of these units. Diabase dykes commonly intrude along these contacts.

L3 (Leucogabbro 3) Zone

The L3 zone is not well exposed and was rarely intersected during the diamond drilling program. Consequently, the zone cannot be characterized in detail. It is laterally discontinuous, reaches a maximum thickness of approximately 40 to 50 m, and comprises interlayered medium- to coarse-grained poikilitic and massive leucogabbro and anorthosite together with subordinate melagabbro and gabbro. It is locally intruded by plagioclase phyric diabase dykes that are both discordant and conformable with layering. Oxide abundances within the zone are typically <5%, and the unit is generally nonmagnetic; however, ilmenite-bearing leucogabbro that contains approximately 10 to 15% disseminated ilmenite and lesser disseminated magnetite is locally developed between the top of the M2 zone and the base of the M3 zone. The exact location of the contact between the L3 and M3 zones is not well defined, therefore correlation of specific layers to either of these zones in the vicinity of the contact is ambiguous. The contact between the L3 and overlying M3 zone was only observed at one locality, where strong shearing and silicification obscured primary relationships between the two zones.

M3 (Melagabbro 3) Zone

The M3 zone is distinguished from the underlying zones (M2 or L3) by the presence of extremely ilmenite- and/or garnet-rich rocks (above the M3-L3 contact) and the development of a modally layered (decimetre- to metre-scale), medium grained leucogabbro-gabbro-melagabbro-pyroxenite succession that is locally strongly enriched in ilmenite. Strong shearing and minor fold development are prevalent in the few scattered outcrops of the M3 zone that are exposed in the PLAC. The M3 zone has a maximum thickness of 40 m, averages 5 to 10 m thick, and diminishes to <1 m in the eastern part of the study area. Irregular blocks (xenoliths?) of oxide-bearing anorthosite (massive to megacrystic), up to several metres in length, are locally present in the zone and display irregular, tectonized contacts with the garnetiferous, layered host rocks.

Garnet occurs in all of the rock types in the M3 zone. It forms pale red to pink, 1 to 20 mm subidiomorphic porphyroblasts, ranges in abundance from <10 to >25%, and is preferentially developed within the most oxide-enriched portions of the M3 zone. Garnet-rich bands, up to 3 cm wide, occur in strongly sheared sections of the zone. Ilmenite commonly occurs as medium grained and, less commonly, coarse grained, disseminated aggregates in abundances that locally exceed 20%. Drilling intersected a 10 to 20 m thick ilmenite-rich section within the M3 zone that is referred to as the North Contact zone. The North Contact zone typically contains 10 to 20% disseminated ilmenite (see detailed description below). Ilmenite also forms semi-massive and, rare massive bands, clots and late veins, up to 2 cm wide, that are generally associated with pyroxene-rich rock types (melagabbro) within the M3 zone. At one locality, toward the eastern end of the map area, there is a 1 m wide gabbro layer that contains semi-massive (30 to 40%) and disseminated ilmenite and subordinate, thin stringers (<3 cm) of massive magnetite. This layer is contained within a medium grained, ilmenite-bearing melagabbro (with up to 10% ilmenite) that is cut by fine grained diabase dykes. Magnetite is erratically distributed within the M3 zone, and is much less abundant than

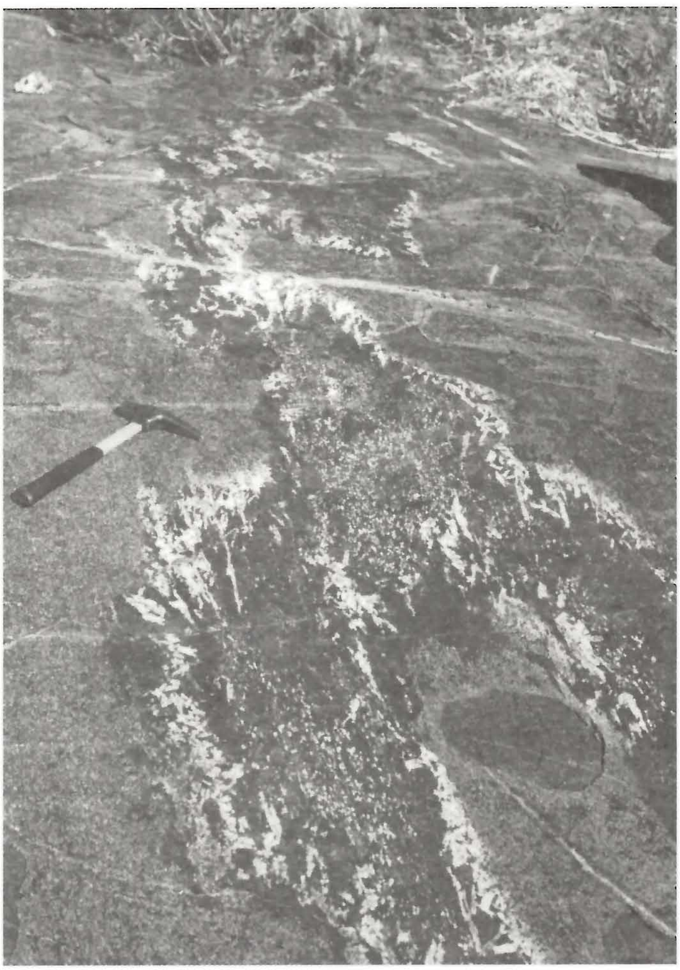

Figure GS-13-8: Gabbro pegmatite vein with large, bladed plagioclase (light) and pyroxene (dark) crystals, M3 zone, Pipestone Lake anorthosite complex. Coarse grained magnetite and ilmenite (not visible) are present throughout the rim and core of the vein.

ilmenite. Cryptic layering, recognized from drill core intersections in ilmenite-rich melagabbro, is defined by alternating <20 cm thick non-magnetic and <40 cm thick magnetite-bearing intervals.

Oxide-bearing mafic pegmatite occurs in a single outcrop of ilmenite-bearing melagabbro from the M3 zone. The pegmatite forms irregular shaped veins up to 1 m wide and 3 to 5 m in length. The veins exhibit a discontinuous, 3 to 9 cm wide plagioclase-rich rim (interrupted by pyroxene-rich sections) that has sharp to diffuse contacts with surrounding melagabbro. Bladed plagioclase and pyroxene crystals radiate toward the plagioclase-rich core (Fig. GS-13-8), and isolated, coarse grained ilmenite and magnetite occur throughout the rim and core of the pegmatite.

The upper contact of the M3 zone is not well exposed and, where present, is obscured by a strong tectonic fabric that is parallel to the regional foliation (~280°-290°).

A2 (Anorthosite 2) Zone

The A2 zone, the uppermost unit of the PLAC, is dominated by thickly layered massive to poikilitic leucogabbro and massive to megacrystic anorthosite. The maximum known thickness is ~75 m (Fig. GS-13-4). Individual layers are typically 10 to 30 m thick and have abrupt contacts that are commonly tectonized. The megacrystic anorthosite is petrologically similar to the megacrystic anorthosite in the A1 zone. The poikilitic leucogabbro comprises ~20% pyroxene oikocrysts (<3 cm long) within a medium grained equigranular anorthositic matrix. Outcrops of the A2 zone are typically strongly sheared and contain abundant easterly trending mylonite and cataclasite zones derived from both megacrystic and massive anorthositic rocks. Total oxides are generally <3%.

Subordinate gabbro and magnetite-bearing gabbro, as well as rare, discontinuous pyroxenite pods occur in this zone. A massive, medium- to coarse-grained gabbro occurs as discontinuous pod-like bodies (~100 m along strike) on the south shoreline of Pipestone Lake in the central portion of the study area. The gabbro locally contains lensoidal blocks up to several metres long of megacrystic anorthosite. The blocks appear to have been stoped from a pre-existing megacrystic anorthosite layer and incorporated into a later pulse of gabbroic magma. The gabbro locally contains up to 10% magnetite.

The A2 zone contains abundant, fine grained diabase dykes, up to 10 m wide, that crosscut, or are conformable with, local layering trends. The contact between the A2 zone and overlying Pipestone Lake Group is highly tectonized where it is exposed, and incorporates narrow bands of anorthosite cataclasite and garnet-bearing basaltic mylonite.

Diabase Veins and Dykes

Irregular to planar diabase veins and dykes cut all of the major lithostratigraphic units. Most of the dykes are fine grained and aphyric. Plagioclase phyric diabase is most abundant in the middle and upper parts of the complex. Diabase locally forms conformable, sill-like bodies and rootless diabase veins and pods. It is typically foliated and predates the major period of deformation and regional metamorphism. Most of the diabase dykes are cut by late brittle northeasterly trending faults along which the Molson dykes were emplaced. Rootless diabase veins and pods tend to have a weak to moderate magnetism, whereas larger dykes are typically nonmagnetic. Contacts between diabase bodies and the PLAC cumulates are generally sharp and commonly sheared, and the larger dykes commonly have chilled margins. At one locality, a funnel-shaped body of diabase (nonmagnetic) intrudes megacrystic anorthosite. The thicker portions of the body (>20 m) have sharp and irregular contacts with the host rock, whereas the narrow portion develops finger-like projections into the anorthosite. At several other locations, the contacts between diabase veins and the interstitial gabbroic to pyroxenitic matrix of megacrystic anorthosite layers are diffuse. Similar findings were reported by Peck *et al.* (1994). It is likely that at least some of the diabase may have formed during emplacement of the PLAC and perhaps represents late-crystallizing intercumulus liquids and/or rapidly cooled parental liquids for some of the layered sequences.

Table GS-13-2
Principal features of oxide-enriched zones in the Pipestone Lake anorthosite complex

Zone	Host Rocks	Oxide Mineralization*	Continuity
North Contact (M3)	garnetiferous melagabbro- to leucogabbro	-disseminated (10-25%) with rare massive veins -ilmenite>>magnetite	not determined*
Disseminated (M2)	melagabbro	-disseminated (5-20%) -ilmenite>>magnetite, with lower magnetite-rich subzone	continuous over 9.5 km
Main Central (M2)	melagabbro, gabbro and pyroxenite with massive oxide layers	-massive and semi-massive oxides (magnetite>ilmenite)	continuous over 9.5 km
South (M1)	leucogabbro to melagabbro	-disseminated to semi-massive (10-50%); rarely massive	discontinous*

*further investigation is required

OXIDE MINERALIZATION

Two principal oxide minerals, *viz.*, ilmenite and vanadium-bearing magnetite, are commonly present in the PLAC (Cameron, 1992; Peck *et al.*, 1994a). Fine grained disseminated ilmenite and magnetite occur throughout the study area, but are only present in trace amounts (<1%) in the lower parts of the stratigraphy (B, A1 and L1 zones). Oxide mineralization (*i.e.*, any rock containing >10% total oxides) that occurs in thick, disseminated zones and, less commonly, as massive to semi-massive oxide layers, is restricted to the middle and upper parts of the stratigraphy. Where disseminated, the oxide minerals are intimately intergrown with interstitial pyroxene.

Four distinct mineralized zones — the South, Main Central, Disseminated, and North Contact zones — are recognized in the PLAC. The zones have been delineated from surface mapping (Cameron, 1992; Peck *et al.*, 1994a, 1994b) and diamond drilling (Gossan Resources Ltd.). Linear magnetic anomalies identified from ground magnetometer surveys (Cameron, 1992; Gossan Resources Ltd. and Cross Lake Mineral Exploration Inc., 1993) can be correlated to three of the four zones, the North Contact zone being the exception. To date, >16,000 m of exploration drilling has been completed by Gossan Resources Ltd. and Cross Lake Mineral Exploration Inc. Drilling has concentrated on the Main Central and Disseminated zones. Each of the four mineralized zones has a unique geochemical signature (established from drilling and preliminary whole rock geochemical investigations; see Cameron, 1992 and Peck *et al.*, 1994a) and petrological association. Their principal characteristics are discussed below and are summarized in Table GS-13-2.

South Zone

The South zone is part of the M1 zone, and is well exposed in the central part of the complex. It is characterized by a moderate to strong magnetic signature. The South zone does not appear to be continuous across the entire length of the PLAC, although it has not been adequately defined by drilling. In several areas, its magnetic expression appears to merge with the anomalies associated with the Main Central zone. The South zone is situated at the base of the M1 zone and although the M1 zone crops out in several locations, the South zone itself is not easily discernible in the field. The zone is exposed in a trench in the central part of the PLAC (see detailed mapping and geochemical studies of Cameron, 1992). Drill core assays (Gossan Resources Ltd. and Cross Lake Minerals Inc.) provide the best confirmation of the South zone that is typically hosted by leucogabbro to gabbro and subordinate melagabbro. The zone ranges from about 3 to 8 m thick and consists of pervasive disseminated magnetite and ilmenite with local semi-massive magnetite + ilmenite layers, stringers and bands. It typically contains 25% to 50% Fe_2O_3, 4% to 8% TiO_2, and 0.4% to 0.8% V_2O_5 (*e.g.*, Cameron, 1992). The upper and lower contacts of the zone are characterized by an abrupt decline in total oxide abundance (with <4% TiO_2) and a distinct decrease in magnetism. The apparent continuity and considerable thickness of this zone in several parts of the PLAC warrants further exploration to establish its economic significance.

Main Central Zone

The Main Central zone represents a steeply dipping ($\pm 10°$ from vertical), tabular Ti-V-Fe-enriched body that defines the base of the M2 zone. The Main Central zone is 3 to >20 m thick and comprises interlayered semi-massive to massive oxide layers and oxide-bearing gabbro, melagabbro and subordinate leucogabbro and pyroxenite. It has between 1 and 8 (typically 2 to 4) massive to semi-massive magnetite layers, which range from a few mm to 3 m thick (generally <1 m thick). The Main Central zone appears to pinch and swell along strike. It attains its greatest thickness (>20 m) in the central portion of the PLAC. Diamond drilling has confirmed that the Main Central zone is continuous over a distance of >9.5 km, as was indicated from magnetic surveys. It is exposed at several localities along the south shore of Pipestone Lake and on the west shore of the east channel of the Nelson River (see Cameron, 1992). Average intersections within this mineralized zone occur between 40 m and 125 m depth (vertical distance), but deeper diamond drillholes indicate the massive oxide mineralization is continuous to depths >300 m.

The lower contact of the Main Central zone with the L2 zone is generally sharp to locally sheared. This contact is commonly marked by a layer of leucogabbro-gabbro within the L2 zone that contains disseminated ilmenite and sporadic semi-massive bands (<2 cm) of magnetite. The upper contact of the Main Central zone with the Disseminated zone is abrupt to sheared (seldom) and is characterized by a distinct change in the magnetite content. Where sheared, the Main Central zone is overlain by a chlorite-amphibole-magnetite (± garnet) schist. The massive oxide layers typically have sharp and planar contacts with adjacent rock types and contain between 60% and 90%, medium grained, equigranular, oxide minerals (V-bearing magnetite with up to 40% ilmenite). Average grades and tonnages for the Main Central zone are discussed in Peck *et al.* (1994a).

Disseminated Zone

The Disseminated zone occurs immediately above the Main Central zone, forms the thickest oxide-enriched zone in the PLAC and ranges from <20 m to 75 m thick. The Disseminated zone is continuous across the entire area mapped in 1994 and 1995 (Peck *et al.*, 1994a; Jobin-Bevans *et al.*, 1995). It is exposed at several localities in the central and eastern parts of the PLAC (Fig. GS-13-4). The Disseminated zone consists of oxide-bearing melagabbro that locally grades into gabbro, and may contain pyroxenitic bands and late, fine grained diabase dykes. The lowermost part of the zone (typically <10 m thick) is magnetite- and ilmenite-bearing; this gives way to a much thicker, ilmenite-rich subzone (up to 60 m thick) that contains <1% magnetite. Magnetite abundance declines systematically upward within the lowermost magnetite-bearing subzone, from ~10% at the base to <1% at the top. In contrast, ilmenite abundances remain relatively constant (from 7 to 12%) throughout the Disseminated zone. The transition between the two segments of this zone is somewhat diffuse and is characterized by the development of several cryptic layers. The cryptic layering is defined by alternating magnetic (magnetite-rich) and nonmagnetic (ilmenite-rich) melagabbro (from <3 cm to 0.5 m) and typically occurs over a width of several metres.

Massive ilmenite bands in this zone in the western portion of the PLAC are described by Peck *et al.* (1994a); however, massive ilmenite and/or magnetite bands are rare (<2 cm wide bands noted at one location) within the Disseminated zone in the central and eastern parts of the PLAC.

North Contact Zone

A distinct assemblage of interlayered oxide-bearing, garnetiferous melagabbro, gabbro and subordinate leucogabbro and garnet-amphibole-biotite-schist constitutes the North Contact zone. The zone is located at the base of the M3 zone and possesses a sharp upper (northern) contact with a gradational increase in magnetism down section (southward). It is unclear whether or not the North Contact zone is stratabound (*i.e.*, confined to a specific stratigraphic interval). It is also not known if the North Contact zone represents the only zone of oxide enrichment within the M3 zone. In drill core, the zone is characterized by erratic, but generally elevated disseminated ilmenite abundances over distances of several metres. Ilmenite abundances generally range from 10 to 25% and magnetite abundances are typically <5% and rarely exceed 10%. Both oxide minerals occur as disseminated grains in melagabbro and gabbro and within the confining leucocratic layers of the M3 zone. Local semi-massive to massive ilmenite layers (up to 5 cm thick) and stringers (<2 cm thick) crop out in the eastern portion of the PLAC. Magnetite also occurs in rare, massive to semi-massive, <2 cm thick bands.

Cryptic layering, defined by alternating layers of magnetite-rich and ilmenite-rich melagabbro, is also present in the North Contact zone. Ilmenite-rich layers dominate and are interlayered with magnetic layers that are generally <20 cm thick, but can be up to 80 cm thick. The result is a zone that, based on results of the magnetometer survey, has poor lateral continuity; however, this poor response may reflect an erratic to nonexistent magnetic signature, and further exploration is warranted.

FURTHER INVESTIGATIONS

This project constitutes the first stage of two related M.Sc. thesis projects with follow-up, detailed mapping planned for the 1996 field season. Most of the remaining field work will incorporate detailed outcrop-scale mapping that, in conjunction with ongoing drill core studies, will help to further define the lithostratigraphy for the PLAC and its mineralized units. Additional field studies will examine the contact relationships between the PLAC and the overlying Pipestone Lake Group, and selected, representative outcrops for each of the different styles of oxide mineralization in the PLAC (including disseminated, semi-massive and massive oxide layers and vein-type mineralization). Petrographic analyses will yield quantitative modal estimates for each of the major rock types, and will assist in further division and correlation of the layered sequences and the host rocks of the mineralized zones. The results from the field and petrographic studies will direct geochemical and mineralogical investigations (whole rock geochemistry, major and trace element analyses of oxide minerals and plagioclase) that will hopefully address the origins of the PLAC and its oxide mineralization, and provide guidelines for future exploration for Fe-Ti-V oxides in the Cross Lake area.

ACKNOWLEDGEMENTS

The authors are indebted to Jim Campbell and Lou Chastko of Gossan Resources Ltd. and John Angus Thomas and George McKay of Cross Lake Mineral Exploration for their continued support. Capable field assistance was rendered by Thor Bochonko, Charles Miller and Michael Spence. George McIvor is thanked for providing working space for the drill core studies. Mark Pacey is thanked for his help in preparing the figures.

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GS-14 ANORTHOSITE STUDIES IN THE KISKITTO LAKE AREA (PARTS OF NTS 63J/7,8,9 AND 10)

by H.D.M. Cameron and D.C. Peck

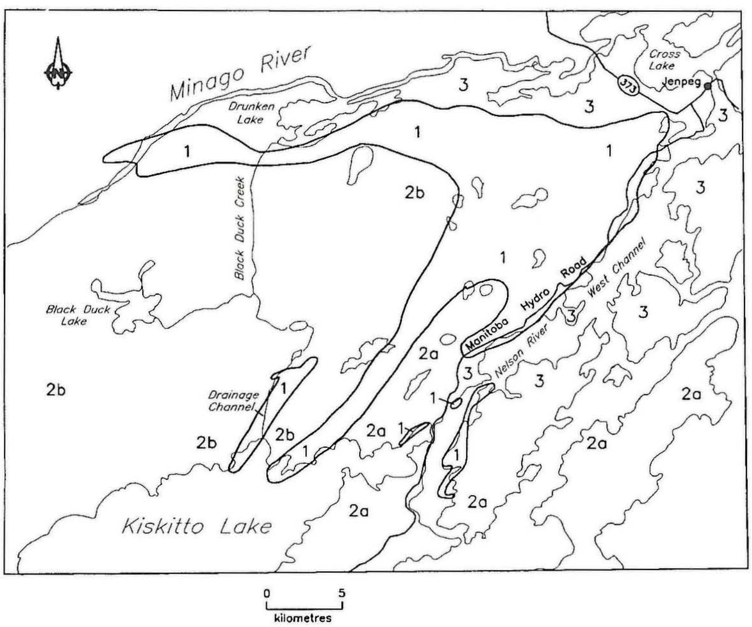
Cameron, H.D.M. and Peck, D.C., 1995: Anorthosite studies in the Kiskitto Lake area; in Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 84-85.

Continuing interest in the titanium-vanadium bearing gabbroic rocks in the Pipestone Lake anorthosite complex (PLAC) (Cameron, 1992; Peck *et al.*, 1994; and Jobin-Bevans *et al.*, GS-13, this volume) prompted further examination of the "West Channel" anorthosite body (Bell, 1978; McRitchie, 1986; Cameron, 1986), the largest of several anorthosite bodies in the Cross Lake area (Fig. GS-14-1). Although earlier studies (Cameron, 1986; McRitchie, 1986) gave little indication of oxide-rich phases similar to those at Pipestone Lake, recent drilling results (Gossan Resources Ltd., see below) have confirmed the existence of oxide-bearing gabbroic rocks in the area.

The West Channel anorthosite body, part of the Nelson River Anorthosite Complex (Bell, 1978), underlies an area of 226 km^2 between the Minago River, the west channel of the Nelson River, and Kiskitto Lake, immediately southwest of Jenpeg (Fig. GS-14-1). Access to Kiskitto Lake is via a Manitoba Hydro road from Jenpeg on Provincial Road 373 (Fig. GS-14-1). Exposure in the area is extremely poor; most of the area is covered by string bog. Two days were spent examining the limited amount of outcrop on the north shore of Kiskitto Lake. Most of the rocks in this area comprise tonalite gneiss and granulite facies enderbite and opdalite gneisses. The rocks commonly contain up to 5% magnetite that gives the entire area a regional aeromagnetic high of over 3000 gammas (Geological Survey of Canada, Aeromagnetic Maps 2580G and 2588G). Linear magnetic highs over 4000 gammas within this high background may indicate the presence of oxide-rich rocks similar to those at Pipestone Lake. Agmatitic zones of well preserved anorthosite rafts in 20% to 70% granite occur sporadically within the gneisses.

One day was spent examining outcrops located to the north of the sluice gate at the north end of the Kiskitto-Minago drainage channel (Fig. GS-14-1). This area includes a major fold structure that is evident on aeromagnetic maps (Geological Survey of Canada, Aeromagnetic Map 2588G). Only a few of the outcrops examined contain recognizable anorthosite or gabbro. The predominant lithologic types include medium- to coarse-grained, intermediate to mafic, hornblende-plagioclase and hornblende-biotite-plagioclase gneiss with local garnet-rich and quartz-rich zones. Disseminated, fine grained oxides (predominantly magnetite) occur in abundances that range from <1 to several percent throughout the area examined. Quartz contents range from <1% to 25%. Quartz and plagioclase-rich enderbitic gneiss was observed in one outcrop. Compositional banding in the gneisses likely reflects original, metre-scale isomodal layering involving anorthosite, leucogabbro and gabbro. Schollen anorthosite, comprising angular metre-size fragments of coarse grained anorthosite, and thinner, intervening tonalite veins, were observed at one locality. Foliations typically strike northeasterly and dip near vertically. Minor folds and narrow, ductile shear zones were observed in several outcrops.

Gossan Resources Ltd. currently holds an exploration permit (484 km^2) that covers a large portion of the West Channel anorthosite body and the adjacent zone of high magnetic intensity underlain by derivative(?) granulite and amphibolite facies gneisses. In the early part of this year, Gossan began exploring the Kiskitto Lake area for oxide mineralization similar to that developed at Pipestone Lake (see Jobin-Bevans *et al.*, GS-13, this volume). Rare, thin (<10 cm) massive oxide layers were intersected in one of four diamond-drill holes completed in February (L. Chastko, Gossan Resources, personal communication, June, 1995). Two of the drillholes intersected coarse grained oxide-bearing leucogabbro that has local ilmenite-rich zones (*e.g.*, 5.74% TiO_2 over a true width of 17 m; Gossan Resources Ltd., News Release, March 2, 1995). A second phase of diamond drilling commenced in August of the current year. Core from the first of these drillholes (KL-95-5) comprises massive and modally layered, oxide-bearing leucogabbro and gabbro with rare anorthosite and pegmatitic gabbro. Unaltered orthopyroxene was observed in much of the core, and is likely metamorphic in origin. The layered oxide-bearing gabbroic rocks are exposed on a small island at the west end of Kiskitto Lake, where drillhole KL-95-5 was collared.



3. Jenpeg Complex: tonalite, granodiorite and granite
2. Playgreen Complex: a) tonalite and granodiorite
b) enderbitic and opdalitic gneisses
1. Nelson River Anorthosite Complex

Figure GS-14-1: Location of anorthositic rocks and derived (?) granulite, migmatite and gneiss, Kiskitto Lake area.

The extent to which relict igneous textures and primary oxide mineralization are preserved in the Kiskitto Lake area is not known. Ongoing investigations of the Pipestone Lake anorthosite complex (Jobin-Bevans *et al.*, GS-13 this volume) will be expanded to include geological and geochemical studies of the West Channel anorthosite body and derivative gneisses, and will necessarily focus on information and sample material obtained from the current drilling program.

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GS-15 DIMENSION STONE POTENTIAL IN THE THOMPSON AREA (NTS 63O AND 64A)

by B.E. Schmidtke

Schmidtke, B.E., 1995: Dimension stone potential in the Thompson area (NTS 63O and 64A); **in** Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 86-87.

Stone distributors and importers in southeastern Canada and the northeastern United States reported in the September 1995 issue of *Dimensional Stone* that they are doing more business in residential construction than in commercial construction. This is because commercial construction has declined and the demand for stone in residential applications has increased (Murray Leighton, pers. comm., Sept. 1995). The increased demand for residential stone is due to an increased public awareness of the uses for granite in homes and to a decrease in the price of granite, which makes granite countertops, furniture and flooring more affordable to homeowners. Although homogeneous, even-textured granites are still popular for residential and commercial construction, variegated granite (*i.e.*, gneissic, foliated or lineated) and wavy granite (*i.e.*, migmatitic rock and rock with pronounced granitic layering) are currently fashionable. In many cases the variegated and wavy granites command a higher price than the more traditional stones; *e.g.*, polished tiles of wavy stone from India command up to three times the price of even-grained tiles of domestic stone.

In response to the demand for wavy and variegated granite, a two-day reconnaissance of migmatitic and gneissic rock was conducted in the vicinity of Thompson (Fig. GS-15-1). Outcrops of Burntwood River Metamorphic Suite migmatite near Notigi Lake and biotite-hornblende gneiss in a road quarry near Split Lake were examined and sampled.

Several roadside outcrops of Burntwood River Metamorphic Suite migmatite were examined between Thompson and Notigi and one was sampled in the vicinity of Notigi (Fig. GS-15-2). The sample consists of fine grained grey to blue gneiss with small garnets and wavy (*i.e.*, folded) pink-white veins. The outcrops tend to be rounded and difficult to sample, have closely spaced (average <1 m) acutely oriented fractures and commonly show rusting of sulphide minerals. Pink-white veins occur consistently throughout the rock. Garnets in the rock, although attractive when polished, can cause damage to polishing equipment.

Black and white variegated granite (*i.e.*, biotite-hornblende gneiss) was sampled in a quarry near Split Lake (Fig. GS-15-3). Large blocks occur in the quarry, but there are tight fractures within them. Most of the fractures exposed on the quarry faces are spaced less than 1m apart, however, this is an aggregate quarry and many of the fractures may have been induced by blasting.

Samples from both sites will be cut and polished. Both rock types examined may be potential sources of dimension stone if outcrops with widely spaced fractures can be found.

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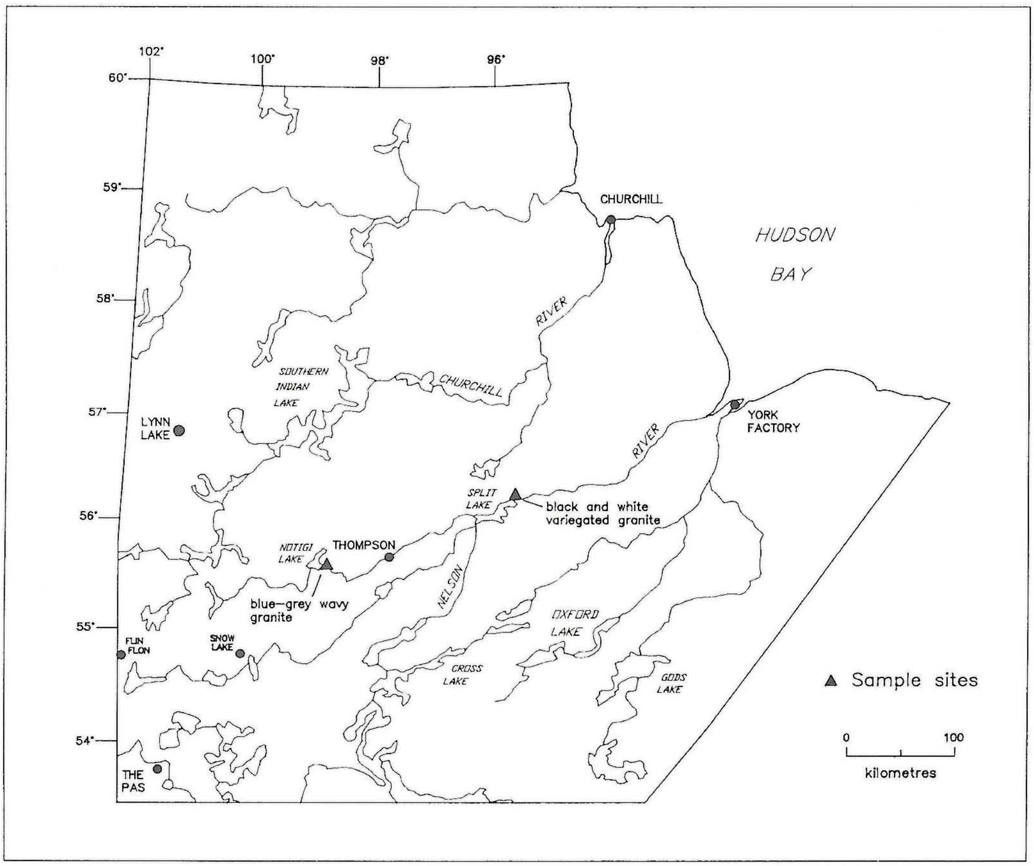

Figure GS-15-1: Project area for the dimension stone reconnaissance study in the Thompson area.

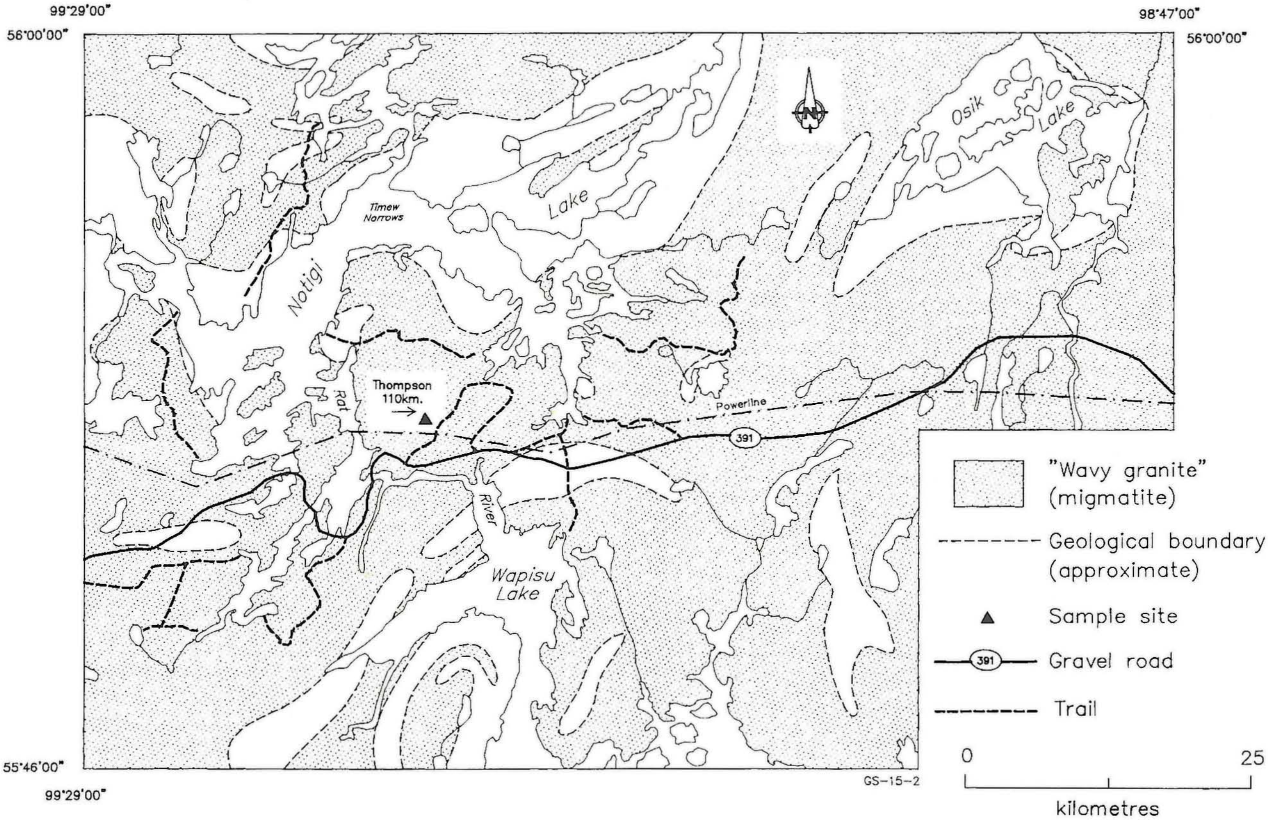

Figure GS-15-2: Sample site in wavy granite (migmatite) near Notigi.

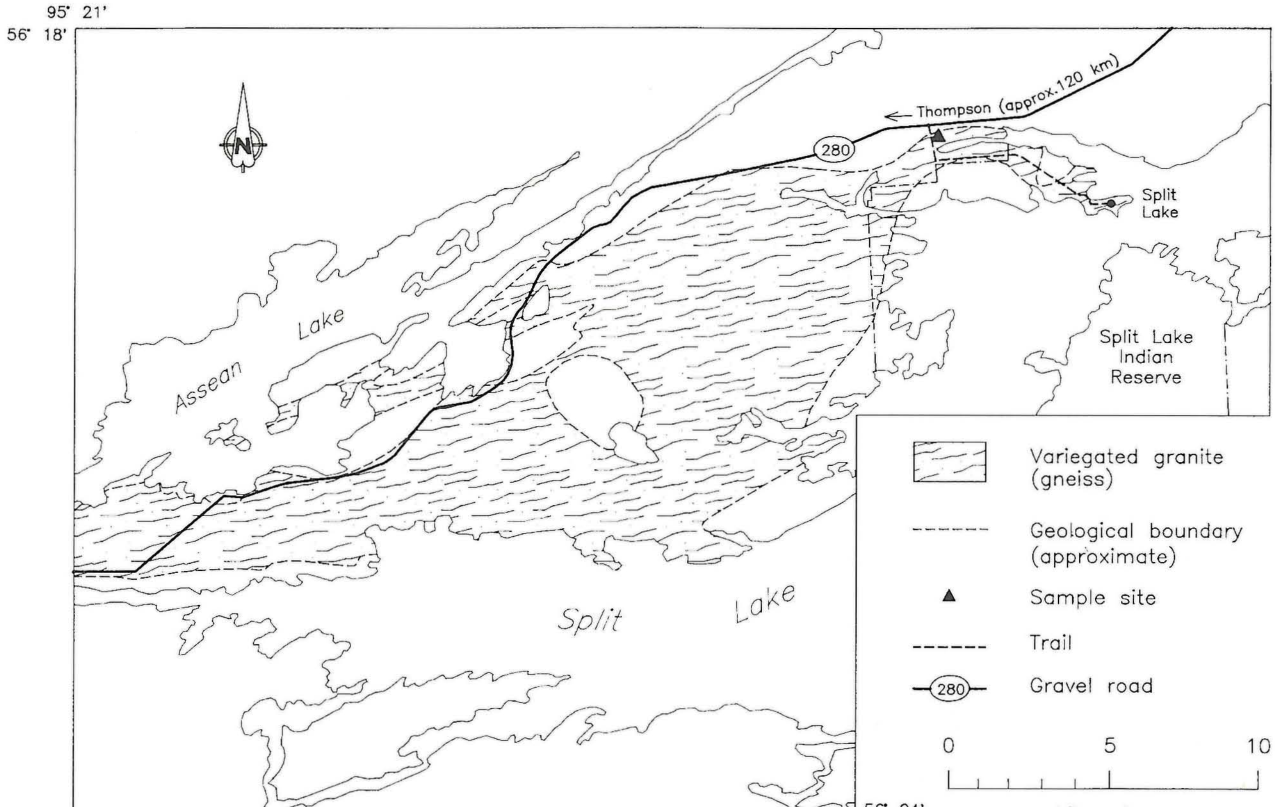

Figure GS-15-3: Sample site in variegated granite (gneiss) near Split Lake.

GS-16 STRATIGRAPHY OF THE QUATERNARY DEPOSITS OF THE GILLAM AREA, NORTHEASTERN MANITOBA (NTS 54D)

by M. Roy[1], M. Lamothe[1] and E. Nielsen[2]

Roy, M., Lamothe, M. and Nielsen, E., 1995: Stratigraphy of the Quaternary deposits of the Gillam area, northeastern Manitoba; in Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 88-90.

INTRODUCTION

The Quaternary geology of the Hudson Bay Lowlands has long been of interest to geologists working on the glacial history of Canada and North America in general (see Dredge *et al.,* 1990; Klassen, 1986; Nielsen *et al.,* 1986; Dredge and Nielsen, 1985; and references therein). However, recent works (Veillette, 1995; Thorleifson *et al.,* 1992; Berger and Nielsen, 1991) have questioned the rank, age, provenance and number of nonglacial and glacial units in this area, which was located near the centre of the Laurentide Ice Sheet.

Since several tills and intertill nonglacial units outcrop along the Nelson River downstream from Gillam, it is considered an ideal area for answering some of these questions. The main objective of this study is to outline a stratigraphic framework that would reconcile former studies (Andrews *et al.,* 1983; Shilts, 1982; Skinner, 1973, McDonald, 1969) with more recent works (Veillette, 1995; Thorleifson *et al.,* 1992; Berger and Nielsen, 1991). In addition, this project is important for several fields of research including studies of the configuration of the Laurentide Ice Sheet, and the glacial history of Canada, paleoclimatic and paleoenvironmental reconstructions, as well as mineral exploration. This research is funded by Manitoba Energy and Mines, the Geological Survey of Canada and by Northern Scientific Training Program.

Detailed stratigraphic work was concentrated on four sections, located immediately downstream from the Limestone Dam, 50 km northeast of Gillam (Fig. GS-16-1). During this survey, four tills and two nonglacial units were recognized. This report outlines the field methods, sampling and future analytical work.

METHODS

Prior to sampling, the sections were cleaned from top to bottom over a width of at least 1 metre in order to observe and describe the units. At each stratigraphic contact and along the nonglacial units, the sections were more extensively cleared.

Eighty-one 7 kg till samples were collected from the four sections for pebble counts, carbonate analysis, geochemistry and grain size analysis. The sampling interval ranged from 0.50 to 2.25 m, depending on the unit thickness and exposure. Detailed sampling was carried out at 20 cm intervals at selected sites. Geochemical analysis and carbonate analysis on the <2 µm fraction will be performed to determine differences between the tills and to detect former pedological horizons.

The two nonglacial units and some Holocene sands were sampled for thermoluminescence dating. The peat sampled from the upper nonglacial unit will be submitted for paleoecological analysis.

Twenty-two till fabrics were measured on the tills in the four sections. In addition, oriented till samples were taken for microfabric analyses from the four till units exposed in the Bird's Island section.

STRATIGRAPHY

Detailed stratigraphic measurements were made on the four sections near Limestone Dam (Fig. GS-16-1). A general composite stratigraphic column based on these measurements is presented in Figure GS-16-2. The Moondance and Bird's Island sections have not been studied before; the Sundance and Limestone sections were studied by Nielsen *et al.* (1986). The Sundance and Limestone sections are included in the present study because little detailed work was previously carried out on the tills in these sections. The remainder of this report will present a brief description of the units shown in Figure GS-16-2 and give their general characteristics. The names of the units and the stratigraphic framework are based on the work by Nielsen *et al.* (1986).

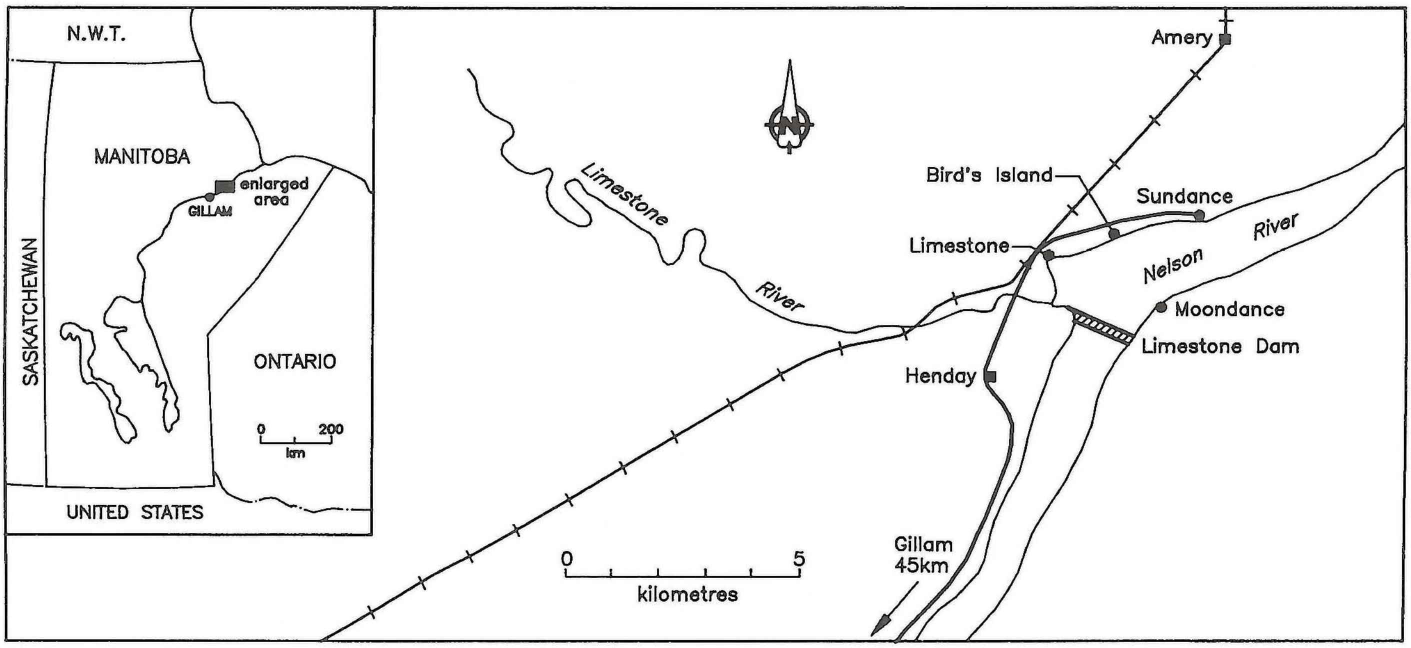

Figure GS-16-1: Location of Quaternary sections (dots) along the Nelson River in the Gillam area.

[1] Université du Québec à Montréal (UQAM), CP 8888, Succ. Centre-Ville, Montréal, PQ H3C 3P8

[2] Manitoba Energy and Mines, Geological Services, Winnipeg, Manitoba

Sundance Till

This till is easily recognized in the field by its sandy texture and its dark greyish brown colour (10YR4/2). This unfossiliferous till is the oldest unit in the area and outcrops at the base of the Moondance, Sundance and Bird's Island sections. The uppermost contact of this unit is marked by the presence of a boulder pavement and by a zone of leaching approximately two metres thick that grades into a zone of less oxidized till. This weathered horizon is believed to be a paleosol. The paleosol can be seen in all the sections containing Sundance Till and represents a period of subareal exposure correlative to the nonglacial episode during which Limestone River Sediments were deposited.

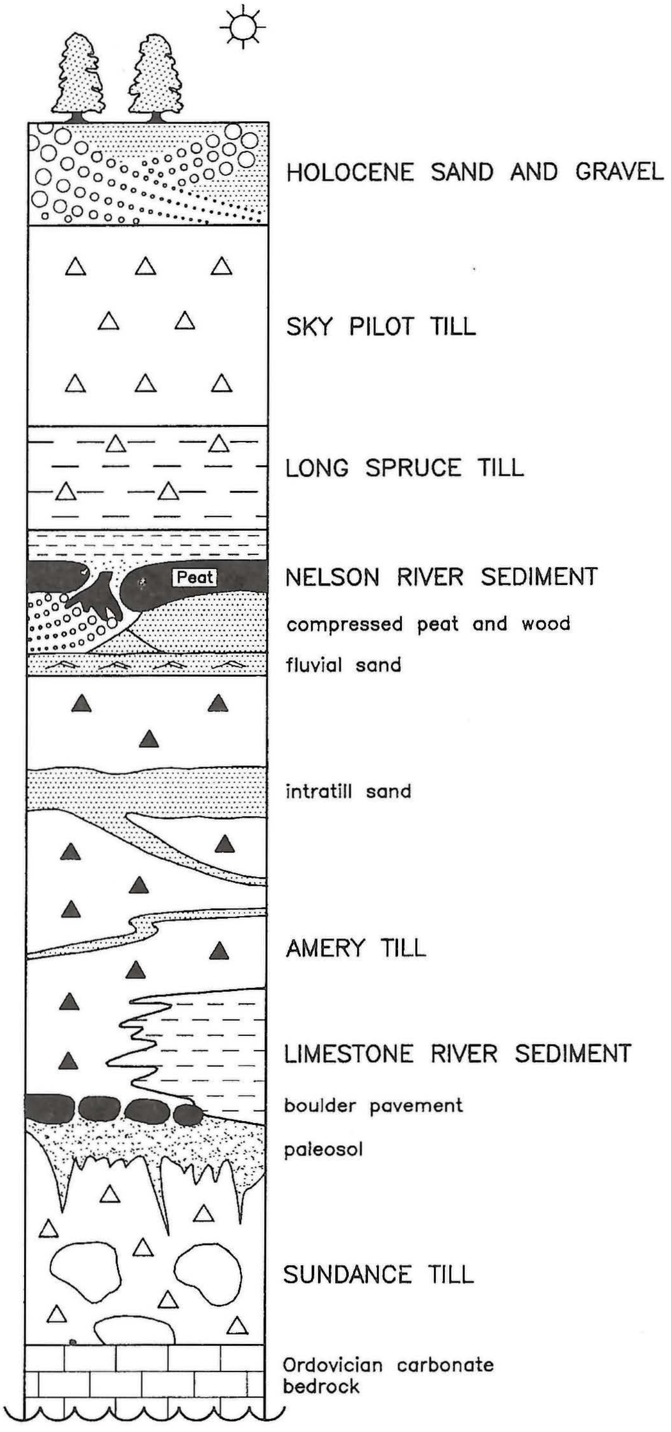

Figure GS-16-2: Composite stratigraphic column for the lower Nelson River area.

Limestone River Sediments

This nonglacial unit outcrops at river level at the base of the Limestone section. This unit has an exposed thickness of 1.80 metres and is composed of massive, compact clay with dropstones near the top. Preliminary micropaleontological analysis suggests it is of marine origin (H. Kling, pers. comm. 1995).

Amery Till

Amery Till is exposed in all four sections studied. This dark greyish-brown (2.5Y4/2) unit is more than ten metres thick and is unoxidized. Amery Till is characterized by a high content of shell fragments and by the presence of intratill sand beds, which are deformed in places. This till is either overlain by the nonglacial Nelson River Sediments or by the Long Spruce Till.

Nelson River Sediments

Nelson River Sediments represent the youngest nonglacial unit exposed in the area and consist of three different facies. The first facies is oxidized, fossiliferous fluvial sand and fine gravel with ripple marks and climbing ripples. The second facies is paludal sediments composed of compressed peat and wood. The last facies is massive, lacustrine clay. Nelson River sediments are best seen in the Limestone and Moondance sections.

Long Spruce Till

Long Spruce Till outcrops discontinuously along the river cliffs, but is exposed in all four sections studied. It generally ranges from 0.30 to 1.5 metres in thickness except at the Moondance Section, where it reaches six metres. The fine texture, evenly dispersed clasts and dark gray colour (5Y3/1) make this unit easily recognizable. It is fossiliferous, unoxidized, massive and compact with sharp upper and lower contacts.

Sky Pilot Till

Sky Pilot Till is the regional surface till throughout the area (Klassen, 1986). It commonly outcrops along the river banks and has a characteristic dark brown colour (10YR3/3), possibly due to the incorporation of orange-red Paleozoic carbonate clasts. The till is compact, massive, unoxidized and has a fine texture that is somewhat coarser than the underlying Long Spruce Till. The uppermost part of this unit is generally truncated by Holocene fluvial sediments.

Holocene Sediments

Holocene sediments that cap most of the sections were not studied in detail. A single sample of Holocene sand was collected to calibrate the thermoluminescent dating procedure. For details on the Holocene stratigraphy of this area, the reader is referred to Nielsen *et al.* (1986).

ICE FLOW RECORD

Two different sets of striae were recognized on the Ordovician carbonate bedrock. One trends 140° and is found under Sundance Till. A southeast ice flow for the Sundance Till is also suggested by the sandy texture and the unfossiliferous character. Erratics from the Dubawnt Group in the District of Keewatin also suggest the Sundance Till was deposited by ice flow from the northwest. The other striae trend west to southwest. The Amery, Long Spruce and Sky Pilot tills contain erratics of eastern provenance, which imply ice flow from Hudson Bay, although this remains to be confirmed by fabric measurements and pebble counts.

CONCLUSION

Field work during the summer of 1995 revealed the presence of four tills and two nonglacial units in the Gillam area. Stratigraphic analyses including detailed fabric measurements, pebble counts and thermoluminescence dating will establish a more refined stratigraphic framework and elucidate the glacial history of the western part of Hudson Bay Lowlands.

ACKNOWLEDGMENTS

The authors acknowledge the invaluable assistance of Liz Dykman in the field and Manitoba Hydro in Gillam for their help with accommodation and access to the area. We are particularly grateful to Hedy Kling of the Freshwater Institute in Winnipeg for looking at the microfossils in the Limestone River Sediments.

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GS-17 THOMPSON ROCK AND CORE VIEWING FACILITY

by P. Theyer

Theyer, P., 1995: Thompson rock and core viewing facility; **in** Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 91.

Construction of a rock and core viewing facility has been recently completed in Thompson. This 150 m² laboratory is housed in one of the two core storage buildings located at the seaplane base compound. The facility is equipped with a rock saw, large viewing benches and numerous electric outlets that allow the use of microscopes, additional lighting, *etc*. Banks of intensive individually switchable fluorescent lights, an exhaust fan and base board and wall mounted fan powered electric heaters serviced through a new 200 A electric panel provide a comfortable working environment in both winter and summer.

This facility is designed to provide the staff of Manitoba Energy and Mines, the mineral industry and the general public with an up to date, safe and comfortable work area in which drill core and other sample media can be studied year round.

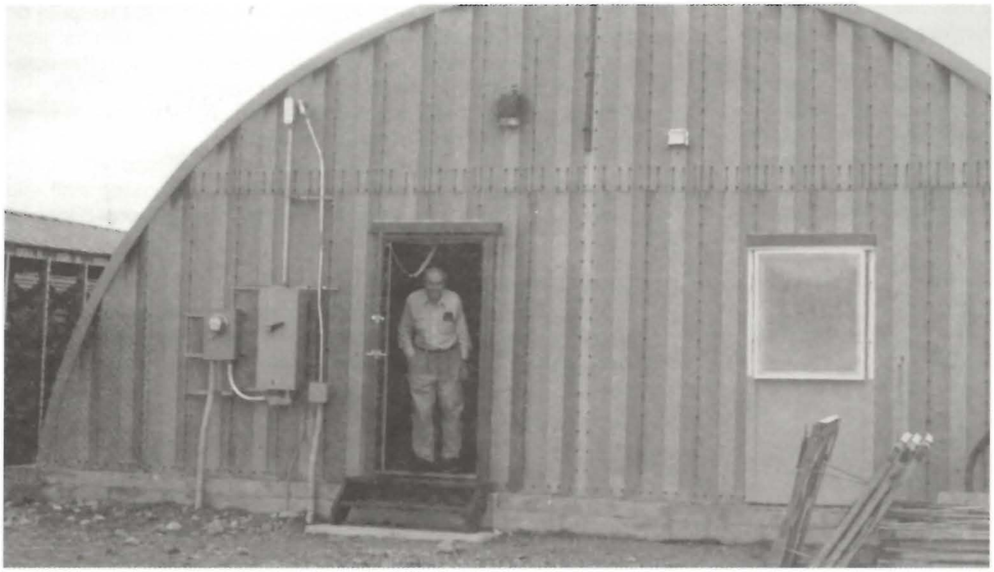

Figure GS-17-1: Outside view and door to the rock examination facility.

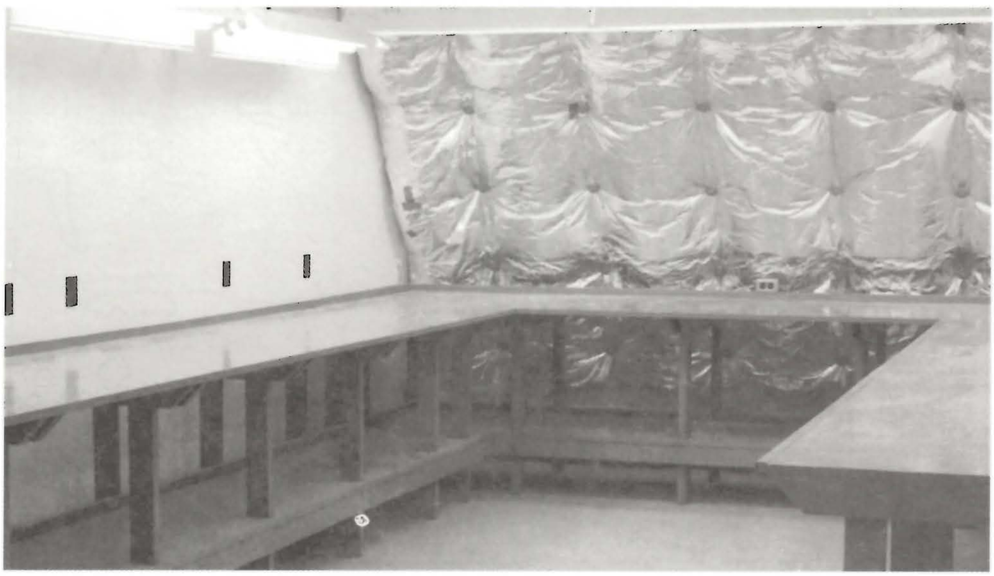

Figure GS-17-2: Inside view showing work benches and custom insulation.

GS-18 ISLAND LAKE REGION MINERAL DEPOSIT SERIES REPORT AND MAP (NTS 53E/9,10; 53E/15,16; AND PARTS OF 53F/12 AND 13)

by P. Theyer and N. MacLellan

Theyer, P. and MacLellan, N., 1995: Island Lake region mineral deposit series report and map (NTS 53E/9,10; 53E/15,16; and parts of 53F/12 and 13); **in** Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 92.

INTRODUCTION

Mineral deposits and occurrences of the Island Lake region (Fig. GS-18-1) were investigated from 1978 until 1982 and in 1990. The data are currently being collated and analyzed and the results of these investigations will be presented in a Mineral Deposit Series Report and accompanying map (Report MDS 32).

REPORT

Forty-four mineral occurrences were investigated and classified. The majority are vein type deposits, but magmatogenic deposits associated with ultramafic rocks and with granitoid porphyry are also common.

In addition to the information normally included in the Mineral Deposit Series Reports, this report will also contain a comprehensive catalogue of all geochemical data available at the time of data collation (summer of 1995). The data for this report will be compiled in digital format on a database and can thus be accessed electronically and electronic searches and retrieval of specified information will be possible.

MAP

The geological map accompanying the report was compiled utilizing seventeen geological maps at diverse scales published by a variety of authors between 1960 and 1987. The final map will be published at 1:100 000 scale and, in addition to the standard information (*i.e.*, location, deposit type, mineralization, host rock to the mineralization, *etc.*), will display the geological information superimposed on the relief of the total magnetic field of the area. This technique is designed to reveal correlations and/or discrepancies between lithologies and magnetic mineral content. Although magnetic mineral content tends to be closely correlated with lithologies, complex processes such as alteration, oxidation and metamorphism introduce variations in the magnetic mineral content that may be used as clues to interpret the history of the rocks. This feature is of course also useful in assessing the mineral potential and metallogeny of an area.

The combined geology/total magnetic relief map will be the product of a Federal-Provincial cooperative effort involving staff and resources of Manitoba Energy and Mines and the Geological Survey of Canada.

ACKNOWLEDGMENTS

The compilation and organization of documents and data to be included in this report was carried out by N. MacLellan. Digitization of the topography and geology of six NTS sheets was completed by B. Lenton.

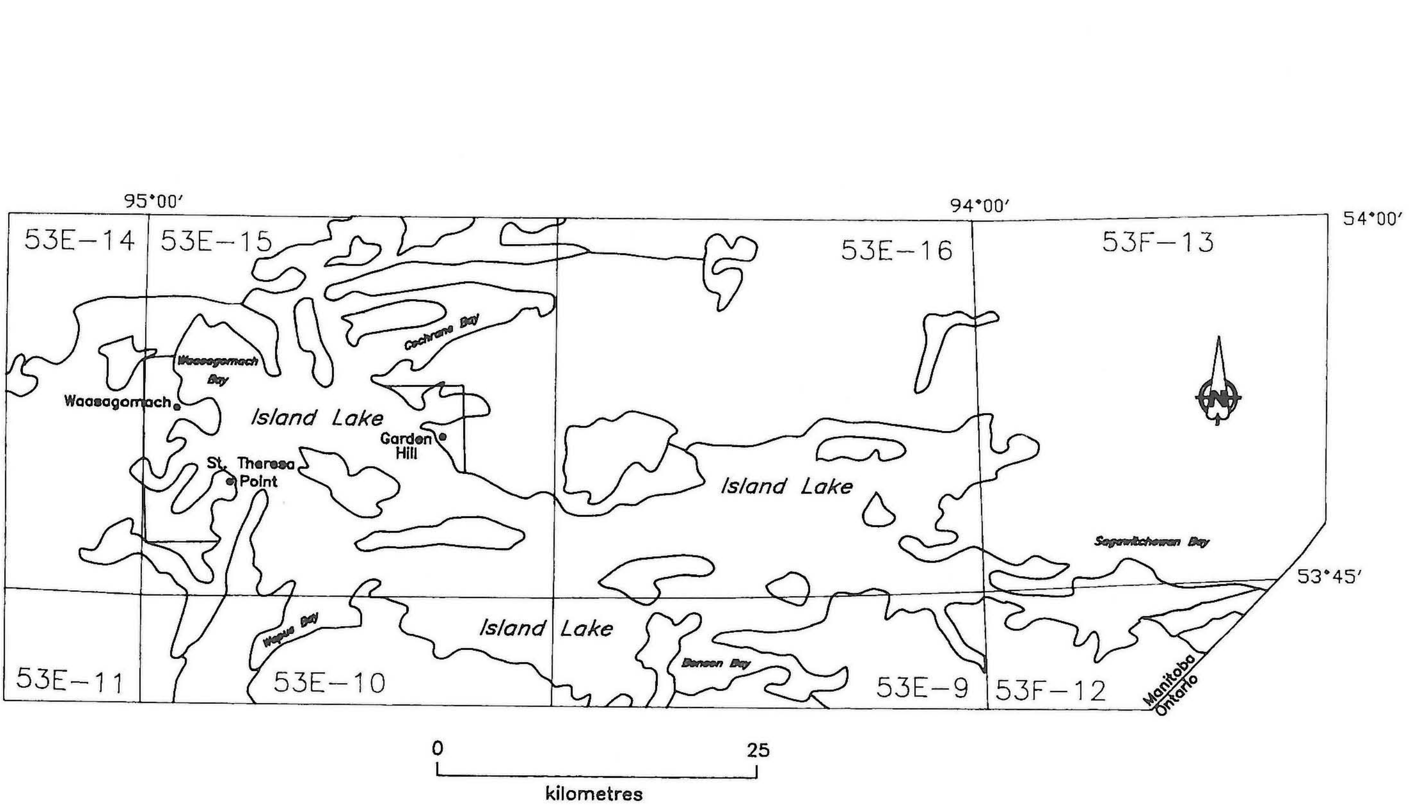

Figure GS-18-1: Extent of the area included in Mineral Deposit Series report for the Island Lake region (MDS #32).

GS-19 PRECAMBRIAN DRILLING ALONG THE SUB-PALEOZOIC EASTERN BOUNDARY OF THE THOMPSON NICKEL BELT

by J.J. Macek

Macek, J.J., 1995: Precambrian drilling along the sub-Paleozoic eastern boundary of the Thompson Nickel Belt; **in** Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 93-96.

SUMMARY

Four vertical diamond-drill holes were cored through Paleozoic cover into Precambrian rock in the area between Foot Print Lake and Little Limestone Lake to 1) further test the inferred eastern boundary of the Thompson Nickel Belt (TNB); 2) explain specific magnetic patterns within this region; and 3) examine the nature of the Reedy Lake Lineament. In addition to logging the drill core, thin sections were examined from typical or informative portions of the cores (Table GS-19-1) Selected samples were analyzed for major and trace elements (Table GS-19-2). The purpose and the background of this drilling program are presented in Macek and Weber (1994) and Bezys (1995, 1994, 1993).

DRILLING RESULTS

Drillhole M-1-95 tested a strongly elongated aeromagnetic anomaly at the northern tip of Foot Print (Geological Survey of Canada, 1969). This anomaly (61 090γ) is a part of a longer (at least 50 km long) linear anomaly trending 025°. The trend is characteristic of the Molson dyke swarm (Scoates and Macek, 1978). Drillhole M-1-95 intersected texturally undisturbed pyroxene-hornblende gabbronorite (Streckeisen, 1976) of the Molson dyke swarm. Since the texture of the dyke is not affected by Hudsonian tectonic reworking, and the regional aeromagnetic pattern is not characteristic of a Pikwitonei granulite, it is deduced that the host terrane to this dyke must be a greenstone belt.

Drillhole M-4-95, located in a regional magnetic low north and east of Buffalo Lake, intersected layered metasedimentary schist and metavolcanic amphibolite. Extensive kaolinization, chloritization and hematization do not permit a more definite identification of the protoliths. Both lithologies could belong to the same greenstone belt indirectly identified from the observation made in core from DDH M-1-95. In addition, severe and pervasive shearing indicates there is a major fault nearby. A distinct E-W break in the regional aeromagnetic pattern (61 000γ) occurs about 5 km north of this drillhole.

Drillholes M-5-95 and M-6-95 targeted the opposite sides of the Reedy Lake Lineament (fault) that coincides more or less with the 030° trending eastern edge of a broad aeromagnetic anomaly (>61 000γ).

Drillhole M-5-95 intersected partly kaolinized and sericitized granite-pegmatite (nondiagnostic lithological unit) and a very fine grained metavolcanic rock. The fine texture and secondary mineralogy of the metavolcanic rock do not allow for closer identification. A pronounced cataclastic texture displayed in thin sections indicates there is a fault nearby.

Drillhole M-6-95 intersected a subtly layered garnet-bearing biotite-muscovite schist. The unit is interpreted as metapelite-rich turbidite. It likely belongs to either the Pipe or Setting formation of the Ospwagan Group (Bleeker, 1990; McGregor and Macek, 1992, 1993).

CONCLUSIONS

1. The terrane north and east of Foot Print Lake is likely underlain by an east-trending greenstone belt. The Molson dyke swarm, unaffected by Hudsonian tectonic reworking, is part of this terrane.

2. The terrane immediately north and east of Buffalo Lake is probably underlain by the same greenstone belt as concluded above. A pronounced east-trending break in the regional aeromagnetic pattern (61 000γ) is likely a major fault zone and might be one of the principal boundaries between the greenstone belt and Pikwitonei granulite terrane to the northeast.

3 A broad aeromagnetic anomaly (>61 10γ) northwest of Oskatukaw Lake and southwest of Little Limestone Lake is underlain by the Ospwagan Group supracrustal rock. The Reedy Lake Lineament (Kawawakehawak Lakes) is a confirmed fault.

ACKNOWLEDGMENT

The cooperation and contribution by P.A. Tirschmann, Falconbridge Limited, in providing the chemical analyses in this report is appreciated.

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Table GS-19-1
Logs and thin section data from 1995 Manitoba Geological Services Branch's diamond drilling program. Drillhole intersection in metres. All holes were drilled vertically; size of core BQ. Core is stored at Manitoba Energy and Mines' drill core library in Winnipeg and is available to the public. Locations of drill holes are shown in Figure GS-19-1

DDH M-1-95
Elongated magnetic anomaly caused by Molson dyke.

Metres	
XXX.X-145.9	PALEOZOIC
145.9-146.5	PYROXENE-HORNBLENDE GABBRONORITE. Gray, coarse grained, severely weathered, non-foliated.
146.5-154.3	PYROXENE-HORNBLENDE GABBRONORITE. Gray, medium- to coarse-grained, homogeneous and nonfoliated rock.

Thin section: 152.55m

Modal analysis	%
Orthopyroxene	17.6
Clinopyroxene	43.0
Hornblende (brown)	5.4
Hornblende (green)	4.8
Plagioclase An_{65-40}(rim)	28.0
Opaques	1.2

Chemical analysis: 151.31-151.42m

Interpretation: Since the texture of the intersected Molson dyke is unaffected by the Hudsonian orogeny and the regional aeromagnetic pattern is not characteristic of a Pikwitonei granulite, the host terrane to this dyke must be a Superior Province greenstone belt.

DDH M-4-95
Magnetic low. Expected rock: felsic gneiss, retrogressed felsic granulite?

Metres	
XXX.X-149.0	PALEOZOIC
149.0-153.5	REGOLITH. Severely kaolinized schist.
153.5-169.0	BIOTITE-QUARTZ-FELDSPAR SCHIST. Light to dark gray, medium- to coarse-grained, well foliated and subtly layered rock. The texture is modified by shearing and mylonitization, as well as by kaolinization and chloritization. A subtle layering is defined by biotite enrichment, fine grained quartz-rich layers 2 to 20 cm thick or concentrations of oval quartz crystals 2 to 7 mm in size. Vein quartz occurs in shear zones.
169.0-172.9	METAVOLCANIC AMPHIBOLITE. Dark gray green, fine- to very fine-grained, foliated, sheared and fractured rock. Fractures (1 to 3 mm wide) are filled with chlorite, quartz or hematite. The contact between schist and amphibolite is tectonized and healed with white quartz.

Thin section: 158.76m

Modal estimate	%
Quartz	60
Plagioclase (chloritized)	20
Biotite (partly chloritized)	20
Tourmaline	Tr.

Thin section: 166.70m

Modal estimate	%
Quartz (Oval clasts?)	5
Quartz (Matrix)	45
Plagioclase (chloritized)	35
Biotite	12
Muscovite	2
Tourmaline, hematite	1

Thin section: 168.09m

Modal estimate	%
Quartz	50
Plagioclase (chloritized)	35
Biotite (partly chloritized)	14
Tourmaline, hematite	1

Thin section: 170.95m

Modal estimate	%
Quartz	40
Plagioclase (chloritized)	40
Biotite (partly chloritized)	20

Thin section: 172.50m

Modal estimate	%
Amphibole	75
Quartz	15
Epidote	10

Chemical analysis: 172.46-172.54m

Interpretation: Severe kaolinization, chloritization and extensive tectonic reworking do not allow definite identification of this layered metasedimentary schist and associated metavolcanic amphibolite. Both intersected lithologies could belong to the same greenstone belt indirectly identified from the observation made in the DDH M-1-95. In addition, severe and pervasive shearing indicates a major fault nearby. A distinct E-W break in the regional aeromagnetic pattern (61 000γ) occurs about 5 km north of this drill hole.

DDH M-5-95

Drillholes M-5-95 and M-6-95 targeted the opposite sides of the Reedy Lake Lineament (possible fault) which coincides with the edge of the 030° trending aeromagnetic anomaly.

XXX.X-141.4	PALEOZOIC
141.4-150.0	PEGMATITE, GRANITE. Severely kaolinized.
150.0-158.2	GRANITE, PEGMATITE. Dark pink, medium- to very coarse-grained, weakly foliated and locally severely kaolinized rock. The granite - pegmatite transition is gradational. Pegmatite is usually 10 to 50 cm thick and may display a macrographic texture.
158.2-168.85	METAVOLCANIC ROCK. Dark gray-green to brown-green, very fine grained, strongly foliated, fractured and brecciated rock. It is enriched locally in white, chert-like layers and lenses 1 to 10 mm thick. Breccia zones and cross cutting fractures are filled with quartz and calcite.

Thin section: 157.15m

Modal estimate	%
Muscovite	3
Plagioclase An_{10}	30
Potash feldspar (sericitized)	15
Quartz	50
Hematite, Epidote, carbonate	2

Thin section: 162m

Modal estimate	%
Chlorite (green, secondary)	60
Quartz (secondary)	10
Sphene	3
Epidote	.2
Chlorite (brown, secondary)	25

Thin section: 166m

Modal estimate	%
Chlorite	40
Quartz	40
Carbonate	15
Opaque	5

Chemical analyses: 159.35-159.45m, 160.58-160.70m.

Interpretation: Very fine grained texture and secondary mineralogy do not allow a closer identification of the metavolcanic rock. Partially altered granite - pegmatite is not diagnostic.

DDH M-6-95

XXX.X-145.4	PALEOZOIC
145.4-157.6	BIOTITE-MUSCOVITE SCHIST, GARNET-BEARING. Silvery light gray, medium- to coarse-grained, layered and well foliated rock. A subtle compositional layering consists of silvery gray, coarse grained, 10 to 50 cm thick layers of muscovite-rich schist irregularly intercalated with gray, medium grained, garnet-biotite-muscovite schist or biotite-muscovite schist. The layered sequence is locally macrocrenulated and moderately kaolinized.

Interpretation: Metapelite-rich turbidite. The schist likely belongs to either the Pipe or Setting formation of the Ospwagan Group.

Thin section: 157.3m

Modal estimate	%
Quartz	50
Biotite, Muscovite	25
Plagioclase	20
Garnet	5

Table GS-19-2
1995 Manitoba Geological Services Branch's diamond drilling program; chemical analyses (provided by Falconbridge Limited)

	WA 38566	WA 38565	WA 38564	WA 38563
SiO_2 %	51.36	49.35	48.25	50.54
Al_2O_3 %	8.95	13.09	15.25	13.65
Fe_2O_3 %	11.95	15.78	13.08	14.15
MgO %	14.54	6.85	10.13	9.67
CaO %	11.51	9.92	0.22	0.37
Na_2O %	1.17	0.93	0.25	0.14
K_2O %	0.10	0.56	4.18	2.78
TiO_2 %	0.56	1.41	1.33	1.36
P_2O_5 %	0.04	0.14	0.12	0.12
MnO %	0.20	0.21	0.11	0.16
S %	0.02	1.11	0.04	1.05
LOI %	0.33	2.21	7.91	6.21
SUM %	100.70	100.45	100.83	99.16
Cu ppm	135	205	100	185
Co ppm	60	50	45	60
Cr ppm	1300	245	205	250
Y ppm	10	20	6	12
Zr ppm	20	80	40	70
Zn ppm	105	130	80	85
Ba ppm	20	40	80	120
Sc ppm	53	47	45	44
Nb ppm	<30	<30	<30	<30
Ni ppm	255	85	120	85
Be ppm	<1	<1	<1	<1
V ppm	245	395	350	375

WA 38566, DDH M-1-95: 151.31-151.42 m, pyroxene-hornblende gabbronorite, Molson dyke swarm.
WA38565, DDH M-4-95: 172.46-172.54 m, metavolcanic amphibolite.
WA 38564, DDH M-5-95: 160.58-160.70 m, metavolcanic rock.
WA 38563, DDH M-5-95: 159.35-159.45 m, metavolcanic rock.

GS-20 RELOGGED DRILL CORE FROM SUB-PHANEROZOIC PRECAMBRIAN BASEMENT IN NTS 63J

by C.R. McGregor

McGregor, C.R., 1995: Relogged drill core from Sub-Phanerozoic Precambrian basement in NTS 63J; **in** Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 97-98.

Thirty-six nonconfidential sub-Phanerozoic Precambrian diamond drill cores drilled by exploration companies and the provincial government, in NTS 63JSW, (Fig. GS-20-1) were relogged in 1995 (McGregor, 1995) in order to further identify major lithologic units within the eastern Churchill Province.

Six of these holes relogged in 1995 were drilled by Granges Inc. in 1989, 15 by Manitoba Minerals Resources Ltd. between 1975 and 1986, 3 by Sholia Resources Ltd. in 1988 and the remaining 12 by Geological Services Branch, Manitoba Department of Energy and Mines between 1979 and 1993. The Geological Services Branch drill core was previously logged and the results published (Bezys, 1993; McCabe, 1983, 1979). The Manitoba Minerals Resources and Granges drill core is stored at the Provincial Core Library in The Pas and the drill core from the other companies is stored at the Midland Core Storage facility in Winnipeg.

Preliminary Geological Report PR95-1 (McGregor, 1995) is a catalogue that contains a summative log, cross section and colour photographs for each drillhole that has been relogged. This report also contains Preliminary Map PR95-1-1 that shows the locations and intersected host and target lithologies of the holes relogged in 1995 at 1:250 000 scale in addition to those done in 1992 (McGregor and Macek, 1992; Macek and Nagerl, 1992), 1993 (McGregor and Macek, 1993) and 1994 (McGregor, 1994). This map does not include provincial government holes drilled and logged in NTS 63G this year (Macek, 1995) and in previous years (Macek and Weber, 1994; Bezys, 1993, 1992, 1991, 1990). A detailed evaluation and further interpretation of the core is in progress.

This report is available at Manitoba Energy and Mines Library in Winnipeg for viewing and/or reproduction at cost.

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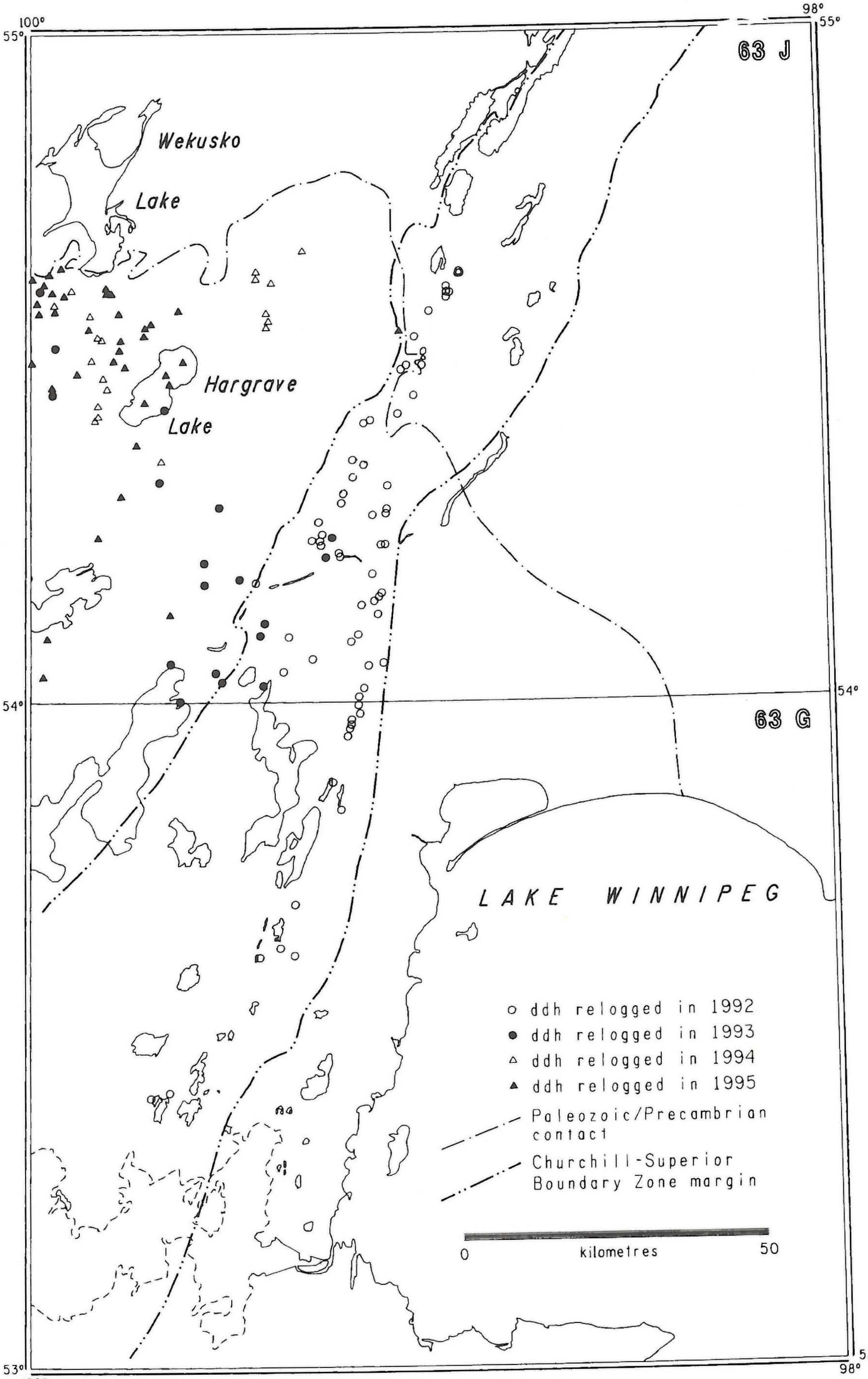

Figure GS-20-1: Location of relogged sub-Phanerozoic Precambrian diamond-drill holes in NTS 63J.

GS-21 STRATIGRAPHIC MAPPING (NTS 62I AND 63G) AND COREHOLE PROGRAM 1995

by R.K. Bezys

Bezys, R.K., 1995: Stratigraphic mapping (NTS 62I and 63G) and corehole program 1995; **in** Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 99-108

SUMMARY

A three week stratigraphic mapping program in the vicinity of Buffalo Lake and east of Provincial Highway 6 confirmed that the Paleozoic stratigraphy is conformable with regional isopach and structural trends. The Geological Services Branch's drilling program completed seven holes with a total of 759.8 m of core. Four holes were drilled to obtain Precambrian core in order to delineate the eastern boundary of the Churchill-Superior Boundary Zone; one hole was drilled to obtain Precambrian core along The Pas moraine; and two holes were drilled on either side of the Reedy Lake Lineament to test the possibility of faulting associated with the Precambrian. Paleozoic core information obtained from this program will be used in the correlation of Ordovician and Silurian stratigraphy in the Grand Rapids area. All stratigraphic data are to be added to the digital Manitoba Stratigraphic Database (MSD), which includes all Lower Paleozoic well tops verified and corrected by the Geological Services Branch.

INTRODUCTION

Four stratigraphic field projects were carried out in 1995:

1. Stratigraphic mapping in the vicinity of Buffalo Lake and east of Provincial Highway 6 (Grand Rapids);
2. Stratigraphic drilling in the Grand Rapids area;
3. Continued core logging of Paleozoic mineral exploration drill core; and
4. Capital region resource evaluation project (NTS 62I/3) (see GS-29, Bamburak and Bezys, this volume).

Locations of the stratigraphic coreholes are shown in Figure GS-21-1 and a summary of corehole data is presented in Table GS-21-1.

Outcrops in the Buffalo Lake area and outcrops near Cross Bay (Cedar Lake) were mapped. In total, 73 stations were examined in NTS 63G/6, 63G/11 and 63G/14 (Fig. GS-21-2).

STRATIGRAPHIC MAPPING

Stratigraphic mapping in the western half of NTS 63G was carried out in the summer of 1995 as a follow-up to previous work in the area (McCabe, 1978, 1979, 1986, 1988; Bezys, 1990, 1994). The Paleozoic bedrock in the study area overlies the Churchill-Superior Boundary Zone of the Precambrian basement, and emphasis was placed on documenting regional stratigraphic correlations.

The bedrock geology consists of the Silurian Interlake Group. Outcrops to the east of Provincial Highway 6 consist primarily of the Fisher Branch, Moose Lake and Atikameg formations (the Silurian escarpment). In the Cross Bay (Cedar Lake) area, the dominant formation is the Cedar Lake (Fig. GS-21-3).

Figure GS-21-4 shows the location of two stratigraphic cross sections constructed in the Grand Rapids area. Figure GS-21-5 (cross section A-A') incorporates the westernmost stratigraphic corehole (M-11-90) in NTS 63G and the easternmost well located along Highway 6 (M-4-94). The datum for both reconstructed sections is the top of the Stonewall Formation's T-zone, a distinct argillaceous marker bed that demarcates the Silurian-Ordovician boundary. Correlations are aided by a gamma ray log for corehole M-4-94, which shows a strong argillaceous peak for the T-zone. The entire sedimentary package is composed of carbonate (all dolomitized), and the Winnipeg Formation is a quartzose sandstone and shale.

Cross section A-A' confirms that the Paleozoic stratigraphy in this area is conformable with regional isopach and structural trends. Two areas of interest on the cross section include the regional stratigraphic dip associated with the East Arm, Atikameg and Moose Lake formations (including the U_2-marker) and the regional dip of the Winnipeg Formation and the Precambrian in the vicinity of the Reedy Lake Lineament (discussed in the next section). The thickening of the Interlake Group may be a result of a carbonate build-up in the Moose Lake Formation, which affected the structural elevation of the overlying formations or may represent regional isopach thinning of the sequence to the east. The dip of the Winnipeg Formation and its slight thinning (M-6-95) may be associated with faulting along the Reedy Lake Lineament (Bezys, in press).

Cross section B-B' (Fig. GS-21-6), approximately 23 km south of section A-A', confirms that the Paleozoic stratigraphy in this area is conformable with regional trends, although the stratigraphic top of the Winnipeg Formation (and the corresponding estimated top of the Precambrian) appear slightly elevated for corehole M-3-89. This may represent a slight Precambrian high which is mimicked by the Winnipeg Formation. The Williams, Gunton and Penitentiary members are very difficult to identify in drill core, and as a result have caused the thickness variations observed in the cross sections.

STRATIGRAPHIC DRILLING IN THE GRAND RAPIDS AREA

The Geological Services Branch's drilling program completed seven holes (four to Precambrian) with a total of 759.0 m of core (71.95 m of Precambrian core). Drill targets were chosen from magnetic anomalies to delineate the eastern boundary of the southwestern extension of the Thompson Nickel Belt (*i.e.,* the Churchill-Superior Boundary Zone) (see GS-19, Macek, this volume, for a detailed description of all Precambrian core). Two holes tested the presence of potential stratigraphic and structural anomalies associated with the Reedy Lake Lineament (M-5-95 and M-6-95).

Corehole M-1-95 (Footprint Lake North) tested a strongly elongated anomaly at the northern tip of Footprint Lake; it intersected texturally undisturbed pyroxene-hornblende gabbronorite of the Molson dyke swarm. Corehole M-2-95 attempted to test a magnetic anomaly within the Churchill-Superior Boundary Zone, but was abandoned at 38.65 m due to poor drilling conditions. Coreholes M-3-95 and M-7-95 were drilled to test magnetic anomalies associated with the eastern boundary of the Churchill-Superior Boundary Zone on the west side of Buffalo Lake; both holes were abandoned due to poor drilling conditions. Corehole M-4-95, located in a regional magnetic low north of Sturgeon Gill Road, intersected layered metasedimentary schist and metavolcanic amphibolite. Coreholes M-5-95 and M-6-95 targeted opposing sides of the Reedy Lake Lineament, which coincides with the 30°-trending eastern edge of a broad magnetic anomaly. Corehole M-5-95 intersected partly kaolinized and sericitized granite-pegmatite and a very fine grained metavolcanic rock. Thin sections display a pronounced cataclastic texture indicating a nearby fault. Corehole M-6-95 intersected a subtly layered garnet-bearing biotite-muscovite schist.

Upon completion of the stratigraphic drilling, staff from the University of North Dakota conducted downhole temperature profiles on open coreholes (see GS-23, Gosnold, this volume). A total of seven coreholes were profiled which will provide information on heat flow, ground water flow and recent climate change. This information will complement earlier downhole logging carried out by the Geological Survey of Canada in the Grand Rapids area (Mwenifumbo, 1994; Mwenifumbo *et al.,* 1995).

CORE LOGGING OF PALEOZOIC MINERAL EXPLORATION DRILLHOLES

Over the last six years, Paleozoic data from 654 sub-Phanerozoic mineral exploration drillholes have been entered into the Manitoba Stratigraphic Database. Recent acquisitions include Falconbridge Ltd.'s drillholes from within the extension of the Thompson Nickel Belt (22 drillholes were logged from their 1994-95 winter drill program). As well, three drillholes were logged from Cominco's 1994-95 winter drill program from within the Churchill-Superior Boundary Zone. This information has been used to construct structure contour maps of the Precambrian and depth to basement maps. Bezys (in press) presents a detailed analysis of Paleozoic core from recent drilling by Falconbridge Ltd. in the William Lake area.

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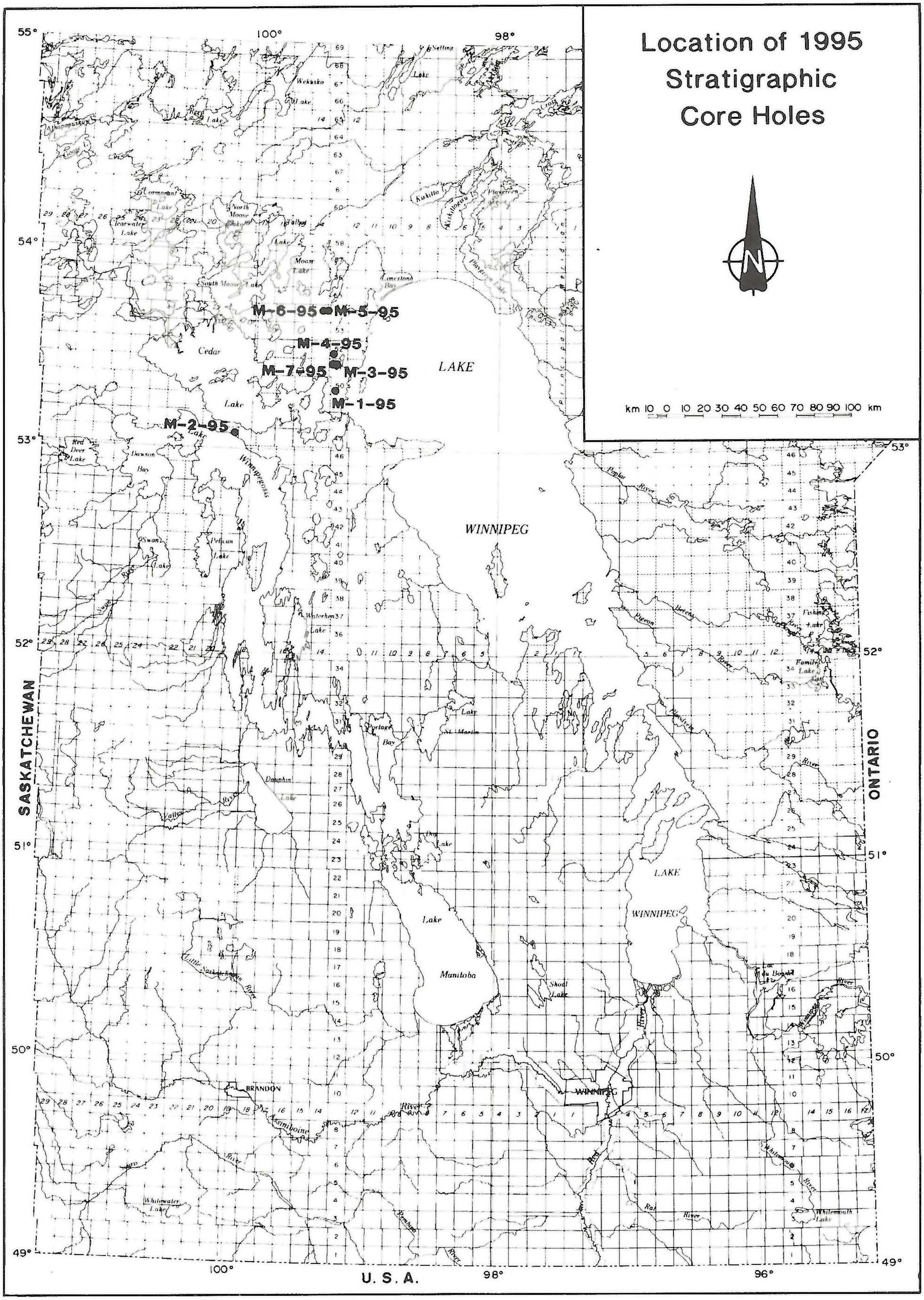

Figure GS-21-1: Location of 1995 stratigraphic coreholes.

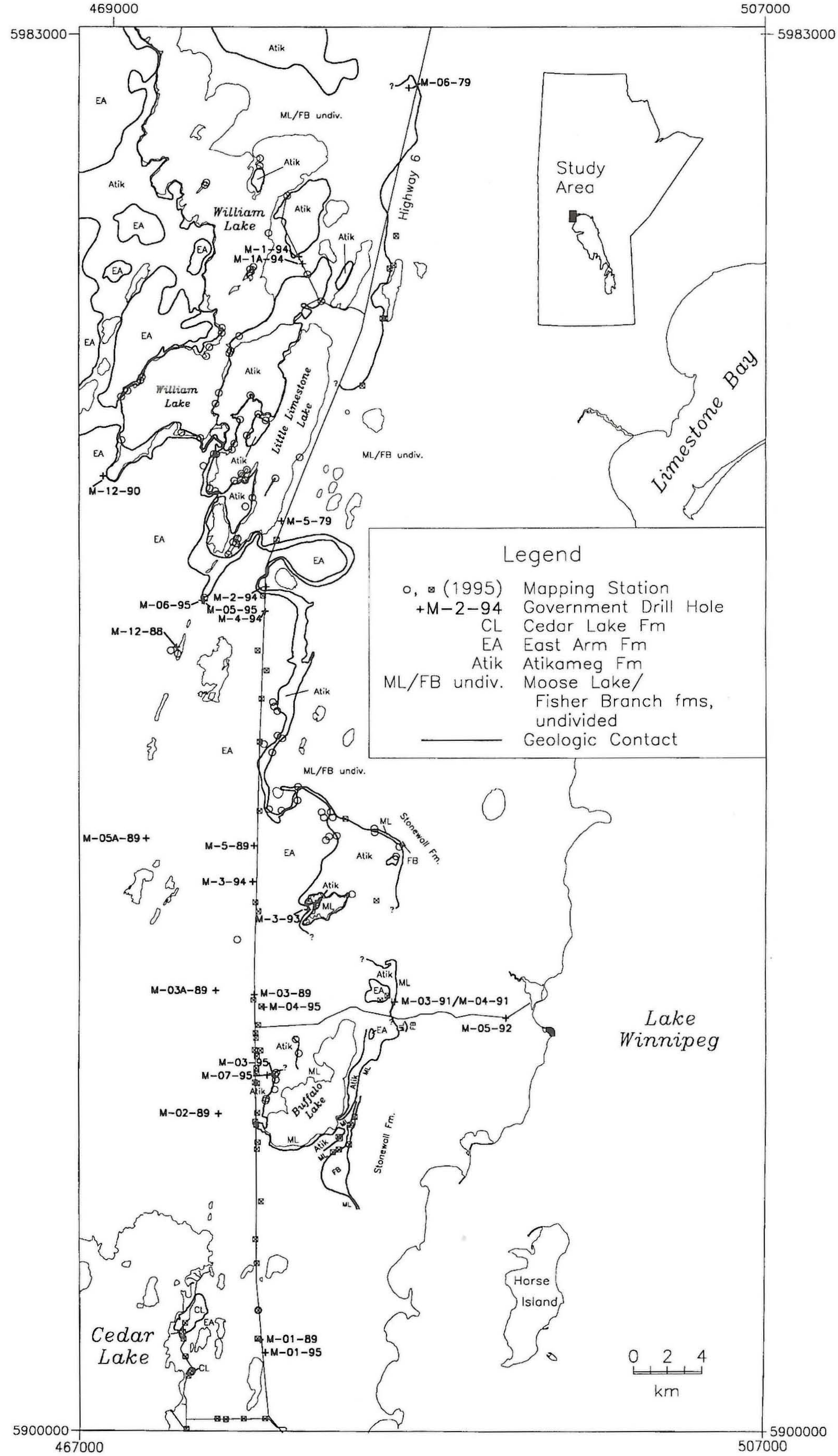

Figure GS-21-2: Location of 1995 mapping stations and geological contacts.

GRAND RAPIDS AREA STRATIGRAPHIC COLUMN

ERA	PERIOD	GROUP/FORMATION/MEMBER		BASIC LITHOLOGY
LOWER PALEOZOIC	SILURIAN	INTERLAKE GROUP	CEDAR LAKE FORMATION (0–60m)	Dolomite; yellow–orange to grey, fossiliferous, oolitic, stromatolitic, interrupted by argillaceous marker beds (0–100m).
			EAST ARM FORMATION (0–10m) — V-marker, U2-marker	
			ATIKAMEG FORMATION (0–8m)	
			MOOSE LAKE FORMATION (0–10m) — U1-marker	
			FISHER BRANCH FORMATION (0–15m)	
		STONEWALL FORMATION — T-zone		Dolomite; yellow–grey, sparsely fossiliferous, interrupted by argillaceous zones and marker beds (0–20m).
	ORDOVICIAN	STONY MOUNTAIN FORMATION		Dolomite; yellow–brown, slightly nodular (0–40m).
		RED RIVER FORMATION	Fort Garry Member	Dolomite; mottled, fossiliferous, cherty, overlain by argillaceous dolomite with breccia beds (Fort Garry) (0–50m).
			lower Red River	
		WINNIPEG FORMATION	upper	Quartzose sandstone; interbedded by green, waxy shale with sand and silt interbeds (0–12m).
			lower	
PRECAMBRIAN				

---- Major unconformities

Figure GS-21-3: Grand Rapids area stratigraphic column.

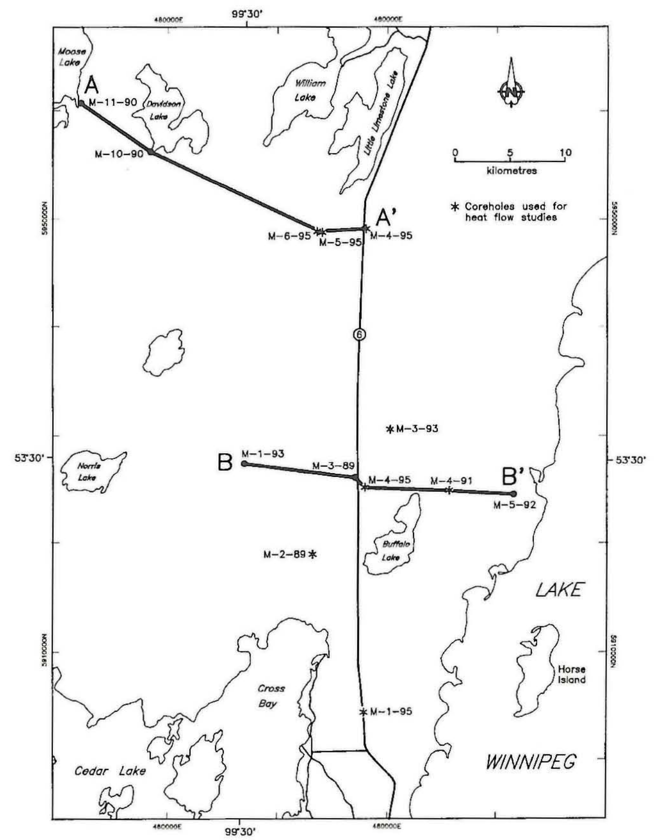

Figure GS-21-4: Location of cross sections A-A' and B-B'.

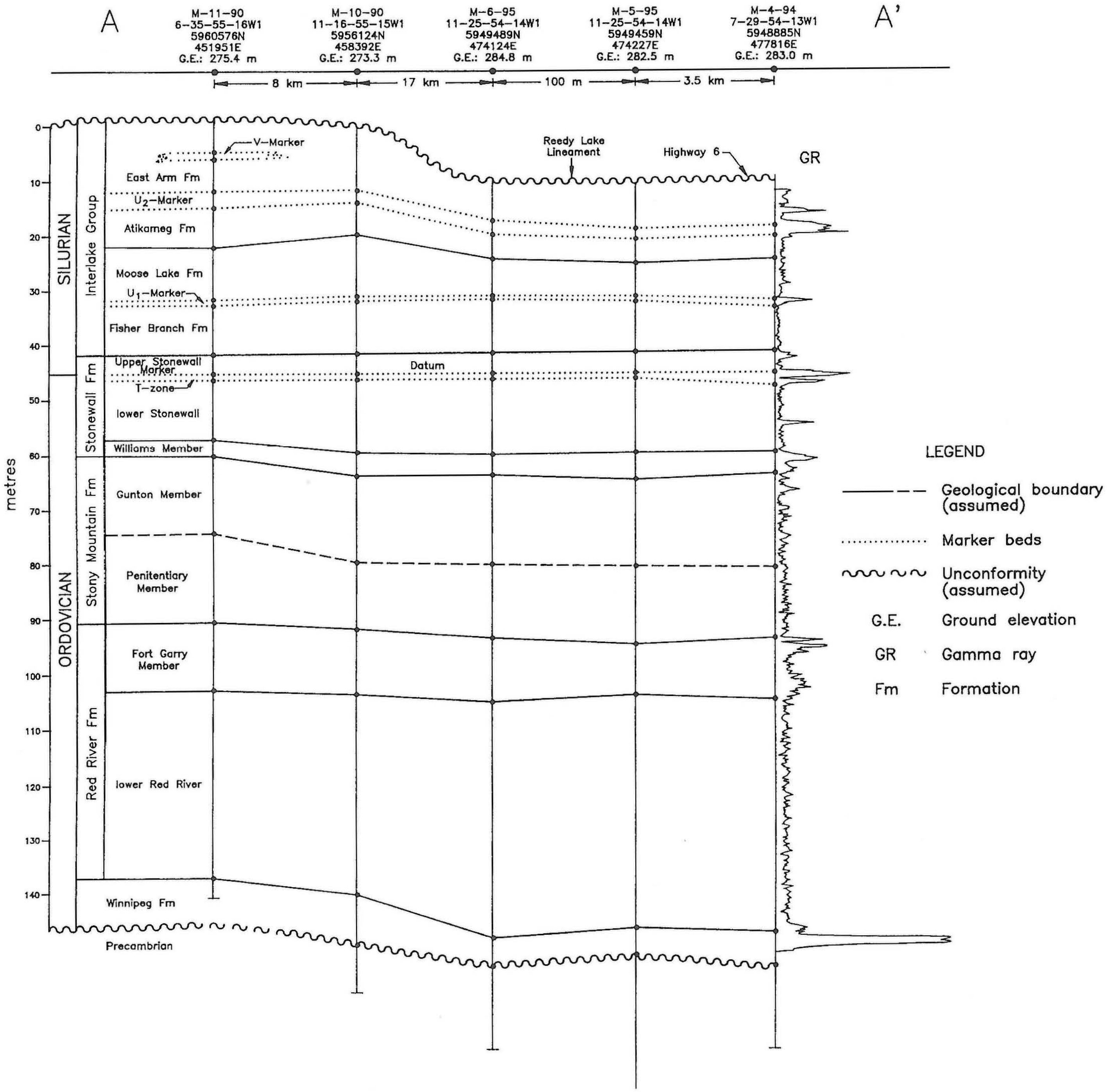

Figure GS-21-5: Stratigraphic cross section A-A'.

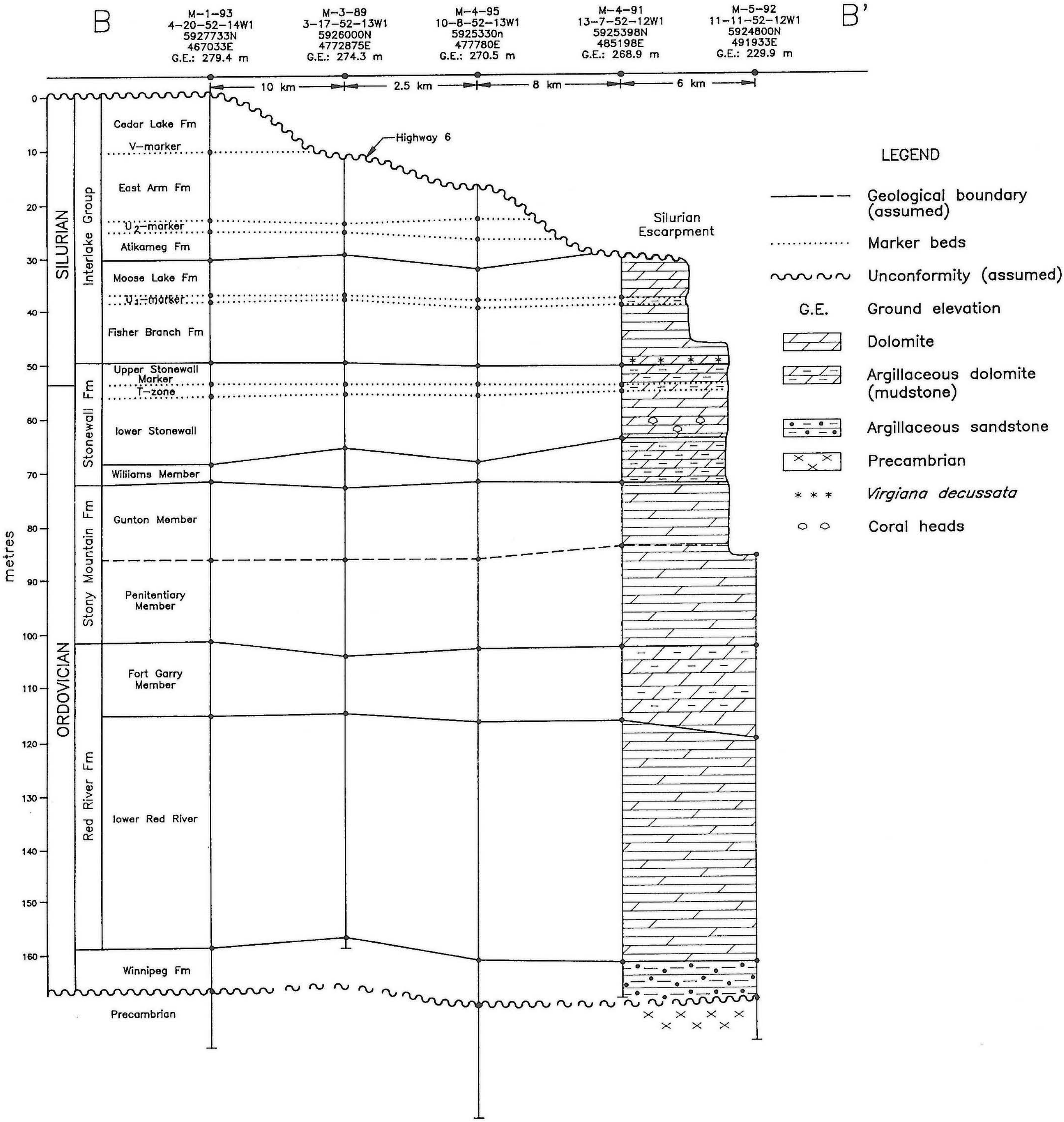

Figure GS-21-6: Stratigraphic cross section B-B'.

Table GS-21-1
Summary of Core Hole Data 1995

Hole No.	Location and Elevation (m)	SYSTEM/Formation/ (Member)	Interval (m)	Summary Lithology
M-1-95	5904550N	OVERBURDEN	0.0-3.0	
Footprint Lake N.	477860E	SILURIAN - Moose Lake	3.0-7.3	Wackestone to mudstone; massive.
	13-5-50-13W1	(U_1-marker)	7.3-8.2	Mudstone; sandy; floating sand grains at the base.
	251.2 m	Fisher Branch	8.2-20.4	Wackestone to packstone; with *Paleofavosites* and *Virgiana decussata*.
		Stonewall	20.4-23.8	Upper Stonewall marker; mudstone; possible conglomeratic beds.
		(T-zone)	23.8-26.1	Mudstone; grey to green grey; slightly conglomeratic.
		ORDOVICIAN-Stonewall	26.1-38.8	Mudstone to wackestone; very rotten core.
		(Williams Member)	38.8-41.9	Mudstone.
		Stony Mountain	41.9-74.5	Wackestone; scattered hardground surfaces towards the base; burrowed.
		Red River (Fort Garry)	74.5-88.8	Mudstone; scattered conglomerate beds.
		lower Red River	88.8-136.0	Wackestone; mottled; burrowed; Hecla beds present at 135.7-136.0 m.
		Winnipeg	136.0-145.9	Sandstone to siltstone; burrowed; poor recovery (only 6.1 m of core).
		PRECAMBRIAN	145.9-146.5	Pyroxene-hornblende gabbronorite; very weathered; nonfoliated.
			146.5-154.3	Pyroxene-hornblende gabbornorite; homogeneous; nonfoliated.
M-2-95	5879124N	OVERBURDEN	0.0-20.5	
East Mossy Portage	425102E	SILURIAN-Cedar Lake	20.5-38.7	Packstone to mudstone; reefal-like in places; scattered brachiopods.
	16-14-47-19W1			
	259.1 m			
M-3-95	5921290N	OVERBURDEN	0.0-13.8	
NW Buffalo	478325E	SILURIAN-Fisher Branch	13.8-14.3	Wackestone; rare *Virgiana decussata* specimens.
Lake -1	4-33-51-13W1	Stonewall	14.3-18.4	Upper Stonewall Marker; mudstone; possible conglomeratic beds.
	259.7 m			
		(T-zone)	18.4-20.0	Mudstone; dark grey.
		ORDOVICIAN-Stonewall	20.0-27.8	Wackestone; minor chert.
		(Williams Member)	27.8-32.8	Mudstone; sandy infill at base.
M-4-95	5925330N	SILURIAN-East Arm	0.0-6.3	Mudstone; slightly sandy; laminated.
N. Sturgeon	477780E	(U_2 - marker)	6.3-9.8	Mudstone; laminated; massive.
Gill Road	10-8-52-13W1	Atikameg	9.8-15.4	Packstone; reefal-like; vuggy.
	270.5 m	Moose Lake	15.4-21.6	Wackestone with minor mudstone.
		(U_1 - marker)	21.6-22.7	Mudstone; laminated.
		Fisher Branch	22.7-33.6	Packstone to wackestone; massive; *Virgiana decussata* at base, corals and bryozoans.
		Stonewall	33.6-36.9	Upper Stonewall marker; mudstone.
		(T-zone)	36.9-39.0	Mudstone; burrowed; slightly conglomeratic.

		ORDOVICIAN-Stonewall	39.0-51.1	Wackestone to mudstone; rare *Paleofavosites*; marker bed between 46.5-47.4 m.
		(Williams Member)	51.1-54.7	Mudstone.
		Stony Mountain	54.7-86.0	Wackestone; mottled; rare hardground surfaces.
		Red River (Fort Garry)	86.0-99.5	Mudstone; minor breccia beds.
		lower Red River	99.5-143.9	Wackestone; mottled; cherty; rare gypsum casts; Hecla beds between 143.7-143.9 m.
		Winnipeg	143.9-149.0	(only 4.2 m of core); siltstone to sandstone; quartzose.
		PRECAMBRIAN	149.0-153.5	Regolith; severely kaolinized schist.
			153.5-169.0	Biotite-quartz-feldspar schist; medium to coarse grained; well foliated; texture has been modified by shearing, mylonitization, kaolinization, and chlorization; vein quartz occurs in shear zones.
			169.0-172.9	Metavolcanic amphibolite; fine to very fine grained; foliated; sheared and fractured; fractures, up to 1 to 3 mm wide, are filled with chlorite, quartz and hematite.
M-5-95	5949459N	SILURIAN-East Arm	0.0-8.0	Grainstone to wackestone; very broken core.
Reedy Lake	474227E	(U_2-marker)	8.0-10.0	Mudstone; sandy; some interclastic breccia; laminated to massive.
Lineament E	11-25-54-14W1			
	282.5 m	Atikameg	10.0-14.5	Grainstone to wackestone; very thin to massive.
		Moose Lake	14.5-20.6	Mudstone to wackestone; some grainstone intervals; scattered *Paleofavosites* fragments.
		(U_1-marker)	20.6-21.3	Mudstone; slightly burrowed.
		Fisher Branch	21.3-30.6	Wackestone; slightly mottled; massive; well preserved *Virgiana decussata* and rare *Paleofavosites*.
		Stonewall	30.6-34.1	Upper Stonewall marker; mudstone.
		(T-zone)	34.1-35.3	Mudstone; massive; burrowed.
		ORDOVICIAN-Stonewall	35.3-48.8	Wackestone to grainstone; minor fossils - *Pycnostylus*; marker bed between 42.3-45.1 m.
		(Williams Member)	48.8-53.9	Mudstone; minor mottling.
		Stony Mountain	53.9-84.2	Wackestone; mottled; massive.
		Red River (Fort Garry)	84.2-93.5	Mudstone; minor intraformational breccia zones; massive.
		lower Red River	93.5-136.0	Wackestone; minor tripolized chert; mottled; minor fossil material; Hecla beds between 134.6-136.0 m.
		Winnipeg	136.0-141.4	Mudstone and sandstone; quartzose.
		PRECAMBRIAN	141.4-150.0	Pegmatite, granite; severely kaolinized.
			150.0-158.2	Granite, pegmatite; weakly foliated; locally severely kaolinized.
			158.2-168.9	Metavolcanic; very fine grained; strongly foliated; fractured and brecciated; enriched in chert-like layers and lenses; breccia zones and crosscutting fractures are infilled with quartz and calcite.

M-6-95	5949489N	SILURIAN-East Arm	0.0-6.4	Mudstone; minor sand.
Reedy Lake	474124E	(U_2-marker)	6.4-8.8	Mudstone; laminated; slightly conglomeratic.
Lineament W	11-25-54-14W1	Atikameg	8.8-13.4	Grainstone to packstone; reefal-like.
	284.8 m	Moose Lake	13.4-20.4	Wackestone to mudstone; minor grainstone; slightly brecciated.
		(U_1-marker)	20.4-20.8	Mudstone; slightly conglomeratic.
		Fisher Branch	20.8-30.7	Packstone to wackestone to mudstone; *Paleofavosites* and *Virgiana decussata* present.
		Stonewall	30.7-34.4	Upper Stonewall marker; mudstone; slightly conglomeratic.
		(T-zone)	34.4-35.6	Mudstone; slightly conglomeratic.
		ORDOVICIAN-Stonewall	35.6-49.2	Wackestone to packstone; very porous and vuggy; marker bed at 44.5 to 45.0 m.
		(Williams Member)	49.2-53.0	Mudstone; laminated.
		Stony Mountain	53.0-82.9	Mudstone to wackestone; slightly mottled; rare hardground surfaces.
		Red River (Fort Garry)	82.9-94.4	Mudstone; some conglomeratic zones.
		lower Red River	94.4-137.7	Wackestone; mottled; scattered chert nodules; clay infilled fractures at 119.4-119.6 and 133.9-135.4 m; Hecla beds at 136.3-137.7 m.
		Winnipeg	137.7-145.4	Siltstone to mudstone and sandstone; minor pyrite; quartzose; (only 1.0 m of core).
		PRECAMBRIAN	145.4-157.6	Biotite-muscovite schist; garnet bearing; layered and well foliated; layered sequence is locally macrocrenulated and moderately kaolinized; (metapelite-rich turbidite).
M-7-95	5921275N	SILURIAN-Moose Lake	0.0-6.0	Wackestone to packstone; some mudstone; small stromatoporoids at the base.
NW Buffalo	477975E			
Lake -2	1-32-51-13W1	(U_1- marker)	6.0-7.4	Mudstone; slightly conglomeratic.
	262.9 m	Fisher Branch	7.4-18.1	Packstone to wackestone; *Paleofavosites* present, no brachiopods.
		Stonewall	18.1-22.5	Upper Stonewall marker; mudstone.
		(T-zone)	22.5-24.5	Mudstone; burrowed.
		ORDOVICIAN-Stonewall	24.5-35.5	Wackestone to mudstone; very leached and porous; cream white silt infill at base (only 0.70 m of core between 32.5-35.5 m).

GS-22 SPRING WATER AND MARL GEOCHEMICAL INVESTIGATIONS, GRAND RAPIDS REGION, 1995 STATUS REPORT (NTS 63G)

by W.D. McRitchie

McRitchie, W.D., 1995: Spring water and marl geochemical investigations, Grand Rapids region, 1995 status report (NTS 63G); **in** Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 109-119.

SUMMARY

Sampling of spring waters and associated marly sediments continued in the Grand Rapids region, with the objective of identifying anomalous concentrations of lead, zinc, barium or fluorine that would flag the potential existence of Mississippi Valley Type (MVT) mineralization in the hinterland to the west of the Silurian escarpment. Analyses of both sample media revealed no significant anomalies along the 80 km strike length of the escarpment from Cypress Creek south to Long Point. Elevated sodium and chloride in one spring water sample near Baldy's Bluffs may reflect the influence of formational brines south of the Saskatchewan River, further east than previously recorded.

INTRODUCTION

Springs and marly fen pools are preferentially concentrated along the foot of the Silurian escarpment throughout Manitoba's Interlake region. Occurrences in the Grand Rapids region are especially well developed and are more accessible than those south of Long Point.

A geochemical sampling program was initiated in 1989 to look for anomalous concentrations of metals that could have been derived from concealed MVT mineralization in Paleozoic carbonates up drainage. The program (McRitchie, 1989, 1994) was continued in 1995, the objective being to complete a continuous string of spring water and/or marl sample sites (average spacing 1-3 km) from Cypress Creek south to Long Point on Lake Winnipeg and the southern limits of NTS map sheet 63G, *i.e.*, 53° N (Fig. GS-22-1).

Low relief along some stretches of the resurgent zone, leading down to the Grand Rapids Lowlands, results in diffuse seepage rather than discrete springs. In these regions marl samples were taken from fen pools to obtain an indirect expression of the spring water chemistry. At other sites both water and marl samples were collected to obtain a comparative database. Variations in marl composition across the zone of precipitation were tested earlier (McRitchie, 1994) by sequential sampling of fen pools in linked chains. The results are outlined in this report. In total, the 1995 program collected 24 marl and 27 spring water samples.

Water samples were analyzed by the Manitoba Environmental Sciences Centre, marl samples by Manitoba Energy and Mines Analytical Laboratory and isotope analyses by the University of Waterloo under a cooperative arrangement with the provincial Water Resources Branch.

WATER SAMPLING PROGRAM

Twenty springs east of Buffalo Lake and south of the road to Sturgeon Gill (Fig. GS-22-2) were sampled using procedures described in earlier reports (McRitchie, 1994). In addition, Buffalo Lake Spring (WS04-24-89) was resampled to evaluate the internal consistency of the water sampling program.

The springs, consistent with those observed elsewhere in this region, typically emerge 5-10 m below small bedrock ledges of Fisher Branch strata containing the marker fossil *Virgiana decussata.* (This stratigraphic level may coincide with a potential aquitard, the argillaceous T-zone in the Stonewall Formation.) The waters then flow down narrow (20-100 cm wide) channels (rivulets or brooks, depending on their size), into gently sloping dolomite shingle- and marl-based surge flats sprinkled with sporadic, remnant tussocks of vegetation (Fig. GS-22-3). The more steeply shelving flats dry up for extended periods of time and runoff is localized into narrow channels scoured into the marly sediments (Fig. GS-22-4). At these locations the surface of the fine grained marly flats is typically coated with a thin disaggregated layer of pea- and bean-sized lozenges that appear to be fragmented rinds of indurated marl.

Down drainage, marly fen pools contain 0-100 cm of water over variable thicknesses (± 1 m) of creamy-white, carbonate-rich mud precipitates.

South of Buffalo Lake, springs at locations 04-95-35 (UTM 482959E 5913854N) and 04-95-39 (UTM 483145E 5913309N) are part of a focussed, profusely flowing complex of resurgences that emerge at a level (235 m A.S.L.), 10 m below the Fisher Branch Formation and more than 15 m above the base of the steep slopes (Figs. GS-22-2, 5). The braided rivulets and brooks converge downslope in a series of small sonorous cascades, across water-saturated clay mounds (carpeted by *Equisetum scirpoides*?) and along narrow channels deeply incised into the moss and humus. The surrounding slopes are covered with *Sarsaparilla* ground cover overshadowed by old growth poplar, birch and spruce.

At location 04-95-18 (Fig. GS-22-2), flows in a unique upwelling spring rise through coarse shingle into a 1.0 x 1.5 m wide pool, 0.5 m deep. Fine aggregates of sand "erupting" from the base of the pool contain a high proportion of minute gastropod and bivalve shells.

The analyses of the spring waters (Tables GS-22-1 and 2) are similar to those of previous years with negligible to undetected lead and zinc contents and generally low fluorides. All samples are saturated in carbonates at their points of emergence (Fig. GS-22-6).

One of the four analyzed samples from south of Grand Rapids (Figs. GS-22-1, -7; Table GS-22-2) has significantly higher sodium and chloride contents and somewhat elevated sulphate, which may be attributed to the influence of formational brines known to exist in the region south of the Saskatchewan River between The Pas and Cedar Lake. The main "brine front", interpreted from earlier reconnaissance sampling programs is generally depicted as swinging sharply to the south near Denbeigh Point on Lake Winnipegosis (R. Betcher, pers. comm.). Similar elevated chloride levels were returned from a Manitoba Water Resources drillhole south of Long Point in Twp 46 Rge 12W (R. Betcher, pers. comm.).

Tritium and oxygen isotope analyses from spring water samples collected in 1994 (Table GS-22-3) confirm the relatively young age of the waters, implying rapid transfer from the catchment areas to the resurgences. Sample 04-94-16, the only anomalous result, probably reflects contamination from surface waters.

MARL SAMPLING PROGRAM

In 1994 and 1995 the water sampling program was extended to include sampling of the marls associated with the springs. The expectation was that higher metal contents might occur in these multi-year, paludal precipitates, offsetting the generally low solubility (and detectability) of lead and zinc in the highly alkaline waters of the Interlake region. Samples were scooped from the upper 10-20 cm of mud in the marly fen pools.

At two locations (04-95-36A and 04-95-46; Figs. GS-22-2, 7), cores through the marl beds were obtained using a Russian Corer, to obtain stratigraphic information and to look for changes in chemistry with depth: 1.1 m of marl was obtained from station 04-95-36; 0.50 m at station 04-95-46. Both marl sections bottomed in peat, which will be forwarded for radio-carbon dating. Test auguring at station 04-95-40 intersected 80 cm marl underlain by 30 cm peat and bottomed in blue-grey lacustrine clay.

Analyses (-200 mesh fractions only) from samples collected in 1994 and 1995 show generally high to very high contents of calcium, low magnesium and very low silica, alumina, iron and alkalies (Table GS-22-4). Most samples appear to be relatively pure calcium carbonate, as would be expected for precipitated solutes derived from groundwater interaction with limestone and dolostone in the hinterland. Lead and zinc levels are low to non existent and strontium consistently ranges between 45 and 80 ppm. Somewhat elevated levels of

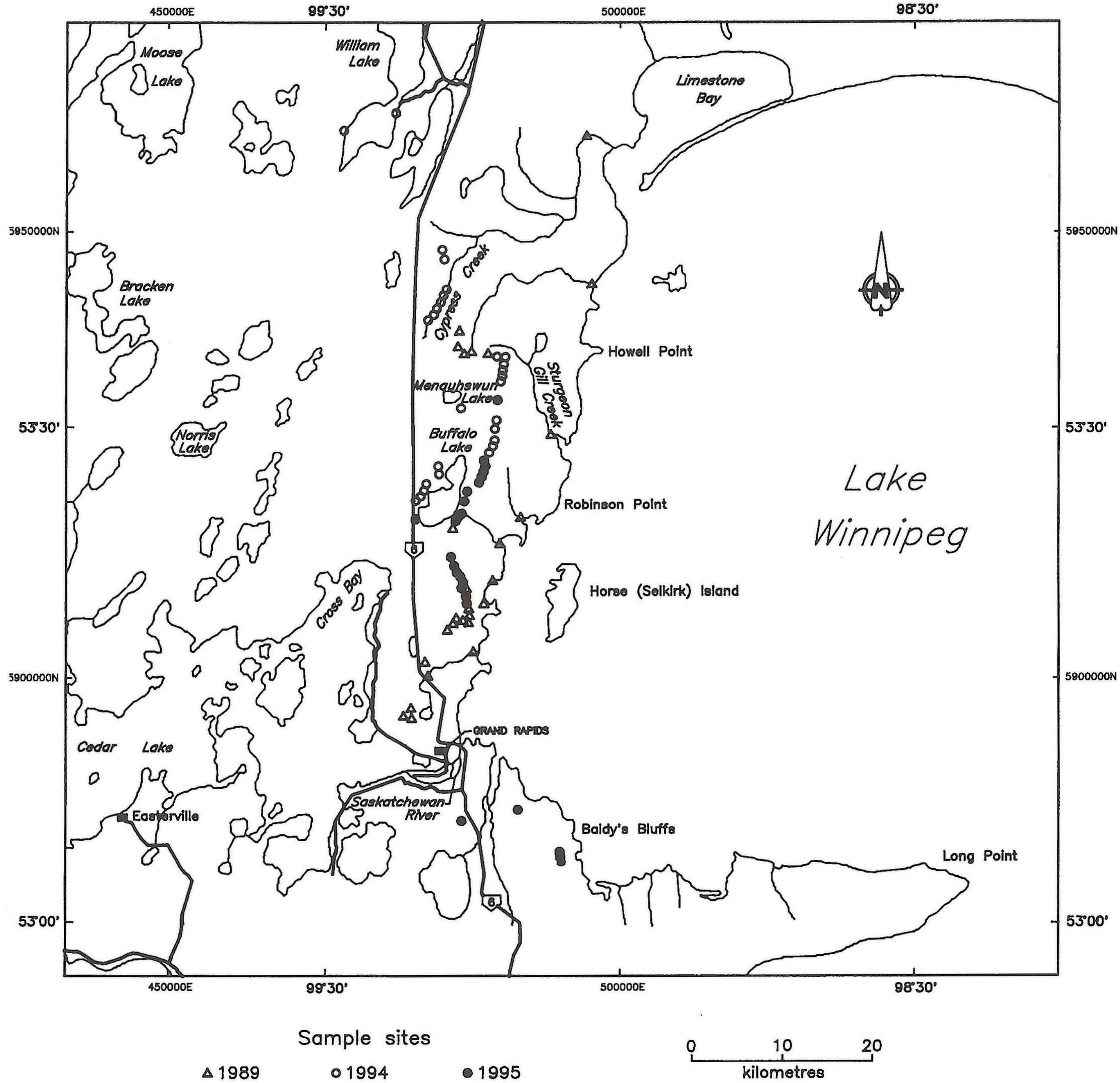

Figure GS-22-1: Spring water and creek sampling program, Cypress Creek to Long Point, Grand Rapids region (1989, 1994 and 1995 sample sites).

barium (400-750 ppm) match those reported from the host Silurian dolostones (unpublished data) in the hinterland to the west.

Marl samples, collected in 1994 from linked chains of fen pools, show systematic variations in chemistry from the resurgent points of the springs, down drainage. Samples 04-24E-94 through 04-24A-94, collected from pools spread over a length of 230 m, show gradual decreases in calcium and magnesium down drainage, as well as increases in silica, alumina, iron, sodium, potassium, and to a lesser extent manganese, phosphorous and titanium (Fig. GS-22-8). Calcium/magnesium ratios stay fairly constant across the zone of precipitation suggesting that there is no to little change in the type of carbonates being deposited. Zinc increases slightly down drainage, whereas strontium and barium remain constant.

A second series of samples (04-13E-94 through 04-13A-94), from pools 2.5 km north of the Sturgeon Gill road, exhibits somewhat similar, yet less systematic trends. Lead and zinc contents are highest at the lower end of the drainage (*i.e.*, sample 04-13A-94). However, values (17 ppm Zn and 19 ppm Pb) are low and of questionable significance.

Calcium/magnesium ratios are fairly constant across the zone of precipitation and are similar to those from stations 04-24E-94 to 04-24A-94. Both sample sets display increases in LOI down drainage, a factor which may reflect increased organic (carbon) contents.

The analyses of the marls from the Grand Rapids region are directly comparable with those from the south part of the Interlake region (Table GS-22-5).

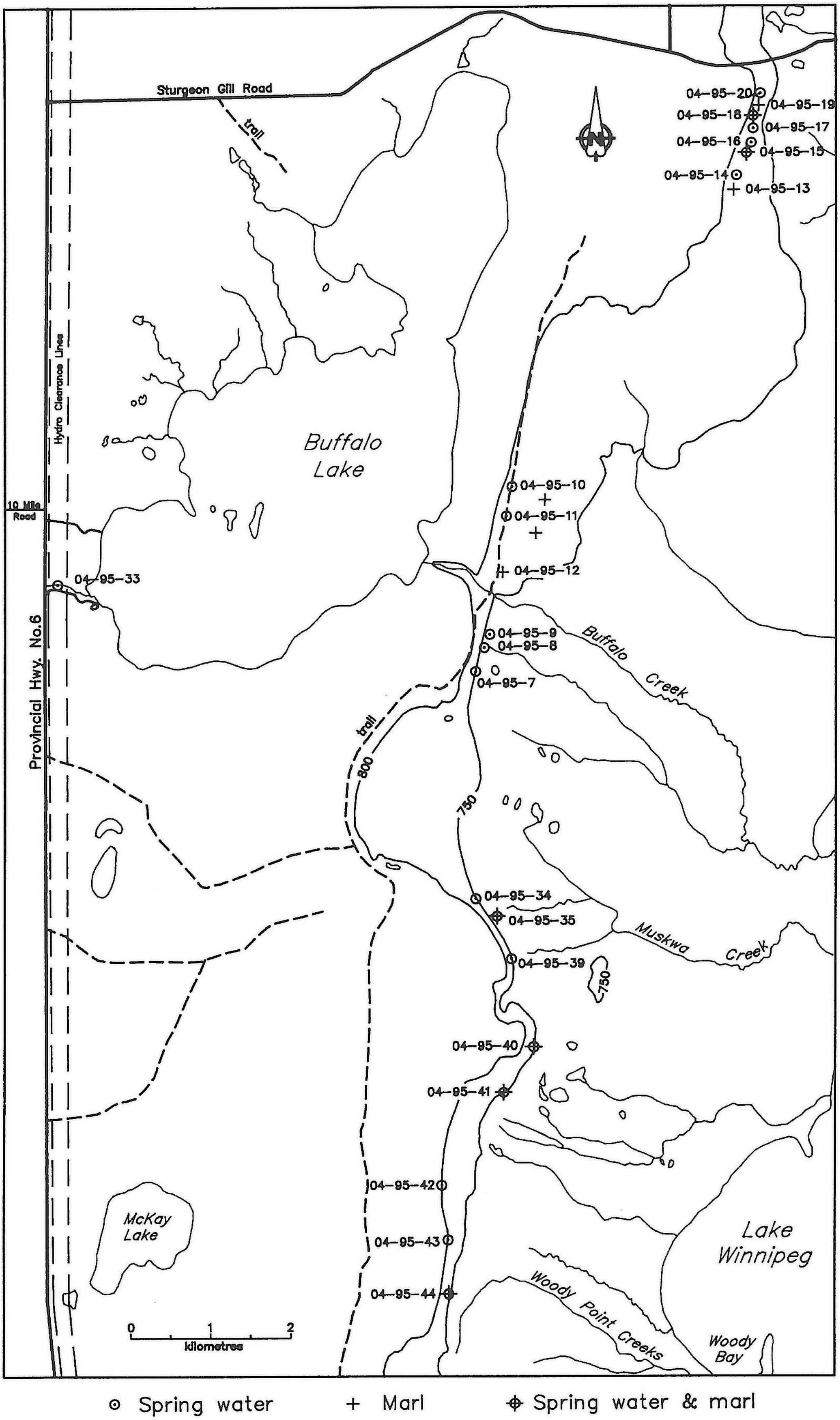

Figure GS-22-2: Spring water and marl sample sites east and south of Buffalo Lake, Grand Rapids region; 1995 sampling program.

Figure GS-22-3: Sporadic tussocks of vegetation in typical marly fen pool, east of Buffalo Lake.

Figure GS-22-4: Narrow runoff channel in surge flats west of Muskwa Creek, Grand Rapids region (Station 04-95-41).

Figure GS-22-5: Cascading brook emerging from steep wooded slopes 10-12 m below bedrock ledge of Fisher Branch Formation containing Virgiana decussata (Station 04-95-39). September 22, 1995.

Table GS-22-1
Chemical analyses of spring waters, Grand Rapids region, 1995 Sampling Program

Sample #	1	2	3	4	5	6	7	8	9	10	11	12	13
04-1-95	285	348	<18.0	<10.2	7.65	0.29	490	<0.05	72	0.17	8.6	18	<0.001
04-7-95	292	356	<18.0	<10.2	7.85	0.16	310	<0.05	0.9	0.42	5.5	<10	<0.001
04-8-95	288	352	<18.0	<10.2	8.03	0.18	310	<0.05	0.9	0.07	5.3	<10	<0.001
04-9A-95	291	355	<18.0	<10.2	7.71	0.21	310	<0.05	0.9	0.10	6.3	<10	<0.001
04-9B-95	287	350	<18.0	<10.2	7.76	0.23	300	<0.05	0.9	0.13	6.4	<10	<0.001
04-10-95	234	286	<18.0	<10.2	7.76	0.15	250	<0.05	0.7	0.14	5.8	<10	<0.001
04-11-95	271	330	<18.0	<10.2	7.87	0.15	280	<0.05	0.9	0.14	7.3	<10	<0.001
04-14-95	241	294	<18.0	<10.2	8.09	0.12	260	<0.05	0.8	0.35	5.7	<10	<0.001
04-15-95	269	328	<18.0	<10.2	8.13	0.12	270	<0.05	0.7	0.16	4.9	<10	<0.001
04-16-95	291	355	<18.0	<10.2	7.88	0.27	310	<0.05	0.8	0.12	5.7	<10	<0.001
04-17-95	276	337	<18.0	<10.2	7.74	0.15	290	<0.05	0.7	0.20	5.1	<10	<0.001
04-18-95	289	353	<18.0	<10.2	7.74	0.26	300	<0.05	0.8	0.19	5.6	<10	<0.001
04-20-95	288	351	<18.0	<10.2	8.10	0.30	300	<0.05	0.8	0.02	6.2	<10	<0.001
04-30W-95	274	335	<18.0	<10.2	7.59	0.18	300	<0.05	4.2	0.43	6.8	<10	<0.001
04-31W-95	266	325	<18.0	<10.2	7.62	0.19	290	<0.05	3.4	0.40	7.0	<10	<0.001
04-32W-95	257	314	<18.0	<10.2	7.94	0.19	290	<0.05	4.1	0.38	7.2	<10	<0.001
04-33W-95	294	359	<18.0	<10.2	7.62	0.18	300	<0.05	1.5	0.24	5.8	<10	<0.001
04-34W-95	290	353	<18.0	<10.2	7.80	0.17	310	<0.05	0.9	0.04	5.6	<10	<0.001
04-35W-95	290	353	<18.0	<10.2	7.56	0.16	300	<0.05	0.8	0.10	5.6	<10	<0.001
04-36-95	234	286	<18.0	<10.2	8.17	0.10	250	<0.05	2.2	0.02	6.4	<10	0.020
04-39-95	302	369	<18.0	<10.2	7.60	0.19	310	<0.05	0.9	0.05	6.4	<10	0.004
04-40-95	298	364	<18.0	<10.2	7.93	0.14	270	<0.05	1.0	0.23	6.6	<10	0.003
04-41-95	295	360	<18.0	<10.2	8.13	0.19	290	<0.05	1.0	0.02	7.0	<10	0.015
04-42-95	293	357	<18.0	<10.2	7.51	0.13	390	<0.05	1.0	0.05	6.4	<10	<0.001
04-43-95	297	362	<18.0	<10.2	7.50	0.17	290	<0.05	1.1	0.03	6.6	<10	<0.001
04-44-95	291	355	<18.0	<10.2	7.67	0.20	300	<0.05	1.6	0.34	6.6	<10	<0.001
04-45-95	265	323	<18.0	<10.2	7.79	0.26	270	<0.05	0.7	0.04	5.8	<10	<0.001

1. Alkalinity - Total ($CaCO_3$) mg/l
2. Alkalinity - Bicarbonate mg/l
3. Alkalinity - Carbonate mg/l
4. Alkalinity - Hydroxide mg/l
5. pH
6. Fluoride mg/l
7. Solids/Residue
8. Boron - soluble mg/l B
9. Chloride - Soluble mg/l
10. Nitrate-Nitrite-N Soluble mg/l N
11. Silica - Soluble Reactive mg/l SiO_2
12. Sulphate - Soluble mg/l SO_4
13. Arsenic - Total mg/l

Table GS-22-1 (cont.)

Sample #	14	15	16	17	18	19	20	21	22	23	24	25
04-1-95	<0.05	61.1	<0.01	0.04	<0.002	39.5	<0.02	<0.005	<5.0	48.8	<0.01	
04-7-95	0.09	59.8	<0.01	0.05	<0.002	40.8	<0.02	<0.005	<5.0	1.74	<0.01	
04-8-95	0.08	54.4	0.01	0.03	<0.002	40.8	<0.02	<0.005	<5.0	1.85	<0.01	
04-9A-95	0.11	56.2	0.01	0.04	<0.002	40.9	<0.02	<0.005	<5.0	1.89	<0.01	
04-9B-95	0.11	54.8	<0.01	0.04	<0.002	39.8	<0.02	<0.005	<5.0	1.76	<0.01	
04-10-95	0.05	44.6	<0.01	0.03	<0.002	33.6	<0.02	<0.005	<5.0	1.80	<0.01	
04-11-95	0.05	51.1	<0.01	0.04	<0.002	37.8	<0.02	<0.005	<5.0	2.69	<0.01	
04-14-95	<0.05	48.4	0.01	0.03	<0.002	33.9	<0.02	<0.005	<5.0	1.40	<0.01	
04-15-95	<0.05	54.2	0.01	0.04	<0.002	37.9	<0.02	<0.005	<5.0	1.65	<0.01	
04-16-95	0.10	55.9	0.01	0.05	<0.002	41.2	<0.02	<0.005	<5.0	1.80	<0.01	
04-17-95	0.06	54.2	<0.01	0.04	<0.002	38.9	<0.02	<0.005	<5.0	1.69	<0.01	
04-18-95	0.09	56.0	0.02	0.04	<0.002	41.8	<0.02	<0.005	<5.0	1.68	0.01	
04-20-95	0.10	52.8	0.01	0.05	<0.002	42.8	<0.02	<0.005	<5.0	1.91	0.02	
04-30W-95	0.042	58.5	<0.01	0.01	<0.0020	32.5	<0.005	<0.005	<1.0	3.76	0.01	<0.020
04-31W-95	0.049	58.0	<0.01	<0.01	<0.0020	31.7	<0.005	<0.005	<1.0	3.23	<0.01	<0.020
04-32W-95	0.052	59.2	<0.01	<0.01	<0.0020	31.9	<0.005	<0.005	<1.0	3.43	0.01	0.040
04-33W-95	0.140	60.6	0.01	<0.01	<0.0020	35.6	<0.005	<0.005	<1.0	1.33	<0.01	<0.020
04-34W-95	0.106	57.3	<0.01	<0.01	<0.0020	37.1	<0.005	<0.005	<1.0	<1.00	<0.01	<0.020
04-35W-95	0.114	57.7	<0.01	<0.01	<0.0020	36.2	<0.005	<0.005	<1.0	<1.00	<0.01	<0.020
04-36-95	0.028	41.7	<0.01	0.09	<0.0020	30.7	<0.005		1.02	1.97	<0.01	0.050
04-39-95	0.141	56.4	0.01	0.03	<0.0020	37.7	<0.005		<1.00	1.10	<0.01	<0.020
04-40-95	0.128	57.9	0.02	0.05	<0.0020	37.1	<0.005		<1.00	1.12	0.01	0.060
04-41-95	0.191	56.0	<0.01	0.06	<0.0020	36.7	<0.005		<1.00	1.29	<0.01	0.020
04-42-95	0.131	56.9	<0.01	0.01	<0.0020	36.2	<0.005		<1.00	1.12	<0.01	<0.020
04-43-95	0.142	58.2	<0.01	0.01	<0.0020	36.0	<0.005		<1.00	1.42	<0.01	<0.020
04-44-95	0.137	55.8	0.01	<0.01	<0.0020	37.3	<0.005		<1.00	2.22	<0.01	<0.020
04-45-95	0.263	49.8	0.01	0.01	<0.0020	33.8	<0.005		<1.00	<1.00	<0.01	<0.020

14. Barium - Extractable mg/l
15. Calcium - Extractable mg/l
16. Copper - Extractable mg/l
17. Iron - Extractable mg/l
18. Lead - Extractable mg/
19. Magnesium - Extractable mg/l
20. Manganese - Extractable mg/l
21. Nickel - Extractable mg/l
22. Potassium - Extractable mg/l
23. Sodium - Extractable mg/l
24. Zinc - Extractable mg/l
25. Ammonia mg/l N[5]

Table GS-22-2
Sample/locality descriptions and *in situ* measurements of pH and T° (C) Spring Water Sampling, Grand Rapids Region 1995

Date	Location	Category	Flow	Base	pH	T° (C)
5/6/95	04-95-1	Rivulet	Moderate	Shingle, large	7.57	6.4
14/6/95	04-95-7	Rivulet	Trickle	Shingle, small	7.91	5.3
	04-95-8	Rivulet	Standing	Precipitate	8.08	8.4
	04-95-9A	Brook	Strong	Shingle, mixed	7.76	5.9
	04-95-9B	Brook	Strong	Shingle, mixed	7.75	5.3
	04-95-10	Brook	Strong	Organic, woody trash	7.89	4.4
	04-95-11	Pool	Trickle	Organic, woody trash	8.25	3.4
15/6/95	04-95-14	Rivulet	Trickle	Organic, precipitate	7.86	8.5
	04-95-15	Rivulet	Trickle	Shingle, small	7.98	8.9
	04-95-16	Brook	Moderate	Precipitate, shingle	7.74	5.6
	04-95-17	Rivulet	Slow	Shingle, small	7.68	5.8
	04-95-18	Brook	Moderate	Precipitate, shingle	7.77	4.9
	04-95-20	Rivulet	Trickle	Shingle, medium	8.14	9.2
22/8/95	04-95-30	Pool/Rivulet	Trickle	Organic, woody trash	7.41	7.8
	04-95-31	Pool/Rivulet	Trickle	Organic, shingle-medium	7.24	12.0
	04-95-32	Pool	Standing	Organic ppt.-mats	8.00	18.7
23/8/95	04-95-33	Brook	Moderate	Organic, woody trash	-	5.2
	04-95-34	Brook	Strong	Shingle large/medium	7.73	8.4
	04-95-35	Brook	Vigorous	Woody trash, ppt.	7.37	5.0
22/9/95	04-95-36B	Creek	Strong	Organic	7.82	7.6
23/9/95	04-95-39	Brook	Vigorous	Organic/mixed shingle	7.41	5.0
	04-95-40	Rivulet	Slow	Shingle, medium	7.71	7.9
	04-95-41	Rivulet	Moderate	Shingle, small	7.70	8.9
	04-95-42	Brook	Strong	Organic/shingle mixed	7.48	4.4
	04-95-43	Brook	Moderate	Organic/shingle mixed	7.36	4.8
	04-95-44	Brook	Moderate	Organic	7.87	6.0
24/9/95	04-95-45	Rivulet	Slow	Organic/shingle mixed	7.64	7.7

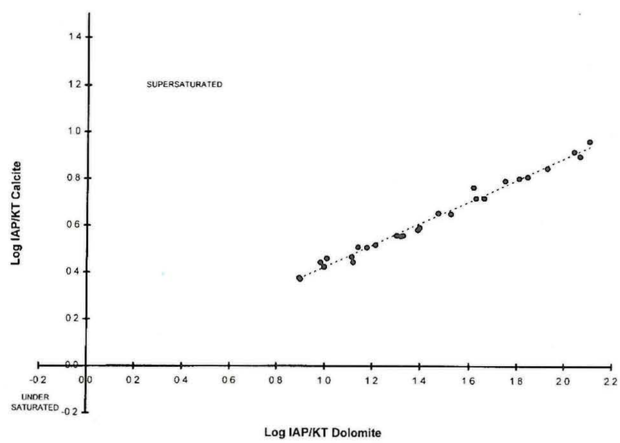

Figure GS-22-6: Calcite and dolomite saturation indices (Log IAP/KT) for spring waters in the Grand Rapids region; 1995 sampling program.

Table GS-22-3
Spring water sampling program, Grand Rapids region, 1994
Tritium (^3H) and oxygen isotope $\delta^{18}O$

Sample No.	^3H	(±8)	$\delta^{18}O$	
BB-SP21	20	20	-16.41	
BB-SP22	34		-16.64	-16.60
04-94-1B	33		-16.32	
04-94-2B	37		-16.38	
04-94-3B	43		-16.34	-16.38
04-94-4B	36		-15.90	-15.91
04-94-5B	31		-16.47	
04-94-7B	32		-15.98	-15.99
04-94-08	30		-16.51	
04-94-11	43	39	-16.62	
04-94-12	52		-16.82	
04-94-13	41	39	-16.45	-16.63
04-94-14	35		-16.65	-16.58
04-94-15	41		-16.70	-16.57
04-94-16	22		-9.67	
04-94-17	37		-16.25	-16.34
04-94-18	28	32	-15.83	-15.88
04-94-19	16		-13.73	-13.82
04-94-20	28		-15.81	
04-94-21	34		-15.95	
04-94-22	38		-16.52	-16.74
04-94-23	43		-16.67	-16.63
04-94-24	37		-15.87	-15.82
04-94-25	34		-16.15	-16.28
04-94-26	49		-16.17	-16.25
04-94-27	23		-16.00	-15.83
04-94-29	21	25	-16.21	-16.16
04-94-30	27		-15.80	
04-94-31	29		-16.15	
04-94-32	30		-16.29	-16.22
04-94-33				

Table GS-22-4
Chemical analyses of marly sediments from fen pools in the Grand Rapids region. 1994 and 1995 sampling programs.

Sample	04-10-94S	04-11-94S	04-13A-94S	04-13B-94S	04-13C-94S	04-13D-94S	04-13E-94S	04-20-94	04-21-94
SiO2	7.00	3.12	2.62	0.97	0.76	1.25	1.60	1.04	2.68
Al2O3	0.33	0.38	0.30	0.13	0.11	0.19	0.28	0.17	0.29
Fe2O3T	0.20	0.19	0.12	0.06	0.09	0.06	0.13	0.08	0.12
CaO	46.84	46.01	40.61	44.53	47.83	45.48	44.36	48.29	47.32
MgO	1.96	2.12	1.30	2.43	2.15	2.09	2.28	2.16	1.98
Na2O	0.09	0.10	0.09	0.09	0.09	0.09	0.09	0.08	0.08
K2O	0.07	0.08	0.07	0.03	0.03	0.05	0.06	0.04	0.06
TiO2	0.02	0.024	0.015	0.007	0.007	0.008	0.015	0.009	0.015
P2O5	0.03	0.03	0.05	0.01	0.00	0.01	0.02	0.01	0.00
MnO	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
S	0.12	0.07	0.03	0.05	0.02	0.04	0.07	0.06	0.01
OTHER	0.07	0.07	0.10	0.10	0.09	0.08	0.08	0.05	0.05
LOI	45.96	46.78	53.39	51.03	48.41	49.05	49.76	47.05	46.16
Zn ppm	28	12	17	10	8	13	19	8	10
Pb ppm	21	12	19	12	-11	17	-11	-11	-11
Sr ppm	65	60	107	83	64	62	66	70	43
Ba ppm	496	553	718	748	706	618	641	407	390
TOTAL	98.450	98.98	98.71	99.45	99.60	98.41	98.76	99.05	98.78

Sample	04-22-94	04-24-94A	04-24-94B	04-24-94C	04-24-94D	04-24-94E	04-25-94	04-27-94	04-28-94
SiO2	1.43	3.22	2.27	1.63	1.13	1.05	1.00	1.17	1.11
Al2O3	0.15	0.28	0.35	0.20	0.18	0.15	0.16	0.20	0.24
Fe2O3T	0.07	0.16	0.18	0.14	0.11	0.10	0.08	0.11	0.17
CaO	46.20	34.74	39.80	43.24	47.02	47.56	48.92	44.43	49.94
MgO	1.96	1.85	1.83	2.15	2.24	2.41	2.27	2.11	1.78
Na2O	0.08	0.13	0.11	0.11	0.09	0.08	0.11	0.10	0.05
K2O	0.04	0.08	0.07	0.05	0.04	0.04	0.04	0.05	0.05
TiO2	0.007	0.015	0.019	0.011	0.011	0.008	0.011	0.012	0.014
P2O5	0.01	0.03	0.04	0.02	0.01	0.00	0.00	0.04	0.02
MnO	0.01	0.03	0.02	0.02	0.01	0.01	0.02	0.02	0.02
S	0.01	0.01	0.01	0.01	0.00	0.00	0.03	0.01	0.01
OTHER	0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.06	0.07
LOI	49.48	58.07	54.52	51.61	48.49	48.03	46.74	51.53	45.63
Zn ppm	8	18	17	15	10	11	14	21	21
Pb ppm	12	19	13	12	13	13	-11	-11	-11
Sr ppm	58	52	58	56	60	58	80	51	81
Ba ppm	432	426	438	484	501	485	521	434	501
TOTAL	99.51	98.68	99.28	99.25	99.40	99.50	99.45	99.84	99.10

NOTE: Negative values denote less than detection limit.
All samples were air dried and sieved through a 200 mesh screen. The -200 particle size was used for the analysis.

Table GS-22-5
Analyses of Interlake Marl by Canada Cement Company

SiO_2%	1.00	0.86	1.26	0.70
R_2O_3%	0.28	0.14	0.26	0.22
CaO%	50.95	50.26	44.44	50.70
MgO%	1.20	1.40	1.48	1.38
LOI%	46.20	47.30	52.58	47.00
TOTAL%	99.63	99.96	100.08	100.00

Sample A: Original samples submitted by G.H. Gunnarson to A.S. Dawson, to Canada Cement, July 5, 1960
Sample 318: 3.0 feet of marl, 300 feet NE of Sample A.
Sample 319: 1.5 feet of peaty marl under Sample 318.
Sample 320: 1.8 feet of marl, half mile west of Sample A.

CONCLUSIONS

Sampling of creeks (N=9), spring waters (N=78) and associated marls (N=43) in the Grand Rapids region has not detected any anomalous lead and/or zinc concentrations in the 80 km long, north-trending, resurgence and precipitation zone from Cypress Creek south to Long Point. Consequently, this program has been unable to find any indications of MVT mineralization in the bedrock carbonates west of the Silurian escarpment. (Some water and marl analyses were not completed at the time of writing.)

Marl samples collected from sequential fen pools in two discrete chains show minor though systematic variations in the concentration of several elements from the points of resurgence to the foot of each of the chains. The extent of these variations is limited and should not affect future sampling programs elsewhere along extensions of the escarpment.

Protrusion of formational brines into the region between Long Point and Grand Rapids, if verified, could impede mineral exploration of this area if the exploration were dependent on electromagnetic geophysical survey techniques (McRitchie, 1995).

ADDENDUM

The rationale for undertaking this program was based on the expectation that the chemistry of the spring waters and marls would reflect to a large degree the chemistry of the carbonate host rocks in the hinterland through which the waters had flowed (*i.e.*,, between the catchment areas and the resurgent points). Though this has been borne out to a large extent by the analyses of the dolostones and spring waters and marls in the zone of precipitation, several lines of evidence suggest the volume of dolostones scavenged by the meteoric waters is relatively limited.

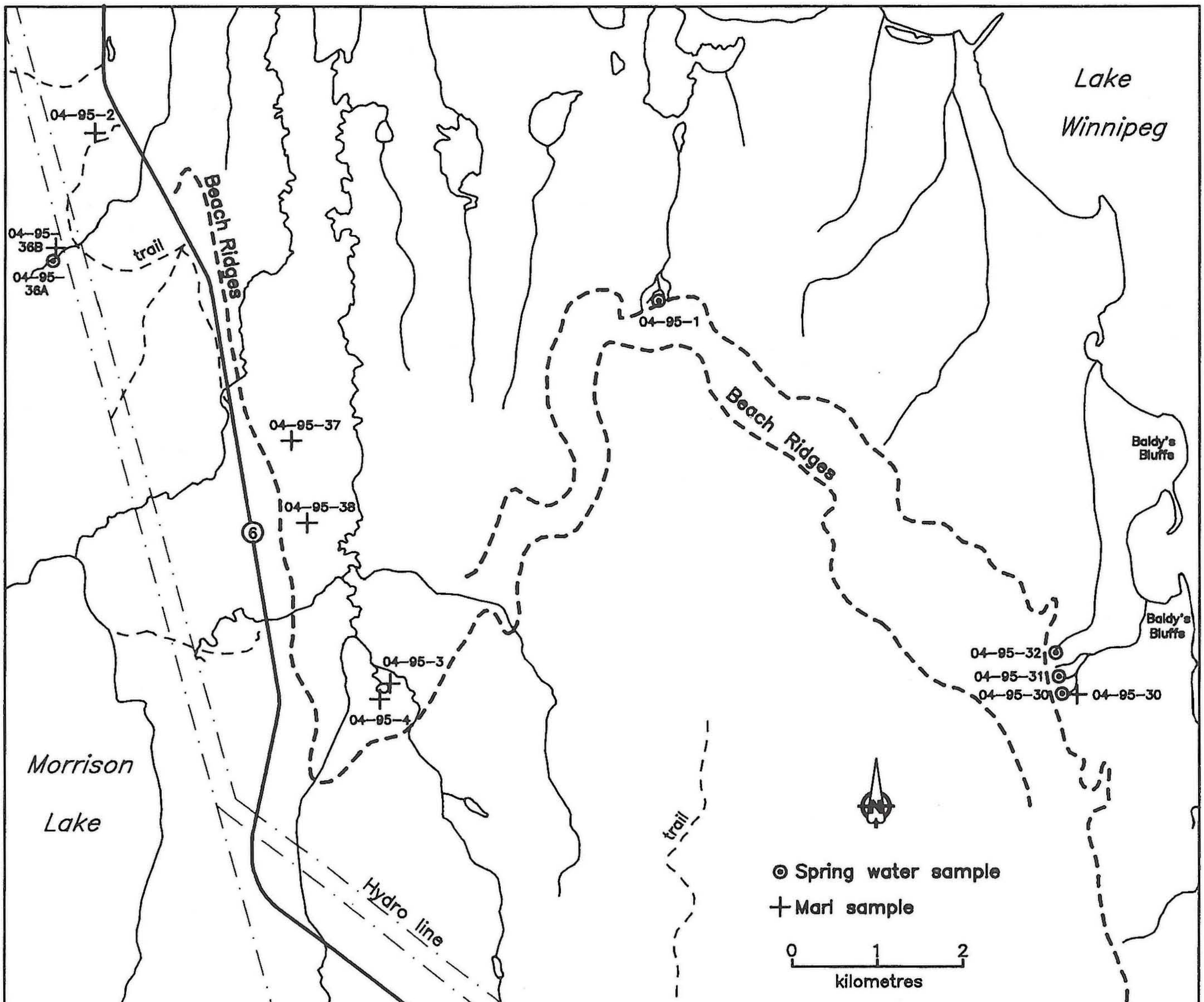

Figure GS-22-7: Spring water and marl sample locations near Baldy's Bluffs, south of Grand Rapids, 1995.

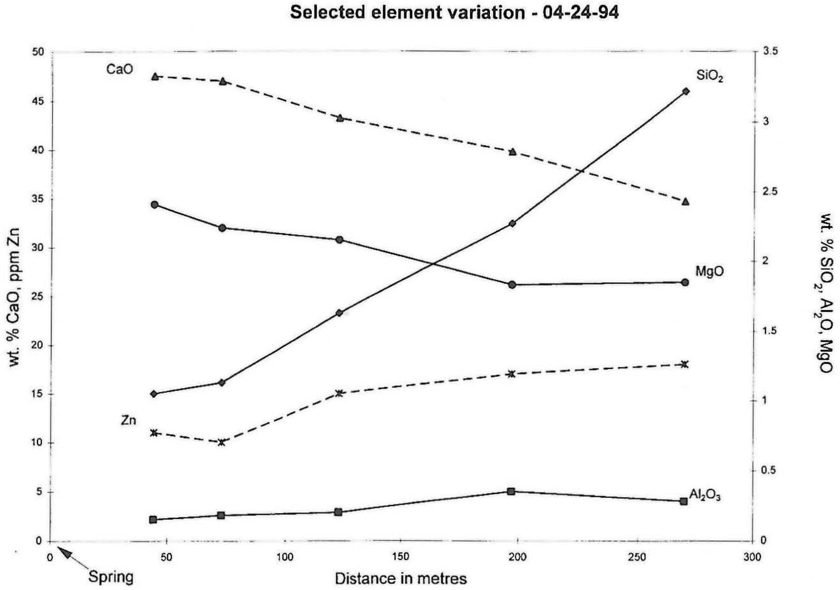

Figure GS-22-8: Systematic trends in CaO, MgO, SiO_2, Zn and Al_2O_3 contents of marls from chain of marly fen pools at stations 04-24E-94 through 04-24A-94; NE of Menauhswun Lake, Grand Rapids region.

Firstly, the topographic relief in the Interlake region is subdued, with maximum elevation difference being less than 100 metres (*i.e.* between Lake Winnipeg - 216 m A.S.L., and the highest land - 290 m A.S.L.). Borehole measurements (McRitchie, 1994) indicate a 10-20 m thick vadose zone of infiltration where interaction of rainwater with bedrock is largely limited to discrete, spaced fractures. Most of the springs emerge at elevations close to 235 m, further reducing the thickness of carbonate rocks through which the ground water is likely to have travelled and interacted with the host dolostones.

Secondly, precipitation in this region is limited to less than 500 mm per year resulting in a generally low level of groundwater recharge. High tritium levels are interpreted to reflect a relatively youthful age (post-1952) for most, if not all, of the waters sampled at the resurgent zones, with little evidence of contributions from deeper formational waters.

Finally, borehole temperature measurements by Gosnold (GS-23, this volume) to a large degree exhibit unbroken temperature gradients below depths of 90 m, suggesting little active circulation of the groundwater below this level and again, little interaction between the deeper formational waters and the zone of active transfer.

All of the above support the existence of a relatively shallow (subcutaneous) groundwater circulation pattern between the recharge areas and resurgent zones. Consequently, the chemistry of the waters and marls sampled at the resurgent points and in the zone of precipitation is likely to represent only a small fraction of the 200 m thick dolostone sequence in the hinterland. Thus, more than 75% of the host rocks may lie beneath the zone of active solute transfer, leaving their potential to contain MVT deposits untested.

ACKNOWLEDGEMENTS

David Wright, Doug Berk, Gaywood Matile and Ruth Bezys are thanked for providing assistance in collecting the spring water and marl samples and for taking associated measurements at the resurgent points. R. Betcher, Water Resources Branch, provided advice on the interpretation of the water analyses and assisted in recalculating the results using WATEQF.

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GS-23 HEAT FLOW, GROUND WATER FLOW AND RECENT CLIMATE CHANGE INFERRED FROM BOREHOLE TEMPERATURE PROFILES, GRAND RAPIDS, MANITOBA (NTS 63G)

by W.D. Gosnold[1]

Gosnold, W.D., 1995: Heat flow, ground water flow and recent climate change inferred from borehole tempertaure profiles, Grand Rapids, Manitoba (NTS 63G); in Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 120-123.

SUMMARY

Analysis of temperature-depth profiles from eight boreholes drilled for stratigraphic studies near Grand Rapids, Manitoba provided information on terrestrial heat flow, fluid flow in the boreholes, climate change in the past century and suggested a possible answer to a puzzling T-z profile in Finland. T-z profiles in five of the boreholes showed temperature disturbances caused by water flowing down, or sometimes up, the boreholes. The nature of the temperature disturbance shows the direction of flow and may be analyzed to estimate the volume and period of flow down the hole. Least-square temperature gradients calculated for boreholes M-4-95, M-5-95, M-6-95 and the carbonate section of M-4-94 average 8.0± 0.47 mK m^{-2}. Assuming a thermal conductivity of 4.0 W $m^{-1}K^{-1}$ for the dolomitic carbonate gives an estimated heat flow density of 33 mW m^{-2}. A heat flow density of 33 mW m^{-2} was also calculated for the granitic section of M-4-94. One borehole, M-4-95, was essentially free of water flow and the T-z profile provided an estimate of a +1.4 K ground surface temperature over the past century. Inclusion of this data point in a study in progress at the University of North Dakota provided valuable insight into the problem of ground-air coupling. Analysis of the T-z profiles in boreholes M-1-95 and M-2-89 suggests the possibility that a nearby wedge of buried permafrost may act as a heat sink and control the subsurface temperature. This T-z profile is similar to two profiles from northern Finland and suggests a mutual explanation for them.

INTRODUCTION

The University of North Dakota is conducting research on climate change in North America using temperature gradient measurements from boreholes to estimate the ground surface temperature history. The project involves precise temperature measurements at 1 m intervals in suitable boreholes in the continental interior in addition to drilling special heat flow holes at sites in Manitoba, South Dakota and Texas. Through discussions with Ruth Bezys and Jim Bamburak at Manitoba Energy and Mines, UND was offered an opportunity to make T-z measurements in a number of stratigraphic coreholes near Grand Rapids, Manitoba. This brief report presents several unexpected results that evolved from what was originally perceived to be routine heat flow research. First, the nature of this research on climate change is described to establish the reasons for logging the boreholes. Interpretations of the results and applications to four different areas of geological research are presented.

CLIMATE CHANGE FROM BOREHOLE TEMPERATURES

Borehole temperature data from North America have been analyzed in many recent studies to assess climatic warming during the past several centuries (Lachenbruch and Marshall, 1986; Wang *et al.*, 1992; Shen and Beck, 1992; Beltrami *et al.*, 1992; Chisholm and Chapman, 1992; Shen *et al.*, 1995). The basis for these studies is that the ground retains changes in surface temperature as thermal signals diffuse downward by conduction and cause transient disturbances in the geothermal gradient (Lachenbruch and Marshall, 1986). The ground surface temperature varies regularly on diurnal, seasonal and annual scales and irregularly in response to weather systems, interannual climate variability and long-term climate change. Each variation becomes negligible over a vertical depth proportional to the period of variation and to the thermal diffusivity of the bedrock. The thermal diffusivity of most continental rocks is such that diurnal signals disappear below a few centimetres, annual signals disappear below about 20 to 30 m, but century-scale disturbances are detectable over lengths of hundreds of metres. Thus, assuming a direct correlation between air temperature and ground temperature, the data acquired in heat flow research may contain considerable information on climate change during the past few centuries.

A common approach to measuring climate change in this type of research is to use a least-squares inversion of the temperature-depth (T-z) profile to calculate a ground surface temperature (GST) history at the borehole site (Wang *et al.*, 1992; Shen and Beck, 1992, Beltrami *et al.*, 1992; Chisholm and Chapman, 1992; Shen *et al.*, 1995). The result of the least-squares inversion is typically reported as warming above the long-term temperature mean; *i.e.*, warming above the GST that would be seen by the borehole in a steady-state condition where no climate change has occurred. An alternate approach is to use a forward model that provides a best fit to the observed T-z profile assuming a ramp or step increase in GST from a steady-state condition (Lachenbruch and Marshall, 1986). The results of these two methods are comparable and show that ground surface warming in North America has been about 0.3 K to 4.0 K, depending on the locality, during the past 100-150 years.

These results have significant implications for our understanding of global climate change in that they show an unambiguous, century-long warming trend. However, questions remain about the precision and nature of the borehole record. Does the warming calculated from borehole data match the warming observed in the air temperature record on local, regional and continental scales? Do changes in ground-surface temperatures correspond 1:1 with changes in air temperatures? How large is the geographic area represented by a single borehole?

GST histories and surface-air-temperature records are being compared along a 2000 km north-south transect in the midcontinent of North America and air-ground coupling are being examined at many localities along the transect. Simulations of global climate change based on increased greenhouse gas concentrations predict that warming should increase with latitude along the transect. Thus, this project offers the possibility to test one of the critical questions about global warming.

In addition to heat flow holes drilled in South Dakota and Texas, T-z profiles have been measured from 28 boreholes drilled specifically for heat flow research in the Great Plains between 1979 and 1990 (Gosnold, 1990). Criteria that determine the suitability of a borehole for climate research include the following: absence of microclimatic disturbances due to surface topography, no land-use changes, no potential for vertical ground water flow, and no terrain effect on the geothermal gradient. Although the boreholes near Grand Rapids are in karst regions, they satisfy all other criteria and offer the possibility of extending the transect northward by 500 km.

WATER FLOW IN THE BOREHOLES

The temperature gradient in a conductive earth is a straight line with a surface temperature intercept at the annual mean ground surface temperature. A conductive gradient is determined by Fourier's law of heat conduction (Equation 1), and changes only with thermal conductivity in a single borehole or with the presence of nearby heat sources or sinks.

1) $$Q=(dT/dx)K$$

Water has a heat capacity several times greater than that of rocks. Thus, water moving in a permeable zone can carry large quantities of heat from one point to another. Applying the second law of thermodynamics, *i.e.*, heat flows from a hot body to a cold body, qualitative interpretation of the direction of water flow can be achieved by inspection of a T-z profile. Water moving up a borehole will carry heat

[1] Department of Geology and Geological Engineering, University of North Dakota

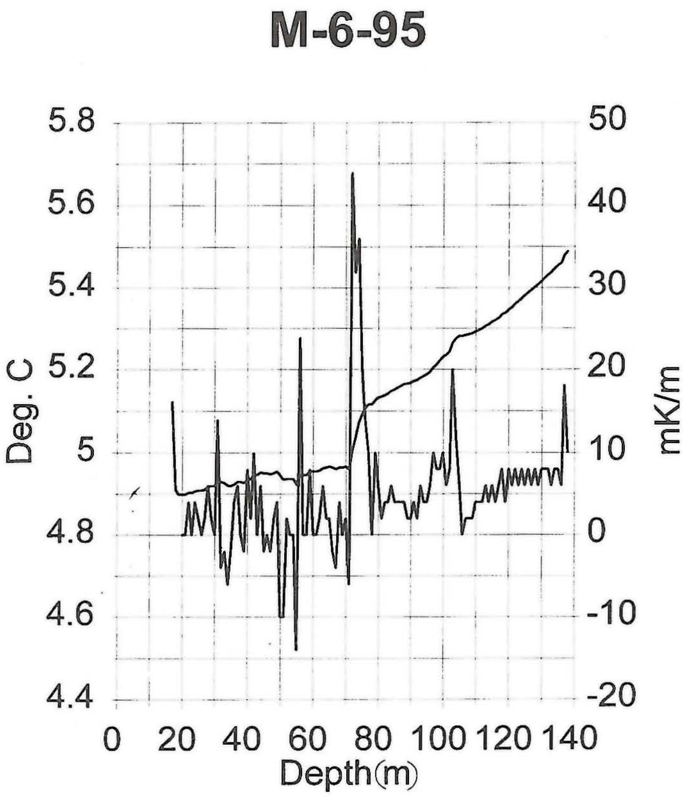

Figure GS-23-1: Temperature and gradient profile of borehole M-6-95.

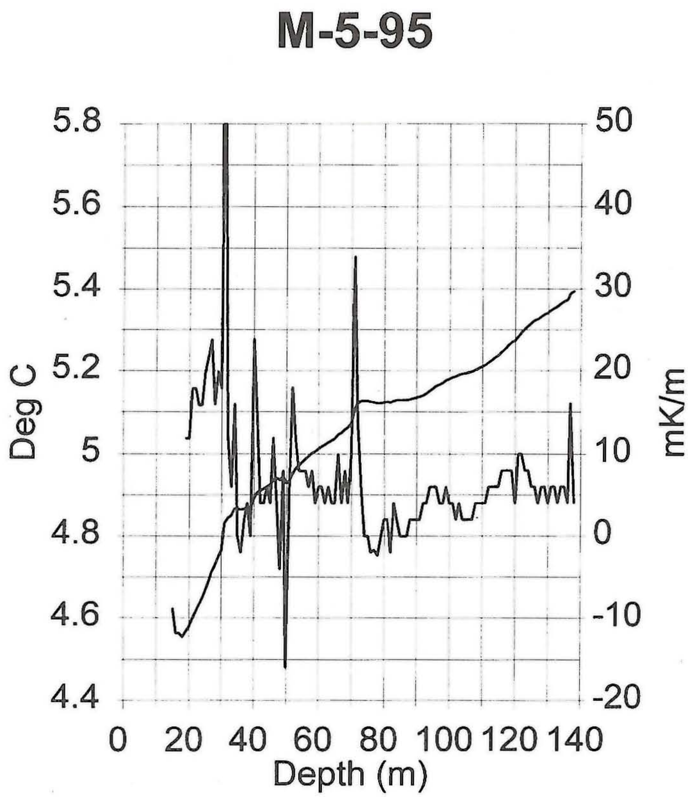

Figure GS-23-2: Temperature and gradient profile of borehole M-5-95.

and cause temperatures to rise above the straight line. Water moving down the borehole causes temperatures to fall below a straight line. These concepts are applied in the following discussion to develop hypotheses on the nature of transient thermal disturbances observed in the Grand Rapids T-z profiles.

T-z profiles in five of the boreholes at Grand Rapids deviate from ideal conductive gradients in patterns that are commonly associated with water flowing down, or sometimes up, the boreholes. We discuss two of these profiles in this report. T-z profiles in boreholes M-6-95 and M-5-95 show abrupt changes in temperature gradient that may be caused by ground water flow (Fig. GS-23-1, -2) (see Fig. GS-21-4, this volume, for borehole locations). The low temperature gradient between 20 m and 71 m in borehole M-6-95 is most likely due to surface water flowing down the borehole to a depth of 71 m. The T-z plot of the upper 71 m of this borehole is highly erratic and displays negative temperature gradients in eight different zones (Fig. GS-23-1). One plausible explanation for the negative gradient zones is that cold water from a higher level has moved downward through nearby fractures and is flowing into the borehole at the negative gradient zone. This is a transient condition caused by drilling and will eventually disappear as hydraulic pressures stabilize. The small kink in the T-z profile between 102 and 110 m could be caused by two different possible conditions. Water flowing up the hole from 110 m to about 103 m could account for the profile. Alternatively, the profile could be caused by changes in stratigraphy where thermal conductivity changes abruptly. If this alternative is correct, then a layer of low conductivity material, *i.e.*, shale, lies between 102 and 103 m on top of a highly dolomitic layer between 104 and 110 m. Dolomite has a higher thermal conductivity than calcite. Thus, gradient changes not caused by water flow may be caused by variability in the degree of dolomitization.

The T-z profile of borehole M-5-95 displays characteristics similar to, but more subtle than, those in the profile of borehole M-6-95 (Fig. GS-23-2). A possible interpretation is that downward flow to 71 m has ceased and the borehole temperatures have begun to recover. It also appears that the zone between 102 and 110 m has nearly recovered from the flow disturbance. As pressures equilibrate and flows cease, the kink at 102 m in the profile of borehole M-6-95 should evolve to a low amplitude bulge like that between about 92 and 110 m in the profile of borehole M-5-95 (Fig. GS-23-2).

Two-dimensional advective heat flow models of these systems may test the above hypothesis. Temperature measurements taken over a period of several months or years, depending on the rate of thermal recovery, would provide constraints on possible water movement and would permit quantitative estimates of the volume and rate of flow that has occurred.

HEAT FLOW

The erratic gradients exhibited in the T-z profiles diminish the reliability of the data for calculation of heat flow. However, the general agreement in temperature gradients in the lower 40 m of four of the boreholes (Fig. GS-23-3) suggests that an average temperature gradient can be calculated. Also, a temperature gradient in the Precambrian granite in borehole M-4-94 was obtained with no indication of ground water disturbance in that section of the borehole. Thermal conductivity has not been measured on any of the rock samples. Thus, conductivity values of 4.0 W $m^{-1}K^{-1}$ for the dolomitic carbonates and 3.0 W $m^{-1}K^{-1}$ for the granite are assumed. Least-square temperature gradients calculated for the lower, and apparently undisturbed, sections of boreholes M-4-95, M-5-95, M-6-95 and the carbonate section of M-4-94 average 8.3 ± 0.47 mK m^{-2}. Applying these values to Equation 1 gives an estimated heat flow density of 33.8 mW m^{-2}. The least-squares gradient in the granite section of M-4-94 is 11.0 mK m^{-2} and gives an estimated heat flow density of 33 mW m^{-2}. This value is low for the Precambrian Superior Province, but it is reasonable.

RESULTS OF CLIMATE CHANGE ANALYSIS

Analysis of century-long warming trends in the Northern Plains by linear regression of air temperature data and inversion of borehole temperatures gives average values of +1.1 K for air temperatures and +1.4 K for borehole temperatures. The amount of warming in both data sets increases with latitude, but the increase is greater for the borehole data (Fig. GS-23-4). Warming amounts determined for the two data sets generally agree south of 42° N, but disagree for points to the north. To investigate the reason for this disagreement, decade-long time series for daily mean air and soil temperatures were analyzed. The two temperatures correspond well when the average daily air temperature is above freezing but not when it is below freezing. The departure between air and soil temperatures varies erratically from year to year in winter, but it consistently begins when the average daily air temperature falls below freezing. This departure point does not necessarily correspond with the onset of seasonal snow cover, but it does correspond with the initiation of freezing. The latent heat released during freezing of a moist soil layer holds the ground temperature near the freezing point. This causes the average annual GST to be warmer than the average annual air temperature. An increase in fall precipitation in the Northern Plains during the past 30 years has increased soil moisture at the time of ground freezing and has caused a secular increase in the average GST. This is significant since only 15 of the 362 borehole sites in North America analyzed for GST histories lie in regions that do not experience seasonal ground freezing.

However, this potential problem may not apply to all borehole sites. Forward modeling and inversion of borehole M-4-94 near Grand Rapids, Manitoba shows that ground warming has been approximately 1.4 K over the past century. This point falls three degrees below the trend predicted from boreholes drilled in the Pierre Shale in the Northern Plains. The critical difference at the site of borehole M-4-94 is that glacial scouring removed the soil cover so the ground cannot become saturated and insulate the subsurface from extreme temperatures. Consequently, the GST history obtained from boreholes in exposed impermeable bedrock may depict an accurate record of temperature change, but the GST history obtained from boreholes drilled in thick soils or porous bedrock may be "contaminated" by secular variations in precipitation.

POSSIBLE PRESENCE OF PERMAFROST

The near-surface temperature gradient in a conductive earth model is a straight line with a surface temperature intercept at the annual mean ground surface temperature. The T-z profiles in the Grand Rapids area suggest that the ground surface temperature is between 4.9° and 5.2°C. Subsurface temperatures below this value would be residual effects from cold air temperatures in the winter and would be confined to the upper 20 metres. T-z profiles from coreholes M-1-95 and M-2-89 show nearly isothermal conditions between 40 and 120 m at a temperature of approximately 4.6°C (Fig. GS-23-3). Isothermal conditions can result from cold surface water flowing down the hole, but not here: the temperature of the surface water is approximately 0.3 K warmer than the isothermal regions in both boreholes. If water flowed down the holes at a velocity sufficient to establish isothermal conditions, it would be thermodynamically impossible for the subsurface temperature to be cooler than the surface temperature. The fact that cooler conditions exist in the subsurface suggests the presence of heat sinks near the boreholes. These heat sinks may be wedges of buried discontinuous permafrost. Preliminary results of two-dimensional heat conduction models suggest that the top of the permafrost lies at a depth of about 40 m and the base is about 100 m. Additional models will be tested to estimate the distances from the boreholes to the permafrost wedges.

INTERDISCIPLINARY RESEARCH

The initial objective of this research was to extend northward the database of borehole temperature profiles available for climate reconstruction. The first two temperature profiles measured in 1993 were isothermal, a condition that indicated that downward ground water flow overwhelmed all other thermal signals. These initial findings suggested that data useful for climate reconstructions could not be obtained from the karst terrain that characterizes the Interlake region. Later, results from a project in South Dakota that relate anomalous heat flow to ground water flow (Gosnold, 1995) suggested that additional temperature measurements in the Interlake boreholes could provide useful data on the nature of regional ground water flow. Subsequent discussions with geologists at Manitoba Energy and Mines led to this year's field activities.

The progression in analysis of simple T-z measurements to provide insight into ground water flow, climate change, terrestrial heat flow, and the inference of subsurface permafrost was unanticipated. Considering that these holes were originally drilled for stratigraphic investigations, the additional results obtained in this study offer strong support for broadly based interdisciplinary research.

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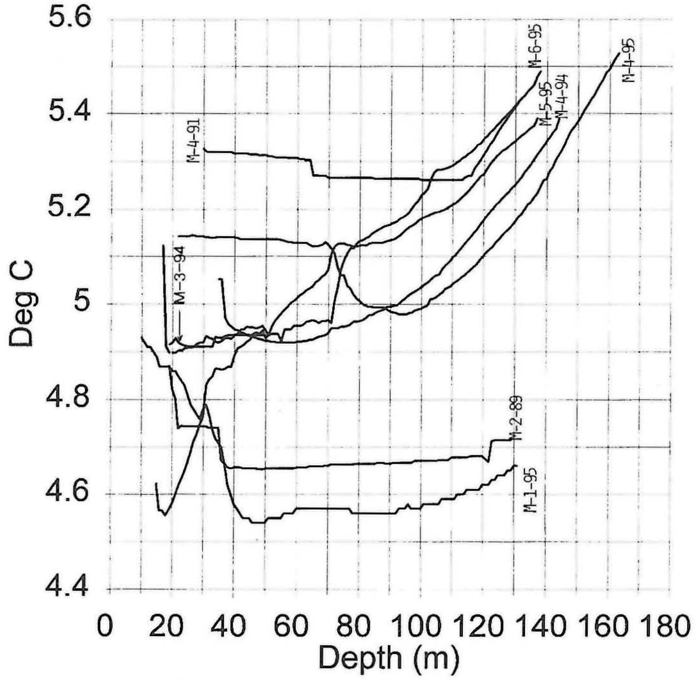

Figure GS-23-3: Composite T-z profiles from the Grand Rapids boreholes.

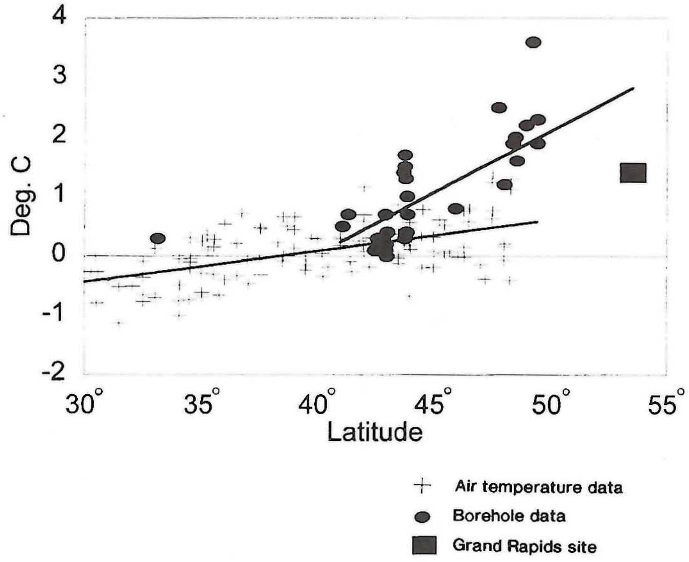

Figure GS-23-4: Latitudinal variation in climate change determined from borehole temperatures.

GS-24 A HIGH-RESOLUTION GRAVITY SURVEY OF THE LAKE ST. MARTIN IMPACT STRUCTURE

by C. Davids[1] and W. Gosnold[1]

Davids, C. and Gosnold, W., 1995: High-resolution gravity survey of the Lake St. Martin impact structure; **in** Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 124-127.

INTRODUCTION

The Lake St. Martin impact structure is a poorly exposed meteorite impact crater located within Manitoba's Interlake region at 51°46' 98°32'W (Fig. GS-24-1). The crater is estimated to be 23 km in diameter and the surrounding country rock is structurally disrupted over a diameter of 45 km (McCabe and Bannatyne, 1970). The structure lies within Silurian and Ordovician sedimentary rocks that overlie Precambrian granite. Apatite fission-track dates (Kohn, *et al.*, 1995) and Rb/Sr isotope age dates (Reimold *et al.*, 1990) place the impact in Late Triassic-Early Jurassic time.

This report gives preliminary results of the first stage of a high-resolution gravity survey of the Lake St. Martin impact structure. The intent of the study is to determine accurately the diameter and depth of the crater and to determine the nature of any associated structures such as the central peak, terraces and concentric fractures. Survey plans include data collection along roads in the area as well as radial traverses that cross the central peak and extend several kilometres beyond the outer limit of structural disturbance. The study area is predominantly covered with swamps and lakes, thus data acquisition during the summer of 1995 was confined to roads. Off-road, radial traverses are planned for the winter months when the surrounding swamps and lakes are frozen.

The products of the project will include a residual Bouguer gravity anomaly map of the area and interpreted structural cross sections of the impact site. The cross sections will be developed using 2-D and 3-D density models of the subsurface. The results of the study may provide a better understanding of the impact structure and may lead to hypotheses on the nature of the impact, *i.e.*, the size of the impact body, its velocity and angle of impact.

GEOLOGIC SETTING

The geology and the structural setting of the crater have been described in detail (McCabe and Bannatyne, 1970) and are briefly summarized below. The impact structure is located within Silurian and Ordovician sedimentary rocks which unconformably overlie Precambrian gneiss and granite. The crater is approximately 23 km in diameter and greater than 300 metres deep. It is filled by approximately 200 m of trachyandesites and Paleozoic carbonate breccias that are overlain by approximately 82 m of an undisturbed sequence of coarse clastic red beds and evaporites. The upper section of the crater is filled with glacial drift. The trachyandesites and carbonate breccias constitute the St. Martin Series (McCabe and Bannatyne, 1970) and the undisturbed upper strata were tentatively assigned to the Jurassic Amaranth Formation (McCabe and Bannatyne, 1970). Initial post-crater erosion was estimated to have lasted for up to 70 m.y. prior to burial by Jurassic sediments (McCabe and Bannatyne, 1970). Subsequent erosional events probably occurred in late Jurassic, late Cretaceous-early Tertiary, and Pleistocene times (McCabe and Bannatyne, 1970). Glaciation both eroded the surface and deposited up to 30 m of drift in southern areas of the crater.

Basement outcrops on the eastern rim are uplifted more than 150 m above the present basement, whereas borehole data on the eastern rim show uplift of only about 61 m (McCabe and Bannatyne, 1970). A central peak of shock-metamorphosed altered granitic gneiss outcrops in two areas within the central portion of the crater and shows an uplift of about 150 m. Post-erosional depth of the crater estimated from the elevation difference between the uplifted granitic rim and the base of the breccia beds is approximately 320 m.

PRELIMINARY RESULTS

Gravity data were collected using a LaCoste and Romberg Model G gravity meter (G744). Four hundred thirty-six stations were occupied during two months of field work in the summer of 1995 (Fig. GS-24-2). Station locations and elevations were determined using 1:50 000 scale topographic maps. The contour interval on the maps are 10 m and elevations are marked at each section line intersection along the roads. Normally, elevation estimates based on map contour lines would be constrained by the contour interval of the map. However, the terrain in the survey area is essentially flat and elevations marked at each section line intersection rarely vary by more than 1 m. Thus, the accuracy of elevation estimates based on map inspection in the field is considered to be at least ±1 m. Assuming a density of 2670 kg m^{-3} for the Bouguer correction gives an error estimate resulting from the elevation measurements of ±0.2 mgal. Four hundred thirty-six gravity stations were occupied twice and at least three gravity readings were obtained at every station. Twenty-nine stations with repeat readings differing by more than 1.0 mgal were rejected. The precision of the repeat readings at the 407 remaining stations was estimated to be ±0.21 mgal. The LaCoste and Romberg gravity meter has an accuracy of 0.1 mgal, thus the accuracy of the gravity readings is estimated to be ±0.5 mgal.

Bouguer gravity anomaly values were calculated using GRS67 and a density of 2670 kg m^{-3}. The data were tied to regional data base by matching co-located sites from this study with the Gravity Anomaly Data Base obtained from the Geophysical Data Centre, Ottawa. The data are presented in three profiles and a residual Bouguer gravity anomaly contour map. However, all of the Bouguer gravity anomaly values shown in the map and profiles are relative to the mean value for the region. Thus a Bouguer gravity anomaly of -2.5 mgal at a particular site, for example, should not be compared to data from published maps of the area. The data from this study will be transformed to match the Gravity Anomaly Data Base after all data have been collected and analyzed.

The profiles shown in Figures GS-24-3, GS-24-4 and GS-24-5 do not have the regional gravity field removed. A first-order regional field was removed from the map (Fig. GS-24-6). Prior to inclusion of the regional gravity anomaly data from Ottawa, an earlier version of the residual contour map produced from the data collected in this study showed a circular gravity low with a circular central gravity anomaly high centred on the impact. Interestingly, inclusion of the regional data from Ottawa shows an even larger gravity low east-southeast of the centre of the impact. Inspection of the data shows that only three points generate this gravity low. Consequently, future field studies will be planned to adequately sample this region.

The east-west anomaly profile (Fig. GS-24-3) was taken along a road located 3 km south of the central peak. The length of the central peak anomaly shown in the profile is approximately 6.8 km and represents only a segment of the entire peak. Assuming the central peak is circular, the diameter of the central peak anomaly is estimated to be approximately 9.0 km.

The east-west anomaly profile (Fig. GS-24-3) and the north-south anomaly profile A-A' (Fig. GS-24-4) both show a sharp change in gravity at the approximate location of the crater rim. The data also show an abrupt, but smaller, change in gravity at the outer limit of structural disturbance.

Preliminary analysis of the gravity data suggests that the structure may be slightly larger than previously thought. Future data collection will test this hypothesis as well as provide data essential for 2-D and 3-D modelling of the subsurface.

ACKNOWLEDGMENTS

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[1] Department of Geology and Geological Engineering, University of North Dakota

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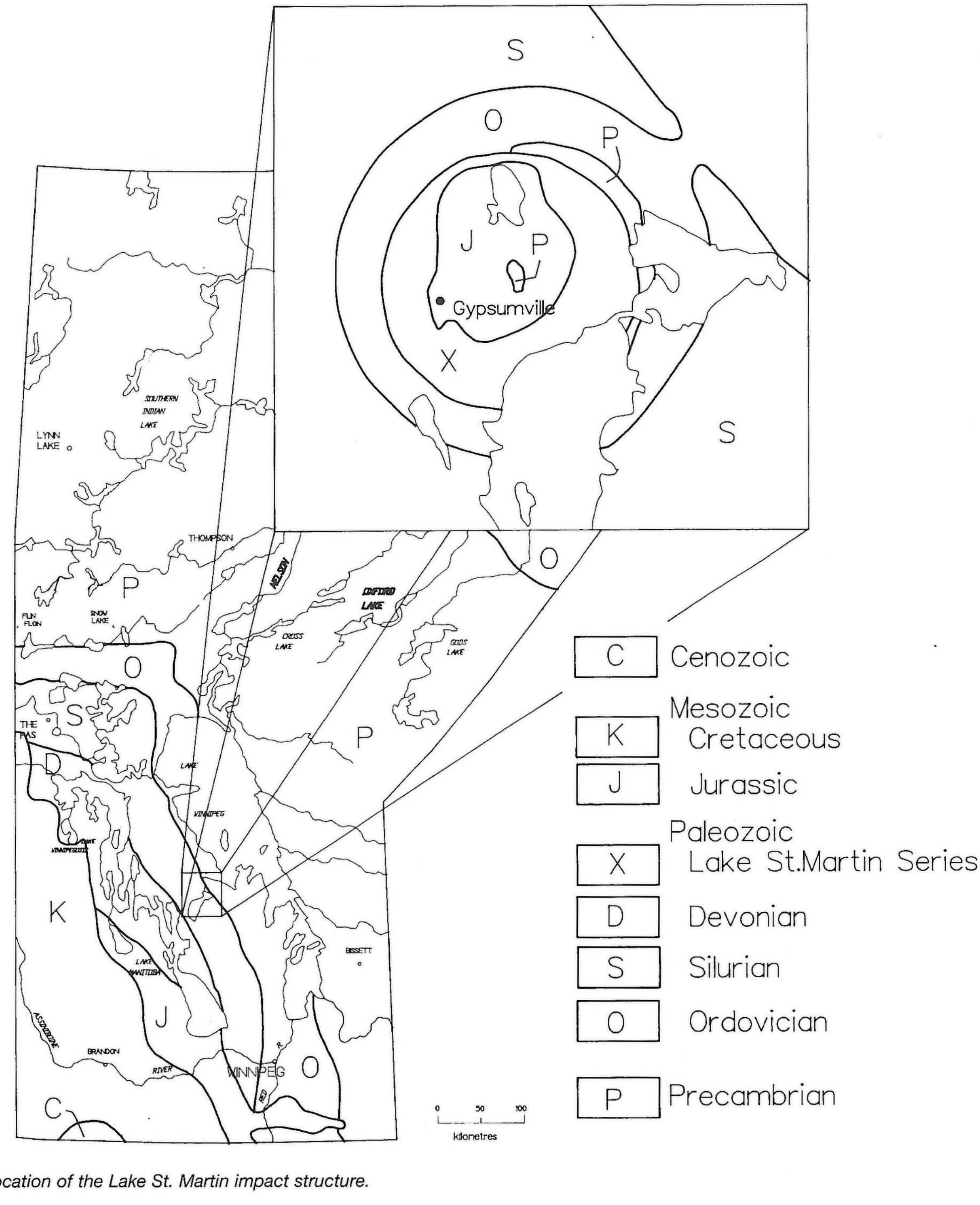

Figure GS-24-1: Location of the Lake St. Martin impact structure.

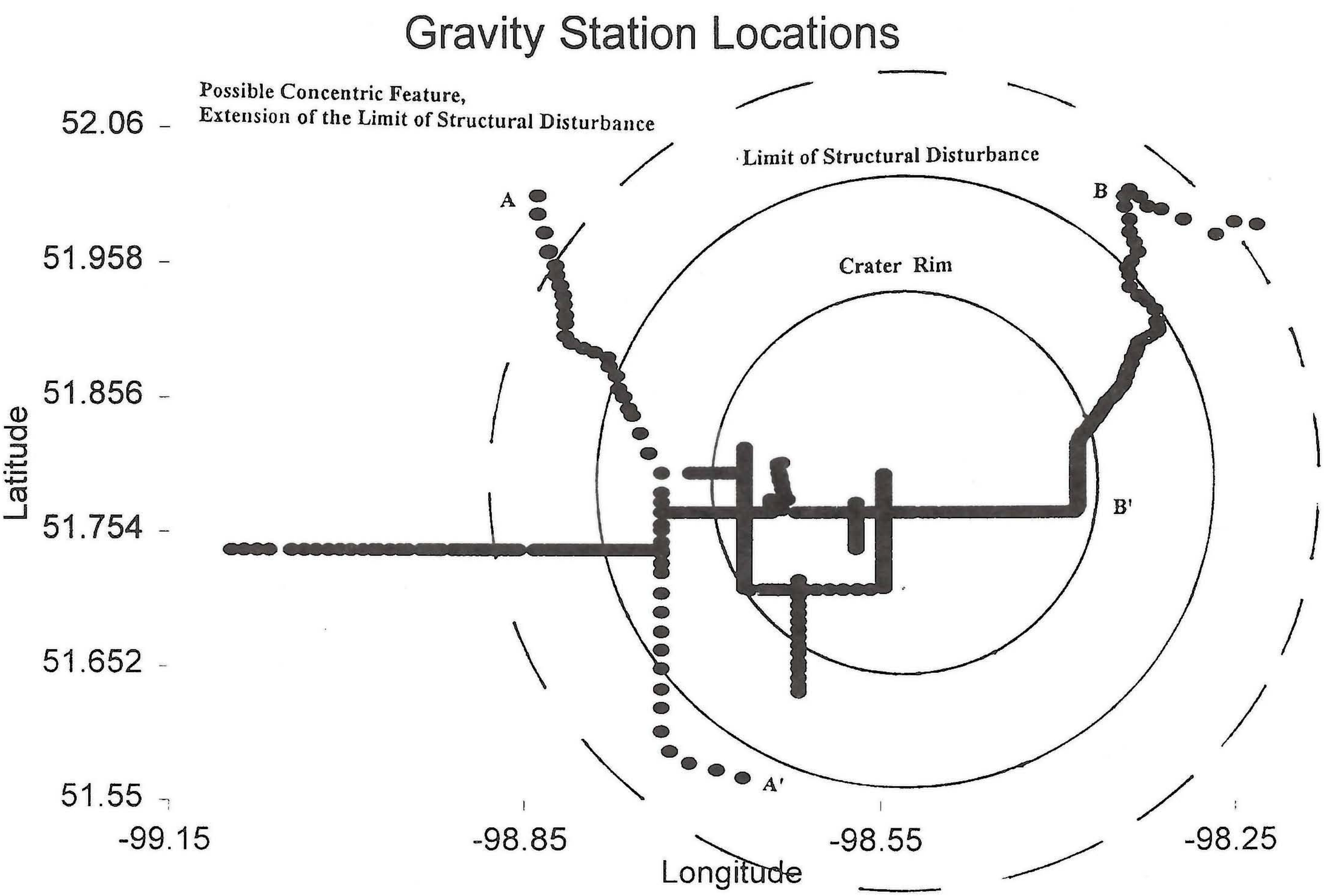

Figure GS-24-2: Gravity station locations.

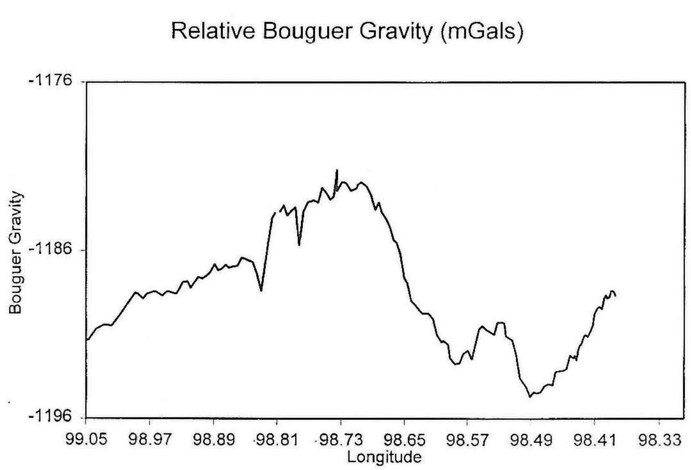

Figure GS-24-3: East-west Bouguer gravity anomaly profile approximately 1 km south of the centre of the Lake St. Martin impact structure.

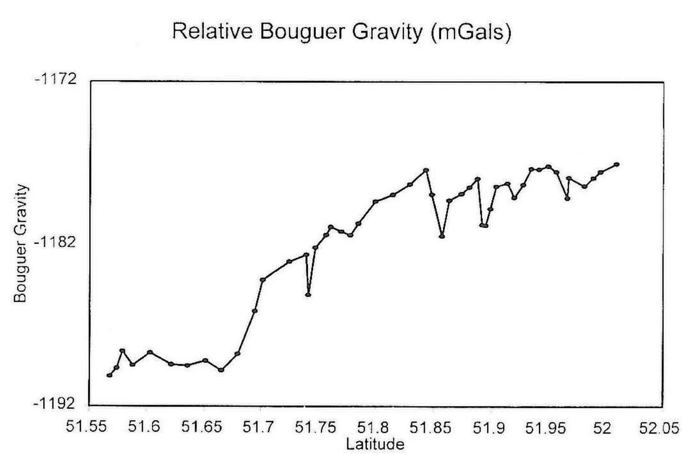

Figure GS-24-4: Bouguer gravity anomaly profile A-A' of the western flank of the Lake St. Martin impact structure. See Figure GS-24-2 for location of A-A'.

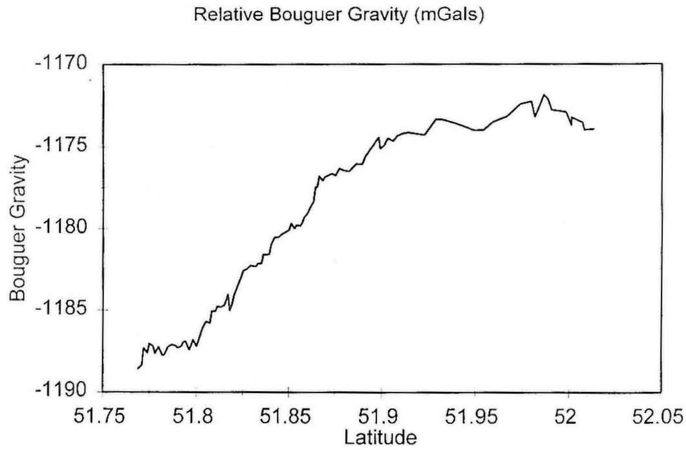

Figure GS-24-5: North-south Bouguer gravity anomaly profile of the northeastern flank of the Lake St. Martin impact structure. See Figure GS-24-2 for location of B-B'.

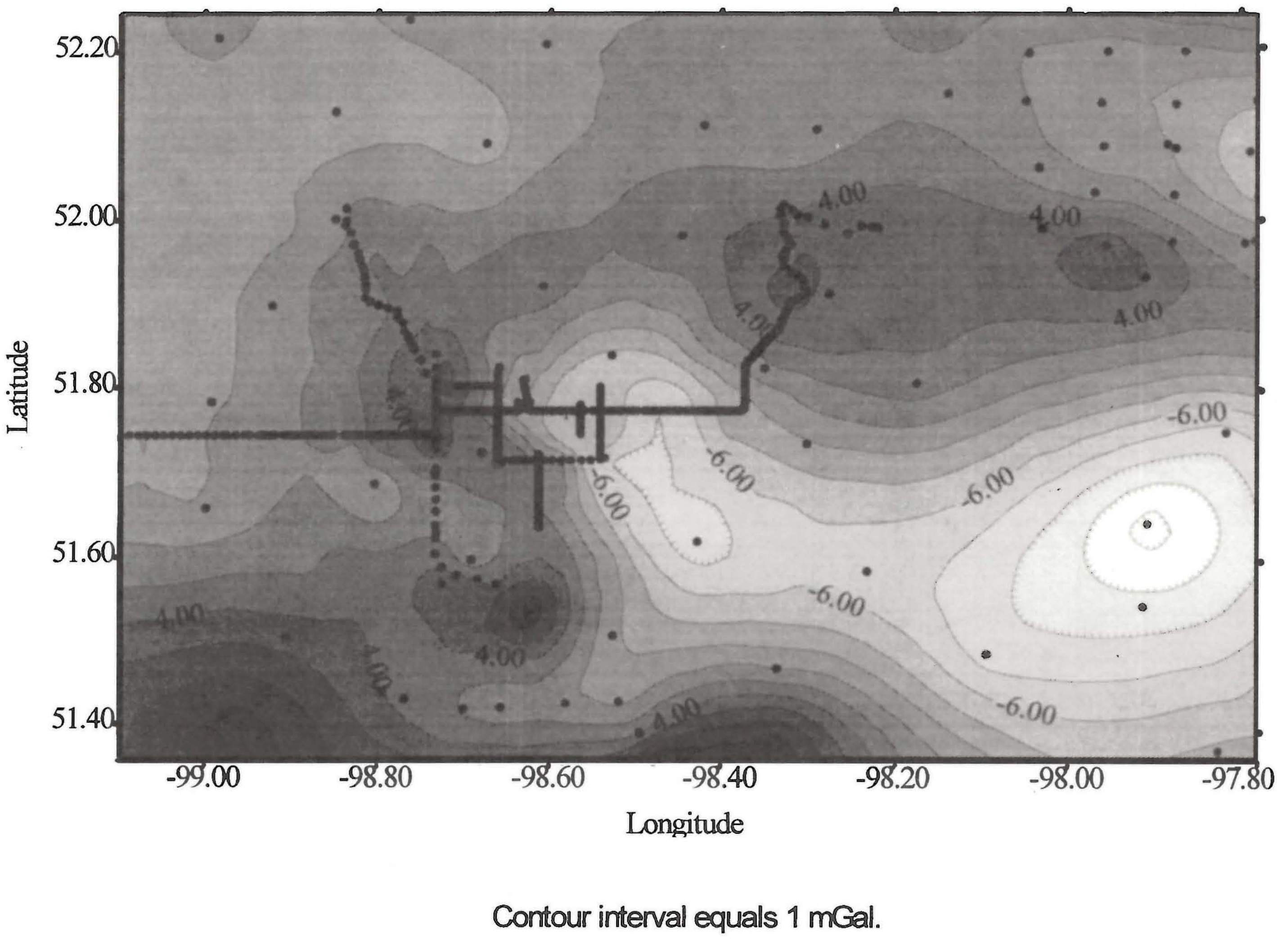

Figure GS-24-6: Contour map of the residual Bouguer gravity anomaly field.

GS-25 GEOCHEMISTRY OF ORDOVICIAN WINNIPEG FORMATION BLACK SHALE, SANDSTONE AND THEIR METAL-RICH ENCRUSTATIONS, BLACK ISLAND, LAKE WINNIPEG (NTS 62P/1)

by M.A.F. Fedikow, J.D. Bamburak and J. Weitzel

Fedikow, M.A.F., Bamburak, J.D., and Weitzel, J., 1995: Geochemistry of Ordovician Winnipeg Formation black shale, sandstone and their metal-enriched encrustations, Black Island, Lake Winnipeg (NTS 62P/1); **in** Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 128-135.

SUMMARY AND CONCLUSIONS

Ordovician Winnipeg Formation black shale and limonitic, nodular sandstone are exposed in the former Selkirk Silica quarry on Black Island in Lake Winnipeg. The black shales are strongly enriched in Co and enriched in Pb, Ag and As based on the definition of "metalliferous" black shale proposed by the United States Working Group On International Geological Correlation Program-Project 254. Aquamarine and canary yellow encrustations on the black shale and sandstone, respectively, formed through interaction of the black shale with groundwater originating at the black shale-overburden contact and trickling down the quarry wall and over the black shales. The encrustations are probably hydrated iron oxide precipitates formed as a product of oxidation of pyrite within the black shale. The crusts are characterized by high concentrations of a wide range of trace elements, including base metals and rare earth elements. The aquamarine, black shale-derived crusts contain the highest concentrations of these metals; both crusts are iron enriched. This study marks the initiation of the development of a black shale geochemical database to permit assessment of the metallogenetic potential of black shales in Manitoba. Additionally, baseline geochemical information, including aqueous dispersion characteristics of the potentially toxic chemical elements resident in black shales, is being developed. These data will be applied to the study of environmentally sensitive areas where natural drainage interacts with these unique lithologies.

INTRODUCTION

The Ordovician Winnipeg Formation, exposed in a quarry on the south side of Black Island (Fig. GS-25-1), has been assessed and mined in the past for its silica sand resources. Silica sand, grading 95.5-97.5% SiO_2, was quarried from this site between 1962 and 1990 by Selkirk Silica Co. Ltd. (Schmidtke and Bamburak, 1993). Although quarry rehabilitation was completed in 1993, representative sections of

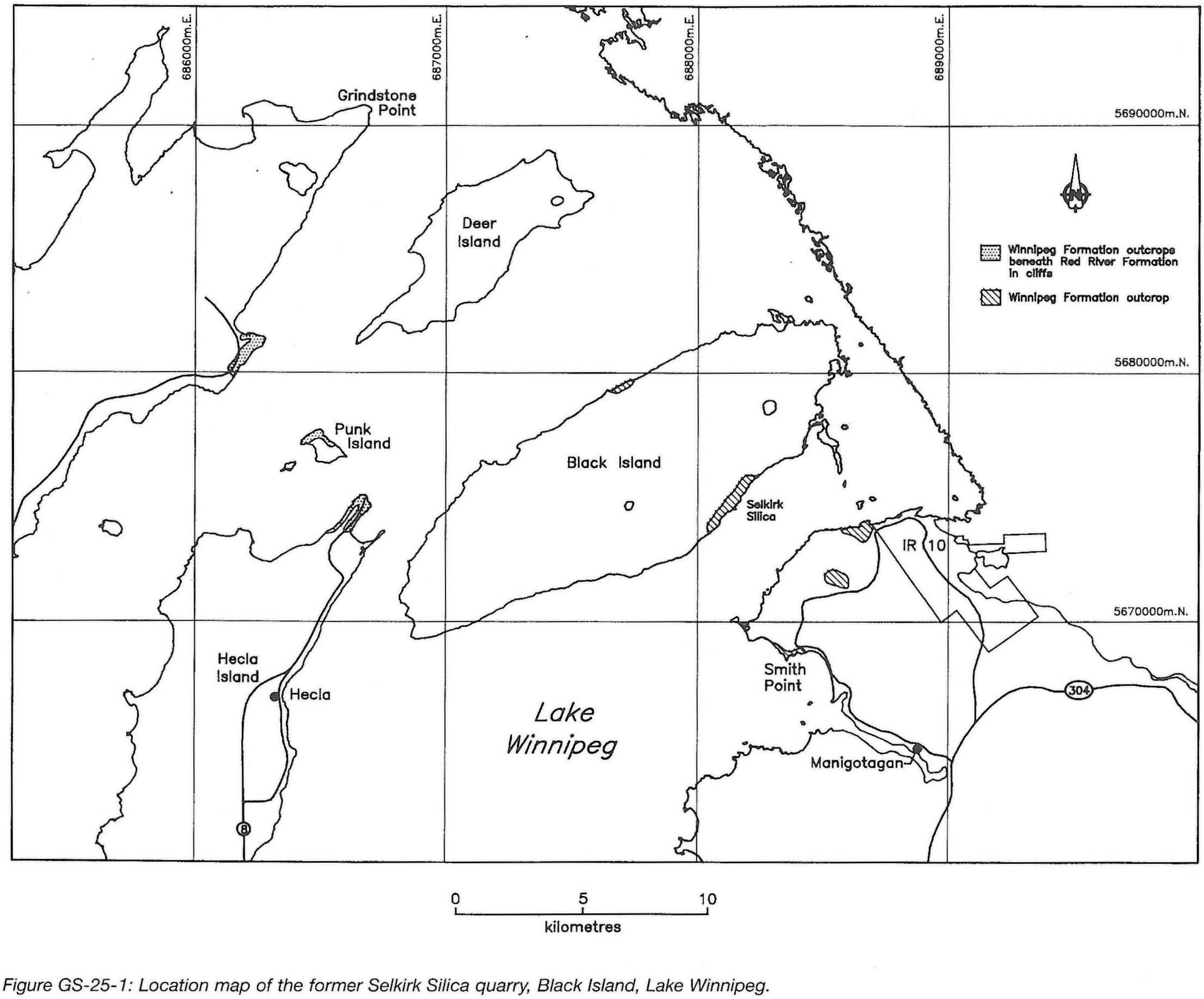

Figure GS-25-1: Location map of the former Selkirk Silica quarry, Black Island, Lake Winnipeg.

the Winnipeg sandstone are still *in situ*. Ongoing studies of the sandstone include the potential for selective mining of high grade sections of SiO_2.

This geochemical study of the black shales and associated rocks at the former Selkirk Silica quarry on Black Island is intended to assess metal contents of the shales, sandstones and their crusts. Additionally, these data represent the first step in the development of a multi-element database for black shales in Manitoba.

The project was initiated to follow-up the results of analyses of black shale and nodular sandstone samples collected by Peter Theyer (Manitoba Energy and Mines) during a cursory examination of the Selkirk Silica quarry in 1993 (Table GS-25-1). A shale and silty shale bed, up to 2 m thick, is interlayered with the Winnipeg sandstone. The shale and sandstone beds were exposed by mining operations at the quarry. A nodular sandstone layer occurs below the shale bed. The chemical analysis of the shale and nodular sandstone (Table GS-25-1) samples was based on an aqua regia digestion with an atomic absorption spectrophotometric finish and, as such, probably does not represent total metal concentration in the sample. Nevertheless, the black shale sample contains unexpectedly high Co, Cu, Pb and Ag compared to published data for "metal-rich" or "metalliferous" black shales. The concentrations of Pb and Co exceed the values for "metal-rich shales" of Vine and Tourtelot (1970). The analysis of the nodules from the nodular sandstone indicates low values for all elements (Table GS-25-1).

Table GS-25-1: Summary of analyses for Ordovician Winnipeg Formation black shale and nodules from the nodular sandstone, Selkirk Silica quarry, Black Island, Lake Winnipeg. Samples collected by P. Theyer. Analyses by atomic absorption spectrophotometry subsequent to aqua regia digest.

Sa. No.	Ag	Cu	Ni	Co	Mn	Mo	Pb
51-93-10 (black shale)	2	176	44	254	68	4	264
51-93-11 (nodules)	<1	12	3	61	4	<1	<2

Munroe Geological Services (1987), however, reports visible gold and high concentrations of Cu, Co, Cr and Pb from a layer of nodular sandstone in the quarry. Sandstone underlying this "oolitic layer" is described as containing native copper and pyrite nodules. The nodules appear to be pyritic and limonitic coatings on pre-existing rounded quartz granules. A 24-element inductively coupled plasma-atomic emission (ICP-AES) analysis of one pyritic-limonitic nodule from the Munroe report documents high contents of Cu, Co, Pb and Ag (Table GS-25-2).

SAMPLE COLLECTION, PREPARATION AND ANALYSIS

Three representative black shale continuous chip samples were collected over a 2.3 m section from the northeast corner of the quarry on October 13, 1993. The stratigraphic setting of these shale samples is presented in Table GS-25-3. In addition, one sample of limonitic nodules and one of the matrix were also collected for analysis. Brightly coloured encrustations coat the black shale as well as the Winnipeg sandstone immediately beneath the black shale layer. These amorphous, gelatinous crusts were mainly observed at the point of intersection between the shale and sandstone and groundwater that trickles over the black shales. The encrustations occur intermittently for 150 m along the north wall of the quarry. The black shale encrustation is bright aquamarine, whereas the sandstone encrustation is bright canary yellow. Individual 55 g samples of both crusts were collected. The gelatinous nature of the crust and difficulties separating it from the shale and the sandstone resulted in a mixed sample of unconsolidated shale and/or sandstone with their respective gelatinous encrustations. A single sample of rusty weathered black shale was also collected from scree at the base of the quarry wall beneath the encrusted black shales.

Table GS-25-2: Analysis of a pyrite-limonite nodule from the nodular layer within the Winnipeg sandstone, Selkirk Silica quarry, Black Island, Lake Winnipeg. Analysis by ICP-AAS; all analyses in ppm unless otherwise indicated. Data from Munroe Geological Services (1987).

Element	Concentration
Al	2.32%
Ba	130
Be	<0.5
Bi	<2.0
Cd	0.5
Ca	0.76%
Cr	111
Co	144
Cu	320
Fe	17.98%
Pb	300
Mg	0.13%
Mn	258
Mo	<1.0
Ni	95
P	70
K	0.15%
Ag	4.5
Sr	58
Ti	0.09%
Na	0.08%
V	17
Zn	10
W	<10

Black shale samples without visible encrustations were jaw crushed, pulverized and analyzed at the Manitoba Energy and Mines Analytical Laboratory for silicate whole rock contents (Table GS-25-4) as well as for the determination of 12 trace elements subsequent to an HF-$HClO_4$ digestion (Table GS-25-5). Silicate whole rock and trace element analyses based on neutron activation and ICP emission spectrometry subsequent to HF-$HClO_4$ digestion are also summarised in Table GS-25-5. Eight rare earth elements were determined for the black shale and sandstone samples by neutron activation and results summarised in Table GS-25-6.

The canary yellow and aquamarine crusts were dissolved from their respective sandstone and black shale hosts using a hot nitric acid dissolution. For each crust, a sample was weighed into a beaker and 10 ml HNO_3 and 90 ml water added for a final volume of 100 ml and acid concentration of 10% HNO_3. These were heated with swirling for 4 hours, cooled, and filtered directly into 250 ml bottles. Final solutions were clear and very dark brown. The residues (undissolved material) were washed three times with water, air dried, weighed, and transferred to vials for storage. These solutions and two reagent blanks were analysed for 65 elements by inductively coupled plasma-mass spectrometry (ICP-MS) at Activation Laboratories Ltd. (Ancaster, Ontario). Analytical results are tabulated in Table GS-25-7.

RESULTS

Black Shale

Major element chemical data for the black shale samples are summarised in Table GS-25-4. A steady marked decrease in the SiO_2 content (63.7 to 35.9%) from top to bottom of the 2.3 m sampling section indicates a reduction in the amount of silt and sand incorporated in the black shale. K_2O is also reduced from 5.04 to 3.83% over the same interval. A concomitant increase in total Fe_2O_3 (8.91 to 28.08%) and loss on ignition (12.2 to 24.6%) probably reflects an increase in iron sulphide, oxide and sulphate minerals towards the base of the unit. Sulphur was not determined.

Trace element data for black shales, including their encrustations, are summarised in Tables GS-25-5, -6 and -7, and compared to data summarised from published geochemical studies of black shale in Table GS-25-8. The determination as to whether the Black Island black shales are "metalliferous" is based upon the definition of the United

States Working Group of I.G.C.P. Project 254. Their proposed definition of "metalliferous" is "enrichment in any metal by a factor of two (except for Be, Co, Mo and U for which an enrichment of one is sufficient) relative to that element's concentration in the United States Geological Survey Standard SDO-1".

On the basis of this definition, the Black Island shales are metalliferous or strongly enriched in Co and enriched in Ag and Pb, possibly as constituents of the organic fraction of the black shales. The shales are also enriched in As, which is possibly resident in the sulphide fraction of the black shale. Gold (6-11 ppb) may also be enriched in these rocks. The Black Island shales have equivalent or higher concentrations of Au, Co, Cu and Pb than the "metal-rich black shales" studied by Vine and Tourtelot (1970). They also have higher Ag, Ba, Co, La, Ni, Pb, Sr, U and Zr than the mean value for black shale calculated by Vine and Tourtelot (1970).

A comparison between the black shales and the stratigraphically underlying limonitic sandstone indicates significant differences in most trace elements between the two units. The limonitic sandstone contains lower concentrations of most elements with the exception of As, Au, Mo and Ta, albeit the differences in these elements are only a few ppm (or ppb in the case of Au).

Amorphous Gelatinous Encrustations

The gelatinous crusts developed on the black shale and sandstone contain high concentrations of many trace elements. The hot nitric acid digest was 100% effective in the removal of these crusts with residual black shale and sandstone left in the digestion vessel. However, owing to the efficacy of the nitric acid attack, the contribution by the host rocks of some portion of the elements identified in the crusts cannot be ignored.

The aquamarine and canary yellow crusts are iron-enriched containing 19.54 and 10.35% Fe, respectively. In addition to Fe content, the aquamarine crust can be differentiated from the yellow crust on the basis of higher Li, B, Mg, Al, Sc, V, Ni, Ga, Rb, Y, Zr, Cd, Ag, In, Sb, Te, Cs, rare earth elements, Hf, Pt, Tl, Pb, Bi, U and Th. The canary yellow crust has higher Ca, Ti, Cu, As, Br, Sr, Nb, Mo, I and Ba. The chemical differences between these two crusts mimic somewhat the differences between black shale and sandstone. The sandstone and its crust are enriched in As and Mo relative to the black shale and the aquamarine crust.

SOURCE OF METALS

Published studies of the geochemistry of black shales have identified the associations between trace metal contents and the mineral fractions present in the black shale. Numerous authors quoted in Reichenbach (1993) attribute Ag, Co, Cr, Cu, Hg, Mo, Ni, Pb, Se, U, V and Zn to the organic fraction of the shales. The sulphide fraction concentrates As, Co, Cr, Cu, Hg, Mo, Ni, Se, V and Zn. Vanadium, Cr and Zn occur in the phosphate fraction, and Zn and Cd in the sphalerite fraction. The source of these metals, and by extrapolation the source of the metals in the Black Island shales, may be attributed to a number of processes. Metal enrichment could have occurred as a result of (1) the precipitation of sulphide from sea water in a reducing environment (2) concentration from sea water by living or decaying organisms (syngenetic) (3) concentration of metals during sediment burial prior to pore water removal (diagenetic) and (4) epigenetic processes including the post-depositional introduction of ore-related fluids (Vine and Tourtelot, 1970). An additional consideration is that the black shales on Black Island are, in fact, host rocks to a base and/or precious metal mineral deposit and the high concentrations of heavy metals are simply an indication of the presence of this mineralized zone.

DISCUSSION AND CONCLUSIONS

It is likely that both syngenetic and diagenetic processes have been involved in the development of the metal-enriched character of the Black Island black shales. Whether or not epigenetic processes have helped enrich the black shale in some ore related elements such as Pb, Cu and Ag is unknown. Interestingly, metal-enriched black shales appear to form part of the stratigraphic/geochemical requirements for the formation of certain base metal (Cu,Pb,Zn) deposits (Colman *et al.*, 1989) and form the hosts for disseminated gold deposits in the Carlin and Getchell Trends in Nevada (Bloomstein and Clark, 1989).

The formation of the aquamarine and canary yellow crusts on the black shales and sandstones, respectively, are related to the chemical interaction of the groundwater that flows over these lithologies and the chemical and mineralogical components of both lithologies. This observation seems reasonable since only minor encrustations were observed in the relatively dry areas of the quarry. The groundwater trickles from points along the quarry wall that correspond to the approximate contact between the black shale and the overlying till. The black shale probably acts as an aquitard with groundwater in the till channelled along the till-shale contact.

Similar deposits of amorphous, gelatinous yellow crusts are not uncommon in areas effected by acid mine drainage. This drainage occurs as a result of the natural oxidation of sulphide minerals that are exposed to air and water. Sulphide oxidation can be accelerated by acidophilic iron-oxidising bacteria such as *Thiobacillus ferroxidans* which creates sulphuric acid and releases heavy metals from the sulphides. The reaction for pyrite oxidation is represented by:

$$2FeS_2 + 7O_2 + 2H_2O \rightarrow 2Fe^{+2} + 4SO_4^{-2} + 4H^+$$

The production of sulphate from sulphide oxidation releases ferrous ions and acid to the water. Subsequently, the dissolved ferrous ion is oxidized to Fe^{3+} which precipitates as hydrated iron oxide according to the reactions:

$$4Fe^{2+} + O_2 + 4H^+ \rightarrow 4Fe^{3+} + 2H_2O$$

$$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_3 + 3H^+$$

A similar process is envisaged for the production of the metal-enriched aquamarine and canary yellow crusts observed at Black Island. These crusts are probably metal-rich hydrated iron hydroxides formed from the oxidation of pyrite within the black shales subsequent to interaction with groundwater.

The development of a broad-based black shale geochemical database for Manitoba has a two-fold application. Firstly, it will assist in the assessment of the metallogenetic potential of stratigraphic sequences with black shales. Secondly, in light of the aqueous geochemistry of the constituent elements, the data will permit assessment of environmental problems arising from the aqueous mobilization of potentially toxic chemical constituents produced during natural or anthropogenic disruption of these unique lithologies.

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Table GS-25-3
Stratigraphic section through the Winnipeg Formation, Selkirk Silica quarry, Black Island, Lake Winnipeg and location of black shale and sandstone samples and their associated crusts that were collected and analysed (italics). The three shale samples are continuous chip samples collected from the top of the bed (0-0.5 m), the middle of the bed (0.5-1.0 m) and the bottom of the bed (1.0-2.3 m).

Sample Number	Interval	Lithology
Central Portion, North Wall		
***************	5.0 m	Glacial till with large slumped blocks of Ordovician Doghead Member of the Red River Formation
99-93-BI-2-2-2	1.0 m	Very "hard" white sand with few phosphate? blebs
99-93-BI-2-2-1	1.0 m	Sand, as above
99-93-BI-2-2-0	0.8 m	White sand, softer near base, minor iron sulphide blebs and veins
***************	0.2 m	covered interval
99-93-BI-2-2-(-1)	0.5 m	Resistant brownish-grey weathering, mottled clayey silt, with worm tubes?
***************	0.5 m	covered interval
Northeast End		
0-0.5, 0.5-1.0, 1.0-2.3m	2.3 m	Black shale with aquamarine crust underlain by sandstone with canary yellow crust
99-93-BI-2-1-9	~0.2 m	Grey clay with hard silt lumps shale
***************	~0.2 m	covered interval
99-93-BI-2-1-8	1.0 m	Hard grey sand, iron stained weathered surface
99-93-BI-2-1-7	1.0 m	Sand, as above
99-93-BI-2-1-6	1.0 m	Sand, as above
99-93-BI-2-1-5	1.3 m	Orange, weathering sand with abundant ironstone concretion layers (some concretions up to 15 cm in diameter) and phosphate blebs; weathered surface shows tiny vertical fractures similar to stylolites; thin horizontal bedding plane at base
99-93-BI-2-1-4	0.5 m	Soft grey weathering sand with short tabular white kaolinitic? specks (worm tubes?); white precipitate salts? near middle at major horizontal bedding plane break quite visible throughout quarry; minor 7 cm ironstone concretions; oxidized pyrite blebs present near] top
99-93-BI-2-1-3	0.4 m	Very hard white sand, almost pyrite free, minor phosphate? blebs
99-93-BI-2-1-2	1.1 m	Sand, as above but upper 0.1 marked by two fine continuous horizontal bedding plane lines that are associated with an increase in clay content (kaolinitic?)
99-93-BI-2-1-1	0.7 m	Sand with abundant oxidized pyrite blebs decreasing in concentration near base
99-93-BI-1-1-2	0.6 m	Very hard white sand with few random oxidized pyrite blebs
99-93-BI-1-1-1	1.0 m	Sand, as above
***************	0.5 m	Covered interval to water line

Table GS-25-4

Silicate whole rock analyses of Winnipeg Formation sands and black shales, Selkirk Silica quarry, Black Island, Lake Winnipeg. Analyses determined by atomic absorption spectrophotometry (Geological Services Branch) and neutron activation (DNA; Activation Laboratories. Ltd., Ancaster, Ontario). Analyses in weight %.

Sample	01884		01885		01886		01887		01888	
	AA	NA	AA	NA	AA	NA	AA	NA	AA	NA
$Si0_2$	93.3	(95.06)	63.7	(63.96)	46.1	(45.45)	35.9	(36.90)	28.9	(30.48)
Al_20_3	1.38	(0.97)	9.38	(8.93)	15.88	(15.59)	6.95	(6.26)	7.76	(7.29)
Fe_20_3	2.05	(2.02)	8.91	(9.08)	11.77	(12.13)	28.08	(29.34)	32.13	(31.83)
Ca0	0.06	(0.03)	0.03	(0.03)	0.04	(0.04)	0.06	(0.05)	0.08	(0.06)
Mg0	0.23	(0.05)	0.34	(0.18)	0.55	(0.36)	0.30	(0.15)	0.18	(0.19)
Na_20	0.10	(<0.01)	0.10	(0.05)	0.13	(0.08)	0.10	(0.08)	0.10	(0.10)
K_20	0.16	(0.15)	5.04	(4.89)	4.46	(4.36)	3.83	(4.13)	4.99	(5.41)
$Ti0_2$	0.13	(0.10)	0.40	(0.36)	0.66	(0.60)	0.27	(0.24)	0.33	(0.30)
P_20_5	0.01	(0.02)	0.02	(<0.01)	0.03	(0.01)	0.01	(<0.01)	0.01	(<0.01)
Mn0	0.00	(<0.01)	0.00	(<0.01)	0.01	(<0.01)	0.02	(0.03)	0.03	(0.04)
L0I	2.3	(2.34)	12.2	(12.13)	20.3	(20.49)	24.6	(23.70)	24.3	(23.35)
Total	99.73	(100.76)	100.20	(99.62)	100.07	(99.11)	100.23	(100.82)	98.92(	98.94)

Sample Descriptions:

01884: limonitic sand, stratigraphically underlying black shale
01885: 0-0.5 m; black shale
01886: 0.5 - 1.0 m; black shale
01887: 1.0 - 2.3 m; black shale
01888: limonitic and hematitic black shale scree sample

Table GS-25-5

Trace element analyses of Winnipeg Formation sand and black shales, Selkirk Silica quarry, Black Island, Lake Winnipeg.

Analyses as follows:

Ba to Zr and Cu to Be determined by total digestion and inductively coupled plasma emission spectrometry (Activation Laboratories Ltd., Ancaster, Ontario). The bracketed figures for Cu, Ni, Pb, Zn, Cr, V, Rb, Sr, Ba, Li, Be and Cs were determined by atomic absorption spectrometry subsequent to a total digestion using HF and HCl04 (Manitoba Energy and Mines Laboratories). Au to U by neutron activation (Activation Laboratories Ltd.). Analyses in ppm unless otherwise indicated.

Sample	**01884** **Limonitic sand**	**01885** **Black shale**	**01886** **Black shale**	**01887** **Black shale**	**01888** **Black shale-scree**
Ba	13 <25)	223 (261)	367 (442)	129 (143)	221 (242)
Sr	19 (20)	55 (50)	84 (74)	53 (48)	54 (50)
Y	7	14	22	6	13
Zr	179	221	320	118	236
Cu	2 (2)	28 (31)	23 (26)	222 (235)	147 (158)
Pb	21(<11)	41 (29)	64 (55)	254 (303)	235 (281)
Zn	2 (3)	6 (11)	25 (26)	15 (22)	12 (23)
Ag	<0.4	<0.4	<0.4	2.5	1.9
Ni	7 (8)	23 (21)	37 (32)	52 (43)	58 (44)
Cd	<0.5	<0.5	<0.5	1.2	1.3
Bi	<5	<5	<5	<5	<5
V	10	31	46	21	23
Be	<2 (<2)	<2 (<2)	<2 (<2)	<2 (<2)	3 (<2)
Au(ppb)	15	10	6	11	9
As	36	7	13	20	31
Br	<0.5	2.4	3.5	8.0	12.0
Co	54.4	79.2	79.0	187.0	160.0
Cr	11.0 (10)	55.6 (59)	90.2 (102)	35.0 (39)	43.2 (44)
Cs	0.3 (<7)	1.7 (<7)	2.7 (<7)	0.9 (<7)	1.1 (<7)
Hf	4.9	5.8	8.0	3.2	5.2
Hg	<1	<1	<1	2	1
Ir	<1	<1	<1	<1	<1
Mo	8	<2	3	4	<2
Rb	<10 (7)	48 (54)	62 (75)	33 (32)	61 (44)
Sb	0.9	0.2	0.4	5.8	4.5
Sc	1.4	5.6	9.8	3.4 4.8	
Se	<0.5	<0.5	<0.5	<0.5	<0.5
Ta	3.4	1.5	1.1	1.2	1.0
Th	2.0	5.9	12.0	4.2	6.3
U	0.8	2.3	3.7	1.5	1.9
V	<27	(44)	67	32	34
Li	11	40	161	20	10

Table GS-25-6

Rare earth element analyses of Winnipeg Formation sand and black shales, Selkirk Silica quarry, Black Island, Lake Winnipeg. Analyses by neutron activation (Activation Laboratories Ltd., Ancaster, Ontario). Sample descriptions as per Table GS-25-4. All analyses in ppm.

Sample	**01884** **Limonitic sand**	**01885** **Black shale**	**01886** **Black shale**	**01887** **Black shale**	**01888** **Black shale-scree**
La	17.7	34.0	48.3	16.2	19.6
Ce	41	68	95	30	37
Nd	17	27	37	11	15
Sm	2.17	3.66	5.31	1.53	2.23
Eu	0.50	0.86	1.25	0.36	0.55
Tb	0.3	0.5	0.8	0.2	0.4
Yb	0.71	1.77	2.34	0.61	1.38
Lu	0.09	0.29	0.36	0.09	0.22

Table GS-25-7
ICP-MS analyses of the aquamarine and canary yellow encrustations, Winnipeg Formation, Selkirk Silica quarry, Black Island, Lake Winnipeg. Analyses by Activation Laboratories Ltd. (Ancaster, Ontario). All analyses in ppb unless otherwise indicated.

	Aquamarine Crust (Shale)	Canary Yellow Crust (Sandstone)	Blank 1	Blank 2
Li	30974	11213	6	16
Be	<0.1	<0.1	<0.1	<0.1
B	2870	2332	67	35
Na(ppm)	136	163	0.20	0.25
Mg(ppm)	3845	3410	0.05	0.04
Al(ppm)	10714	3425	<0.05	<0.05
Si(ppm)	68	88	0.5	0.5
Ca(ppm)	1775.1	2785	0.15	0.14
Sc	1140	380	<0.1	<0.1
Ti(ppm)	9.1	15.0	<0.01	<0.01
V	35467	22030	4	7
Cr(ppm)	<9	<5	<0.02	<0.02
Mn(ppm)	135	114	<0.01	<0.01
Fe(ppm)	19.54%	10.35%	0.24	0.11
Co	>999999	>999999	48	100
Ni	288195	204262	110	134
Cu	26535	98231	48	47
Zn	18718	19591	39	37
Ga	9137	3821	0.7	1.2
As	45570	99453	21	23
Se	542	586	2	1
Br	1627	2014	<5	<5
Rb	15654	4854	2.5	1.8
Sr	25911	27741	6.5	7.7
Y	8817	4803	0.8	1.7
Zr	18996	5634	3.2	3
Nb	39	138	<0.01	<0.01
Mo	3079	3227	<0.1	<0.1
Ru	<0.1	<0.1	<0.1	<0.1
Pd	236	154	<0.1	<0.1
Ag	128	34	2	0.7
Cd	227	126	0.7	0.6
In	109	63	<0.01	<0.01
Sn	213	281	1.6	1.6
Sb	397	127	<0.1	<0.1
Te	268	105	<0.1	<0.1
I	959	1550	474	225
Cs	216	76	<0.01	<0.01
Ba	1599	4200	3.5	2.8
La	10245	2539	2	2
Ce	41247	8346	2	6
Pr	10251	1730	1	1
Nd	46427	7753	3	8
Sm	8293	1648	1	1
Eu	2008	470	0.1	0.2
Gd	9035	2238	0.5	1.3
Tb	993	250	0.1	0.1
Dy	2700	928	0.3	0.4
Ho	433	165	<0.01	0.1
Er	663	276	<0.01	0.1
Tm	109	47	<0.01	<0.01
Yb	1017	407	0.1	0.1
Lu	136	58	<0.01	<0.01
Hf	311	77	<0.01	<0.01
Ta	7	3	0.3	0.1
W	12	9	0.2	0.2
Re	<0.01	<0.01	<0.01	<0.01
Os	0.7	0.6	<0.01	<0.01
Pt	12	2	<0.01	<0.01
Au	<0.01	<0.01	<0.01	<0.01
Hg	<0.01	<0.01	<0.01	<0.01
Tl	474	272	0.1	<0.01
Pb	50839	9984	42	26
Bi	125	14	0.1	<0.01
Th	26948	4618	1	2
U	15583	2123	0.5	0.7

Table GS-25-8
Comparison between trace element geochemical data for Winnipeg Formation black shales and published data for average black shale (1*), metal-rich shale (2*) and metalliferous black shales (3*).
Analyses in ppm except for Au, which is quoted in ppb.

	01885 Black shale	01886 Black shale	01887 Black shale	01888 Black shale-scree	1*	2*	3*
Ag	<0.4	<0.4	2.5	1.9	1	7	0.262
As	7	13	20	31		68.5	1.4
Au(ppb)	10	6	11	9		2.8	5.6
Ba	223	367	129	221	300	1000	694
Bi	<5	<5	<5	<5			10
Cd	<0.5	<0.5	1.2	1.3			10
Ce	68	95	30	37			158.6
Co	79.2	79.0	187.0	160.0	10	30	46.8
Cr	55.6	90.2	35.0	43.2	100	700	132.8
Cs	1.7	2.7	0.9	1.1			13.8
Cu	28	23	222	147	70	200	120.4
Eu	0.86	1.25	0.36	0.55			3.2
Hf	5.8	8.0	3.2	5.2			9.4
Hg	<1	<1	2	1			4.4
La	34.0	48.3	16.2	19.6	30	70	77
Mo	<2	3	4	<2	10	200	134
Ni	23	37	52	58	50	300	199
Pb	41	64	254	235	20	100	55.8
Rb	48	62	33	61			252
Sb	0.2	0.4	5.8	4.5			8.9
Sc	5.6	9.8	3.4	4.8	10	30	26.4
Se	<0.5	<0.5	<0.5	<0.5			9.8
Sm	3.66	5.31	1.53	2.23			9.8
Sr	223	367	129	221	200	1500	150.2
Ta	1.5	1.1	1.2	1.0			2.2
Th	5.9	12.0	4.2	6.3			21
U	2.3	3.7	1.5	1.9	2	30	48.8
V	44	67	32	34	150	1000	320
Y	14	22	6	13	30	70	81.2
Yb	1.77	2.34	0.61	1.38			6.8
Zn	6	25	15	12	<300	1500	128.2
Zr	221	320	118	236	70		330

1* - Black shale mean value (Vine and Tourtelot, 1970)
2* - Metal-rich black shale (Vine and Tourtelot, 1970)
3* - "Metalliferous" black shale ("USGS SDO-1", Huyck, 1990)

GS-26 GEOLOGIC MAPPING IN THE GARNER LAKE-BERESFORD LAKE AREA OF THE RICE LAKE GREENSTONE BELT*

by M. T. Corkery

Corkery, M.T., 1995: Geologic mapping in the Garner Lake-Beresford Lake area of the Rice Lake greenstone belt; **in** Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 136-139 .

SUMMARY

This report presents of a review of recent mapping and geochronology in the Rice Lake belt. Previously published U-Pb ages indicate that the age of the Bidou Lake Subgroup is 2.73 Ga, contemporaneous with the intrusion of the Ross River pluton. The Gem Lake Subgroup, originally thought to be younger, has a wide range of ages: 2.72 Ga in the Gem Lake area, 2.87 Ga in the Garner Lake area. The Conley Formation in the Wallace Lake area gives an age of 3.0 Ga. The broad spectrum of ages as well as the variations in associated lithologies indicate a more complex history for the Gem Lake and Wallace Lake subgroups.

Structural studies indicate major dislocations and possible bounding faults between the Bidou Lake and Gem Lake subgroups. However, subdivision of the Gem Lake Subgroup is the subject of continuing investigations, as is the association between the Bidou Lake Subgroup and rocks of similar age in the Gem Lake area.

Similarities between old (3.0 Ga) platformal sequences and younger (2.7 Ga) intermediate to felsic volcanic sequences in both the Rice Lake and Red Lake greenstone belts have been interpreted to indicate a parallel geologic development along the southern margin of the Berens River Subprovince.

Two weeks of mapping during the field season were centred on the Garner Lake area, where east-trending ductile shear zones indicate a possible structural contact between the felsic volcanic and sedimentary formations on Gem Lake and the mixed sedimentary and mafic volcanic sequence in the Garner Lake Beresford Lake area. The major Moore Lake—Beresford Lake deformation zone appears to truncate these east west structures.

INTRODUCTION

During the past five years under the Canada-Manitoba Partnership Agreement on Mineral Development, mapping, geochemical and geochronological studies have provided new insights into the complex nature of the Rice Lake greenstone belt. What had been considered a structurally complex belt with relatively simple supracrustal units, divided into two major subgroups, has produced U-Pb ages that indicate a more complex geologic history. The diversity in ages and recognition of regional and local structural breaks, interpreted to bound terranes of different ages, has posed intriguing geologic problems whose solutions require further mapping.

It has become apparent that the terminology in the belt needs revision. Some sequences are now better defined as groups or assemblages whereas others still require clarification. It is suggested that a wholesale reworking at this point would be premature; however, some preliminary suggestions are put forward.

In response, a mapping program in the Garner Lake area was initiated during the past field season to 1) define the nature of the boundary between the Bidou Lake Subgroup and the Gem Lake Subgroup; 2) document the contact between younger felsic volcanics of the Gem Lake area and the older sedimentary and mafic volcanic rocks north of Garner Lake; and 3) document the extent of komatiitic basalts southeast of Beresford Lake.

GENERAL SETTING

The Rice Lake greenstone belt, in southeastern Manitoba, consists of a polydeformed assemblage of supracrustal and intrusive rocks. Recent structural, geochemical and geochronological studies indicate a complex sequence of development for the belt: 1) 3.0 Ga granitoid basement north of the Wanipigow River, 2) unconformably overlain by 2.9 Ga platformal sedimentary rocks and possible rift sequence mafic volcanic rocks, 3) followed by juxtaposition of 2.7 Ga arc volcanic rocks of the Bidou Lake Subgroup and 4) overlain by basinal sediments during the Kenoran orogeny (Turek *et al.* 1989; Brommecker, 1991; Brommecker *et al.*, 1993; Poulsen *et al.,* 1993; Davis, 1994; Turek and Weber, 1994). Prior to these studies the belt had been divided into two major divisions: the Gem Lake Subgroup and the Bidou Lake Subgroup (Weber, 1971a). The sequence in the Wallace Lake area was separated as the Wallace Lake Subgroup (McRitchie, 1971). A minor subdivision consisting of the San Antonio Formation, a subaerial sedimentary sequence that unconformably overlies the Bidou Lake Subgroup in the Bissett area, represents the youngest supracrustal rocks in the belt. The regional distribution of major units and structures in the Rice Lake Belt is shown in Figure GS-26-1.

GEM LAKE SUBGROUP AND WALLACE LAKE SUBGROUP

The Gem Lake Subgroup, as defined by Weber (1971a), consists of a discontinuous band of supracrustal rocks that extend westward from Wallace Lake along the north edge of the supracrustal belt. South of Wallace Lake, it forms the eastern margin of the belt in a southeasterly trend through Moore and Gem lakes (Fig. GS-26-1). The northern segment is bounded to the north by the granitoid Berens River Domain and the south by the Wanipigow Fault, which offsets the Wallace Lake segment 22 km in a dextral sense (McRitchie, 1969, Brommecker *et al.*, 1993). In the eastern segment of the belt, the southeast-trending Moore Lake—Beresford Lake shear zone separates northwest-facing basalt of the Gem Lake Subgroup on the east from the east-facing Bidou Lake Subgroup felsic volcanic and sedimentary rocks on the west (Brommecker *et al.*, 1989) (Fig. GS-26-2). Thus the major faults have been interpreted as the discontinuities that form the boundaries between the subgroups.

The Gem Lake Subgroup and the Wallace Lake Subgroup contain several distinct lithological suites in various areas of the belt. Recent U-Pb age determinations indicate different ages for the formation of some of these suites.

In the Wallace Lake area a sequence of quartz-rich sedimentary rocks, the Conley Formation (McRitchie, 1971), has been reinterpreted as the base of the Wallace Lake Subgroup. The upper portion of the formation consists of a sequence of carbonate rocks and iron formation that is overlain by a thick sequence of mafic volcanic rocks with several ultramafic intrusions. Recent mapping by W. Weber indicated that prior to regional deformation, the basal quartz arenite is successively intruded by gabbro, diorite, feldspar porphyry and quartz porphyry dykes. U-Pb zircon analysis by Davis (1994) of a sample from the younger quartz porphyry dyke indicated an intrusive age of 2920 Ma. Confirmation of an older age for the quartz arenite was demonstrated by an abundant homogeneous population of 2999 Ma detrital zircons. This lithological assemblage is comparable to ancient platformal sequences and subsequent rift volcanic sequences in northwestern Ontario described by Thurston *et al.* (1991).

The Gem Lake Subgroup in the Garner Lake area consists of a sequence of metasedimentary rocks overlain by northwest-facing basalts that contain komatiitic flows (Poulsen *et al.* 1993) and minor iron formation. The sedimentary rocks are intruded by the Garner Lake mafic-ultramafic intrusion (Scoates, 1971). Pegmatitic phases of this intrusion yielded an age of 2871 Ma (Davis, 1994), indicating a minimum age for this sequence. However, Brommecker *et al.* (1993) suggest that the Garner Lake mafic-ultramafic intrusion represents a fault bounded magma chamber for the komatiitic flows in the overlying basalt sequence, inferring a similar age for the volcanism (*i.e.*, 2871 Ma). This would place the Garner Lake volcanism at least 50 m.y. younger than the sequence at Wallace Lake and possibly as much as

* Funded by Provincial A-base

120 m.y. younger. This necessitates further geochemical studies to test the magma chamber interpretation and thus determine the relationship between the Wallace Lake Subgroup and the Garner Lake Subgroup.

In the Gem Lake area, several kilometres south of Garner Lake, but still east of the Moore Lake—Beresford Lake shear zone, a rhyolite flow yielded an U-Pb age of 2722 Ma (Davis, 1994). This age is 10 m.y. younger than those reported for felsic volcanic rocks of the Bidou Lake Subgroup to the west and about 250 m.y. younger than the rest of the Gem Lake Subgroup to the north.

The newly determined pre-2.8 Ga ages for similar sequences in both the Wallace Lake area and the Garner Lake area strengthens the probable correlation of these sequences as previously suggested by Brommecker *et al.* (1993) and Poulsen *et al.* (1994). However, the 2.7 Ga age for volcanism in the Gem Lake area indicates a major break must exist between the Garner Lake sedimentary sequence and the Gem Lake felsic volcanic and sedimentary rocks to the south.

BIDOU LAKE SUBGROUP

The Bidou Lake Subgroup consists primarily of a sequence of intermediate to felsic volcanic rocks interlayered with volcaniclastic and epiclastic metasedimentary rocks with minor basalt flows. Basalt in the core of the Beresford anticline forms the base of the subgroup. The sequence is interpreted to grade upward into the basinal metagreywacke of the Edwards Lake Formation, which may be equivalent to the highly metamorphosed sedimentary gneisses of the Manigotagan gneiss belt that flanks the greenstone belt to the southwest.

Relatively few U-Pb zircon age determinations are available from this subgroup. A dacite from The Narrows Formation gives an age of 2731 Ma, and another from the Hare's Island rhyolite, 2729 Ma (Turek *et al.*, 1989). This is similar to an age of 2737 Ma reported by Ermanovics (1981) for felsic volcanics in the western end of the Rice Lake belt. Several ages in the same age range as the felsic volcanics have been reported for intrusive phases: *e.g.*, the Ross River quartz diorite, 2728 Ma; and the Gunnar porphyry, 2731 Ma. A quartz diorite

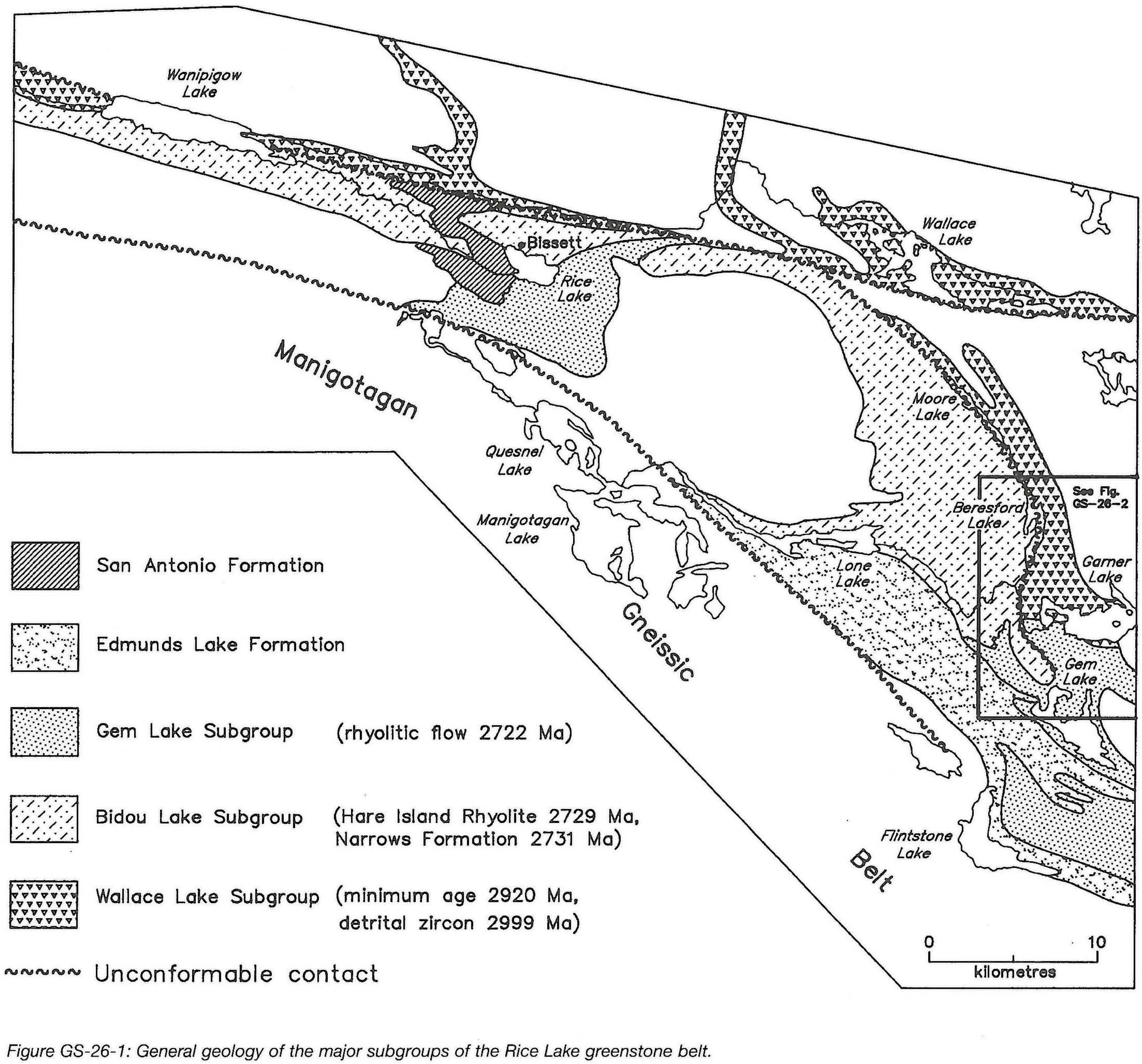

Figure GS-26-1: General geology of the major subgroups of the Rice Lake greenstone belt.

intrusion in the Wallace Lake area dated at 2731 Ma (Turek *et al.*, 1989) indicates magmatic activity in the older plutonic and supracrustal rocks correlative with the development of the Bidou Lake Subgroup. This cluster of U-Pb ages obtained from the Bidou Lake Subgroup and related intrusive rocks was interpreted to indicate a dominant volcano-plutonic event at 2730 Ma and that the volcanic and plutonic rocks were comagmatic. These observations reinforce the interpretation of a relatively simple sequence of deposition over a restricted time span for the Bidou Lake Subgroup.

RESULTS OF MAPPING

The Garner Lake area seems to be key to many of the problems posed by recent mapping and age determination programs. In this area the Moore Lake—Beresford Lake shear zone marks the boundary between the Bidou Lake Subgroup and the Gem Lake Subgroup. To the east, the Garner Lake shear zone (Poulsen *et al.*, 1994) truncates the west end of the Garner Lake mafic-ultramafic intrusion. However, between these shear zones is another parallel shear along the west margin of Garner Lake (Fig. GS-26-2).

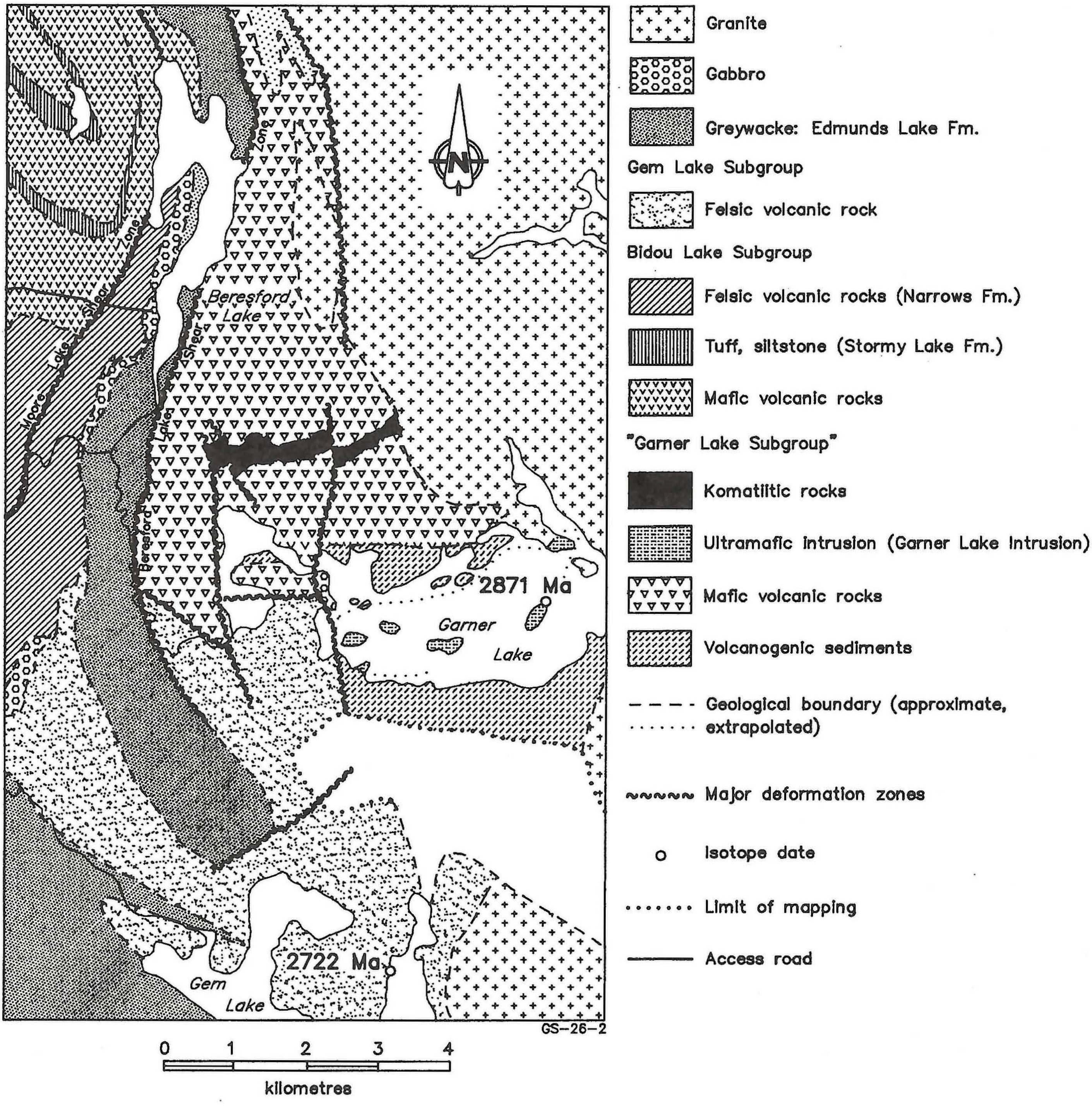

Figure GS-26-2: Revised geology of the Beresford Lake-Garner Lake area.

These major north-trending shear zones are the dominant features that separate the older and younger suites; provide a discontinuity along which the metamorphic grade increases; and offset and transpose the major earlier east-trending parallel primary and secondary fabrics. They also truncate an early east-trending ductile shear zone between felsic volcanic rock and basalt and gabbro in the west bay of Garner Lake (Fig. GS-26-2). The east-trending deformation zones do not contain the quartz-carbonate veins or pervasive alteration reported from the younger shear zones. As well, early east-trending primary layering and fabric exists in the > 2.8 Ga supracrustal sequence in the Garner Lake area. This is similar to trends in the older units at Wallace Lake.

The southeast-trending shear zones described by Brommecker *et al.* (1989) as early D_{1b} structures, related to the oldest recognized deformation within the Bidou Lake Subgroup, significantly offset these east-trending features and mark a structural contact between the Gem Lake Subgroup and the Bidou Lake Subgroup in the Beresford Lake area. However, at the west end of Garner Lake (Fig. GS-26-2), the east-trending shear zone, with felsic volcanics to the south and basalt and gabbro to the north is proposed as the break between the Gem Lake sequence (2.72 Ga) and the Garner Lake sequence (minimum age 2.87 Ga). This is similar to the east-trending Wanipigow Fault that separates the older portion of the Gem Lake and Wallace Lake subgroups from the Bidou Lake Subgroup. This may indicate early juxtaposition with the Bidou Lake Subgroup along an east-trending suture parallel to the Berens River Domain boundary with subsequent deformation during the Kenoran Orogeny (*ca.* 2.69 Ga).

Additional mapping and isotopic dating will be required to document the nature of the remnants of older lithologic units and structural trends in the supracrustal sequences.

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GS-27 GEOPHYSICAL SURVEYS FOR KAOLIN - SYLVAN AREA, MANITOBA

by I.T. Hosain, I. Ferguson[1], J. Ristou[1] and J. Cassels[1]

Hosain, I.T., Ferguson, I., Ristou, J., and Cassels, J., 1995: Geophysical surveys for kaolin - Sylvan area, Manitoba; **in** Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 140-147 .

SUMMARY

A range of geophysical methods were used in 1992 to delineate the kaolin deposits in the Sylvan area (Hosain, 1992). The program continued in 1994-95 with EM-31, VLF-EM, time-domain electromagnetic (TDEM), DC-resistivity and seismic refraction surveys. A gravity survey was also carried out in 1992 and 1994-95 but repeatability was not good and instrument drift was excessive in the later survey. Some of the 1994-95 surveys were conducted by Manitoba Geological Services Branch (GSB) whereas the remaining surveys as part of a field school coordinated in cooperation with the University of Manitoba's Department of Geological Sciences.

The objective of the surveys was to select the best technique for delineating the known kaolin-bearing channels and exploring for additional channels. All the techniques were successful in outlining the principal kaolin channels and confirmed the new probable channels delineated in 1992. The EM-31 data revealed the presence of additional shallow conductors, whereas the VLF-EM was successful in mapping the main deposit but provided poorer resolution of small-scale features. Time-domain EM measurements were considerably slower than EM-31 or VLF-EM measurements, but gave valuable information on the deeper structure of the deposits. Hammer seismic refraction was useful for defining locations of the channels and thickness of glacial drift.

LOCATION, GEOLOGY AND DRILLING

Location of the area is shown in Figure GS-27-1. Plans of some of the drill holes in section 14 are shown in Figures GS-27-2 and GS-27-3. For details on the geology of the area and drilling results refer to Hosain (1992).

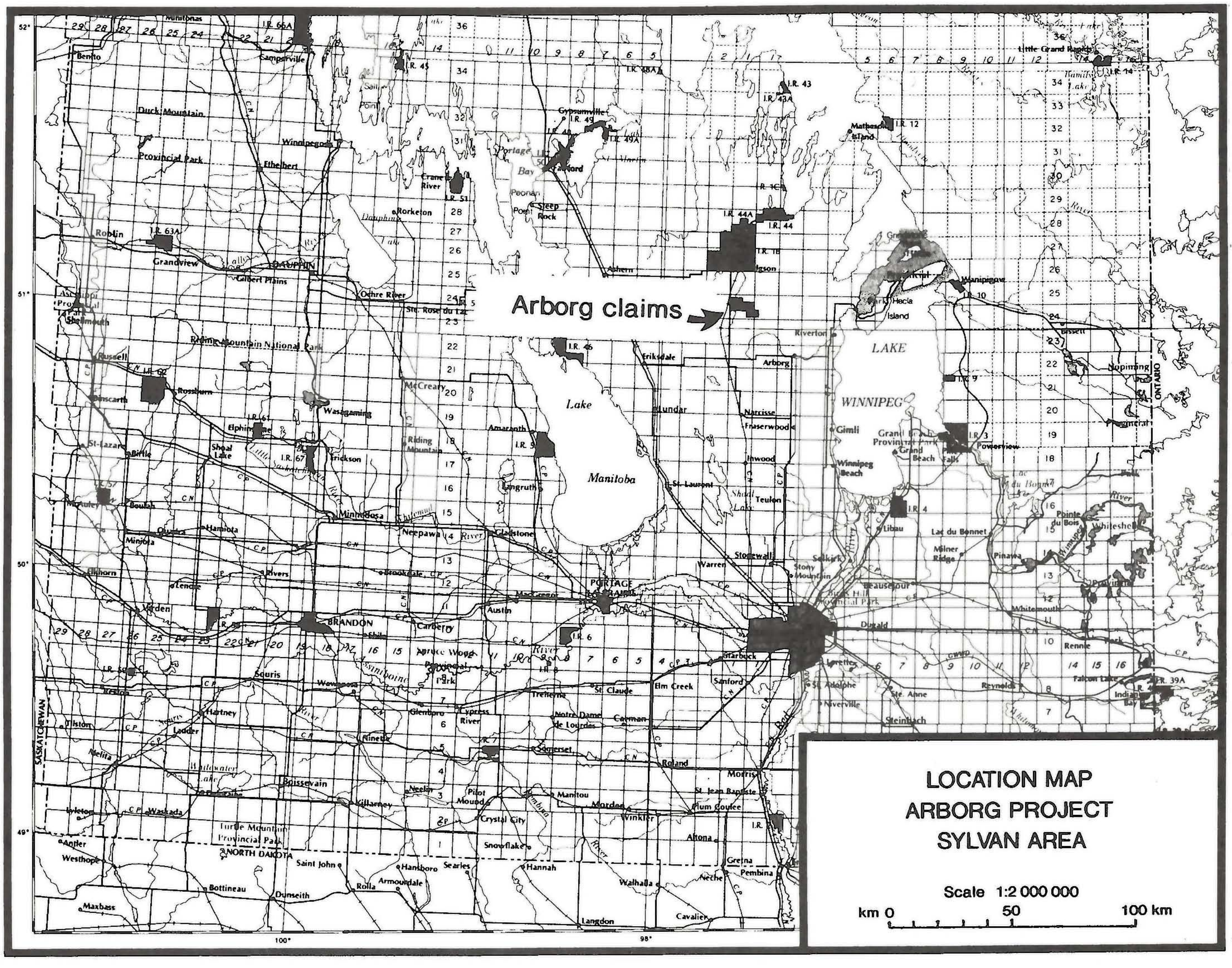

Figure GS-27-1: Location map, Arborg Project, Sylvan area.

[1] Department of Geological Sciences, University of Manitoba, Winnipeg, Manitoba R3T 2W8

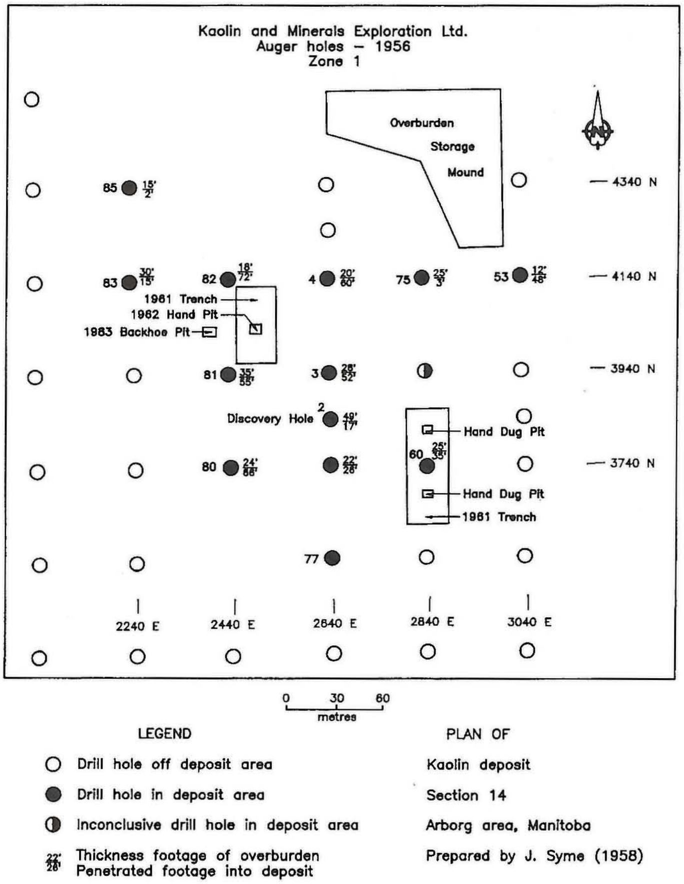

Figure GS-27-2: Plan of Kaolin and Mineral Exploration Ltd. auger holes 1956, zone 1.

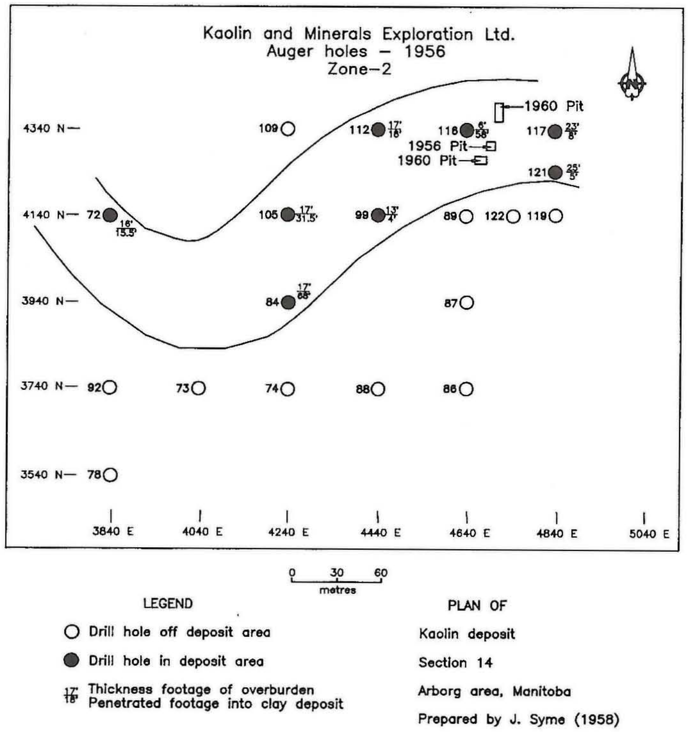

Figure GS-27-3: Plan of Kaolin and Mineral Exploration Ltd. auger holes 1956, zone 2.

RESULTS OF CURRENT WORK

Geological Services Branch Surveys

Results of this year's surveys by the GSB are shown in Figures GS-27-4 to -9. A rectangular traverse around the eastern pit was surveyed using EM-31 to determine the strike of the possible channel. Gravity readings were taken along the eastern north-south line of the rectangle. Reading were taken at 15 m intervals. The penetration of the EM-31 is approximately 6 m and it gives a direct read out of the conductivity in millimhos per metre. Figure GS-27-4 shows the outlines of the anomalous areas determined using the EM-31 data. Comparing the results from this figure with those in Figure GS-27-2, one can see the close relationship between the measured conductivity and drillhole results. The kaolin deposit seems to pinch out just east of the pit, and another northwest-southeast striking anomalous area is located towards the northeast part of the rectangle. This corresponds to the drill results shown in Figure GS-27-3.

Results of the gravity traverse are shown in Figure GS-27-5. A computer interpretation of the gravity data using the GSC's MAGRAV 2 modelling program (Broome, 1989) is shown in Figure GS-27-6.

A north-south line adjacent to the western pit previously surveyed using the VLF-EM, gravity and EM-34 was resurveyed using the EM-31 instrument. The anomalous areas from the EM-31 coincide with the strong anomaly in proximity to the pit and two lower amplitude anomalies to the south shown in Figure GS-27-7.

University of Manitoba Surveys

Various geophysical methods were applied in the area of the pits and along some section roads as part of the field training of students from the University of Manitoba. Figure GS-27-8 shows the grid and the recording stations of the various surveys. Figure GS-27-9 shows the apparent conductivity results using the EM-31 unit. Note the high conductivity area between the pits as well as to the south and northeast. These results suggest that the form of the deposit is more complex than a series of discrete channels.

The results of the VLF-EM surveys are shown in Figure GS-27-10. There is clearly a correlation with the EM-31 results. However, many of the VLF-EM anomalies are shifted to the north or south of the EM-31 anomalies. The VLF-EM response is spatially smoother than the EM-31 response. The slight offset of the same anomalies outlined by both methods may be caused by the contrasting depth of penetration. (The EM-31 is reflecting the shallow part of the channel, and the EM-16, the deeper part of the same channel).

The DC-resistivity results confirmed the EM-31 and VLF-EM results. The TDEM results shown in Figure GS-27-11 outline the conducting layers in the area of the pits and the southern extension of the probable conducting material. The skin-depth (depth of exploration) with this method is greater than 200 m, and therefore would be adequate to determine the probable depth extent of the conducting horizons.

The hammer seismic survey produced a less uniform response within the high-conductivity areas than in the background areas. The profiles show three layers - (1) an upper layer with a velocity of 330 ms^{-1} and thickness of 3 m overlying (2) a layer of velocity of 1200 mS^{-1}, which is probably the kaolinite/silica-sand/lignite material, and (3) a bedrock (limestone) velocity of approximately 3000 mS^{-1}.

Approximately 4 line-km of EM-31 profiles and 1 line-km of VLF-EM profile were carried out on section roads surrounding the main survey site in order to investigate other probable kaolinite-bearing channels. The results are shown in Figure GS-27-12. The anomalous areas of the 1992 surveys correlate well with the anomalous areas outlined by this survey.

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1989: An interactive magnetics and gravity modelling program for microcomputers (version 1.5); Geological Survey of Canada, Open File 1334, 43p.

Hosain, I.
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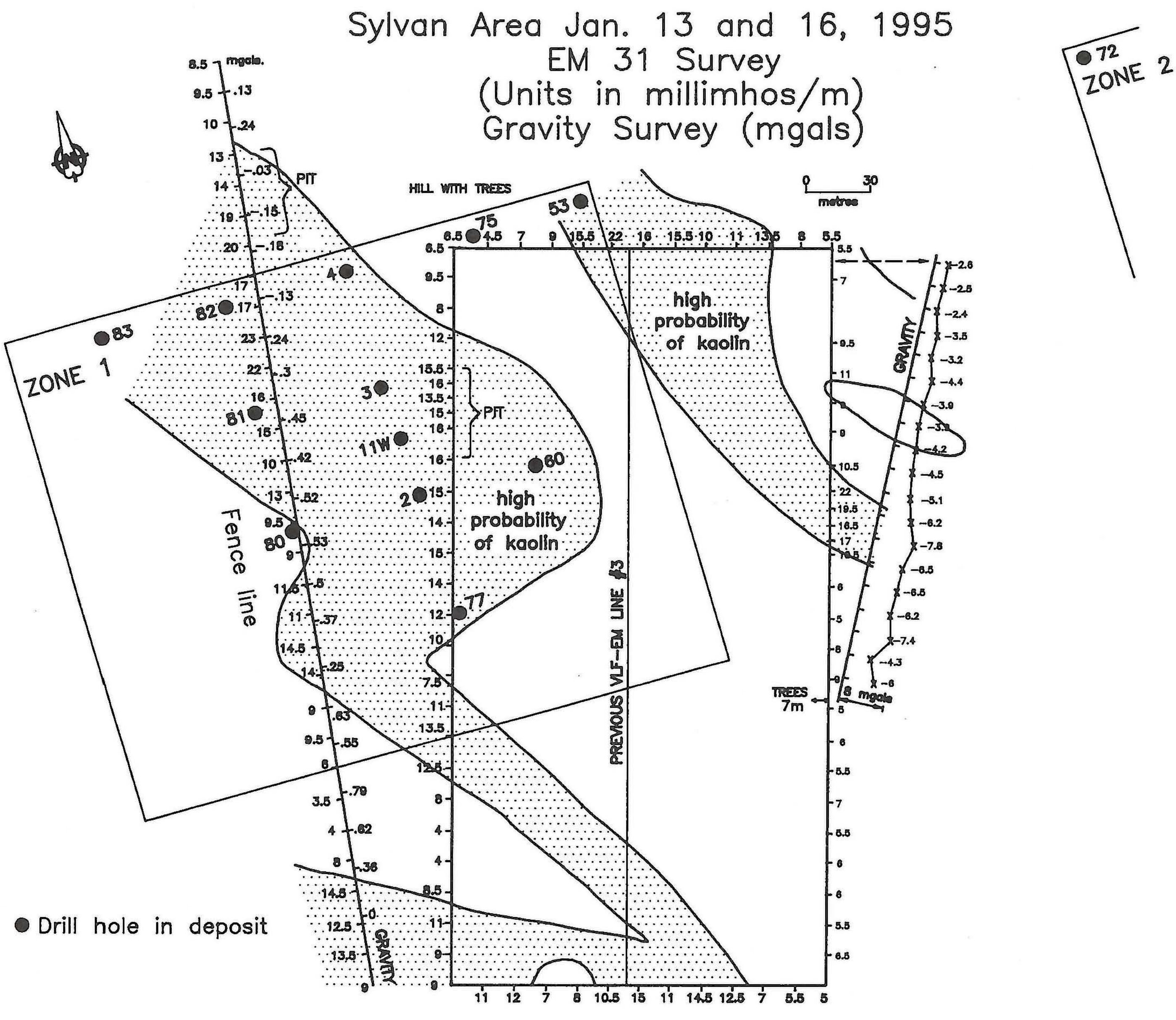

Figure GS-27-4: Sylvan area, January 13 and 16, 1995 EM31 survey (units in millimhos/m) and gravity survey (mgals).

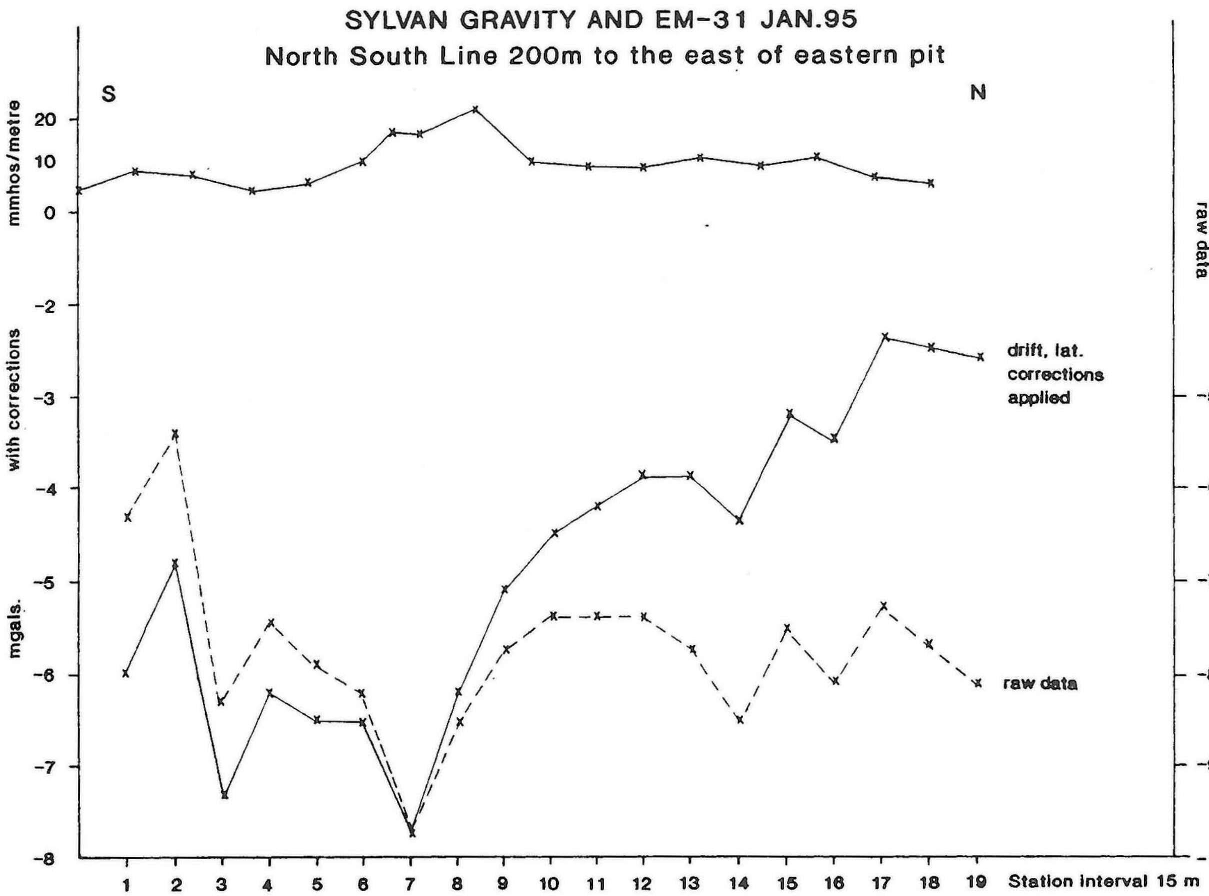

Figure GS-27-5: Profile of Sylvan gravity and EM31 surveys, January 1995. North-south line 200 m east of eastern pit.

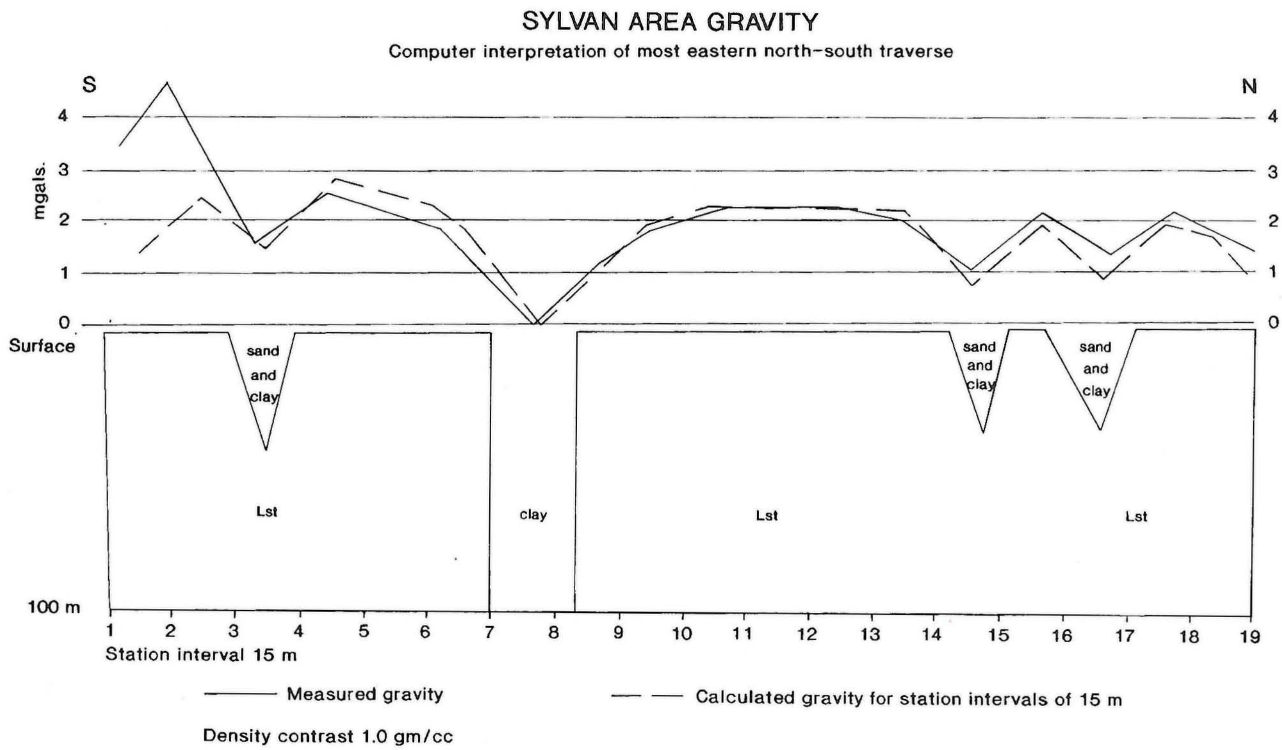

Figure GS-27-6: Computer interpretation of Sylvan area gravity survey, easterly north-south traverse of rectangle.

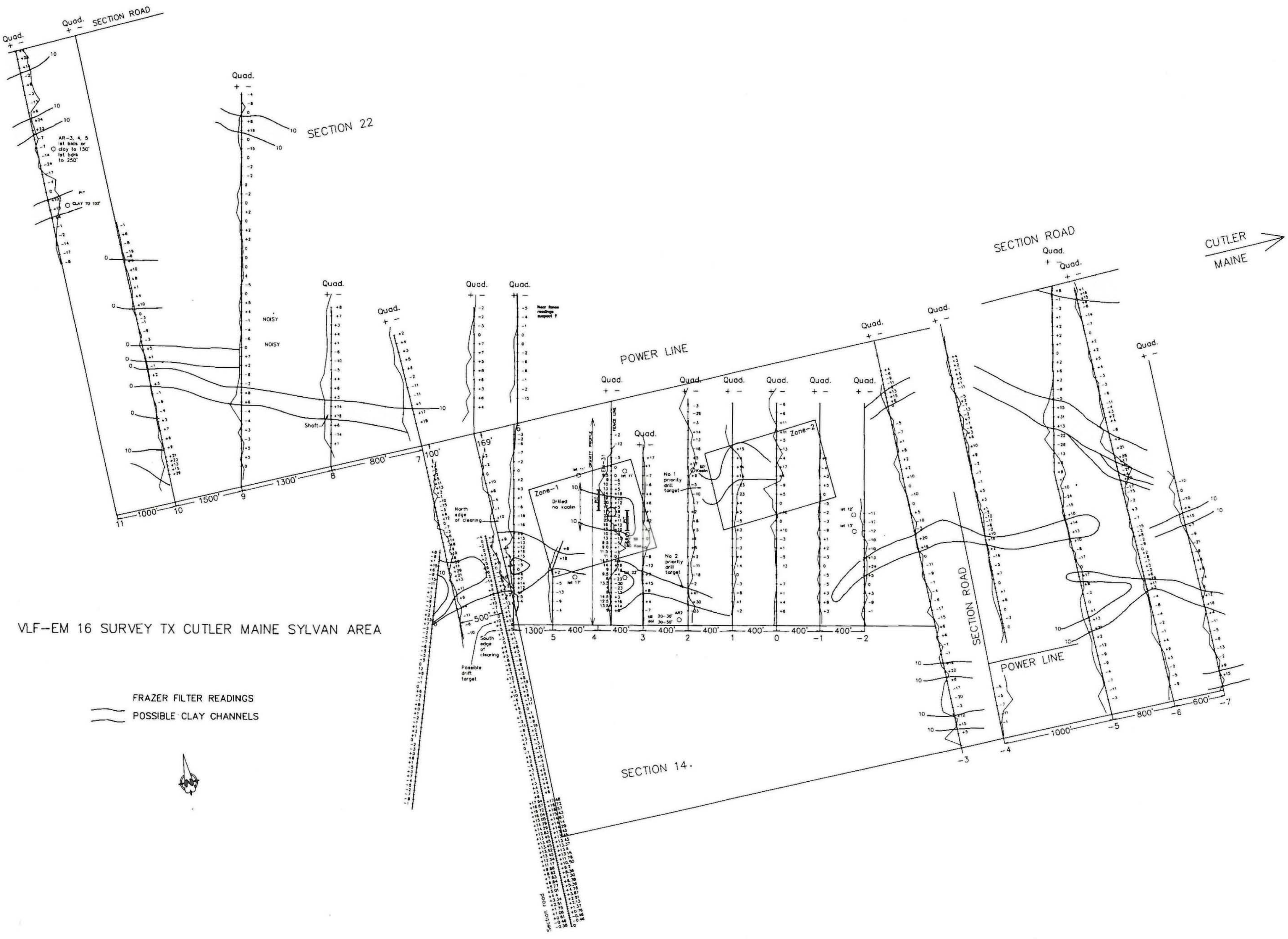

Figure GS-27-7: VLF-EM 16 survey, Sylvan area. Tx Cutler, Maine.

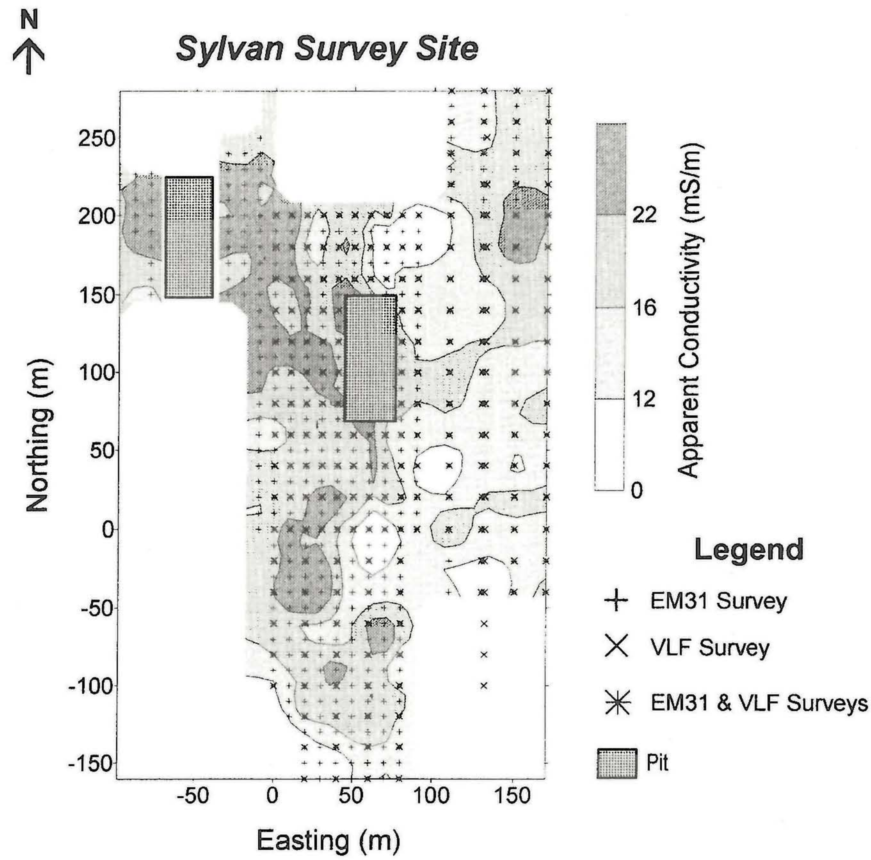

Figure GS-27-8: Detailed map of the EM-31 and VLF-EM surveys. Note the locations of the test pits. The Blank area in the southwest section of the map corresponds to a wooded area. The shaded areas show regions of low, intermediate, and high conductivity as mapped in the EM-31 vertical dipole response.

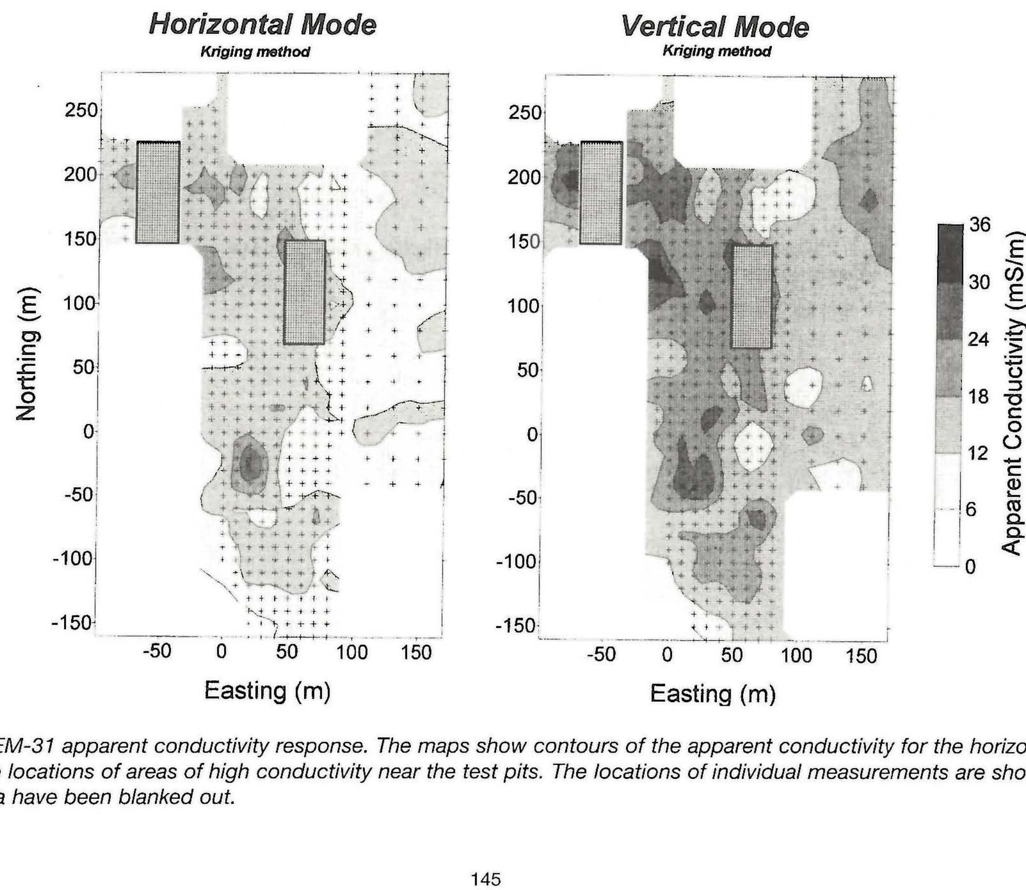

Figure GS-27-9: The EM-31 apparent conductivity response. The maps show contours of the apparent conductivity for the horizontal and vertical components. Note the locations of areas of high conductivity near the test pits. The locations of individual measurements are shown by crosses and areas with no data have been blanked out.

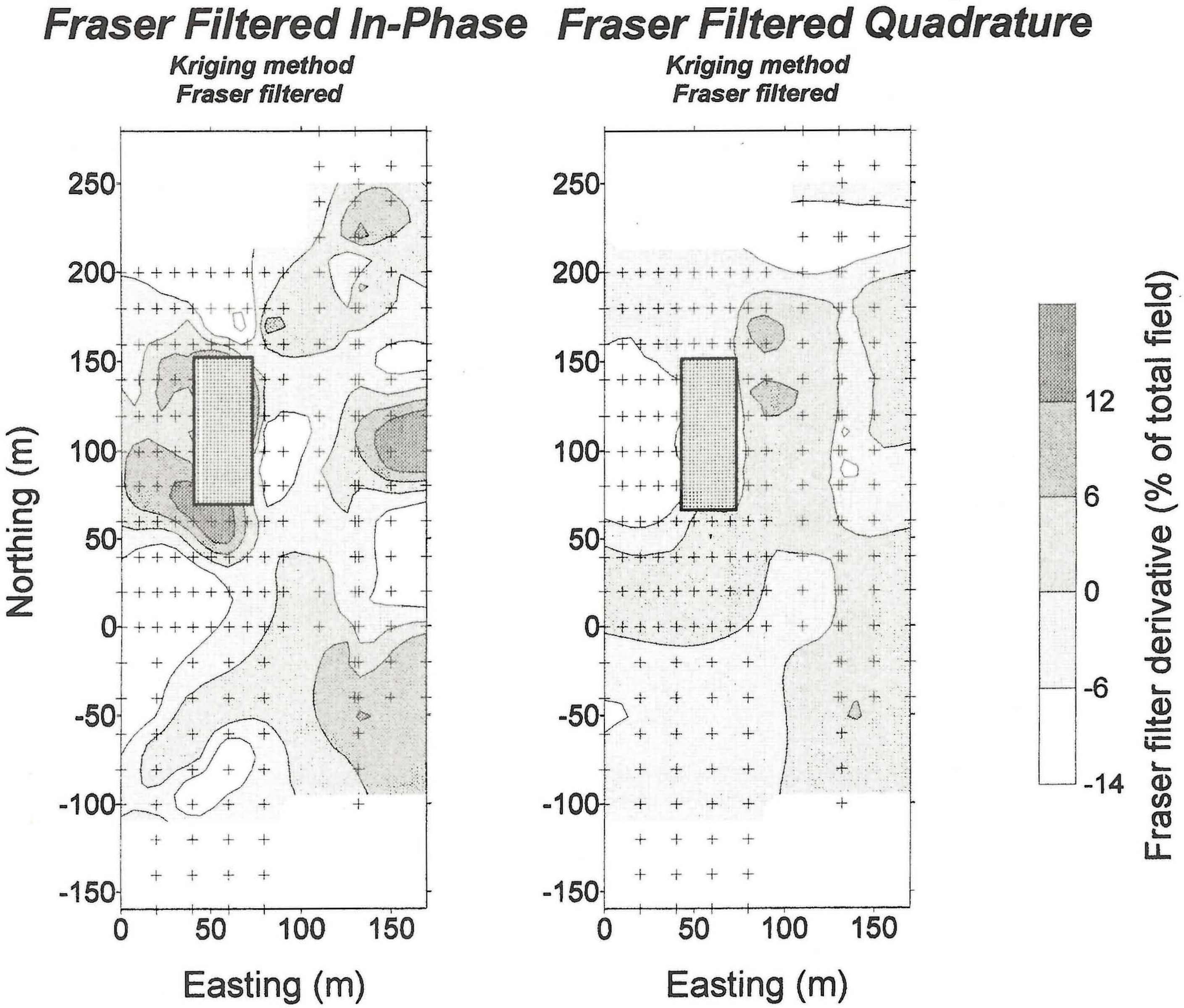

Figure GS-27-10: The Fraser filtered VLF-EM response. The in-phase and quadrature components of the total field are shown. Areas of high conductivity correlate with positive values of the in-phase response. Note the location of areas of positive in-phase response around the test pit.

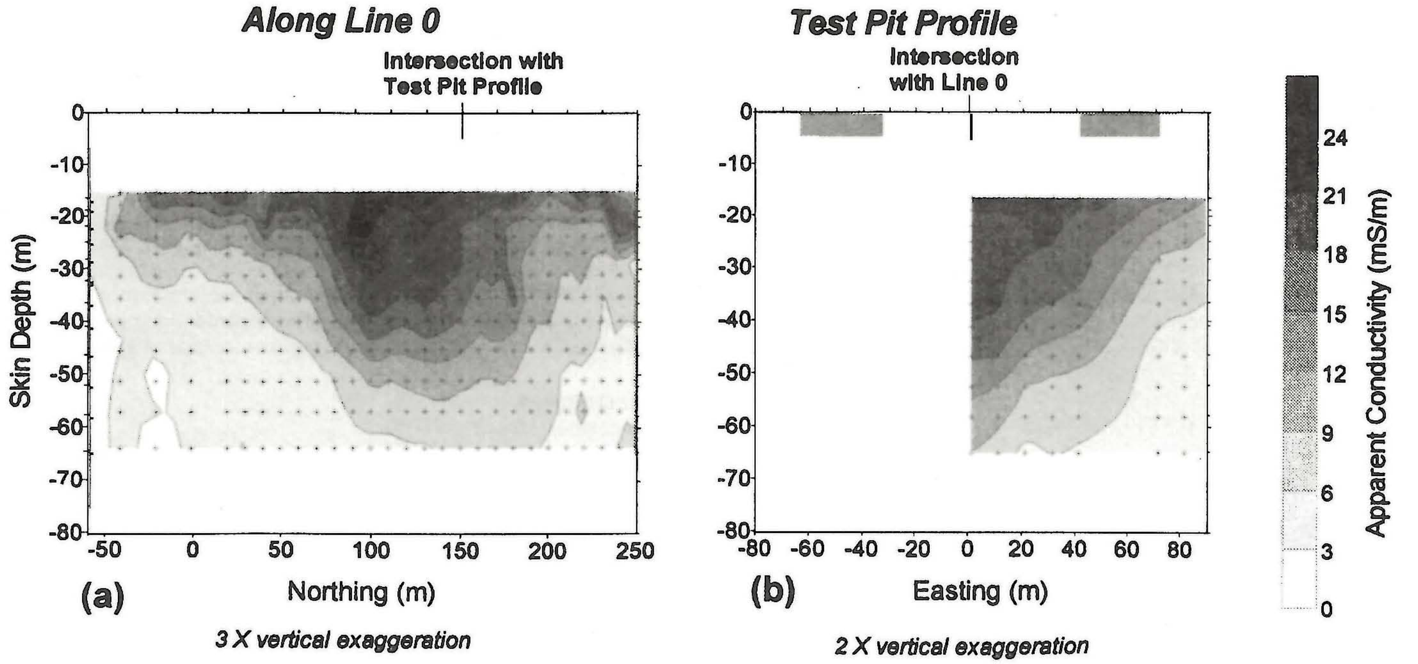

Figure GS-27-11: Pseudosections of the TDEM apparent conductivity response. (a) Results for Line 0E. (b) Results for profile between the two test pits. Note the different horizontal scale (and vertical exaggeration) for the two profiles. The point of intersection of the profiles is at 150 m on line 0E and 0 m on the test pit profile.

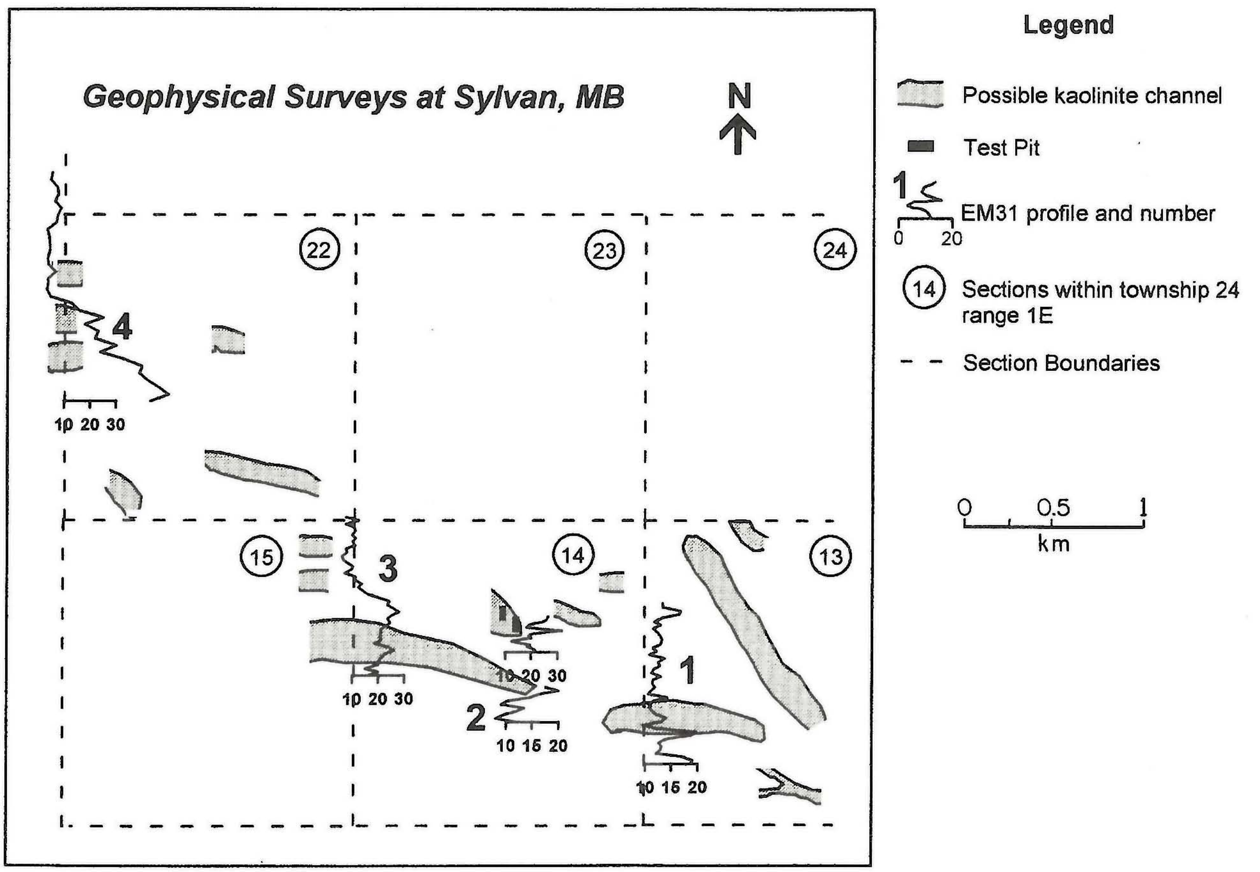

Figure GS-27-12: Map showing profile locations and response for the large-scale EM-31 surveys. Line 0E results have also been included. Shaded areas show postulated kaolinite-filled channel deposits identified from VLF-EM surveys (Hosain, 1992). Note varying scale for the different profiles.

GS-28 SPHAGNUM PEAT INVENTORY IN SOUTHEAST MANITOBA (NTS 52E)

by B.E. Schmidtke

Schmidtke, B.E., 1995: Sphagnum peat inventory in southeast Manitoba (NTS 52E); **in** Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 148-150.

The 1995 peatland inventory program was designed to provide experience in collecting and analyzing peat samples, to ground truth a map of wetlands in the NTS 52E map area (Fig. GS-28-1) and to determine if there are reserves of horticultural quality sphagnum in southeast Manitoba additional to those described by Bannatyne (1980).

Linda Halsey (University of Alberta) mapped the wetlands in the entire Province of Manitoba at 1:250 000 scale using aerial photograph interpretation. The 55 draft 1:250 000 maps are being compiled into a 1:1 000 000 map in a joint project between the University of Alberta and Manitoba Energy and Mines. A three-week field season to document and sample sphagnum bogs identified in the NTS 52E map sheet was undertaken.

Several small bogs classified as 70 to 100% bog were identified in NTS map area 52E by Halsey (1995) (Fig. GS-28-2). These are exclusive of the bogs described in Bannatyne (1980). Seven of the bogs that can be safely accessed on foot were sampled. Six of the seven bogs are sphagnum bogs. The Piney bog contains sphagnum over less than 25% of the area identified by Halsey. This is probably because it is within developed farmland and may have been drained since the photographs were taken. The Caribou Point bog is located 1 km south of the site shown on the draft map.

None of the six bogs contain economic reserves of horticultural quality sphagnum. In all of the bogs, samples below one metre of surface are humified (H5+ on the Von Post scale) and appear in field examination to contain less than 75% sphagnum. Although none of the bogs are commercial, the north lobe of the Birch Lake bog (Fig. GS-28-3) was sampled in detail to provide material for further research. These samples have been analyzed for moisture content and pH and will be analyzed for botanical assemblage and percentage of sphagnum.

REFERENCES

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Halsey, L.

1995: Wetlands in NTS 52E, University of Alberta, unpublished map.

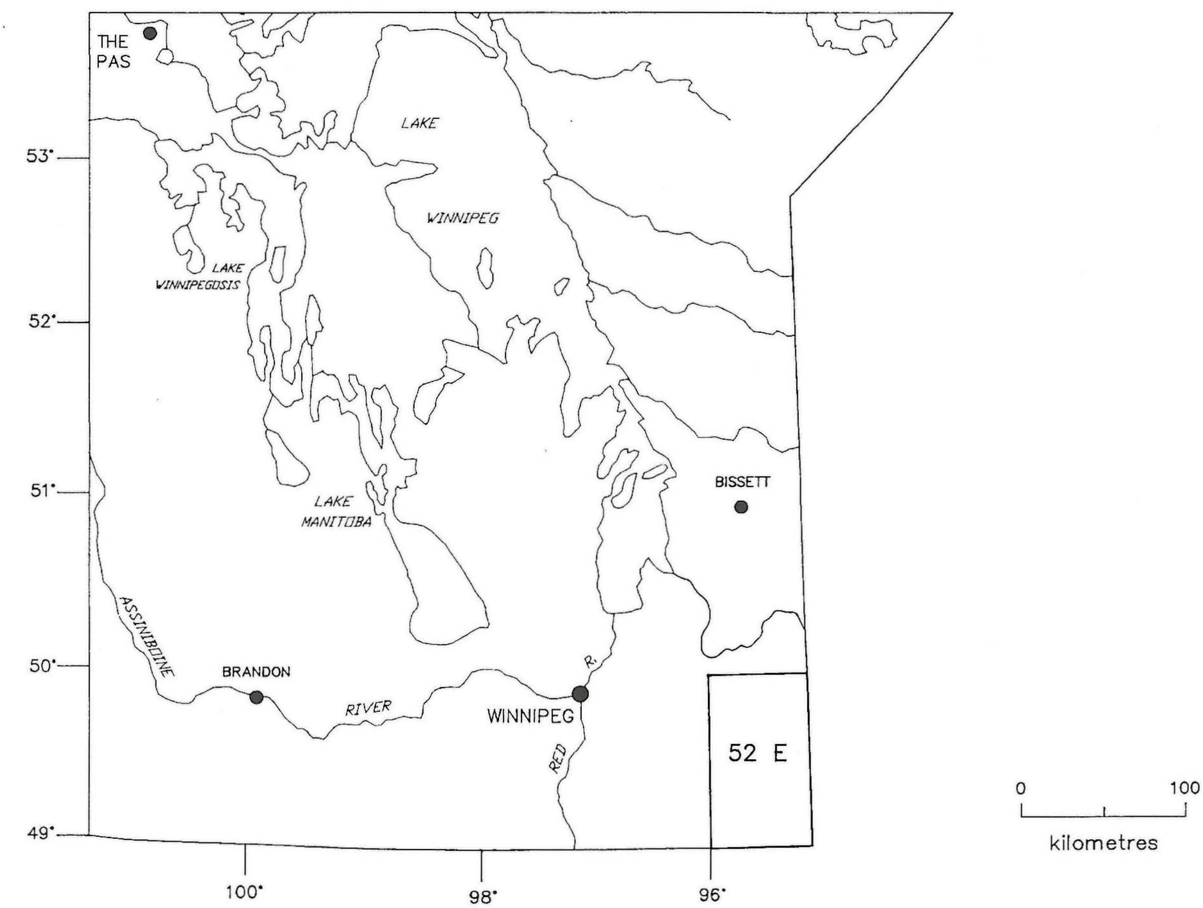

Figure GS-28-1: Study area for the sphagnum peat inventory in southeast Manitoba.

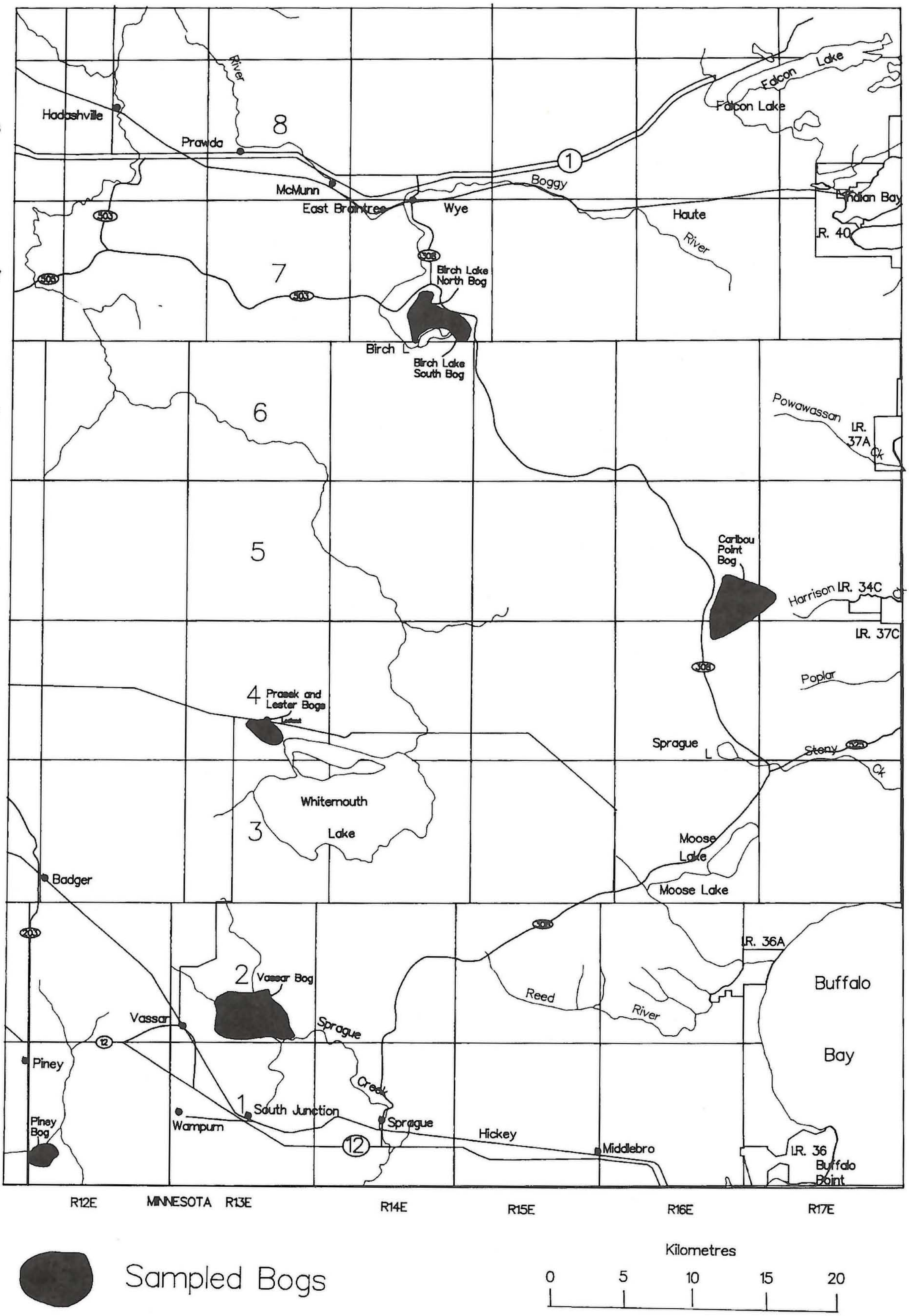

Figure GS-28-2: Sampled bogs in the study area.

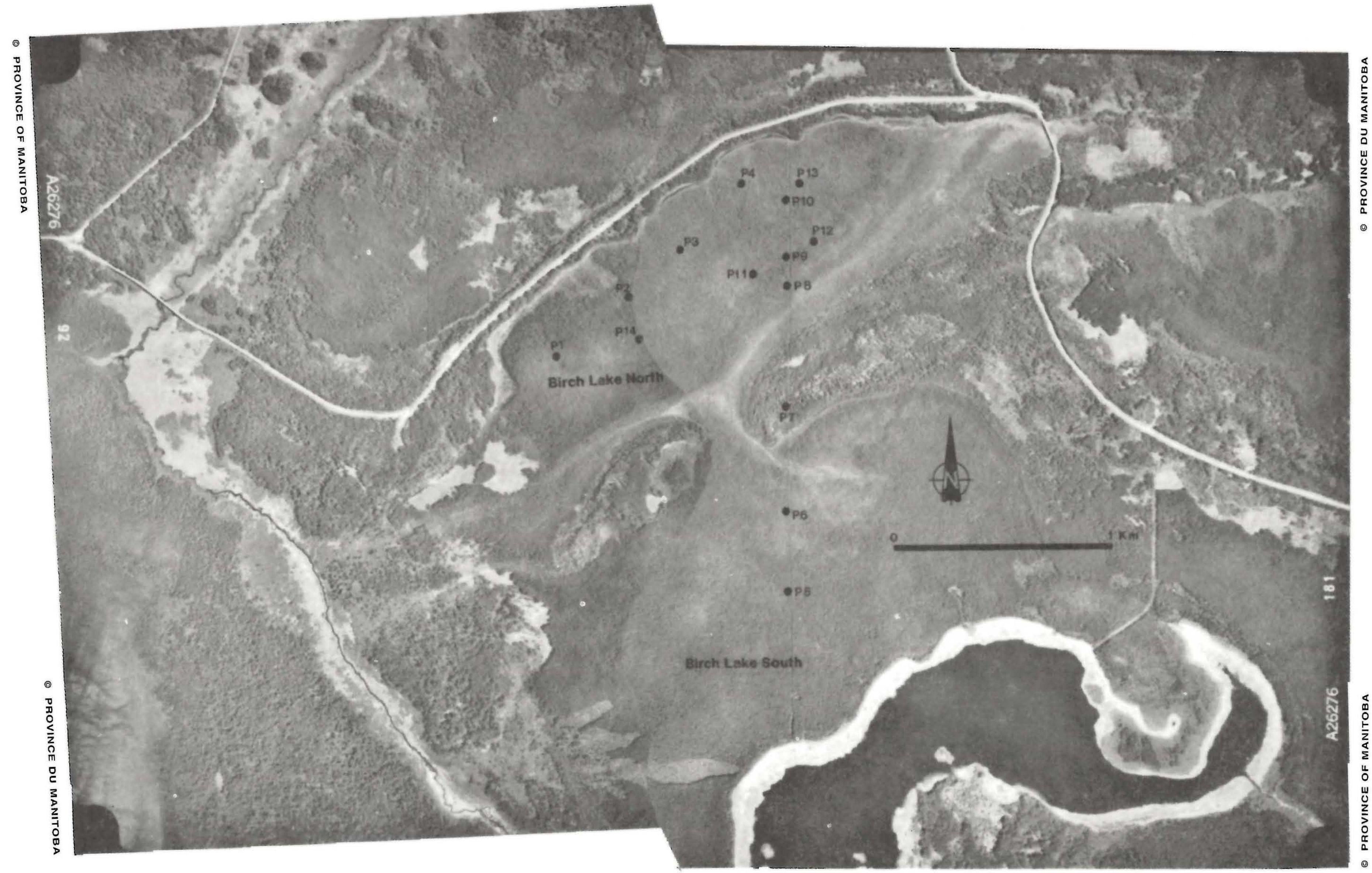

Figure GS-28-3: Aerial photograph showing sample locations in the Birch Lake North and Birch Lake South bogs.

GS-29 CAPITAL REGION RESOURCE EVALUATION PROJECT (NTS 62I/3)

by J.D. Bamburak and R.K. Bezys

Bamburak, J.D., and Bezys, R.K., 1995: Capital region resource evaluation project (NTS 62I/3); **in** Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 151-154.

SUMMARY

A reverse population movement from Winnipeg to the surrounding municipalities has been occurring since the early 1970s. This movement has resulted in the municipalities changing from rural agricultural to semi-urban environments. This change has been accompanied by increased pressure by environmentalists to restrict quarrying of sand, gravel and crushed stone. Extraction of these commodities forms the largest mining sector in the province by volume produced and land acreage disturbed.

To address this and other problems within a sustainable development framework, the Manitoba Round Table initiated the **Capital Region Strategy**. In response, the Mines and Geological Services branches of Manitoba Energy and Mines are jointly conducting a staged mineral resource and a land use assessment of the region to provide sound technical information and evaluation of the mineral resources (within the **Minerals Strategy** of the Round Table's Land and Water Strategy).

The first portion of the Capital Region to be evaluated comprises the rural municipalities of Rockwood, St. Clements and St. Andrews. Within these municipalities, the Rockwood area was selected for geological mapping at 1:20 000 scale based upon quarry inventories and water-well records. Depth to bedrock, regional geology and mineral potential maps (showing resources of crushed stone, sand and gravel, *etc.*) will be compiled to assist in the production of municipal development plans for the Capital Region.

INTRODUCTION

A reverse population movement from Winnipeg to outlying towns and municipalities (Fig. GS-29-1) has been taking place since the early 1970s. This has resulted in these surrounding rural agricultural municipalities becoming semi-urban in character. Land use conflicts have arisen where rural residential development occurs near mining activities or on top of potential mineral resources. Quarrying is a heavy industrial land use, which can involve blasting, crushing, screening, operation of heavy equipment and local truck traffic that may be disruptive to local residents.

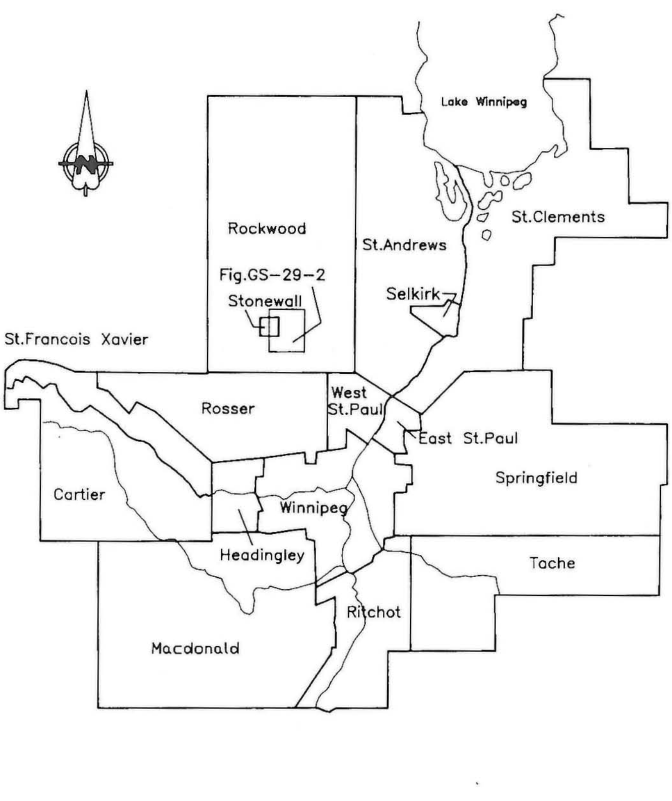

Figure GS-29-1: Capital Region map.

The Manitoba Round Table on the Environment and the Economy (established in 1988) initiated the definition of a Sustainable Development Strategy for Manitoba's Capital Region in 1993. This is part of a larger strategy to deal with the environment, economy and people of Winnipeg, Selkirk, Stonewall and the surrounding municipalities shown in Figure GS-29-1, This process is discussed in a *Workbook on the Capital Region Strategy* (Manitoba Round Table, 1995) that was released in March 1995, and which was used in public open houses and workshops during the summer.

Policy 4.3 of the Capital Region Strategy states that "Economically valuable mineral deposits shall be protected from land uses which limit mineral exploration and development. Mitigative action shall be taken to minimize environmental and human health impacts from mining operations." Within the strategy, these mineral deposits will be protected in municipal development plans (with reviews every 5 years) and in zoning bylaws under the Planning Act. Until the plans or bylaws are in place, Provincial Land Use Policy #9 is used to protect known deposits.

Under Policy 4.3, the identification, evaluation and protection of significant mineral deposits is the responsibility of the Manitoba Government. This policy corresponds with Policy 3.1 of the Manitoba Round Table's Minerals Strategy (within its Land and Water Strategy). The Minerals Strategy is documented in *Applying Manitoba's Mineral Policies* (Manitoba Round Table, 1994), which was produced after public consultation in 1991.

To identify and evaluate these mineral deposits, Manitoba Energy and Mines' Mines Branch requested Geological Services Branch (GSB) assistance in the compilation of mineral resource and other geological information. The rural municipalities of Rockwood, St. Clements and St. Andrews (Fig. GS-29-1) were selected as the first municipalities to be assessed and mapped. To provide the required information in sufficient detail for land-use purposes, it was decided to produce a computerized database consisting of: digitized 1:20 000 topographic maps; depth to bedrock maps using water-well records; detailed stratigraphy from outcrop, quarries and coreholes; and mineral potential rating, based on end use.

The Rockwood map sheet (UTM AN35; Fig. GS-29-2) was selected as the initial target for assessment because it contains economically important crushed stone production. The sheet covers the northern two-thirds of Tp. 13 and southern one-third of Tp. 14, Rge. 2EPM and is totally contained in the Rural Municipality of Rockwood. The south margin of the sheet contains the northern half of Stony Mountain and the west margin contains the eastern town limit of Stonewall. The sheet is roughly bisected north-south by P.T.H. 7 and east-west by P.T.H. 67.

STRATIGRAPHY

The Paleozoic bedrock geology of the Rockwood area, as mapped by Bannatyne (1988), is Ordovician dolomite and argillaceous dolomite and shale (Table GS-29-1). The beds dip shallowly west-southwest and appear as a series of nearly parallel north-south trending outcrop belts. These belts are mostly covered by glacial till and lacustrine sediments, but exposures or near-surface bedrock occur in the west half of the area and at Stony Mountain.

The resistant dolomite of the Gunton Member, Stony Mountain Formation acts as a caprock above softer, more argillaceous Penitentiary and Gunn members (Table GS-29-1). The Gunton Member forms the top of a shallowly buried east-facing escarpment 4 km east of Stonewall (parallel to P.T.H. 7, immediately east). It also caps Stony

Table GS-29-1
Table of Ordovician Formations in the Rockwood Area

Formation	Maximum Thickness	Lithology
Lower Stonewall	7.3 m	
lower beds		Dolomite, marker beds
Williams Member		Dolomite, argillaceous, arenaceous
Stony Mountain	41.2 m	
Gunton Member		Dolomite
Penitentiary Member		Argillaceous dolomite
Gunn Member		Calcareous shale to argillaceous dolomite, fossiliferous
Red River Formation	135.7 m	
Fort Garry Member		Dolomite; limestone
Selkirk*		Dolomitic limestone; cherty, limestone
Cat Head*		Dolomite
Dog Head*		Dolomitic limestone
Winnipeg Formation*	40.2 m	Sandstone, shale

* present in subsurface only.

Mountain, an erosional outlier 7 km southwest of Stonewall. Similarly, dolomite beds of the lower Stonewall Formation (beneath the T-zone) are more resistant than the underlying argillaceous Williams Member, and form the top of another escarpment that underlies the town of Stonewall.

RESOURCE EVALUATION

Three principal sets of data will be used to compile the bedrock resource base for the Capital Region:

1. digital 1:20 000 topographic base (provided by Land Information Division);
2. depth to bedrock information from water well logs (from Water Resources Branch); and
3. stratigraphic data from surface mapping and near-surface drilling (GSB).

The final composite map including depth to bedrock contours and stratigraphic contours, will be used to assess the economic potential of the quarries and resource quality and reserves. The mineral potential map will identify depleted deposits and new targets for exploration.

A parallel assessment is being undertaken for sand and gravel resources in the Capital Region by Mines Branch.

ROCKWOOD AREA

Sixteen quarries were inventoried in the Rockwood area. A data sheet (Fig. GS-29-3), modelled after Goudge (1944), was generated for each quarry. The areal extent of each quarry was sketched and selected quarry sections were described, sampled and photographed.

All field information will be combined with historical descriptions, mineral inventory cards, property ownership maps, and mineral disposition maps. This information will be available for reproduction on demand.

Crushed Stone

Extraction of crushed stone, sand and gravel forms the largest mining sector in the province by volume produced and by acreage of disturbed land. These are non-renewable resources that have no suitable, cost-effective engineering substitute for most end uses, *e.g.*, road construction, concrete and asphalt.

The most important crushed stone source in the province is located in the Rockwood area. The near-surface Gunton Member of Stony Mountain Formation meets the required engineering specifications (most bedrock formations in the province do not). During the summer months, hundreds of crushed stone truckloads per hour leave the nine operating quarries, situated 1 to 4 km northeast of Stonewall (Fig. GS-29-2). Much of the production travels along P.T.H. 7 to construction projects in Winnipeg. Of the nine quarries, two are almost depleted of the Gunton beds and have been essentially replaced by newer quarries. Two other quarries in the vicinity with abundant stone are dormant.

Building Stone

In the late 1800s and early 1900s, building stone blocks were removed from the lower Stonewall Formation (Table GS-29-1) in quarries near Stonewall (Fig. GS-29-2). Some of this stone was used locally, but some was shipped to Winnipeg for building construction. Similarly at Stony Mountain, quarried stone from the Gunton Member was used locally, such as for the Stony Mountain Institution, as well as for churches, homes, stores and other buildings.

Tyndall stone from Garson has replaced local stone usage in Rockwood area. This can be seen in older buildings that have been remodelled or in newer construction. This may be due to several factors:

1. the change in construction methods, from building stone (to support the weight of the structure) to dimension stone (to cover the internal wood and steel supports;
2. the lack of local skilled artisans to "work" the stone;
3. the bland appearance of the local stone compared to the mottled Tyndall stone, which has been called "Tapestry stone"; and
4. shortage of stone with suitable bedding plane separation

Dolomitic Lime

Seven quarries operated at Stonewall from the late 1800s to 1967, producing mostly dolomitic lime for whitewash, plaster, cement and paper making. Two of these quarries were situated in the Rockwood area (Fig. GS-29-2). The lime was produced in pot and draw kilns, many of which are still standing. The most notable operators were Manitoba Quarries Ltd. and The Winnipeg Supply and Fuel Company, Limited. The lime was known among local masons for its high quality. Dolomite reserves were exhausted in 1965.

Winnipeg Supply's Irwin Quarry and its kilns are preserved as Stonewall Quarry Park (located just west of the Rockwood map area), where an interpretive centre has been built to document the history of dolomitic lime production at Stonewall.

FURTHER WORK

Priority for future resource evaluations will be given to map areas where previous mineral extraction has occurred, such as near the towns of Gunton and Garson. Subsequent map areas with near-surface bedrock, as identified by Bannatyne (1988), will also be evaluated.

ACKNOWLEDGEMENTS

Chuck Jones (Mines Branch) is gratefully acknowledged for the contribution of his speaking notes of a talk on the "Aggregate Industry in the Winnipeg Region" presented to the Winnipeg Branch of the C.I.M. on May 11, 1995. Ed Truman greatly assisted this project by acquiring the 1:20 000 digital base from the Land Information Division of Manitoba Natural Resources. The locations of water-wells and logs were extracted from the Water Resources Branch database by Barbara

Miskimmin. The inventory of sand and gravel resources is ably being carried out by Heather Groom. Assistance in the field was conscientiously provided by Terrie Hoppe.

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Goudge, M.F.

1944: Limestones of Canada; their occurrence and characteristics: Part V, Western Canada; Bureau of Mines, Canada, Mines and Geology Branch, Report 811, 233p.

Manitoba Round Table

1994: Applying Manitoba's mineral policy; Manitoba Round Table on Environment and the Economy; Sustainable Development Coordination Unit, 71p.

1995: Workbook on the Capital Region Strategy; Manitoba Round Table on Environment and the Economy; Sustainable Development Coordination Unit, 59 p.

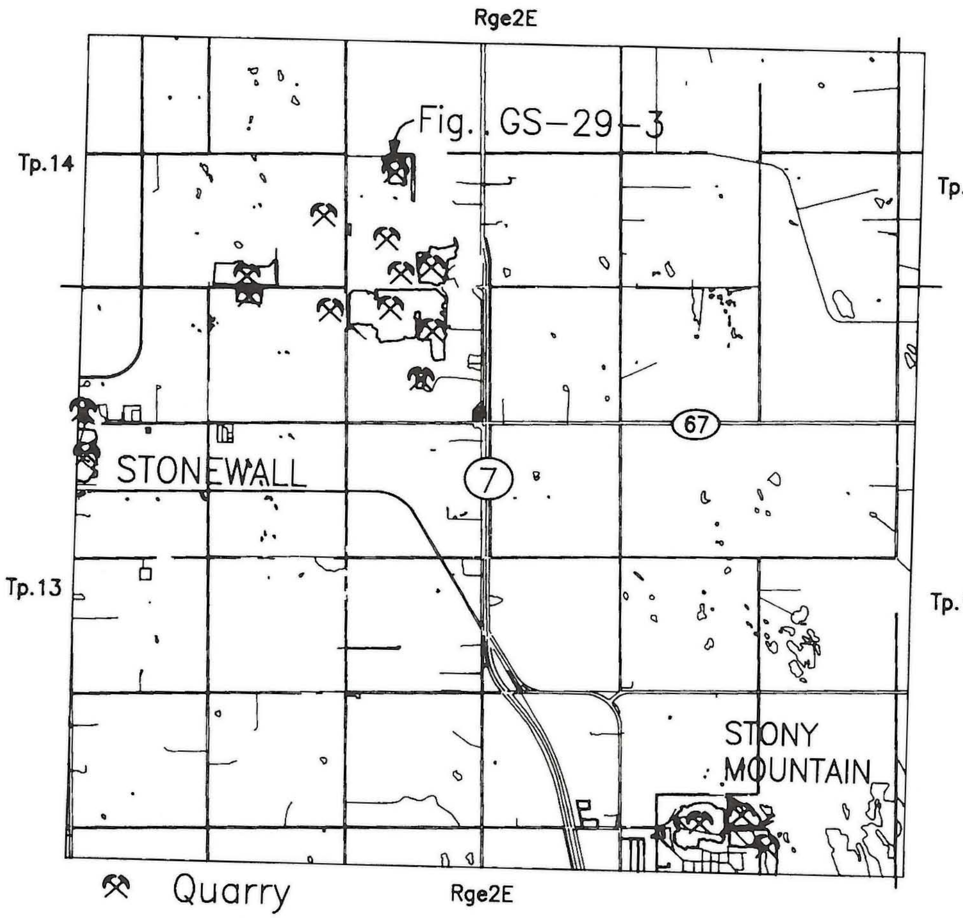


Figure GS-29-2: Rockwood area (map sheet, UTM AN35).

QUARRY / OUTCROP DATA SHEET

UQI: 1Q/14-04-14-02E1 **UTM (at section):** 623800E 5558525N

NAME: Bison Quarry **DATE:** June 27/95

OWNER: Riverside Gravel Ltd. **VISITED BY:** RB / JB

OPERATING: Y N

LOCATION: Stonewall area

SIZE: Very large

THICKNESS: 4.2 m in pit / 4.9 m in quarry **OVERBURDEN THICKNESS:** 0.5 to 2.0 m

USE: crushed stone

REFS: Bannatyne (1988) **MAPS:** Rockwood AN35, 62I/3

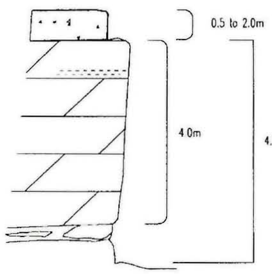
PHOTO #s: 88-1-11 O/B; 12-13 pit; 14 section; 15-16 top; 17-19 panoramic **JOINTS:** 30°

FORMATION: Stony Mountain Fm, Gunton and Penitentiary mbrs. **FRACTURES:** blocky

FOSSILS: worm burrows, chondrites **MINERALIZATION:** no

SECTION:

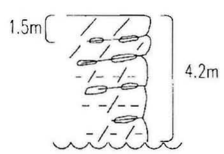
Quarry



overburden 0.5-2.0 m

Gunton Member; lt. brown buff (weathered and fresh); wackestone; thin to medium bedded; 8-10% Φ, vuggy; f-m xline; some recessive beds, especially at top (dolomite); at base are interbedded red brown to blue green mudstones

Pit:



Gunton Mbr.

Penitentiary Mbr: dolomite; interbedded red to brn to blue green mudstone; medium to thick bedded; fg; abdt worm burrows (Chondrites); recessive seams are red brn and extensively burrowed; 1-2% Φ, p.p..

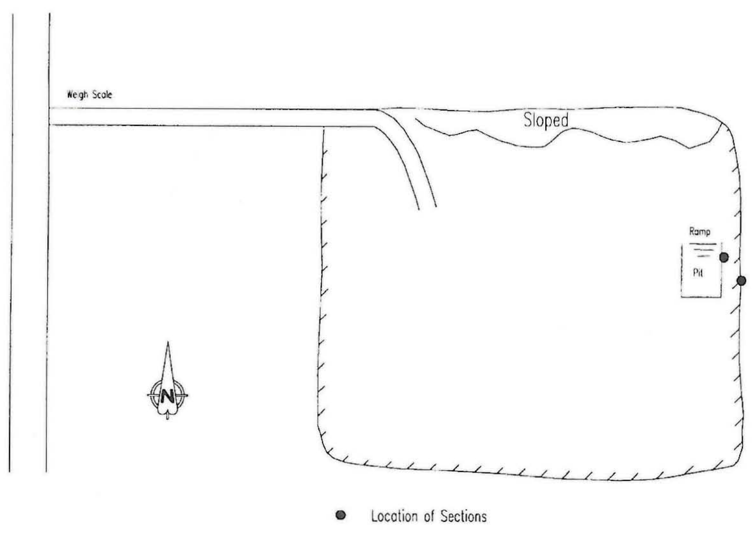


Figure GS-29-3: Bison Quarry data sheet.

GS-30 QUATERNARY STUDIES IN SOUTHERN MANITOBA, A PROGRESS REPORT

by G.L.D. Matile

Matile, G.L.D., 1995: Quaternary studies in southern Manitoba, a progress report; **in** Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 155.

SUMMARY

Field mapping was completed in the Virden area (southwestern Manitoba) this summer. This completes all field mapping in the Southern Prairie NATMAP, as the southeastern Manitoba portion was completed in the summer of 1994. Data collected emphasized engineering, environmental, and groundwater geology and will be included in a GIS-oriented database. Four preliminary maps at 1:100 000 scale have been released: two for the Virden area (Oak Lake-62F/NE and Whitewater-62F/SE) and two for the southeastern Manitoba area (Falcon Lake-52E/NE and Whitemouth Lake-52E/SE). Till samples from the Westlake Plain, in west-central Manitoba, have been analysed for kimberlite indicator minerals, geochemistry, matrix carbonate content and pebble composition. Data will be displayed at the 1995 Manitoba Mining and Minerals Convention. Interpretation of biostratigraphical analysis of core from the Wampum area in southeastern Manitoba is in progress.

INTRODUCTION

During 1995, preliminary map compilation and laboratory activity by Manitoba Geological Services Branch staff continued in support of surficial geological mapping and stratigraphic studies initiated in 1991. Much of the activity was carried out under the jointly funded federal/provincial Southern Prairie National Mapping Program (NATMAP). NATMAP is an initiative coordinated by provincial, federal, private sector and academic agencies to develop new mapping methods and enhance interprovincial cooperation. In the Prairie region, two areas were selected for GIS-oriented Quaternary geological mapping programs: an area in southeastern Manitoba and adjacent Ontario (52E/West half and 62H/East Half) that spans the Prairie/Shield contact and the provincial boundary, and the Virden area (62F) in southwestern Manitoba that extends into adjacent Saskatchewan.

SOUTHEASTERN MANITOBA

A preliminary surficial geological map covering the Whitemouth Lake area (GSC Open File 2993 /ME&M Open File 95-1) was released in May, 1995. The map of the Falcon Lake area (GSC Open File 3030 /ME&M Open File 95-2) will be released in November, 1995. Aerial photographic interpretation and map compilation for the Steinbach sheet (62H/NE) is nearing completion.

A detailed biostratigraphical investigation in a glacial Lake Agassiz lagoon near Wampum, southeastern Manitoba, was conducted in 1994 by Manitoba Geological Services Branch and the University of Manitoba. Drilling was funded by the Geological Survey of Canada and the University of Manitoba. Diatom, pollen and macrophyte analyses are being carried out by the Universities of Manitoba and Alberta. Initial results suggest that the influence of glacial Lake Agassiz on sedimentation ended 9330 ± 80 years B.P. (TO-4856), at which time marl began to accumulate at the centre of the west basin at a rate of 8.3 cm per 100 years. Fen peat accumulation began 3890 ± 60 years B.P. (TO-4865) at a rate of 7.7 cm per 100 years and is ongoing.

SOUTHWESTERN MANITOBA

The Geological Survey of Canada completed field mapping in the remainder of NTS 62F during the summer of 1995. Two 1:100 000 scale preliminary mapsheets have been released by S. Sun and R.J. Fulton: Surficial Geology of the Whitewater Area, 62F/SE (GSC Open File 3056) and Surficial Geology of the Oak Lake Area, 62F/NE (GSC Open File 3065).

The Manitoba Water Resources water well database has been upgraded. UTM coordinates and standardized unit descriptions have been added to water wells in the Southern Prairie NATMAP area and will be useful in constructing a 3-D geological model of those areas. The Saskatchewan Research Council is presently correlating stratigraphic drill holes from Manitoba to the well established Saskatchewan stratigraphy.

A radiocarbon age of 33 860 ± 330 years B.P. (TO-4639) was obtained from a mammoth tusk collected 10 km southeast of Deloraine (Fulton, 1995). The tusk, which came from sub-till gravel, is believed to have been redeposited from older mid-Wisconsinan sediments, rather than date the last advance of Late Wisconsinan glaciation, which was the initial interpretation.

WEST-CENTRAL MANITOBA

Analysis of 182 till samples collected in 1993 from the Westlake Plain, south and north of Dauphin, is nearing completion. This till sampling project was initiated as a follow-up to the Prairie Kimberlite Study, which found five G10 garnets in the Westlake Plain and the area immediate to the south (Thorleifson and Garrett, 1993). A more detailed sampling grid was established and larger samples have been collected for analysis from that area.

Geochemical analysis has been carried out on the silt and clay fraction of the samples: atomic absorption spectrometry for nine elements, instrumental neutron activation analysis for Au + 33 elements and Chittick analysis for calcite and dolomite. The sand fraction has been analysed for kimberlite indicator minerals and the 8 to 16 mm gravel fraction has undergone lithological analysis. These data will be displayed at the 1995 Manitoba Mining and Minerals Convention.

REFERENCES

Fulton, R.J.
1995: Proboscidean tusk of Middle Wisconsinan age from sub-till gravel, near Turtle Mountain, southwestern Manitoba; in Current Research 1995-E; Geological Survey of Canada, p. 91-96.

Thorleifson, L.H. and Garrett, R.G.
1993: Prairie kimberlite study - till matrix geochemistry and preliminary indicator mineral data; Geological Survey of Canada, Open File 2745, one diskette.

GS-31 MINERAL DEPOSIT SERIES: AN UPDATE

by K.J. Ferreira

Ferreira, K.J., 1995: Mineral deposit series: an update; **in** Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 156-157.

The Mineral Deposit Series (MDS) is designed to provide a summary of current data and accurate locations for known mineralization. The MDS was initiated under the Canada-Manitoba Mineral Development Agreement (1984-1989) and produced by staff of the Mineral Deposits Section of Manitoba Energy and Mines. The initial goal was to provide MDS coverage for the Flin Flon-Snow Lake, Lynn Lake and Rice Lake greenstone belts, *i.e.*, the areas that have traditionally held great interest for mineral exploration in Manitoba, have infrastructure and have abundant exploration data available. Goals are to complete this initial coverage, to extend coverage to the northern Superior Province, to the sub-Paleozoic rocks south of the Flin Flon-Snow Lake greenstone belt, and eventually to the entire Province.

Production of the MDS involves field visits to many of the known mineral occurrences and deposits, as well as compilation from cancelled assessment files, published articles, the Manitoba Energy and Mines' Mineral Inventory Card file, and other sources, such as unpublished company data and personal communications. For all known occurrences of mineralization, however large or small, the MDS reports systematically present known data: a summary of exploration work, descriptions of the geological setting and mineralization, geochemical data, a list of references, name(s), UTM coordinates, means of access, airphoto number, and a classification of mineral deposit types. The accompanying maps consist of a simplified geological base map, on which are plotted electromagnetic conductors, locations of mineralization, and symbols that reflect the type and amount of mineralization and host lithology. The reports and maps are organized by NTS area. Most maps are published at 1:50 000, but 1:20 000 was initially used for part of the Flin Flon area where exploration data are particularly abundant. As well, some areas where exploration data are sparse are presented on 1:100 000 maps.

Figure GS-31-1 shows progress on the series to date. Table GS-31-1 lists MDS reports that have been published; these may be obtained from Information Centre, Manitoba Energy and Mines, 360-1395 Ellice Ave., Winnipeg, MB R3G 3P2. The data files summarized in these reports are resident with the individual authors of the MDS reports, and interested individuals or companies are invited to contact the author(s) for further assistance.

Table GS-31-1: Areas for which MDS reports have been published and are currently available.

NTS Area	NTS Name
Rice Lake Greenstone Belt	
52L/11	Flintstone Lake
52L/13	Manigotagan Lake
52L/14	Garner Lake
52M/3	Aikens Lake
52M/4	Bissett
Flin Flon-Snow Lake Greenstone Belt	
63J/12	Buzz Lake
63J/13	Wekusko Lake
63J/14	Saw Lake
63K/9	Tramping Lake
63K/12	Schist Lake
63K/13SE	Mikanagan Lake
63K/13SW	Flin Flon
63K/13N	Flin Flon: Weasel Bay, Defender Lake
63K/16	File Lake
Kisseynew Gneiss Terrane	
63N/2	Batty Lake
63N/4	Duval Lake
63O/4	Wimapedi Lake
Lynn Lake Greenstone Belt	
64C/10	Sickle Lake
64C/11	McGavock Lake
64C/12	Laurie Lake
64C/14	Lynn Lake
64C/16	Barrington Lake
Leaf Rapids Greenstone Belt	
64B/Northwest	Uhlman Lake (northwest quadrant)
64B/South	Uhlman Lake (south half)

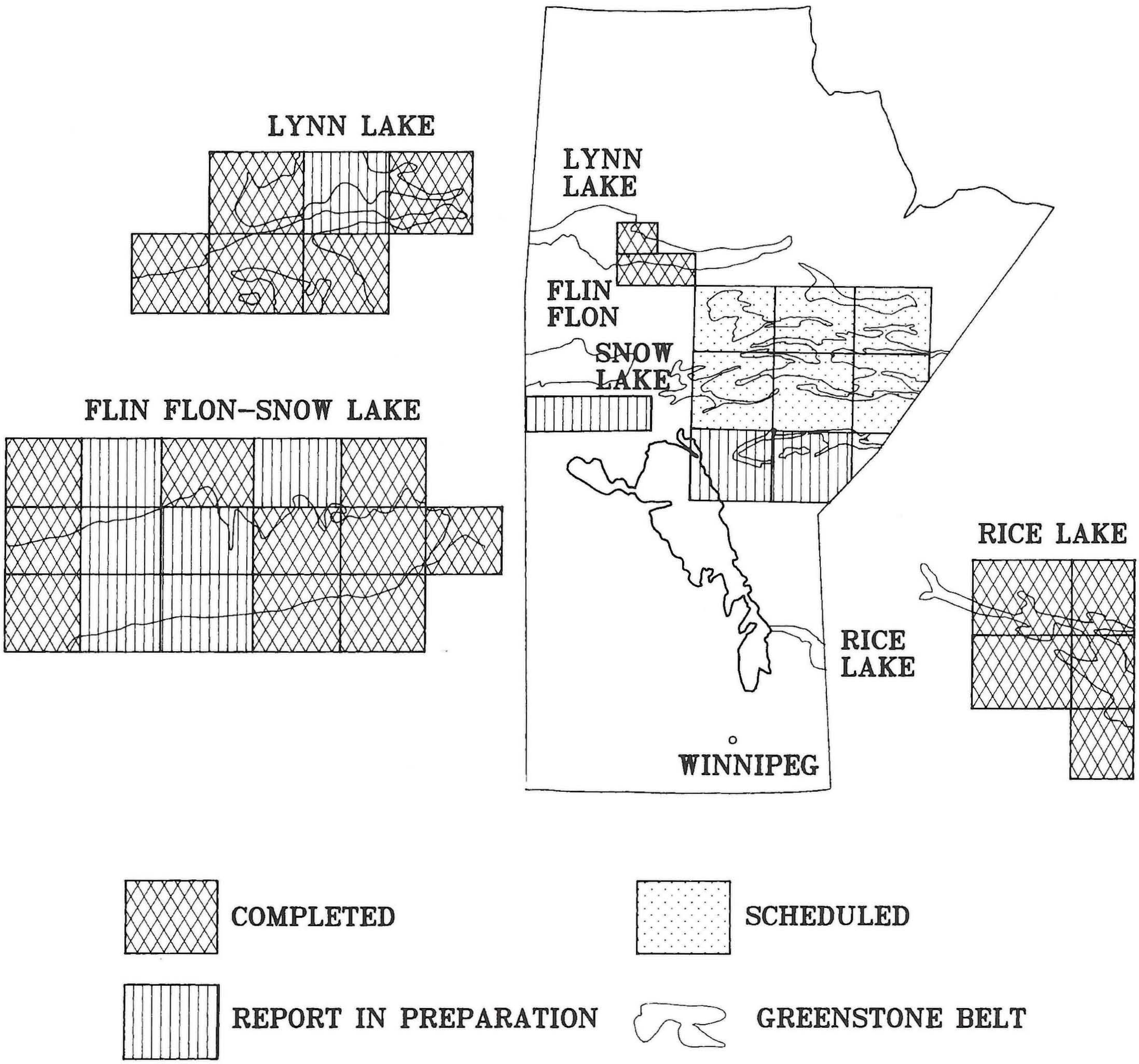


Figure GS-31-1: Summary of progress on Mineral Deposit Series reports.

GS-32 STATUS OF THE MANITOBA STRATIGRAPHIC DATABASE

by G.G. Conley

Conley, G.G., 1995: Status of the Manitoba stratigraphic database; **in** Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 158.

BACKGROUND AND OBJECTIVES

The Geological Services Branch's (GSB) Manitoba Stratigraphic Database (MSD) is a database of all subsurface Phanerozoic stratigraphic data and core storage data for all relevant Phanerozoic wells in Manitoba. These wells include petroleum, stratigraphic, mineral exploration, Manitoba Hydro, and some water wells. When completed, this database will be the most comprehensive collection of information on the Phanerozoic bedrock of Manitoba.

Manitoba Stratigraphic Database will eventually incorporate existing paper and computer stratigraphic databases into one integrated system that will provide rapid access to all subsurface well records for internal users and external clients. The goal of the MSD is to assist clients in the exploration and development of the mineral resource and oil and natural gas potential of Manitoba.

A major objective of the MSD is to generate accurate isopach, structure contour, and depth to Precambrian maps for Phanerozoic data by extracting data directly from MSD into a mapping and contouring software package or into a Geographic Information System.

CURRENT STATUS OF THE PROJECT

The schema that GSB is currently using was modified from PPDM (Public Petroleum Data Model) version 3.2 (see previous status reports).

All deep Lower Paleozoic wells within the Province have been verified for the interval between the Silurian Interlake Group to the top of the Precambrian. The tops conform to stratigraphic nomenclature established by the Western Canada Sedimentary Basin Atlas Project. Several products that are readily reproducible and of interest to exploration geologists include Overburden Thickness and Depth to Precambrian maps.

The database currently contains a total of 5140 wells. Of these, 1052 wells are Lower Paleozoic wells that have been verified. The verified wells include 209 stratigraphic wells (23390 m), 654 mineral exploration wells (125925 m), 2 Manitoba Hydro wells (295 m), 2 water wells (207 m), and 185 petroleum wells (180947 m).

The stratigraphic data are stored in a well header table and a well tops table. The well header data include UWI (Unique Well Indicator), well location (UTM and NTS), NTS map sheet reference, well name, license number, assessment file number, Kelly Bushing elevation, ground elevation, well type, core log availability, confidentiality, faulted well, source of the data, and date of last update. The well tops data for each well include stratigraphic picks, isopach values, subseas elevations, geologist responsible for the pick, the date the pick was made or revised, and indicators for faulted, eroded and incomplete formations and for quality of the pick. An incomplete formation is one where the drill has stopped within the formation and has not completely penetrated it. An eroded or incomplete designation indicates that the formation should be excluded from isopach calculation. Data can be displayed in either feet or metres.

In 1995, GSB produced a series of isopach and structure contour maps to test the accuracy of the data. As a result, the database has been cleaned of erroneous data. It was found that although some errors were generated during data entry, many errors were also present in the recording of the original data.

Core storage location data are being maintained as a separate stand-alone database at the GSB Midland core storage facility. The core storage locations are merged into MSD following all major updates. Drill chip sample storage will be added as soon as practical.

FUTURE DEVELOPMENTS

In early 1996, MSD will be moved onto a database server to provide concurrent access for GSB internal users as well as on-line access to the core storage facility. As soon as the technology is available, GSB will make nonconfidential data available to external clients via a Web Page on the Internet. For those users without digital capabilities, the data will continue to be made available to clients (upon request) in the form of printouts, or digitally in the form of ASCII text or Foxpro (or dBase IV) database files.

Once the database server is available, the core storage location data will be merged into MSD and the data will be directly updated by the Midland staff. Detailed core descriptions are currently being gathered in a word processor by R. Bezys (Paleozoic Stratigrapher) and will be incorporated into MSD once it has been moved onto the server. As time permits, historical picks maintained by GSB will continue to be entered into the database. The picks will cover the entire stratigraphic column in Manitoba and will serve as a valuable permanent reference.

A comprehensive database of selected Precambrian wells and existing detailed log descriptions will also be added to MSD. This database is currently maintained in paper and computer form by C. McGregor (Sub-Phanerozoic Precambrian Geologist).

GS-33 GEOLOGICAL INFORMATION SYSTEM PROJECTS

by P.G. Lenton and L. Chackowsky

Lenton, P.G., and Chackowsky, L., 1995: Geological information system projects; in Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 159.

SUMMARY

The NATMAP Shield Margin Project is nearing completion with approximately 80% of the project area compiled in digital form. A new map production project involves a digital map of the wetland areas of Manitoba produced in conjunction with the University of Alberta. The current 1:1 000 000 Geology of Manitoba has been converted to digital form and will be jointly released by the GSC and Manitoba Energy and Mines. The comprehensive Minerals database has been revised to increase versatility and content.

NATMAP SHIELD MARGIN PROJECT

The Shield Margin Project is currently in the final year of the field program. Several mapping programs contribute to the SMP compilation (Zwanzig, GS-4 and Schledewitz, GS-5 this report). Work on Reed Lake (Syme *et al.*, GS-10 this report) was specifically intended to update the mapping in the south-central and southeast part of the project area for the NATMAP compilation.

The 1:100 000 compilation is nearing completion in first draft format. The preliminary geological map for the Reed Lake area will be incorporated into the main compilation with a target date of early 1996 for completion of the first draft of the entire Manitoba segment of the NATMAP Shield Margin Project. Release of the final maps and accompanying database on CD-ROM is scheduled for early 1997.

WETLANDS PROJECT

Manitoba Energy and Mines has entered into a cooperative project with the University of Alberta to produce a digital 1:1 000 000 colour map of the wetlands of Manitoba. The University of Alberta has interpreted wetland cover for the entire province using airphotos accompanied by limited ground truth studies. The results were compiled on 1:250 000 base maps as outlines delineating wetland classes. The initial classification for the 1:250 000 scale maps was simplified to 15 units for the 1:1 000 000 compilation.

The University of Alberta supplied Energy and Mines with 55 mylar maps containing outlines of wetland areas classified into 15 units based on the type of wetland and the degree of forest cover. The map production project involves conversion of these 1:250 000 scale mylar maps into digital GIS files. Scanning, vectorizing and final printing are contracted to Linnet Geomatics Inc. Energy and Mines will undertake geo-referencing, edge matching, rubber sheeting and GIS classification prior to printing the 1:1 000 000 colour map.

MANITOBA MINERALS DATABASE

The Minerals Database is a comprehensive data file designed to encompass all of the information currently available through the Manitoba Energy and Mines Mineral Deposit Series of reports. A preliminary version of the database structure was complete last year. After extensive testing it was decided to revise and expand the database to include more detail on mineralization, alteration and occurrence geology. This necessitated extensive alteration to the database structure. Revisions currently underway will incorporate expanded detail, more versatile query capability and facilities for co-ordinate and unit conversion.

DIGITAL GEOLOGY OF MANITOBA MAP

The current 1:1 000 000 geological map of Manitoba, Map 79-2, is now out of print. In order to make this map available and to allow rapid future updating of the map it is being converted to a digital GIS map. This project originated with the Geological Survey of Canada. The intent is to release the current version of the map in digital form on CD-ROM and make a limited quantity of colour prints of the map available. The map will be a joint Open File report of the GSC and Energy and Mines. The CD-ROM version will also include magnetic and gravity data for the province.

GS-34 METAMORPHISM OF THE FILE LAKE FORMATION, SNOW LAKE: PRELIMINARY RESULTS

by J. Kraus[1] and T. Menard[2]

Kraus, J., and Menard T., 1995: Metamorphism of the File Lake formation, Snow Lake: Preliminary results; in Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 160-163 .

SUMMARY

At Snow Lake, over a distance of approximately 15 km, garnet and staurolite in File Lake Formation metaturbidites grew nearly isothermally close to peak metamorphic conditions of around 540°C. Metamorphic pressures at the thermal peak are consistently around 4 kb (for samples XX5 and 93–40), lower than pressures of 5 to 6 kb reported south of the Snow Lake fault at Photo Lake (Menard and Gordon, 1995a) and 5 kb at the Linda deposit (Zaleski *et al.,* 1991). Nearly isothermal garnet growth and the lack of retrograde pressure and/or temperature sensitive equilibria prohibited determination of a temperature–pressure–deformation–time path. Porphyroblast growth occurred quickly with respect to strain rates.

INTRODUCTION

The File Lake Formation (Bailes, 1980a, 1980b) in the Snow Lake area comprises Fe–rich, Al–poor turbidites metamorphosed at sub–greenschist to upper–amphibolite facies (Froese and Gasparrini, 1975; Froese and Moore, 1980) during F_2 isoclinal folding (Kraus and Williams, 1994a, 1994b, 1995). The age of the metamorphic peak in the File Lake Formation has not yet been determined in the Snow Lake area, but is between 1.815 Ga and 1.805 Ga elsewhere in the Flin Flon greenstone and Kisseynew belts (Gordon, 1989; Machado and David, 1992; Hunt and Zwanzig, 1993). Metamorphic zones have been described in Snow Lake on the basis of discontinuous reactions, but differences in bulk rock chemistry between sedimentary and volcanic/volcaniclastic rocks were ignored (Froese and Gasparrini, 1975; Froese and Moore, 1980). The zones reflect a general increase of metamorphic grade to the north (Fig. GS-34-1) and are separated by the following reactions (Froese and Gasparrini, 1975):

chlorite+almandine+muscovite = biotite+staurolite+quartz+H_2O (1)
chlorite+staurolite+muscovite+quartz = biotite+sillimanite+H_2O (2)
staurolite+muscovite+quartz = biotite+sillimanite+almandine+H_2O (3)

The present study concentrates on metamorphism of File Lake Formation metaturbidites at Snow Lake (Fig. GS-34-1). We evaluate these reactions using relationships between mineral growth and fabric development in the area, and we present thermobarometric calculations for three samples from the southern limb of the F_2 McLeod Lake synform taken over a strike distance of ~15 km. The samples discussed here are all from approximately the same tectonostratigraphic level between the McLeod Road thrust and the Snow Lake fault (Fig. GS-34-1). The Snow Lake fault is regarded to be syn-F_1 (Connors and Ansdell, 1994; Connors, in review; Kraus and Williams, 1994a), whereas the McLeod Road thrust dismembered the F_2 McLeod Lake syncline during late F_2 (Kraus and Williams, 1994a, 1994b, 1995).

PETROGRAPHY AND MINERAL CHEMISTRY

Prograde metamorphism

File Lake Formation metaturbidites in the study area contain the assemblage staurolite + biotite + garnet + muscovite + plagioclase + graphite ± chlorite, with minor ilmenite, rutile, zircon, and monazite. Chlorite is abundant only as inclusions in porphyroblasts and as a retrograde phase partially replacing biotite and rims of garnet. The turbidites in the study area do not contain cordierite, in contrast with the rocks in the File Lake area (Bailes, 1980a), possibly the result of differing metamorphic grades or bulk rock compositions. Muscovite (Si/Al$^{[4]}$ = 3.12 to 3.26; Fe/(Fe + Mg) = 0.47 to 0.57) grew during F_1 on the S_1 cleavage planes, parallel to bedding. S_1 was subsequently crenulated and differentiated into an S_2 spaced cleavage during F_2 layer-parallel shortening (Kraus and Williams, 1994b, 1995). Inclusion trails (S_i) in porphyroblasts of garnet, staurolite and biotite preserve F_2 crenulations and thus document early increments of the S_2 development. The curvature of the S_i is consistent from core to rim in all porphyroblasts, suggesting that mineral growth was relatively fast compared to strain rates.

Almandine-rich garnet grains vary in diameter from 1 to 3 mm. The garnet rims were locally replaced in part by chlorite and/or are locally coated with Fe-hydroxide. Uncorroded rims of seven garnets were considered for microprobe analysis. Garnets are compositionally zoned from core to rim with an increase of X_{Alm}, constant X_{Prp} and slightly decreasing X_{Grs} (Fig. GS-34-2). In all examined garnets, the Fe/(Fe+ Mg) ratio is constant from core to rim (Fig. GS-34-2), which implies garnet growth under nearly isothermal conditions (*e.g.,* Spear *et al.,* 1991). Nearly isothermal garnet growth and the lack of retrograde pressure and/or temperature sensitive equilibria make it impossible to determine a temperature–pressure–deformation–time path using these samples. The zoning also suggests that temperature was not high enough to homogenize the garnets by diffusion, despite their small size.

Porphyroblastic biotite laths are up to 2 mm long. Inclusions of prograde chlorite demonstrate that chlorite was part of the matrix and was consumed during growth of biotite and staurolite (reaction 1). Multiple analyses in single grains yielded consistent Fe/(Fe + Mg) ratios, but Fe/(Fe+Mg) of biotite varies from 0.54-0.56 in sample XX5,

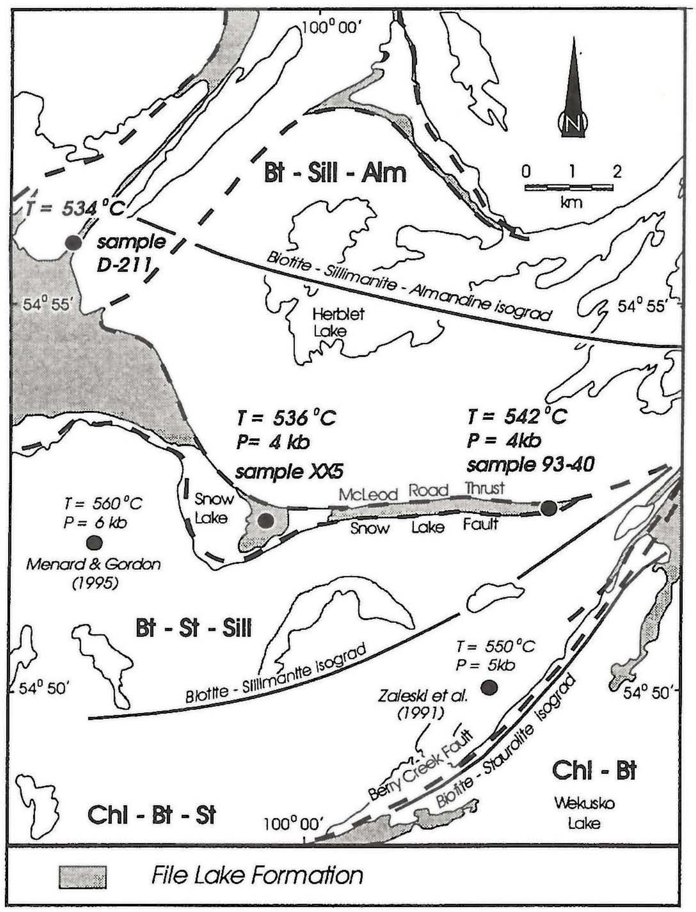


Figure GS-34-1: Metamorphic zones of Froese and Gasparrini (1975) and available P-T data for the Snow Lake area.

[1] Department of Geology, University of New Brunswick, Fredericton, NB E3B 5A3
[2] Department of Geology and Geophysics, University of Calgary, Calgary, AB T2N 1N4

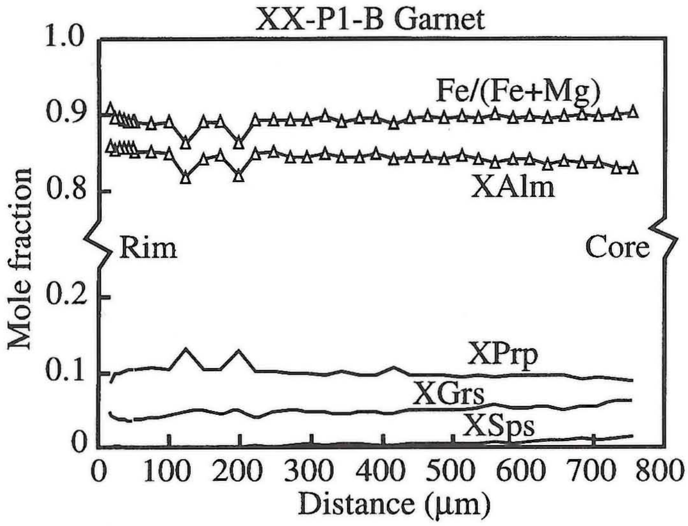


Figure GS-34-2: Compositional profile of garnet XX5-P1-B.

to 0.584 in sample D-211, to 0.5 in sample 93-40, likely reflecting differences in bulk-rock composition. In sample D-211, biotite is partially replaced by chlorite, but consistency of the calculated temperatures suggests that this reaction did not variably modify the compositions of older portions of the biotite.

Euhedral, poikiloblastic, compositionally zoned staurolite, up to 8 cm long, is present in all three samples. It contains abundant, partially corroded inclusions of garnet, indicating that garnet was consumed during reaction (1) of Froese and Gasparrini (1975) and that staurolite grew later than garnet. The pattern of S_i also suggests this growth sequence occurred during progressive development of S_2. S_i of deformed quartz grains in garnet is straight or gently curved, whereas biotite and staurolite porphyroblasts contain curved S_i of deformed quartz and graphite. Graphite occurs also as inclusions in muscovite and within the rare inclusions of prograde chlorite in biotite and garnet. The lack of graphite in or concentrated around the rims of the garnets implies that graphite was a reactant in the garnet-forming equilibrium.

Plagioclase contained in the matrix is generally scarce, small (≤ 0.25 mm), untwinned and nearly unzoned. Compositions range from An_{22} in sample 93-40 to An_{32} in sample XX5. A second generation of albite-twinned plagioclase occurs in pressure shadows of staurolite and biotite that had been boudinaged during F_2. This plagioclase grew during or slightly after the metamorphic peak and was not considered for geobarometric calculations. Since there were no other Na-bearing phases present in the rock, the new plagioclase must have grown at the expense of older plagioclase (*cf.* Menard and Spear, 1993).

Although the study area (Fig. GS-34-1) lies above the sillimanite isograd in the biotite + staurolite + sillimanite zone of Froese and Gasparrini (1975), no aluminosilicate was found in 150 thin sections examined. Apparently, reaction (2) of Froese and Gasparrini (1975) did not proceed, because peak metamorphic temperatures were not high enough and/or chlorite as a reactant was consumed in reaction (1). In either case metamorphic conditions in the study area were below reaction (3) of Froese and Gasparrini.

Retrograde metamorphism

Chlorite and minor, coarse, platy muscovite occur between parts of staurolite grains that were pulled apart during F_2 (Kraus and Williams, 1994b, 1995). Also, some staurolite rims are sericitized, and, as mentioned above, garnet rims and portions of biotite are replaced by chlorite. Textures of muscovite replacing staurolite have been reported in the upper limit of the staurolite zone and above the sillimanite–in isograd (Zwart, 1962; Guidotti, 1968; Bailes, 1980a; Lang and Dunn, 1990). In the File Lake area, for example, a second muscovite generation coincides with the first appearance of sillimanite and is associated with growth of plagioclase and biotite (Bailes, 1980a). In our samples, these additional phases are missing, and the appearance of a second muscovite generation appears to be a retrograde event for several reasons: 1) the muscovite is associated with retrograde chlorite, 2) there are no plagioclase, sillimanite, prograde chlorite or new biotite in the sample, and 3) the platy, idiomorphic muscovite is not altered on its rims to chlorite. These features suggest the retrograde reaction

staurolite + biotite + quartz + H_2O = muscovite + chlorite.

Many samples lack prograde muscovite and chlorite in their matrix. Both phases were required as reactants for reaction (1) of Froese and Gasparrini (1975) to proceed and muscovite must have been left over when the reaction stopped. The presence of these phyllosilicates prior to reaction (1) is indicated by inclusions and by the crenulation shape of S_i in porphyroblasts. Some of the Al liberated by the dissolution of muscovite in reaction (1) of Froese and Gasparrini (1975) may have been used in the growth of plagioclase in pressure shadows around staurolite or biotite. Nonetheless, the volume of the new phases cannot account for the local disappearance of muscovite originally present in the S_2 cleavage septa. The lack of muscovite in the matrix and corroded rims of biotite and staurolite without replacement textures of many samples point to widespread fluid infiltration postdating porphyroblast growth. Although Al is considered relatively immobile (*e.g.,* Carmichael, 1969), muscovite appears to have been dissolved and removed from the rock, possibly by high-pH fluids. The timing of muscovite leaching can be bracketed based on the F_3 crenulation geometries. F_3 crenulations have identical shapes independent of whether matrix muscovite is present or not. However, such regular microfolds require a well–developed layered anisotropy such as the S_2 fabric for their formation (*e.g.,* Williams, 1972; Weber, 1981). Thus, muscovite was removed syn– or post-F_3.

Sample D-211 contains significant amounts of a fibrous mineral that displays textures typical of fibrolitic sillimanite replacing biotite (*e.g.,* Vernon, 1987). Microprobe analyses, however, indicate an Al:Si ratio of 1:1 and totals of 83%, which suggest that the phase is kaolinite. The local presence of kaolinite also supports retrograde fluid activity. The kaolinite may have replaced sillimanite during retrograde metamorphism, but we have yet to demonstrate that sillimanite was present in the rock (see also Menard and Gordon, 1995a).

Quartz inclusions that form S_i in the porphyroblasts are smaller than quartz grains in the matrix. An equigranular S_2 quartz shape–fabric is locally preserved in the matrix, but was replaced by quartz with an inequigranular granoblastic texture in most parts of the rock. This indicates normal grain growth postdating porphyroblast growth. Quartz coarsening must have continued until after muscovite dissolution, as otherwise mica (001) faces would have restricted quartz grain growth, which should have resulted in inequant grains in all samples. Relatively high temperature during F_3 is also supported by kink band boundary migration in F_3 kinks, which suggests temperatures above 450°C (Williams and Compagnoni, 1983) and indicates relatively slow cooling.

GEOTHERMOBAROMETRY

Garnet–biotite thermometry

The calibration of Kleemann and Reinhardt (1994) was used for garnet-biotite thermometry. It incorporates a new activity model for biotite that accounts for the non–ideality of Mg–Fe–Al mixing and Mg–Fe–Ti mixing. Multiple temperatures were calculated for each sample by combining all garnet rim and biotite analyses. The resulting computed temperatures of randomly combined pairs are similar to temperatures obtained using compositions of biotite directly adjacent to garnet rim (± 3°C), permitting statistical treatment of the results. We report the mean temperature and, as uncertainty, the standard deviation. Temperatures calculated using two garnets and matrix biotite in sample D–211 (Fig. GS-34-1) are 534 ± 8°C (n=9; all temperatures reported for an assigned pressure of 4 kb). Rim compositions of three garnets and matrix biotite in sample XX5 yield a temperature of 536 ±11°C (n=28), and the calculated rim temperature from two garnets in sample 93-40 is 542± 9°C (n=10). A slight increase of the Fe/(Fe + Mg) ratio at the rim suggests only minor diffusional modification during cooling. We used garnet compositions 10 to 20 mm away from the rim for temperature calculations in order to avoid this late modification.

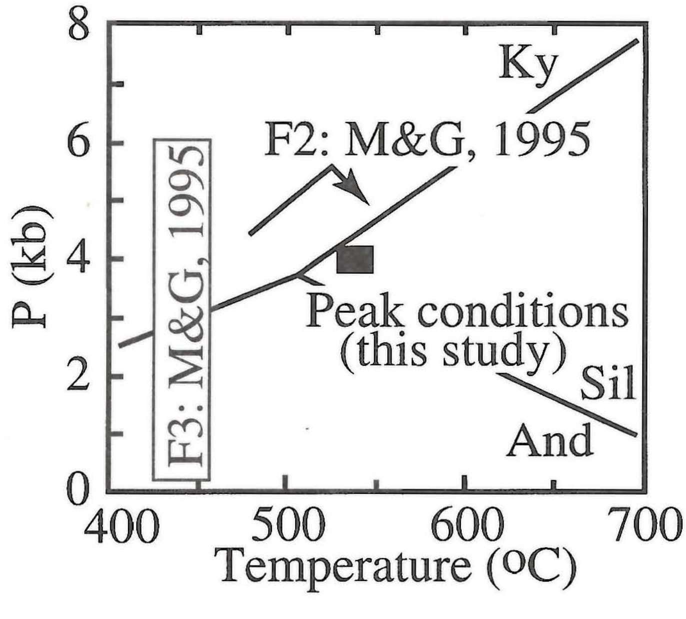


Figure GS-34-3: Metamorphic peak conditions in P-T space, Snow Lake area. Aluminosilicate triple point after Holdaway (1971).

Garnet-biotite-muscovite-plagioclase barometry

Pressures were calculated using the garnet-biotite-muscovite-plagioclase barometer of Ghent and Stout (1981). Calculated pressures for samples XX5 and 93–40 are similar and cluster around 4 kb (Fig. GS-34-1), consistent with peak metamorphism in the sillimanite stability field (Fig. GS-34-3). Sample D–211 does not contain plagioclase, preventing application of this barometer. Ghent and Stout (1981) suggested an uncertainty of ± 1 kb for their barometer, but error in relative barometry between similar samples should be less. We conclude that samples XX5 and 93–40 were at similar depths during garnet growth. Data are insufficient for statististical treatment.

DISCUSSION

Reaction sequence

Based on our observations on fabric development with respect to mineral growth, we suggest two additions to the prograde reaction sequence of the Snow Lake area. With rising temperature and before reaction (1) of Froese and Gasparrini (1975), garnet grew during F_2 by the reaction

chlorite+biotite+plagioclase+graphite = garnet+muscovite+H_2O (i).

At slightly higher temperatures, porphyroblasts of biotite and staurolite grew by reaction (1) of Froese and Gasparrini (1975). As some of the garnets near or included in staurolite are apparently not resorbed, we propose an additional reaction, which does not need garnet as a reactant (Winkler, 1979, p.77; see also Bailes, 1980a):

chlorite+muscovite = staurolite+biotite+quartz+H_2O (ii).

Correlation and regional significance of P-T data

In a metamorphic study of volcanic rocks at Photo Lake, structurally below the F_1 Snow Lake fault, Menard and Gordon (1995g) report that garnet grew during F_2 and record a temperature and pressure increase of ~50°C and 1 kb, respectively, starting at approximately 500°C and 5 kb (Figs. GS-34-1 and GS-34-3). Our results indicate a narrower temperature interval for garnet growth in the File Lake metaturbidites, which may be a function of differences in bulk rock chemistry between our samples and theirs (Fig. GS-34-3). Zaleski *et al.* (1991) report a peak-metamorphic temperature of 550°C and an associated pressure of 5 kb for the Linda deposit in fluid-altered volcanic rocks close to Wekusko Lake (Fig. GS-34-1). Calculated peak temperatures in volcanic and sedimentary rocks between Wekusko Lake and Snow Lake of ~550°C (Zaleski *et al.*, 1991; Menard and Gordon, 1995a) mean fairly constant temperatures across a tectonometamorphic sequence of more than 10 km across strike, possibly related to thermal relaxation. The distribution of calculated pressures shows a general trend of lower pressures upwards in the tectonostratigraphic sequence towards the north and east (taking into account the effects of open large-scale F_3 refolding; Kraus and Williams, 1994a, 1994b). This indicates that no major southwest-directed thrusting (*e.g.,* Kraus and Williams, 1995) has occurred after the metamorphic peak. The apparent absence of a metamorphic break across the Snow Lake fault thus supports the F_1 age of the structure. This trend might change across the post-peak metamorphic F_2 McLeod Road thrust (Kraus and Williams, 1994a, 1995), but P-T data are not yet available.

Reaction isograds

Metamorphic minerals of the same phase can start to grow at different temperatures in rocks of different composition. For example, the formation temperature of garnet can be below 450°C if the Mn and Ca contents of the rock are high (Spear, 1993). Similarly, high F and low Fe contents in biotite in the altered volcanic rocks of the Linda deposit are responsible for the occurrence of kyanite below the temperature of the kyanite + biotite isograd in normal pelites (Zaleski *et al.,* 1991). Thus, reaction isograds based on index minerals across a variety of bulk rock compositions, as defined for the Snow Lake area by Froese and Gasparrini (1975), are problematic and do not constitute isothermal surfaces. If, however, independent of temperature, the formation of porphyroblasts commenced during early F_2 everywhere in the Snow Lake area south of the McLeod Road fault, then the isograds should be isoclinally folded (Kraus and Williams, 1995). The relative straight isograds inferred by Froese and Gasparrini (1975; Fig. GS-34-1) might therefore be more complicated after more detailed work and a higher sample density.

PERSPECTIVES

Future work will focus on additional samples from the File Lake Formation and the Missi Group (J.K.) and samples of volcanic rocks (T.M.) and will provide a greater density of calculated P–T conditions and P–T paths in order to identify the effects of possible, unexposed thrust faults.

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GS-35 SYNTECTONIC ALTERATION OF VMS DEPOSITS, SNOW LAKE, MANITOBA*

by T. Menard[2] and T.M. Gordon[1]

Menard T., Gordon, T.M., 1995: Syntectonic alteration of VMS deposits, Snow Lake, Manitoba; **in** Manitoba Energy and Mines, Minerals Division, Report of Activities, 1995, p. 164-167 .

SUMMARY

Metamorphism of alteration zones around volcanogenic massive sulphide (VMS) deposits in the Snow Lake area involved several additional generations of compositional alteration. Metamorphic alterations in some rocks were as strong as the original hydrothermal alteration and mask its geochemical signature. Features that demonstrate whole rock compositional alteration during metamorphism include: 1) different minerals included in cores of porphyroblasts than in rims; 2) partial replacement textures by incompatible minerals; and 3) compositional zoning of minerals (and their inclusions) where it cannot be interpreted to reflect changes of pressure and temperature. Some of the textures are spectacular.

F_2 deformation and peak metamorphism are associated with at least two patterns of alteration. One involved stripping of sulphides from altered wall rocks within 10 m of massive sulphide zones, observed in the Photo Lake mine. Although we cannot demonstrate it yet, the high grades of the ore in the mine suggest the possibility that chalcopyrite removed from the wall rocks was added to the massive sulphide zones. The other is chlorite + plagioclase schists (with variable amounts of staurolite, magnetite, and amphibole) having apparent thickness of 5 to 20 m in drill core from several VMS deposits. These schists have textures indicating strong whole rock compositional alteration, and are interpreted as reflecting compositional alteration by fluids flowing along fault zones.

During F_3 crenulation and retrograde metamorphism, fluid flow contributed to variable chloritization, possibly concentrated along preexisting and new faults and other zones of permeability. During subsequent brittle faulting, quartz veins were emplaced with associated 1 m wide zones altered to carbonate and epidote. We speculate that one or more of these fluid flow events is associated with deposition of ore and alteration of host rocks in the New Brittania gold mine in Snow Lake.

INTRODUCTION

New, underground exposures of a VMS deposit are accessible in the Photo Lake Cu-Zn-Au mine, opened in the past year by Hudson Bay Exploration & Development Company Limited, 4 km north of the Chisel Lake mine. The site has been mapped by Bailes and Simms (1994) and Bailes and Galley (1992). Related work in the area includes alteration geochemistry of the Chisel Lake deposit (Galley *et al*., 1993), metamorphic petrology (Froese and Moore, 1980; Menard and Gordon, 1995; Kraus and Menard, 1995), and detailed structural geology (Kraus and Williams, 1994a,b and 1995). Also in the past year, TVX Gold reopened the New Brittania gold mine (formerly, the Nor-Acme mine) in Snow Lake. Together, these two mines provide new incentive to understand the geology of the area.

The samples used in this study were collected from diamond-drill core of altered Amisk volcanic rocks near VMS deposits in the Snow Lake area, with the permission of Hudson Bay Exploration & Development Company Limited, TVX Gold Inc. and Falconbridge limited (Fig. GS-35-1). Work related to some of these locations includes Galley *et al.* (1988), Fedikow and Lemkow (1989), Fedikow and Ziprick (1991), Zaleski *et al.* (1991), and Hodges and Manojlovic (1993). Textures interpreted here as indicating whole rock compositional modification accomplished by fluid flow during regional tectonism and metamorphism were found in the locations marked in Figure GS-35-1, which demonstrates that the processes involved were widespread. We do not know whether the syntectonic alteration only affected rocks previously altered during emplacement of VMS deposits, but those are the only rocks in which we have evidence for it. In this report, we describe three samples chosen to illustrate syntectonic metasomatism in the Snow Lake area.

DEFORMATIONAL AND METAMORPHIC HISTORY

Based on recent and current detailed structural work in the Snow Lake area (Kraus and Williams, 1994a, 1994b, 1995), we can summarize the deformational events at Snow Lake as follows. F_1 tight to isoclinal folds have an associated muscovite cleavage. F_2 folds, interpreted from map relations, have a schistosity that wraps around the peak (F_2) metamorphic porphyroblasts of staurolite, garnet, and biotite in the File Lake Formation, but has a more variable relation to porphyroblasts in the altered volcanic rocks. Peak metamorphic assemblages in the altered volcanic rocks vary with rock composition and include staurolite + garnet + biotite and kyanite + chlorite (Zaleski *et al*., 1991; Menard and Gordon, 1995). During F_2, P increased by 1 kbar and T increased by 50 (C up to approximately 5 kbar and 535° C at Photo Lake (Menard and Gordon, 1995). The main schistosity, S_2, developed at the end of this pressure increase in a sudden shearing event as shown by textures, compositional zoning, and inclusion suites in garnet (Menard and Gordon, 1995). Shearing was followed by continued T increase of 10-20° C. This P-T path differs from those typical of overthrust and nappe terranes where the increase of P is commonly isothermal (*e.g*., Menard and Spear, 1994), and the difference suggests that tectonism at Snow Lake was relatively slow with respect to time constants of thermal relaxation, or that deformation was vertically distributed in the block (in contrast with a single fault slice). F_3 produced broad, upright, open folds, including the Threehouse Lake fold, crenulated S_2, and has associated minor chloritization. F_4 deformation is localized around gneiss domes north of the present study area, and

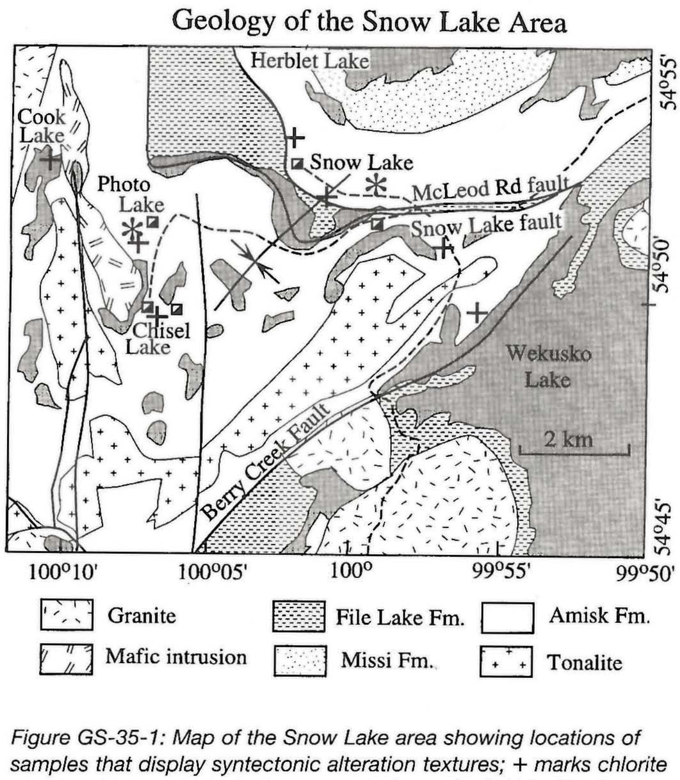

*Figure GS-35-1: Map of the Snow Lake area showing locations of samples that display syntectonic alteration textures; + marks chlorite schists with zoned plagioclase, * marks loss of sulphide. Geology from Froese and Moore (1977) and Bailes and Galley (1992).*

[1] Funded by NSERC Lithoprobe

[2] Department of Geology and Geophysics, University of Calgary, Calgary, AB T2N 1N4

does not affect the rocks at the deposits. In addition, one or more brittle deformations affected the area.

METASOMATISM

Two styles of syntectonic alteration have been found: removal of sulphides from schists near massive sulphide lenses during F_2 shearing; and whole rock compositional alteration in narrow zones interpreted as faults.

Removal of sulphides during shearing

Sample Dub48-1852 is from diamond-drill core from the Photo Lake deposit and contains the assemblage staurolite + garnet + biotite + chlorite + quartz + magnetite with trace amounts of S_3 muscovite. Chlorite and quartz display an S_2 foliation and S_3 crenulation. Staurolite and biotite porphyroblasts overgrew the S_2 fabric and postdate garnet growth. A folded S_1 fabric is preserved in the garnet core (best seen in crossed polarized light); most of the garnet contains S_2 inclusion trails of thin quartz, and the edge of the garnet contains coarse grained, equant inclusions of quartz (Fig. GS-35-2). Garnet cores contain inclusions of chalcopyrite, whereas garnet rims do not, nor do staurolite or biotite that grew later, nor does the matrix.

Similar textures occur in other samples from the Photo Lake drill core, and in samples from 0.6 km north of the McLeod Road fault and the Wim zone 16 km northeast of Snow Lake (Fig. GS-35-1). In some cases, the sulphide included in the garnet is relatively coarse grained (1.5 mm, as shown in Fig. GS-35-2), in others it is fine grained (0.1 mm) and evenly disseminated within the garnet. The distribution suggests that it was evenly distributed throughout the rock but was removed during F_2 shearing after growth of the garnet core. An alternative explanation that a local variation of composition around sulphides promoted garnet nucleation is not preferred. Sulphide in a rock incorporates Fe, lowering Fe/(Fe+Mg), which is the opposite of what is appropriate for almandine garnet. Further support for the notion that sulphides were mobile during F_2 shearing is provided by textures in another sample where sulphides are concentrated in the hinge of an F_2 fold.

Similar textures of sulphides occurring only as inclusions in garnet are also displayed in underground exposures in the Photo Lake mine at the -40 m level. The footwall dacite varies from unaltered dacite 30 m from the contact, to dacite with small garnets, to dacite with garnet and chlorite, to a 5 m wide zone of garnet + chlorite schists. Garnet porphyroblasts in these schists are up to 6 cm in size, overgrow the S_1 fabric, and contain inclusions of disseminated sulphides. In contrast the chlorite matrix contains only trace amounts of sulphide. These schists have a sharp, tectonic contact to the massive sulphide lens, which was intensely deformed during F_2. The massive sulphide at this location contains pyrite + pyrrhotite + chalcopyrite; at lower levels in the mine, it contains more sphalerite than chalcopyrite. Although we cannot demonstrate where the chalcopyrite went that was removed from the garnet + chlorite schist, the high grades of the adjacent ore suggest the possibility that it was added to the massive sulphide lens. If true, syntectonic alteration contributed significantly to the profitability of the mine by reducing the amount of rock that has to be removed.

Alteration focused along faults (?)

In several locations (Fig. GS-35-1), 5- to 20-m thick sections of diamond-drill core are chlorite schists with variable amounts of plagioclase, garnet, staurolite, biotite, amphibole, sulphide, and ilmenite. Combinations of these minerals occur in assemblages that vary on a scale of millimeters and centimeters. Plagioclase is compositionally zoned, as described below. Biotite varies from 40% of the rock in chlorite + biotite schists to occurring only as inclusions in plagioclase. Staurolite grains are generally small (1 mm), whereas garnet grains vary in size up to 3 cm. Sulphide varies from 30% of rocks with biotite + quartz + feldspar to trace amounts in most of the drill core. Amphibole is monomineralic within 1 cm of quartz veins and less abundant elsewhere; it overgrew plagioclase and chlorite, possibly at the end of F_3.

Sample Dub42-642 is from diamond-drill core from the Photo Lake deposit. Similar rocks occur above and below the main ore horizon. The matrix assemblage is chlorite + plagioclase + magnetite + ilmenite with minor epidote and carbonate. Chlorite and ilmenite are aligned in the S_2 fabric and were crenulated by F_3. Assignment of fabric generations is based on correlation with other samples from the area where the S_2 schistosity obliterated the S_1 fabric, except inside early F_2 porphyroblasts, and was subsequently crenulated. Porphyroblasts of plagioclase 5 mm in size have distinct core and rim regions (Fig. GS-35-3). The core (An_{80}) contains abundant inclusions of biotite and quartz. In some samples, these biotite inclusions have the same orientation within any plagioclase grain. In contrast, the plagioclase rim (An_{95}) contains abundant inclusions of epidote and allanite, but no biotite. The edges of the plagioclase grains are partially replaced by S_3 chlorite, demonstrating that the plagioclase grew prior to F_3, and likely during F_2.

Sample Dub42-701 is from 18 m below sample Dub42-642 and contains the assemblage chlorite + biotite + plagioclase + amphibole + quartz + ilmenite + sulphide (Fig. GS-35-4). Again, chlorite is foliated in S_2 and crenulated in S_3, which is the dominant fabric. Plagioclase grains are small (1 mm) and compositionally zoned. They overgrew the S_2 chlorite fabric, are wrapped by S_3, and were partially replaced by S_3 chlorite. Cores of plagioclase contain abundant, tiny (20 μm) quartz inclusions, whereas the rims contain only minor amounts of quartz, suggesting that quartz may have been removed from the rock during plagioclase growth. Quartz in the matrix is now equant and 250 μm in size, demonstrating that it coarsened sometime after plagioclase growth. Amphibole is lath shaped, porphyroblastic, aligned in S_3, and contains inclusions of plagioclase and quartz. The quartz inclusions in the core of the amphibole are thin (10x50 μm) and some are aligned in curved inclusion trails, but in the rim, the quartz inclusions are equant (50x50 (m). Thus, amphibole grew during F_3 and coarsening of quartz. Biotite occurs only in S_3 orientations.

The textures indicate that after F_1 deformation the rock was a schist with the assemblage biotite + quartz + plagioclase + ilmenite ± sulphide ± chlorite (?). Thus, alteration during F_2 was locally strong enough to change the apparent lithology; these chlorite schists do not reflect strong sea-floor hydrothermal alteration. The evidence is ambiguous as to what these rocks were prior to F_1, possibly felsic volcanic rocks. Observations in these two rocks suggest three stages of alteration:

1. During F_2 shearing, quartz was depleted from the rock part way through plagioclase growth and the mineral assemblage changed, suggesting loss of SiO_2, K_2O, Na_2O, and addition of Fe_2O_3 (or oxidation) and REE.
2. During F_3 crenulation, biotite and amphibole were added, plagioclase was partially replaced by chlorite, and quartz coarsened, indicating addition of K_2O, CaO, H_2O and possibly other components.
3. Subsequently, amphibole and magnetite were partially replaced by chlorite, ilmenite, calcite, allanite, and parisite, indicating another episode of fluid infiltration with addition of H_2O, CO_2, F, CaO, FeO, MgO, and REE, and removal of K_2O, Na_2O, and Fe_2O_3. This event may correlate with bleaching and alteration around quartz veins that crosscut S_2 and S_3, but the correlation is uncertain.

Rocks with this chemistry and deformational history have not been identified in any of the local underground or open pit mines, so the geometry of the metamorphic alteration zones is unknown. Nevertheless, we interpret these rocks as reflecting metamorphic fluid-flow focused along faults because of their limited thickness, the variability of mineral assemblage and rock composition on a cm scale, their occurrence above and below the main ore zone at Photo Lake, and their occurrence at several VMS deposits in the area.

MOBILIZATION OF GOLD

The deformational, metamorphic, and metasomatic alteration events described here also affected the rocks in the New Brittania Mine. The spatial association of the VMS deposits in Snow Lake with the largest gold mine in the Flin Flon greenstone belt suggests the possibility that the gold may have been leached from the VMS deposits. Shearing and recrystallization during F_2 may have liberated gold from the sulphides in the VMS deposits, allowing gold to be remobilized during subsequent events. The alteration effects reported in the literature for deposition of shear-zone hosted gold match fairly well, but with opposite direction, as the retrograde metasomatism seen in the Photo Lake VMS deposit (Powell *et al.*, 1991). Gold could have been trans-

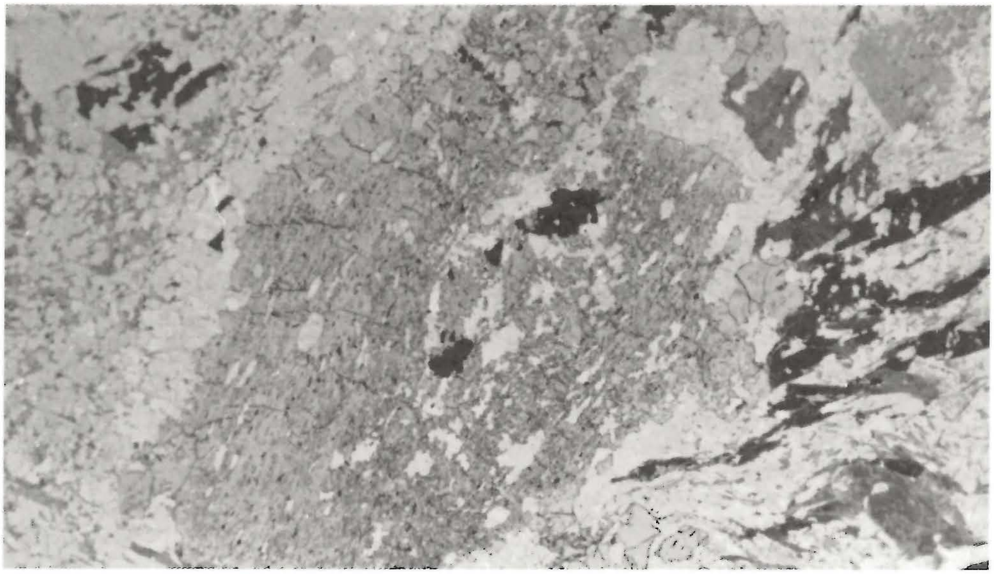

Figure GS-35-2: Photomicrograph of sample Dub48-1582 showing garnet with inclusions of chalcopyrite only in the core. In the garnet core, quartz inclusions are equant, whereas in the outer part of the garnet, quartz inclusions are thin and foliated in S_2. Thus, chalcopyrite present in the rock prior to the development of S_2 was removed during F_2 shearing and prior to growth of the garnet rim. Also shown are quartz (white), ilmenite (small black inclusions in garnet rim), biotite (grey), and staurolite (small, indistinct grain on left side of garnet). Base of photo is 20 μm.

Figure GS-35-3: Photomicrograph of sample Dub42-642 showing zoned plagioclase grains in chlorite schist. The core of the plagioclase (outlined by dashes) contains inclusions of quartz, biotite, and ilmenite, whereas the rim contains inclusions of epidote, allanite, and ilmenite. This difference indicates a change of rock composition during growth of metamorphic plagioclase. The plagioclase and magnetite are partially replaced by F_3 chlorite, indicating a second stage of metamorphism. Base of photo is 15 μm.

Figure GS-35-4: Photomicrograph of sample Dub42-701 showing a chlorite schist with several episodes of alteration. Plagioclase (round, grey) grains are zoned with abundant quartz inclusions only in the core, similar to those in Figure GS-35-2, suggesting that quartz was more abundant when the core grew than at present. Amphibole (large laths containing inclusions of quartz and plagioclase) and minor biotite (darker mica) grew during F_3. Also shown are quartz (white) and ilmenite (black). Base of photo is 5 μm.

ported by metamorphic fluids, which were subsequently focused along the McLeod Road fault and splay faults.

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PRELIMINARY MAPS 1995

GEOLOGICAL SERVICES BRANCH		SCALE
1995-F-1	Reed Lake (parts of 63/K9 and 10) by E.C. Syme, A.H. Bailes and S.B. Lucas	1:50 000
1995K-2	Dow Lake (parts of NTS 63K/15 and 63N/2) by H.V. Zwanzig	1:20 000
1995K-3	Collins Point and Yakushavich Island, Kississing Lake (NTS 63N/3NW) by D.C.P. Schledewitz	1:20 000
1995K-4	Northwest Kississing Lake (NTS 63N/3NW and 63N/6SW) by D.C.P. Schledewitz	1:50 000
1995T-1	Geology and oxide mineral occurrences of the central and eastern portions of the Pipestone Lake anorthosite complex (parts of NTS 63I/5 and 63I/12) by L.S. Jobin-Bevans, J.P. McDonald, H.D.M. Cameron and D.C. Peck	1:2500
1995T-2	Geology and oxide mineral occurrences of the central and eastern portions of the Pipestone Lake anorthosite complex (parts of NTS 63I/5 and 63I/12) by L.S. Jobin-Bevans	1:2500
1995T-3	Geology and oxide mineral occurrences of the central and eastern portions of the Pipestone Lake anorthosite complex (parts of NTS 63I/5 and 63I/12) by L.S. Jobin-Bevans	1:2500
1995T-4	Geology and oxide mineral occurrences of the central and eastern portions of the Pipestone Lake anorthosite complex (parts of NTS 63I/5 and 63I/12) by L.S. Jobin-Bevans	1:2500

LIST OF GEOLOGICAL STAFF AND AREAS OF CURRENT INVOLVEMENT

GEOLOGICAL SERVICES

POSITION	PERSONNEL	AREA OF CURRENT INVOLVEMENT
Director	Dr. W.D. McRitchie	Manitoba
Geological Survey:		
Senior Precambrian Geologist	Vacant	
Precambrian Geologists	Dr. A.H. Bailes	Snow Lake, Wekusko Lake, Reed Lake
	M.T. Corkery	Cross Lake-Northern Superior Province, Nelson and Churchill Rivers, Partridge Breast Lake, SE Manitoba
	H.P. Gilbert	Tartan Lake, Wekusko Lake-South, Dion Lake
	Dr. J.J. Macek	Thompson belt and SW extension
	D.C.P. Schledewitz	Kississing Lake, Webb/Fay Lakes
	E.C. Syme	Flin Flon, Athapapuskow Lake, Elbow Lake, Iskwasum Lake, Reed Lake
	Dr. H.V. Zwanzig	Churchill Province, Kisseynew belt
Compilation Geologist/Mineralogist	C.R. McGregor	Sub-Phanerozoic Precambrian compilations; mineralogy
Phanerozoic Geologist	R.K. Bezys	Southwest Manitoba, Hudson Bay Lowlands, and Interlake
Mineral Investigations:		
Senior Mineral Deposit Geologist	Dr. G.H. Gale	Flin Flon
Mineral Deposit Geologist	K. Ferreira	Mineral Deposit Series; Editorial Assistant
Industrial Minerals Geologists	B.E. Schmidtke	Industrial mineral inventory, dimension stone, peat
	J.D. Bamburak	High-magnesium dolomite, dimension stone High-calcium limestone, silica, bentonite
Resident Geologist (The Pas)	D.E. Prouse	Bakers Narrows; exploration activity, drill core program
Resident Geologist (Flin Flon)	T. Heine	Flin Flon - Snow Lake region; Iskwasum Lake
	L. Norquay	North Star Lake
Resident Geologist NE (Thompson)	Dr. P. Theyer	Thompson Nickel Belt, Island Lake
Resident Geologist NW (Thompson)	Dr. D. Peck	Cross Lake anorthosites, Lynn Lake
Staff Geologist (Thompson)	H.D.M. Cameron	Cross Lake anorthosites, Lynn Lake
Geoscience Information Services:	P.G. Lenton	Geological Data Management and Analysis
	G.G. Conley	Stratigraphic data files
	L.E. Chackowsky	Geographic Information Systems
Geological Compiler (Atlas)	D. Lindal	1:250 000 bedrock compilation maps
Geophysics, Geochemistry and Terrain Sciences:		
Section Head/Geophysicist	I.T. Hosain	Superior Province
Geochemist/Mineral Deposit Geologist	Dr. M.A.F. Fedikow	Snow Lake
Quaternary Geologists	Dr. E. Nielsen	Elbow Lake, Naosap Lake, Lake Winnipeg, Superior Province
	G. Matile	Southern Manitoba, Westlake Plain

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