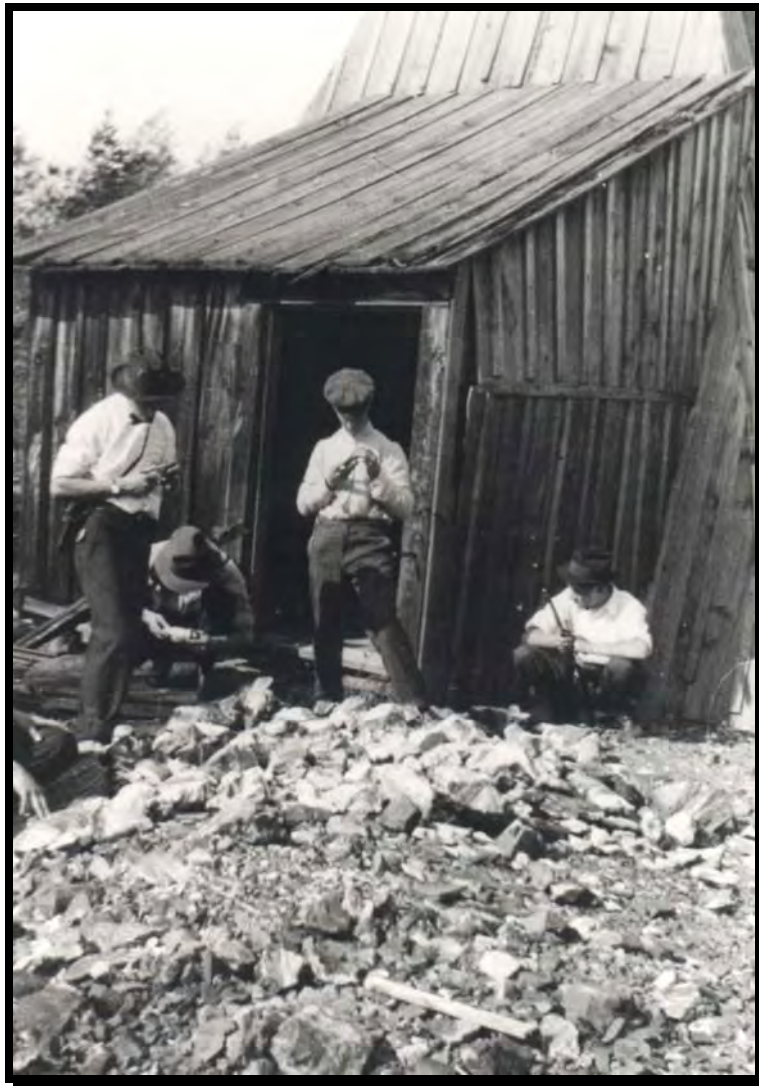




INSTITUTE ON LAKE SUPERIOR GEOLOGY 48th Annual Meeting

Proceedings Volume 48 Part 2 - Field Trip Guidebook



Kenora, Ontario – May 12-16, 2002

INSTITUTE ON LAKE SUPERIOR GEOLOGY

**48th Annual Meeting
May 12-16, 2002
Kenora, Ontario**

Hosted by:

**Peter Hinz and Richard C. Beard
Co-Chairs**

**Sponsored by the
Ontario Geological Survey**

**Proceedings
Volume 48**

Part 2 - Field Trip Guidebook
(Compiled by Blackburn Geological Services)

48th Annual Meeting Institute on Lake Superior Geology

Volume 48 contains the following parts:

Part 1: Program and Abstracts

Part 2: Field Trip Guidebook

- 1 - Tanco Rare-Element Pegmatite, Southeastern Manitoba
- 2 - Quaternary Geology of Southeastern Manitoba
- 3 - Structure and Sedimentology of the Seine Conglomerate, Mine Centre Area, Ontario
- 4 - Industrial Minerals and Paleozoic Geology of Southeastern Manitoba
- 5 - Separation Rapids Rare-Element Pegmatite Field, Ontario
- 6 - Geology of the Red Lake Camp, Ontario

Reference to the material in this volume should follow the example below:

Lichtblau, A. and Storey, C.C. 2002. Geology of the Red Lake Camp, Ontario: Institute on Lake Superior Geology Proceedings, 48th Annual Meeting, Kenora, Ontario, 2002, v. 48, Part 2, p. 121-138.

Volume 48 is published by the Institute on Lake Superior Geology and distributed by the Institute Secretary-Treasurer:

Mark Jirsa
Minnesota Geological Survey
2642 University Avenue
St. Paul, MN USA 55114-1057
(612) 627-4780
email: jirsa001@tc.umn.edu
ILSG website <http://www.ilsgeology.org/>

ISSN 1042-9964

Cover Illustration:

Geologists examining a dump at the Gold Hill mine, Kirkup Township, 13 km southeast of Kenora, in 1914. Between 1886 and 1893 this mine produced 1090 ounces of gold from 220 tons milled. Four shallow shafts were sunk to a combined depth of 258 feet: the headframe for one of them is seen in the picture. The winning of gold from narrow discontinuous quartz veins was typical of the numerous small-scale mines of the Kenora goldfields in the latter part of the 19th and the early 20th century.

CONTENTS

Proceedings Volume 48

Part 2 – Field Trips

Trip1: The Tanco Rare-Element Pegmatite, Southeastern Manitoba 1

Leaders:

Staff, *Tantalum Mining Corporation of Canada, Ltd.*

Trip 2: Quaternary Geology of Southeastern Manitoba 23

Stop 1: Striated outcrop, West Hawk Lake 26

Stop 2: West Hawk Lake, Till Section 27

Stop 3: West Hawk Lake, Meteorite Impact Structure 28

Stop 4: Sapping Channels (Upper Cambell Beach) 30

Stop 5: Upper Campbell Beach of Lake Agassiz 31

Stop 6: Interglacial Site at Grunthal 32

Leaders:

E. Nielsen, *Manitoba Geological Survey*

G. Matile, *Manitoba Geological Survey*

Trip 3: Structure and Sedimentology of the Seine Conglomerate, Mine Centre Area, Ontario 37

Stop 1: Basal facies, low deformation, Shoal Lake road.....60

Stop 2: 2D view, sandy lenses, dextral shear, Forest Tour road 61

Stop 3: 3D view, moderate deformation, Horsecollar Junction, Hwy 11 61

Stop 4: Ultra deformed conglomerate, Hwy 11 61

Stop 5: Small fold, Seine River bridge, Hwy 11 62

Leaders:

D. Czeck, *Oberlin College*

P. Fralick, *Lakehead University*

Trip 4: Industrial Minerals and Paleozoic Geology of Southeastern Manitoba 69

Stop 1: Sungro horticultural shagnum peat bog and plant 90

Stop 2: Cold Spring Granite dimension stone quarry and plant.....90

Stop 3: Gillis Tyndall Stone quarry and plant.....91

Leaders:

J. Bamburak, *Manitoba Geological Survey*

R. Bezys, *Manitoba Geological Survey*

Trip 5: Separation Rapids Rare-Element Pegmatite Field, Ontario	95
Stop 1: Big Mack pegmatite	107
Stop 2: Separation Rapids pluton	109
Stop 3: Big Whopper pegmatite	110
Stop 4: Marko's pegmatite	115
Stop 5: James' pegmatite	116

Leaders:

C. Blackburn, *Blackburn Geological Services*
D. Bubar, C. Pedersen, K. Rees, *Avalon Ventures Ltd.*
C. Galeschuk, *Tantalum Mining Corporation of Canada, Ltd.*
A. Mowatt, *Emerald Fields Resource Corp.*
T. Pryslak, *A.P. Pryslak Geological Services*

Trip 6: Geology of the Red Lake Camp, Ontario	121
Stop 1: Meso-neoarchean contact, Woodland Cemetery road	130
Stop 2: Calcite carbonatized pillowed flows, Sandy Bay road	130
Stop 3: Cofederation/Balmer assemblages contact, Suffel Lake road	130
Stop 4: Madsen deposit, power line outcrops	131
Stop 5: Buffalo deposit	133
Stop 6: Howey mine	134
Stop 7: Howey Bay-Flat Lake deformation zone	134
Stop 8: Redcon carbonate zone, Nungesser road	135

Leaders:

A. Lichtblau, *Ontario Geological Survey*
C. Storey, *Ontario Geological Survey*
Staff, *Goldcorp Inc. - Red Lake Mine*
Staff, *Placer Dome North America - Campbell Mine*

Field Trip 1

The Tanco Rare-Element Pegmatite, Southeastern Manitoba

Peter Vanstone
Chief Geologist

Steven Young
Mill Superintendent

Roland Simard
Mine Superintendent

Carey Galeschuk
Project Geologist

Alistair Gibb
Chemical Plant Superintendent

*Tantalum Mining Corporation of Canada Limited
P.O. Box 2000
Lac du Bonnet, Manitoba R0E 1A0*



"Giraffe" underground at the Tanco mine.

INTRODUCTION

Pegmatites throughout the world range in age from late Archean (2,500-2,800 million years) to Miocene (5-23 million years) (Cerny 1989a). Within Canada, there are noticeable concentrations of rare-element pegmatites associated with the following orogenic events:

1. the Kenoran Orogeny (2,750-2,550 million years) in the Archean Superior Province;
2. the Hudsonian Orogeny (1,800 – 1,600 million years) in the Churchill Province; and,
3. the Grenville Orogeny (1,200 – 900 million years) in the Grenville Province.

The pegmatite being commercially exploited by Tantalum Mining Corporation of Canada Limited (Tanco) is an example of an extremely fractionated, pollucite-bearing pegmatite which was emplaced during the Kenoran Orogeny.

The Tanco pegmatite is located at Bernic Lake in the Canadian Shield of southeastern Manitoba, approximately 180 kilometres by paved and all-weather gravel road northeast of Winnipeg (Figure 1). The nearest communities, Lac du Bonnet and Pinawa, are located approximately 60 kilometres and 75 kilometres, respectively, from the minesite.

Tanco has been a significant producer of tantalum concentrates, ceramic-grade spodumene concentrates, pollucite and other materials since the late 1960's. More recently cesium

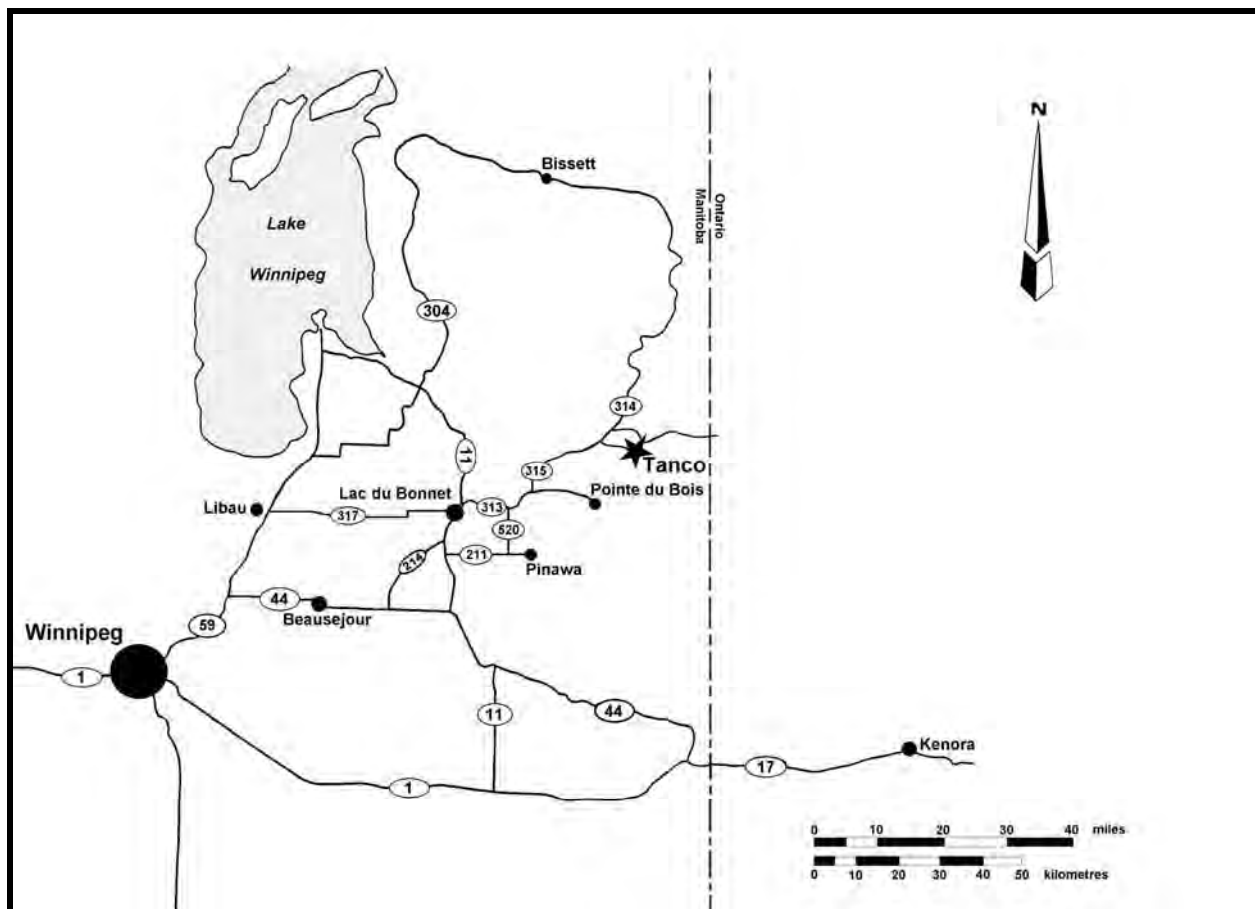


Figure 1. Location of Tanco

chemicals have been produced at the minesite. During this time, the pegmatite has been the subject of numerous studies because of its very limited low temperature alteration, lack of post-emplacement, structural deformation and its absence of weathering effects. The geographic location of the pegmatite and the willingness of Tanco to allow access to its extensive diamond drill core library, as well as, the underground workings have also been contributing factors.

For more information on the Tanco pegmatite and pegmatites in general, the reader is referred to the Canadian Mineralogist issues by Berry (1972), Cerny (1982), Martin and Cerny (1992), and Anderson et al (1998). Also, Brown and Ewing (1986) edited an issue of the American Mineralogist focused on pegmatites and granitic rocks, and Moller et al (1989) edited the proceedings of a workshop on the lanthanides, tantalum and niobium. Brisbin (1986) discusses pegmatite intrusion mechanisms and Ercit (1986) discusses tantalum mineralogy. An overview of the Tanco pegmatite and the mining/milling operations was published by Crouse, et al (1979) and Thomas (1984) completed a fluid inclusion study of the Tanco pegmatite.

Tanco is 100% owned by Cabot Corporation of Boston, Massachusetts and is operated by the Cabot Specialty Fluids division headquartered in Houston, Texas.

TANCO HISTORY

In 1928, Jack Nutt Mines staked and explored the Bernic Lake area pegmatites for tin. During the following two years, shaft sinking began and a small tin concentrator was established on what is now the Tanco minesite. Feed for this mill came from the nearby exposed pegmatites. At this same time, a four hole drill program was underway to explore the pegmatites at depth. It was during this program that the Tanco pegmatite was intersected in Hole #3. Work on the property continued through 1930, but poor economic conditions forced the company to abandon the property. The claims subsequently reverted back to the Crown.

In 1955, Montgary Petroleum Corporation Limited acquired the property and completed an extensive surface drill program. Over the next couple of years, a power transmission line from Pointe du Bois and a mine access road were constructed. Also, the sinking of a three-compartment shaft began and some surface facilities were built. In 1957, American Metals Company, Limited optioned the property from Montgary and completed a surface drill program. It was during this work that the internal zonation of the pegmatite was recognized and documented (Hutchinson 1959), and pollucite was identified.

During 1959 and 1960, Chemalloy Minerals Limited (formerly Montgary) completed both surface and underground drill programs, and extracted small quantities of pollucite and quartz. In 1961, the mine was placed on care and maintenance and then allowed to flood in 1962.

In 1966, Chemalloy started to evaluate the tantalum potential of the pegmatite. Extensive diamond drilling was carried out from surface and underground over the subsequent three years. The initial result of this activity was the formation in 1967, of Tantalum Mining Corporation of Canada Limited (Tanco), a joint venture between Chemalloy and Northern Goldfield Limited. In 1969, construction of a 500 ton per day tantalum gravity concentrator was completed and Tanco began commercial production.

Production of ceramic grade spodumene concentrates began on a pilot scale in 1984, and went commercial in 1986 when the new spodumene concentrator was completed. Although the lithium potential of the pegmatite had been investigated over the years for the production of

ceramic grade spodumene concentrates and lithium carbonate, none of these investigations proceeded beyond the feasibility stage.

The Tanco joint venture remained in place until 1993 when Cabot Corporation acquired 100% of the operation. Up to 1993, different companies, in addition to the original two companies, were involved in the joint venture. These include: Manitoba Development Corporation (1972-1993), Kawecki Berylco Industries/Cabot (1974-1993) and Hudson Bay Mining and Smelting Co. Ltd. (1978-1993).

In 1996, Cabot formed the Cabot Specialty Fluids division and started construction of the cesium brine plant. In 2001, the plant was expanded to allow for the manufacture of conventional cesium chemicals.

RARE-ELEMENT PEGMATITE FORMATION

Rare-element pegmatites, like the Tanco pegmatite, occur in synclinoria of metavolcanic-metasedimentary sequences that separate granitoid batholiths from gneissic tonalities. The pegmatites evolve from late orogenic, peraluminous ($A/[C+N+K]>1$), S-type granites. The resultant pegmatite fields are situated on the lower portions of relatively steep geothermal gradients ($\pm 40^{\circ}$ - 50° C/km.). The complex type pegmatites are commonly emplaced in low pressure/high temperature facies (upper greenschist to lower amphibolite) metamorphic terrains with emplacement generally at a depth of four to six kilometers (Cerny 1989a).

The parental, fertile granite is late- to post-tectonic and post-dates the peak of regional metamorphism. These granites are leucocratic and although commonly equigranular, may be porphyritic. At depth, they are biotite bearing and grade upward or laterally into a two-mica granite or a muscovite granite which is capped by a coarse grained to pegmatitic, megacrystic K-feldspar, graphic leucogranite (Cerny and Meintzer 1988). This pegmatitic granite stage is an integral step in the formation of rare-element pegmatites.

The pegmatitic melt forms within the parental, fertile granite through the process of magmatic differentiation. This melt collects in the upper portion of the fertile granite pluton, with the volatiles and other liquidus-depressing constituents such as H_2O , F, Li, B and P increasing outward from the parental granite. These constituents, plus even small amounts of exsolved supercritical fluid, reduce the viscosity of the melt. The lower the liquidus temperature and the less viscous the melt, the more mobile the melt becomes and the further out it will migrate.

Melt migration occurs when there is sufficient internal pressure and the magma reservoir is tapped by a tectonic disturbance of the outermost solidified shell of the pegmatitic granite. Pegmatite groups form a regional zonation around the parental granite with the complexity of the pegmatites increasing away from the parental granite (Cerny 1991b) (Figure 2).

Rare-Element Pegmatite Classification

Pegmatites can be divided into two types, the lithium-cesium-tantalum (LCT) type and the niobium-yttrium-fluorine (NYF) type. Over the years, the LCT type pegmatites have been well studied because of their economic significance. These pegmatites have been an economic source of lithium, tantalum, tin, cesium and rubidium minerals with mica, quartz and feldspathic sand by-products. The LCT type of pegmatites can be subdivided into classes based on mineralogy/chemistry and complexity (Table 1).

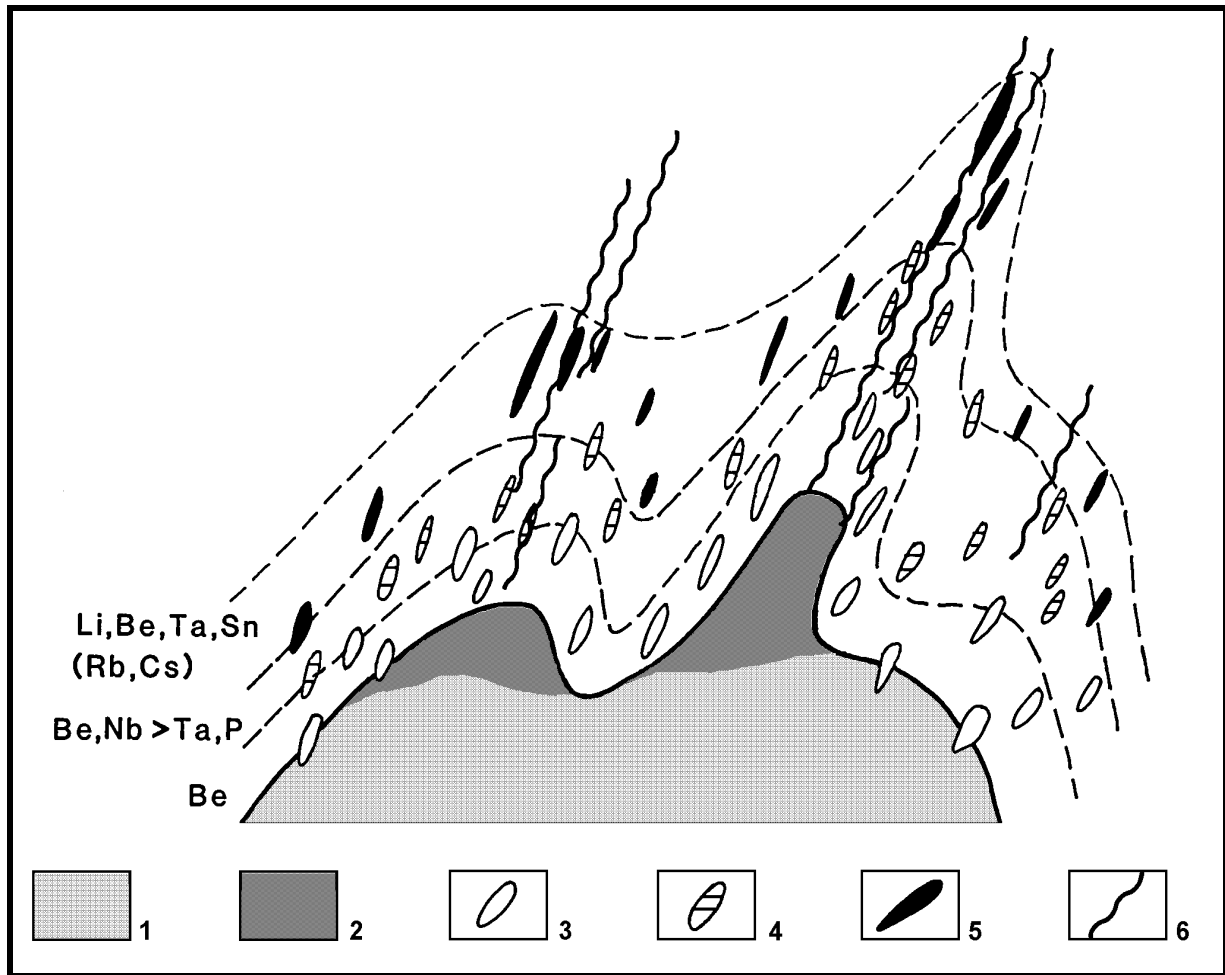


Figure 2. Schematic section of a zoned fertile granite-pegmatite system.

1. fertile granite; 2. pegmatitic granite; 3. barren to beryl bearing pegmatites; 4. beryl-type, columbite- to phosphate-bearing pegmatites; 5. complex spodumene (or petalite) bearing pegmatites with Sn, Ta, $\pm$ Cs; 6. faults. (modified from Cerny 1989b)

LCT type pegmatites have a number of chemical characteristics that distinguish them from the NYF type pegmatites. Some of these features include the following:

- the tantalum content exceeds the niobium content;
- the tin content can equal tantalum content;
- they contain low levels of the light and heavy rare earths;
- the pegmatites are enriched in boron and alkali elements; and,
- they have low levels of uranium and thorium.

Mineralogical characteristics can also be used to distinguish between LCT type and NYF type pegmatites. Some of the characteristics of the LCT type pegmatites include:

- a general absence of fluorite (fluorine is tied up in minerals such as topaz, lepidolite, amblygonite);
- a common occurrence of lithium and phosphate minerals;
- the presence of tourmaline;

- simpler oxides of tantalum and niobium $\pm$ tin with essentially no rare earth element (REE) content; and,
- beryl can be present.

The Tanco pegmatite is a good example of the complex type-petalite subtype of LCT pegmatite and is probably the most studied pegmatite of its type.

Pegmatite Types	Subtypes	Characteristics	Examples
Beryl	(i) beryl-columbite	• relatively simple	Greer Lake, MB
	(ii) beryl-columbite-phosphate		PEG Group, NWT
Complex	(iii) spodumene	• complex internal zonation • lithium rich • diverse mineralogy • primary crystallization is greater than secondary replacement bodies	Hugo, SD; Harding, NM
	(iv) petalite		Tanco, MB; Bikita, ZM,
	(v) amblygonite		Peerless, SD
Complex	Lepidolite	• high fluorine activity	Brown Derby #1, CO
Albite-Spodumene			Kings Mountain, NC
Albite		• least common	Hengshan Field, P.R.C.
		• generally small	

Table 1. Classification of LCT type pegmatites. (modified from Cerny 1991a)

GEOLOGIC SETTING

The Bernic Lake pegmatite group, of which the Tanco pegmatite is a member, is one of a number of such groups comprising the Winnipeg River Pegmatite Field located in the Archean Bird River Greenstone Belt of the western Superior Province in the Canadian Shield (Figure 3).

The Bird River Greenstone Belt is bounded on the north by the English River Subprovince, a belt of highly metamorphosed metasediments and metavolcanic rocks, and mafic to felsic batholiths and plutons (Beakhouse 1991a). To the south, this belt is bounded by the pluton-dominant Winnipeg River Subprovince (Beakhouse 1991b).

The Bird River Greenstone Belt is comprised of six formations of the Rice Lake Group. In general terms, the belt consists of mafic to felsic metavolcanic and derived metasedimentary rocks all of which have been intruded by synvolcanic to late tectonic mafic to felsic intrusives. Of these formations, the Eaglenest Formation is the oldest and the Booster Lake Formation is the youngest (Trueman 1980). The six formations are listed below in chronological order.

- 1) Booster Lake Formation: metapelite and metagreywacke
- unconformity -
- 2) Flanders Lake Formation: lithic meta-arenites and metaconglomerate
- unconformity -
- 3) Bernic Lake Formation: felsic to mafic metavolcanic and metasedimentary units, felsic and mafic intrusive with porphyry units

- unconformity-

- | | |
|------------------------------|--|
| 4) Peterson Creek Formation: | metarhyolites and clastic components |
| 5) Lamprey Falls Formation: | metabasalts, Bird River Sill, metagabbro |
| 6) Eaglenest Lake Formation: | metamorphosed volcanic wacke |

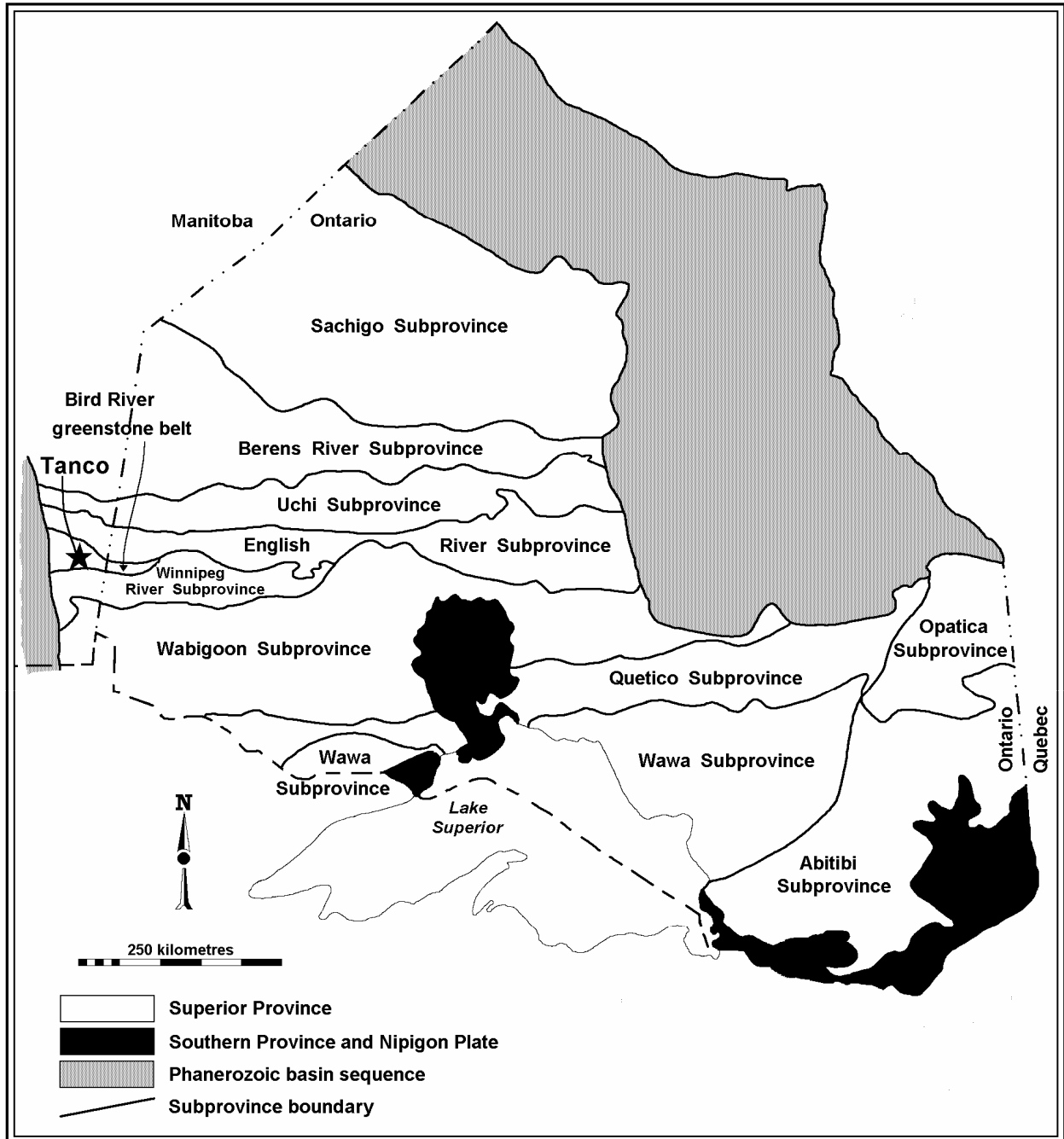


Figure 3. Regional geological setting of the Tanco pegmatite (modified from Beakhouse 1991b).

Trueman (1980) defined four major structural events in the area. The first two events were episodes of east-west folding, the second event being associated with the emplacement of large regional batholiths. These events led to associated prograde, low pressure/high temperature metamorphism (Abukuma type) in the Bernic Lake Formation. The third event was major east-west faulting, with associated retrograde metamorphism. The last major event was a second faulting episode that propagated a series of northwest trending faults. With this event there was localized retrograde metamorphism. Overall the metamorphic grade throughout the Bernic Lake Formation is upper greenschist to lower amphibolite facies (Cerny, et al 1981).

Numerous synvolcanic intrusive units intrude the Bird River Greenstone Belt. They range in size from a kilometre up to about 25 kilometres and generally display an elongated east-west shape. The compositions of these intrusives vary from body to body and even within an individual intrusive, and include gabbro, anorthositic gabbro, diorite, quartz monzonite, granodiorite and granite. Quartz and quartz-feldspar porphyries are also found throughout the belt.

The Bernic Lake Formation, which is in fault contact with the Booster Lake Formation to the north and the Peterson Creek Formation to the south, consists of a complex array of layers of metamorphosed basalt, andesite, dacite, rhyolite, iron formation, conglomerates, volcanic wackes and sandstone. Lateral continuity is not common among most of the rock types and is only persistent in the mafic to intermediate metavolcanics and, in part, the iron formations. Other volcanic units in the area seem to be composed of flows of limited lateral extent.

Syn- to post-tectonic emplacement of granite and pegmatitic granite stocks throughout the Bird River Greenstone Belt provided the source for a number of rare-element pegmatite groups found within the belt. Of all the pegmatites identified in the area, the largest and most economically significant ones occur within the Bernic Lake pegmatite group situated within the Bernic Lake Formation. The major pegmatites of this group include the Tanco, Dibs, Buck, Coe, and Pegli. All of these pegmatites have an east-west elongation, are horizontal to sub-horizontal in orientation and are hosted by either mafic intrusives or associated mafic metavolcanic units.

TANCO PEGMATITE GEOLOGY

The Tanco pegmatite, situated at the western end of Bernic Lake, is an extremely fractionated, rare-metal, complex type-petalite subtype, LCT pegmatite and is hosted by a late-stage, subvolcanic, metagabbro (Tanco amphibolite) intrusive. The age of the Tanco pegmatite is 2,650 – 2,550 million years (Cerny 1989a).

The pegmatite is completely blind or buried, and only sub-crops in a limited area in the bottom of Bernic Lake. Based on hundreds of diamond drill hole intercepts, the pegmatite has a maximum length of approximately 1,990 metres and a maximum width of 1,060 metres (Figure 4), and is up to 100 metres thick. The total tonnage of the pegmatite has been calculated to be approximately 25 million tonnes (Stilling, 1998).

Emplacement is hypothesized to be within the pressure shadow of an easterly trending, dual plunging, anticlinal axis (Cerny, et al 1981). More recent data has given rise to the possibility that dilation may have been aided by a number of pre-existing faults that could have freed up the overlying block of metagabbro, thus allowing the intruding pegmatitic fluid to “hydraulically” lift the overlying host rock. Initial intrusion of this fluid appears to be into a sub-horizontal joint

set that is ubiquitous throughout the Bernic Lake area. The bi-lobate shape of the pegmatite may also be influenced by a possible sinistral offset of the host anticline.

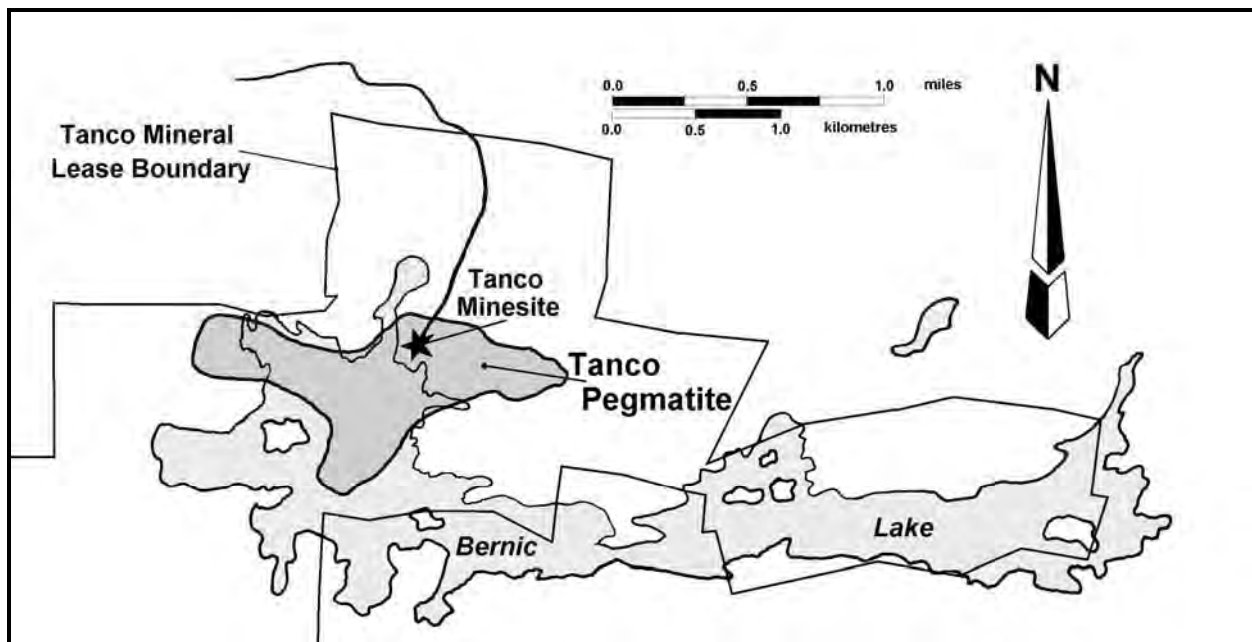


Figure 4. Plan view of the Tanco Pegmatite

Pegmatite Zonation

Internally, the pegmatite is composed of nine discrete mineralogical zones with the different ores of economic interest – those of tantalum, spodumene, cesium and rubidium – each essentially occurring in different zones. Characteristic textures and mineralogical assemblages distinguish each zone. The pegmatite is the host to approximately 100 different minerals (Cerny, et al 1998).

A coloured longitudinal section of the Tanco pegmatite is appended and a brief description of each of the internal zones is given below. A more complete description of the pegmatite zonation and mineralogy can be found in Cerny, et al (1998).

Of the nine zones comprising the pegmatite, only the Border and Wall Zones occur as concentric shells enveloping the entire pegmatite. When combined, however, the Lower and Upper Intermediate Zones also form a concentric shell within the pegmatite. The Central Intermediate and Lepidolite Zones have both been subjected to late stage micaceous alteration. Unlike the stereotypical zoned pegmatite, the location of the Quartz Zone or core is in the upper portion of the dike for most of the mine and in its more traditional, central location only in the western portion.

Border Zone (Zone 10)

This is a very thin zone (a few to 30 centimetres) that envelops the pegmatite and is composed of fine-grained, saccharoidal assemblage of albite and quartz with lesser to rare tourmaline, apatite, biotite, beryl and triphylite. In places it may have a layered appearance.

Wall Zone (Zone 20)

The Wall Zone consists of very coarse grained, brick-red perthite, quartz, fine to coarse-grained tourmaline, albite, brown to greenish muscovite books and accessory white beryl. In general, the hanging-wall Wall Zone is thinner and coarser grained than the footwall Wall Zone. Increased albite (cleavelandite) content and bands of “footwall” aplite characterize this latter Wall Zone. The tin content of the zone generally exceeds the tantalum content.

Aplitic Albite Zone (Zone 30)

This zone is one of the main tantalum ore zones and is most prominent in the eastern portion of the pegmatite. The dominant mineral is a pale blue to white, fine-grained, saccharoidal albite. Quartz is a common constituent with subordinate to rare minerals including muscovite, Ta-oxides (predominantly wodginite), beryl and apatite. Texturally, undulating layers of the saccharoidal albite distinguish the zone.

Where the Aplitic Albite Zone is in contact with the Quartz Zone, the contact is generally characterized by increased tantalum along the contact and within the albite in very close proximity to the contact (“nugget effect”). In some places, white beryl crystals that have grown off the albite into the quartz mark this contact.

Lower Intermediate Zone (Zone 40)

The locally known Mixed Zone is characterized by both its diversity of minerals and grain size. The mineral assemblage that distinguishes this zone is comprised of coarser grained microcline-perthite and SQUI pseudomorphs (**S**podumene-**Q**uartz **I**ntergrowth after primary petalite) in a finer grained matrix of albite, quartz and micas. Assemblages consisting of quartz pods containing amblygonite and/or spodumene, and radial rims of cleavelandite and lithian-muscovite around feldspar rich assemblages are less common. Common subordinate to rare minerals include lithian-muscovite, lithiophilite, lepidolite, petalite and Ta-oxides. The generally gradational contacts with the tantalum and spodumene zones allow for the selective mining of this zone for both tantalum and spodumene, but only under strict grade control.

Upper Intermediate Zone (Zone 50)

The Spodumene Zone as it is referred to, has evolved from the Lower Intermediate Zone and is comprised of very coarse-grained microcline-perthite and SQUI with lesser spodumene blades, quartz and amblygonite. Subordinate to rare mineralogy consists of pollucite, lithiophilite, albite, lithian-muscovite, petalite, eucryptite and Ta-oxides (predominantly tantalite).

The SQUI, which is an oriented intergrowth of cogenetic spodumene and quartz, has resulted from the isochemical breakdown of the primary petalite. This process occurs under decreasing pressure conditions during the cooling of the intrusion (London (1986)). This zone displays the largest crystals in the pegmatite with the petalite pseudomorphs (SQUI) attaining lengths up to approximately seven metres and the microcline-perthite reaching up to ten metres in length.

Central Intermediate Zone (Zone 60):

The MQM (Muscovite and Quartz after Microcline) Zone is another of the main tantalum ore zones. The zone is comprised of microcline-perthite, quartz, albite and muscovite with

subordinate to rare beryl, Ta-oxides (predominantly wodginite), spodumene, sulphides, and apatite. The minerals are medium to coarse grained.

Quartz Zone (Zone 70)

This is a massive, monomineralic zone with accessory spodumene (SQUI) and amblygonite. When in contact with the tantalum zones, the contact is commonly characterized by increased tantalum concentration (“nugget effect”)

Pollucite Zone (Zone 80)

The Pollucite Zone is a sub-zone of the Upper Intermediate Zone with a gradational contact occurring between the two, and consists of a monomineralic core of pollucite enveloped by an assemblage of SQUI, microcline-perthite, amblygonite, petalite and interstitial pollucite. Polygonal fracturing with lithian-muscovite and/or quartz filling is not uncommon within the core. Accessory minerals include apatite and albite. This is the zone from which the cesium ore is mined.

Lepidolite Zone (Zone 90)

This zone forms two flat lying, east-west elongated sheets within, (at least in part) the Central Intermediate Zone and in contact with the Upper Intermediate Zone. The mineral assemblage consists of fine-grained, purple lithian-muscovite and lepidolite with lesser microcline-perthite, and subordinate to accessory albite, quartz, beryl and Ta-oxides (predominantly microlite). The zone is mined for tantalum and has been mined, on a limited scale, for rubidium.

MINING

The heart of the Tanco pegmatite is situated some 60 metres (~200 feet) below Bernic Lake, and is accessible from surface either via a shaft or via a 400 metre (~1,300 foot), 20 percent decline.

Mining is carried out using the “room and pillar” method. The mine’s shallow depth contributes to lower inherent ground stresses and generally stable ground conditions. After weighing these factors, and considering the diverse mineralogy encountered at Tanco, it was decided that the Room and Pillar mining method would provide the optimum approach for economic extraction at Tanco.

The first pillar design saw pillars 16 metres square (50 ft. x 50 ft.), with mining rooms also at 16 metres wide. As mining progressed over the years, ongoing rock mechanics studies showed that the rooms could be increased to 22 metres or 72 feet, without excessively loading the pillars. Pillar reduction has now been done successfully throughout the mine and continues as an integral part of the mining plan.

Two-boom hydraulic jumbos perform all drilling for drifts, slashes, benches and arches. During the initial top slice development, the roof is carefully arched, utilizing smooth blasting techniques. The roof arches allow residual ground stresses to be redirected to the post pillars. Ground stress in the Tanco mine is considered low, relative to other hard rock mines, and as such, rock bolting is rarely required.

At Tanco, the roof of mature mine workings may often average 20 metres (~65 feet) above the working levels below, and in places, may reach 30 metres (~95 feet). These high backs are

carefully monitored throughout mining operations, utilizing custom designed aerial lift devices (referred to as Giraffes). Where suited, mining is carried out, utilizing a single boom Simba long-hole drill. In particular, the longhole method has been the primary approach to pillar reduction.

The broken ore is transported utilizing 5 yd³, 6 yd³ and 7 yd³, load-haul-dumps (LHD's) – mobile, front-end loader units - and a 20 ton truck to various ore-passes, which are located throughout the mine. The ore is broken on grizzlies (metal grates at the top of the ore pass), utilizing either mobile or stationary hydraulic rock breakers. The ore is then passed to an underlying tramming level where it is transported to the shaft by a train of 4 ton, Granby style, side dump ore cars, and hoisted to surface coarse ore bins via 4 ton Kimberly style skips.

Tantalum and spodumene ores are stored in one of two loading pockets and skipped on a daily basis up the two-compartment shaft, into dedicated surface coarse ore bins. The mine however, must produce and provide three distinct ores to the mill. To overcome the limitation of the system, one loading pocket and associated coarse ore bin is emptied weekly and an appropriate tonnage of pollucite ore is batched through.

Mine ventilation air is downcast from surface through one of two vent raises, one being, in part, the Jack Nutt shaft from 1929/30 and the other, a 1.8-m (6 foot) diameter bore-hole raise. The exhaust mine air up-casts through the access decline. Total fresh air volume exceeds 5300 m³ per minute (190,000 ft³ per minute) and is appropriate for the operation of Tanco's fleet of diesel mining equipment.

A fleet of personnel carriers and service trucks supports mining operations. Tanco maintains all of its mine equipment at its own on-site facilities.

MINERAL PROCESSING

Due to land constraints, the concentrator is constructed on a peninsula formed by two bays on Bernic Lake. The building is multi-floored, with equipment on a total of six levels. The major items of concentration equipment are on two levels, with feed preparation equipment, filters and driers, on the upper levels, with pumps on the lower levels.

The first stage of processing, common to all four mineral products, is crushing, where the coarse ore from underground (-300 mm in size) is broken down to -12 mm. in size. The tantalum, spodumene and pollucite ores are crushed into separate fine-ore, storage bins. The new dry grinding plant supplies ground pollucite for the cesium formate plant.

Different processes concentrate each ore. Tantalum is processed by gravity concentration, a process that makes use of the fact that tantalum minerals are much heavier than the waste minerals. Spodumene, on the other hand, is primarily processed by flotation, which makes use of the different physical and chemical characteristics of the surfaces of the various minerals. Pollucite is ground and then subjected to acid leaching and other chemical processing to produce cesium chemicals.

Tantalum Processing (Figure 5.)

There are three main elements in the gravity concentration of Tanco's minerals: liberation of the values from the gangue or waste rock; feed preparation of the ground product into different size fractions; and concentration of the different fractions. At Tanco, the plant is split effectively into four fractions – grinding/spiral circuit, coarse sand circuit, fine sand circuit and slime circuit.

Fine ore is first ground to pass 2 mm. The -2 mm. product passes to the spirals, which recover the coarse, free, tantalum minerals, which may otherwise have been ground too fine for effective recovery. The spiral tailing is sized at 0.30 mm. by a Linatex hydrosizer with the underflow recirculating to the main grinding mill.

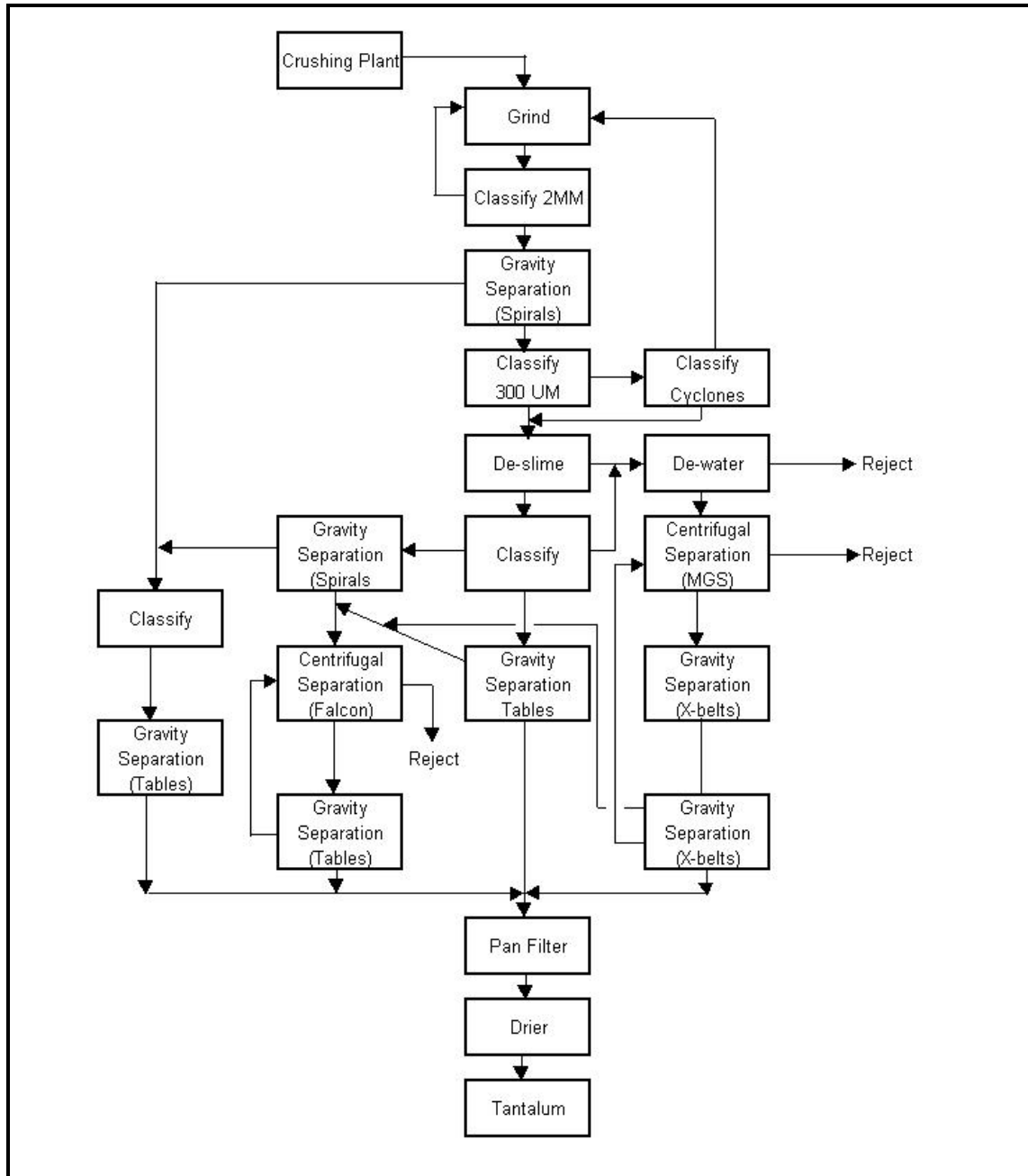


Figure 5. Tanco's tantalum gravity separation flowsheet.

Effective feed preparation is essential for satisfactory separation on shaking tables, and this is carried out with cyclones, followed by Bartles-Stokes hydrosizers. The hydrosizers contain four spigots and an overflow. The spigot products, or sand fractions, are distributed to further banks of spirals. These spirals each produce a low-grade concentrate, a recirculated middling, and a

tailings product. Falcon concentrators scavenge the fine sand tailings products. This centrifugal separator is one of the newest concentration devices, confirming Tanco's commitment to "leading edge technology" in the pursuit of performance.

Rougher concentrates from all sections are collected in a storage tank from which the cleaner section is fed at constant flowrate and density. Classification in cyclones and a hydrosizer sizes feed to four cleaner tables, which produce a fine, 35% Ta₂O₅ concentrate, a recirculated middling, and a tailing.

Overflows from the various cyclones along with the Stokes hydrosizer overflow constitute the feed to the ultrafines circuit. These are thickened in another bank of cyclones and treated on a Mozley MultiGravity Separator (MGS). The MGS produces a rougher concentrate, upgraded on Bartles CrossBelts.

Overall recovery of tantalum ranges from 69-72%.

During the summer months accumulated tailings can be processed along with the ore; the same flowsheet being used. Recovery from the tailing portion of the feed is of the order of 30%, upgrading the feed from 0.05% to 30% Ta₂O₅.

The specifications of a typical tantalum concentrate produced at Tanco is given in Table 2.

Element	Typical Concentrate (wt. %)
Ta ₂ O ₅	35% - 38%
SnO ₂	14% - 18%
Nb ₂ O ₅	5% - 8%
TiO ₂	2% - 4%

Table 2. Typical tantalum concentrate

Tantalum Markets

Tanco's tantalum concentrates are shipped to the Cabot Performance Materials facility in Boyertown, Pennsylvania for conversion to the metal or tantalum compounds.

The major uses for tantalum are in the electronics industry and for cutting tools. High quality capacitors are the major single use for tantalum. Europe is the major consumer of tantalum carbide used in production of hardmetal alloys for cutting tools. Other tantalum alloys are important constituents of aero engines, and for acid resistant pipes and tanks used in the chemical industry. One minor but important use of tantalum is in the medical industry, for "spare-part" surgery – tantalum "pins" are used for such areas as hip-joint replacements, as it is the only metal that is not rejected by body fluids.

Spodumene Processing (Figure 6)

After crushing to -12 mm., the heavy medium Triflo circuit rejects the feldspar from the -12 mm. +0.5 mm. range. Ferrosilicon and magnetite as a 70:30 mixture are used with a feed density of 2.74 kg/l. and effective density of separation of 2.65 kg/l. The -0.5 mm. fraction continues to the grinding circuit.

The sink product and the -0.5 mm. fraction are ground in closed circuit with a 2 mm. primary screen and a Linatex hydrosizer with an approximate cut point of 150 micron. Rougher and cleaner spirals recover coarse free tantalum within the grinding circuit. A 5 foot, low intensity drum magnet removes ground steel produced during the grinding process.

The grinding circuit product is scavenged for tantalum by two Falcon concentrators. Tantalum from the Falcon concentrators is upgraded on a Double Deck Holman Table with the tailings and middlings returning to the grinding circuit. Coarse tantalum from the cleaner spiral is also

upgraded on a single Holman Table. The tantalum recovered from the spodumene circuit is a valuable by-product.

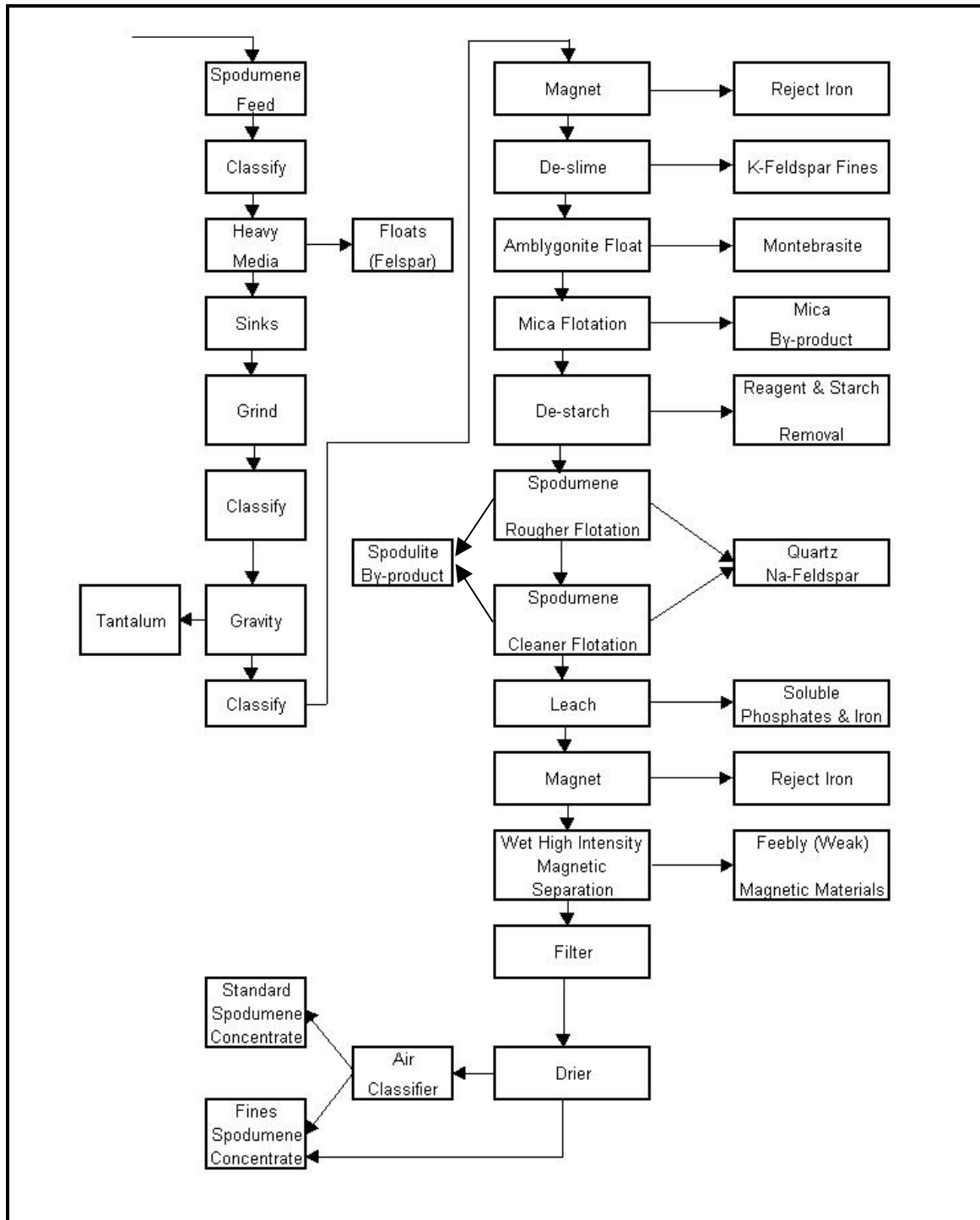


Figure 6. Schematic flowsheet of the spodumene circuit

Prior to the amblygonite flotation stage, in order to control phosphate levels, the pulp is deslimed by single stage cycloning. Due to the nugget-like appearance of the amblygonite, close control of this flotation stage must be maintained. Starvation quantities of collector are used based on

feed tonnage and previous tails assays. Starch is used as a depressant for spodumene at pH 9.2. A spodumene-phosphate by-product called Montebasite is produced to meet market requirements. This concentrate is subjected to wet high intensity magnetic separation to remove weakly magnetic iron materials. This concentrate is pumped to a belt filter and propane fired rotary drier. The dried concentrate goes to a storage bin prior to bagging or bulk shipping to meet the customers' requirements.

Mica is then removed with a single flotation stage. This step assists in the removal of K_2O from the final concentrate product. The mica flotation tailings are two stage cycloned to remove starch. Two conditioning stages for automatic pH control and collector addition are carried out prior to rougher flotation. The rougher concentrate goes on to two or three stages of cleaning to

The Wet High Intensity Magnetic Separator (WHIMS) non-magnetic fraction is thickened by two stages of cycloning and stored in a holding tank prior to tonnage controlled feeding to the belt filter and propane fired rotary drier.

Final product handling is carried out utilizing air slides and dense phase pneumatic pumping to storage bins. The final product can be shipped to the customer in 25 kg, 1,000-kg bags, or bulk, via road or rail. The concentrate is sold to markets worldwide.

Water used within the circuits is either fresh (from Bernic Lake) or re-cycled pond overflow depending on the section of the plant.

Spodumene Product Specifications

Clients can accept different levels of impurities, depending on their specific use of the material. Specifications of Tanco's 7.25%, -200 Mesh, 6.8%, and Spodulite grade concentrates are shown in Table 3.

Spodumene Markets

Customers specify tight impurity levels for the use of spodumene concentrates in the glass and ceramics industries, and the process for the production of these concentrates is based on removal of contaminant minerals.

Spodumene can be used either as a feedstock for the production of lithium carbonate and metal, or directly, in its mineral form, in the glass and ceramics industries. Since the development of the "salars" in the USA and Chile, most lithium carbonate is recovered from these sources, and little spodumene is now used for chemical production.

Lithia is a very powerful flux, especially when used in conjunction with potash and soda feldspars. In ceramics, lithium lowers thermal expansion and decreases the firing temperature. Glasses containing lithia are much more fluid in the molten state than those containing proportionate amounts of sodium or potassium. Lower viscosity and faster melting can be utilized to improve glass quality in terms of fewer defects such as unmelted or partially melted raw material grains, and more rapid removal of small bubbles. Lower viscosity can permit the glassmaker to run a forming machinery at a higher rate, or create more elaborate products such as some perfume bottles. In frits and glazes, lithia is used to reduce the viscosity and thereby increase the fluidity of the coatings. This reduces maturing times and lowers firing temperatures. Small amounts of lithia also increase gloss.

Element/Sizing	7.25% Grade	-200 Mesh	6.8% Mesh	Spodulite
Li₂O	7.25 ± -0.1%	7.10% ± -0.2%	6.80% min.	5.00% min.
Fe₂O₃	0.06% ± -0.01%	0.15% max.	0.08% max.	0.10% max.
Na₂O	0.35% max.	0.30% max.	0.45% max.	0.75% max.
K₂O	0.30% max.	0.60% max.	0.40% max.	0.75% max.
P₂O₅	0.27% max.	0.40%	0.27% max.	0.20% max.
MnO₂	0.04% max.	0.06% max.	0.04% max.	0.05% max.
Al₂O₃	24.0% min.	25.0% min.	23.0% min.	20.0% typ.
Tyler 20 Mesh	0.0% max.			
Tyler 28 Mesh	Trace max.			
Tyler 48 Mesh	1.0% max.			
Tyler 200 Mesh	50.0% min.	10.0% max.	55.0% min.	80.0% typ.

Table 3. Tanco's spodumene products specifications.

CESIUM FORMATE

Cesium formate is a clear, water soluble fluid with a specific gravity of 2.3 g/cm³ (i.e. it is two and one third times heavier than water) and a viscosity similar to water. It is used in the oil drilling industry as a drilling fluid, where the properties of low viscosity, high specific gravity and complete solution confer significant benefits over traditional mud (bentonite) based drilling fluids in deep wells greater than 4,575 metres (15,000 ft.).

Use of cesium formate eliminates formation damage, particularly skin formation while drilling through the reservoir (oil bearing) rock. This results in improved hydrocarbon flows to the well giving better daily production from the well, in addition to enhanced recoveries from the reservoir in the long term - that is more hydrocarbons may be extracted from the well before well stimulation techniques become necessary.

From an occupational health and safety perspective, there are considerable benefits to the use of cesium formate. The pH is between 10 - 11, and skin contact, although undesirable, has no immediate consequences. Low mammalian toxicity is an added benefit.

The low environmental toxicity of cesium formate makes it the fluid of choice in areas where environmental sensitivities are particularly acute.

Cesium Formate Plant

The cesium formate pilot plant was designed, built and commissioned in 1996/97 in response to a potential market for formate brines. The focus of plant production was aimed at the oil and gas industries' demand for a high-density, solids free drilling fluids. The plant was designed to

readily incorporate process changes and modifications enabling it to produce a wide variety of cesium-based products, thus allowing Tanco and Cabot to rapidly respond to these future markets. The original plant was designed to produce 500 barrels/month of 2.3 g/cm³ specific gravity cesium formate. In 1999, expansion of the plant allowed for the production of 700 bbl/month. In 2001, the plant underwent a further expansion in order to accommodate the manufacturing of conventional cesium chemicals.

Since Bernic Lake is a headwater lake and therefore very susceptible to environmental damage, the plant design minimizes environmental impacts on the surrounding area. All areas of the plant are contained to capture any spilled material, and wastes are stored in a lined disposal cell, which eliminates the discharges to the lake.

Cesium Formate Manufacture

Pollucite ore is mined from the Tanco mine along with the spodumene and tantalum ores. The mine contains approximately 75% of the worlds proven reserves of pollucite. The ore is crushed to -12 mm., and then dry ground in a ball mill to a powder form. Utilizing a series of acid/base reactions, the cesium is extracted from the pollucite ore and converted to a high-density, cesium formate solution.

The final product is shipped by container to Aberdeen, Scotland and Bergen, Norway for use by the drilling industry in the North Sea, and to Houston, Texas for use in the Gulf of Mexico.

Markets

Cesium chemicals are currently used primarily in catalyst and chemical synthesis applications. While current worldwide demand for fine cesium chemicals is approximately 700,000 pounds a year, it is expected that new applications in the oil, gas and chemical industries for these products will increase in demand by more than ten-fold.

TANCO UNDERGROUND TOUR STOPS

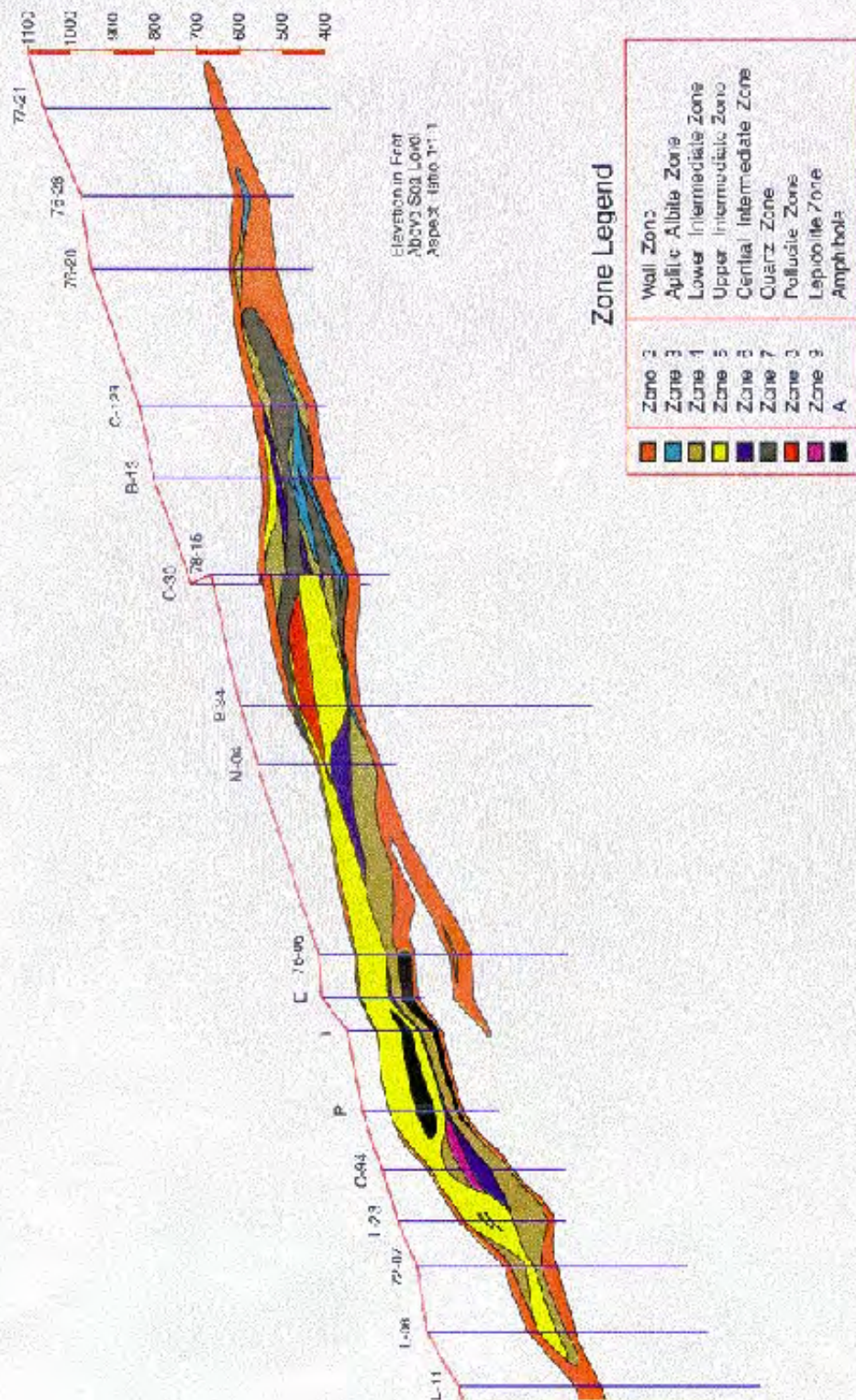
Due to the constant changes underground as a result of on-going mining activities, the stops for the tour will not be determined until closer to the date of the tour. The tour participants will receive a tour stop handout upon arrival at the minesite.

REFERENCES

- Anderson, A.J., Groat, L.A. and Simmons, W.B.Jr. (eds.) (1998): Granitic Pegmatites: The Cerny – Foord Volume. The Canadian Mineralogist, vol. 36, pt. 2.
- Beakhouse, G.P. (1991a): Winnipeg River Subprovince, *in* Thurston, P.C., Williams, H.R., Sutcliffe, R.H. and Stott, G.M., (eds.), Geology of Ontario: Ministry of Northern Development and Mines, Special Volume 4, Part 1, pp.239-278.
- Beakhouse, G.P. (1991b): Winnipeg River Subprovince, *in* Thurston, P.C., Williams, H.R., Sutcliffe, R.H. and Stott, G.M., (eds.), Geology of Ontario: Ministry of Northern Development and Mines, Special Volume 4, Part 1, pp.279-302.
- Berry, L.G. (ed.) (1972): The Tanco Pegmatite at Bernic Lake, Manitoba. The Canadian Mineralogist, vol. 11, pt. 3.
- Brisbin, W.C. (1986): Mechanics of pegmatite intrusion. The American Mineralogist, vol. 71. N°s. 3 and 4, pp. 644-651.
- Brown, G.E., Jr., and Ewing, R.C. (eds.) (1986): R. H. Jahns Memorial Issue: The mineralogy, petrology, and geochemistry of granitic pegmatites and related granitic rocks. The American Mineralogist, vol. 71, N°.'s 3 and 4.
- Cerny, P. (ed.) (1982): Granitic Pegmatites in Science and Industry. Mineralogical Association of Canada Short Course Handbook 8.
- Cerny, P. (1989a): Characteristics of pegmatite deposits of tantalum, *in* Moller, P., Cerny, P. and Saupe, F., (eds.), Lanthanides, Tantalum and Niobium: Society for Geology Applied to Mineral Deposits, Special Publication 7, Springer-Verlag, pp.195-239.
- Cerny, P. (1989b): Exploration strategy and methods for pegmatite deposits of tantalum, *in* Moller, P., Cerny, P. and Saupe, F., (eds.), Lanthanides, Tantalum and Niobium: Society for Geology Applied to Mineral Deposits, Special Publication 7, Springer-Verlag, pp.274-302.
- Cerny, P. (1991a): Rare-element Granitic Pegmatites. Part II: Regional to Global Environments and Petrogenesis. Geoscience Canada, vol. 18, pp. 49-67.
- Cerny, P. (1991b): Rare-element Granitic Pegmatites. Part 1: Anatomy and Internal Evolution of Pegmatite Deposits. Geoscience Canada, vol. 18, pp.68-81.
- Cerny, P., Ercit, T.S. and Vanstone, P.J. (1998): Mineralogy and Petrology of the Tanco Rare-element Pegmatite Deposit, Southeastern Manitoba. International Mineralogical Association, Field Trip Guidebook B6, 17th General Meeting, Toronto, Ontario, Canada.
- Cerny, P. and Meintzer, R.E. (1988): Fertile granites in the Archean and Proterozoic fields of rare-element pegmatites: crustal environment, geochemistry, and petrogenetic relationships, *in* Taylor, R.P. and Strong, D.F. (eds.), Recent advances in the geology of granite related mineral deposits: Canadian Institute of Mining and Metallurgy, Special Volume 39, pp. 170-207.
- Cerny, P., Trueman, D.L., Ziehlke, D.V., Goad, B.E., and Paul, B.J. (1981): The Cat Lake-Winnipeg River and Wekusko Lake Pegmatite Fields, Manitoba. Manitoba Department of Energy and Mines, Mineral Resources Division, Economic Geology Report ER80-1.
- Crouse, R.A., Cerny, P., Trueman, D.L. and Burt, R.O. (1979): The Tanco Pegmatite, Southeastern Manitoba. The Canadian Mining and Metallurgy Bulletin, Feb. 1979, pp.142-151.

- Ercit, T.S. (1986): The simpsonite paragenesis: the crystal chemistry and geochemistry of extreme Ta fractionation. Ph.D. thesis, University of Manitoba, Winnipeg, Manitoba, Canada.
- Hutchinson, R.W. (1959): Geology of the Montgary Pegmatite. *Economic Geology*, vol. 54, pp. 1525-1542..
- London, David (1984): Experimental phase equilibria in the system $\text{LiAlSiO}_4\text{-SiO}_2\text{-H}_2\text{O}$: a petrogenetic grid for lithium rich pegmatites. *American Mineralogist*, vol. 69, pp. 995-1004.
- Martin, R.F. and Cerny, P. (eds.) (1992): Granitic Pegmatites. *The Canadian Mineralogist*, vol. 30, part 3.
- Moller, P., Cerny, P. and Saupe, F. (eds.) (1989): Lanthanides, Tantalum and Niobium. Society for Geology Applied to Mineral Deposits, Special Publication N°. 7, Springer-Verlag, New York, NY.
- Stilling, A. (1998): Bulk composition of the Tanco Pegmatite at Bernic Lake, Manitoba, Canada. M.Sc. thesis, University of Manitoba, Winnipeg, Manitoba, Canada.
- Thomas, A.V. (1984): A petrological and fluid inclusion study of the Tanco pegmatite, S.E. Manitoba. M.Sc. thesis, University of Toronto, Toronto, Ontario, Canada.
- Trueman, D.L. (1980): Stratigraphy, structure, and metamorphic petrology of the Archean greenstone belt at Bird River, Manitoba. Ph.D. thesis, University of Manitoba, Winnipeg, Manitoba, Canada.

Tanco Pegmatite, Bernic Lake, Manitoba, Canada 3D Cross Section 9500N



Andy Stilling 96-Aug-90

Field Trip 2

Quaternary Geology of Southeastern Manitoba

Erik Nielsen and Gaywood Matile
Quaternary Geologists
Manitoba Geological Survey
Industry, Trade and Mines
360-1395 Ellice Avenue
Winnipeg, Manitoba R3G 3P2
Canada



Extensive wetlands that started to form in response to mid-Holocene climate change, are a common feature of the southeastern Manitoba landscape. The photo was taken approximately 25 km east of Sandilands.

INTRODUCTION

The climatic, geomorphic and ecological changes that have occurred in northwestern Ontario, southeastern Manitoba and Canada in general, over the last 100 000 years have been nothing short of spectacular. The Sangamonian Interglacial, which was not unlike the present interglacial, lasted from approximately 125 000 to 75 000 years ago, and ended with the advance of the Laurentide Ice Sheet in what was the greatest ecological catastrophe to befall Canada in recent geological time. The Laurentide Ice Sheet flowed southward out of Quebec and Nunavut and covered most of Canada and the northern parts of the United States as far south as New York City and De Moines, Iowa. The southern ice margin fluctuated periodically throughout the Wisconsinian, but northwestern Ontario and southeastern Manitoba and most of the rest of Canada were locked in the icy grip of the continental ice sheet until almost 10 000 years ago. For an estimated 65 000 years, northwestern Ontario and southeastern Manitoba lay devoid of trees, grasses and all living things, under a one kilometre thick ice mass! Ameliorating climate in the late Pleistocene saw the rapid northward and northeastward retreat of the ice margin and the establishment of glacial Lake Agassiz between the retreating ice margin and the high ground to the south, east and west. Lake Agassiz, at times over 200 m deep persisted for about 4 000 years from approximately 11 700 to 7 700 years BP and occupied all of Manitoba below the Cretaceous Escarpment, as well as much of northwestern Ontario. The flat fertile plains of the Red River valley and parts of northwestern Ontario, such as the Fort Francis area, resulted from the deposition of thick deposits of deepwater glaciolacustrine sediments. The numerous beach deposits in northwestern Ontario, southeastern Manitoba and elsewhere, record successive lake levels. Water levels recorded by the beaches relate to differential isostatic rebound and stepwise drainage of Lake Agassiz into the Gulf of Mexico, the Great Lakes and the Arctic Ocean before the lake finally drained into Hudson Bay.

POSTGLACIAL VEGETATION AND CLIMATE

Little is known of the postglacial vegetation of southeastern Manitoba despite the extensive and detailed work in the region by the Geological Survey of Canada and the Manitoba Geological Survey over the last fifteen years. Information on the postglacial climate and vegetational history of the region is inferred from a single pollen diagram from Hayes Lake near Kenora (McAndrews, 1982). The vegetational history of Hayes Lake suggests that the area was invaded by spruce forest immediately upon deglaciation and regression of Lake Agassiz. The early spruce forest changed to pine, birch, poplar and alder forest after 10 000 years BP. Based on the available data from Hayes Lake, open, mixed woodland existed in the northwestern Ontario and southeastern Manitoba during the early to mid-Holocene. Spruce and fir increased at the expense of alder after about 3 600 years BP, in response to a cooling climate. The present vegetation has remained relatively stable for the past 3 600 years.

QUATERNARY GEOLOGY OF SOUTHEASTERN MANITOBA

Twelve thousand years ago all of Manitoba, except possibly isolated areas above the Manitoba Escarpment, was completely covered by glacial ice, which at its maximum extended as far south

as Des Moines, Iowa. Rapid glacial retreat, caused by the rapid amelioration of climate, was enhanced by a proglacial lake environment, which promoted accelerated ice break-up by means of iceberg calving along the glacier margin. By ten thousand years ago the ice margin was at the south end of Lake Winnipeg, and southeastern Manitoba was ice-free.

As ice retreated into southeastern Manitoba it divided into two glacial lobes, the Rainy Lobe which advanced from the northeast and the Red River Lobe which advanced from the northwest. Sediments deposited by the Rainy Lobe typically have a sand-rich matrix and Precambrian-rich clast lithology, whereas sediments carried by the Red River Lobe are typically silt-rich and predominantly Paleozoic carbonate clasts, reflecting the lithologies of the bedrock that the glacier was advancing over. The interlobate position between these two ice-lobes is defined by large, sorted sand deposits in the south, the Sandilands Moraine, and sand and gravel deposits further north (Figure 1). Retreat was rapid, commonly followed by minor glacial readvances that eroded or destroyed previously deposited recessional moraines.

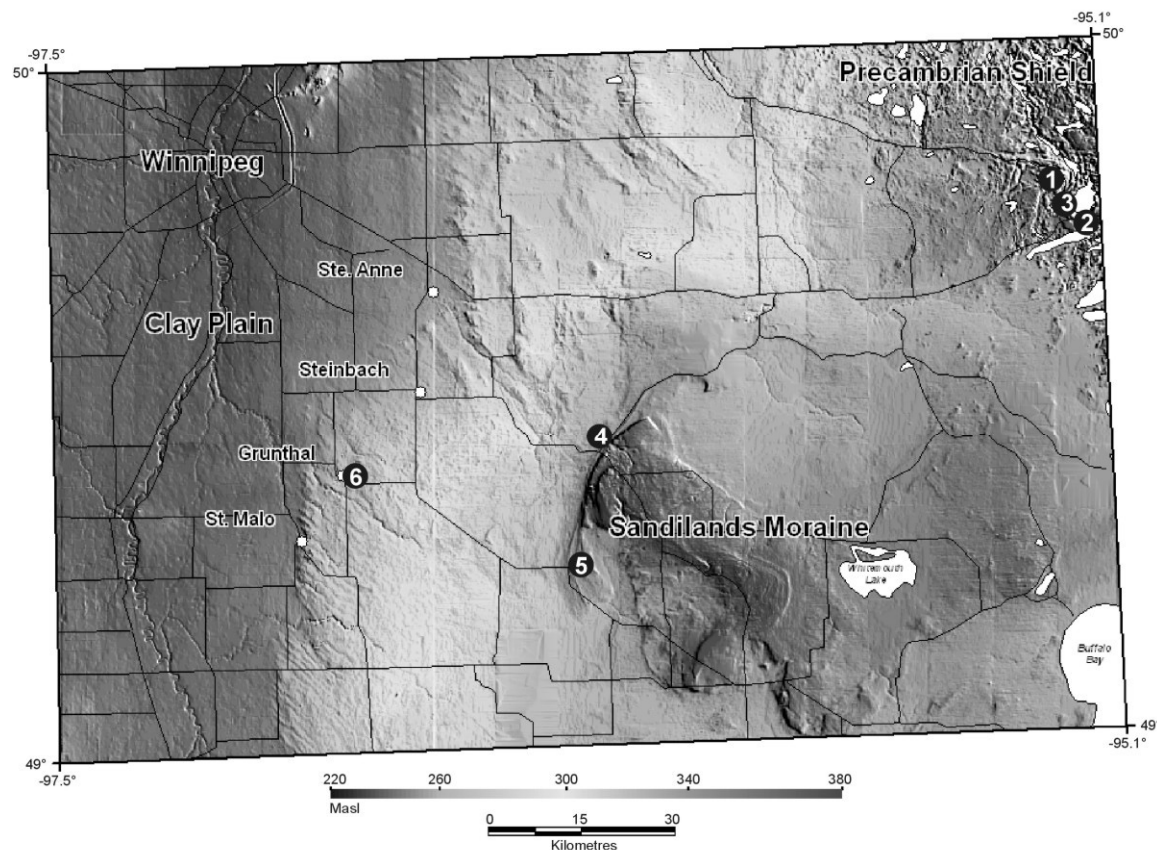


Figure 1. Field trip stops plotted on a Digital Elevation Model of a portion of southeastern Manitoba

Glaciation in Manitoba blocks the natural northward drainage and consequently a proglacial lake, glacial Lake Agassiz, formed as the ice front retreated north of the continental divide in South Dakota. Lake Agassiz existed for about four thousand years, from about 11 700 years before present (BP) until about 7 700 years BP when it finally drained into Hudson Bay (Thorleifson, 1996). Paleostrandlines and associated radiocarbon dates from southeastern

Manitoba document much of Lake Agassiz history (Figure 1). The initial phase of Lake Agassiz, the Lockhart Phase, during which time the lake drained southward into the Gulf of Mexico, and encompasses the highest levels of the lake lasted until about 11 000 years BP. The Lockhart Phase in southeastern Manitoba is represented by numerous, but poorly defined strandlines along the higher parts of Sandilands Moraine and by most of the clay deposited in the Red River valley to the west. The Lockhart Phase was followed by the Moorhead Phase which ended about 9 900 years BP. The Moorhead Phase is characterized by relatively low water levels, due to glacial retreat in the Lake Nipigon area of northwestern Ontario, which allowed drainage through lower outlets to Lake Superior and the Atlantic Ocean. Several, well-developed beaches and wave-cut escarpments and at least one in-filled abandoned river channel represent the Moorhead Phase north and west of the Sandilands Moraine. The following Emerson Phase, spanned the interval from about 9 900 to 9 300 years BP. A glacial readvance in northern Ontario blocked the eastern outlets. This caused the level of Lake Agassiz to rise to approximately the level it was at the end of the Lockhart Phase. The elevation difference was the result of about 1 000 years of isostatic rebound. Lake Agassiz again drained south into the Gulf of Mexico *via* the Mississippi River. Four prominent lake levels formed during the Emerson Phase, the Norcross, Tintah, Upper Campbell and the Lower Campbell. The Upper and Lower Campbell levels are the best-developed strandlines in Lake Agassiz and can be traced in this region around the Sandilands Moraine and eastward almost to the Ontario border. A great deal of erosion occurred along the Sandilands Moraine at this time as a result of the prevailing winds coming from the northwest, across the open expanse of the lake. The final phase of Lake Agassiz, the Morris Phase, is represented by a series of regularly spaced, moderately well developed strandlines (Figure 1). The final drainage of the lake, occurred as successively lower eastern outlets opened, first draining through Lake Superior and then through more northerly outlets to the north Atlantic, until the final drainage into Hudson Bay about 7 700 years BP.

During the rise and fall of Lake Agassiz water levels, the Sandiland Moraine, a large generally unconfined sand aquifer, rapidly became saturated and de-watered. The rapid de-watering caused the formation of sapping channels throughout the moraine, one of which is truncated by the Upper Campbell, and is therefore clearly related to the final drainage of Lake Agassiz from the area.

FIELD TRIP STOPS

STOP 1 - STRIATED OUTCROP, WEST HAWK LAKE

Northwestern Ontario and the adjacent parts of southeastern Manitoba have been glaciated numerous times throughout the Pleistocene. Each successive glaciation in large part removes the evidence of previous glaciation. Previously deposited sediments are stripped away and bedrock outcrops are molded and striated such that they record only the most recent events. Consequently, the terrestrial glacial record is largely incomplete.

The outcrop of pillow basalt at this stop was striated and polished by the last ice flow to affect this area (Figure 2). The striations, orientated towards 230°, are common throughout the area and

record glacier movement out of Hudson Bay towards the southwest. Striations are typically fine scratches on the gentle stoss sides of this outcrop. The plucking and steep sides at the down glacier side of the outcrop, indicates that the ice flow was towards the southwest and not the northeast. Minor variations in striation direction across the outcrop is due to topographic deflection at the glacier sole and is not related to different glacial events. In addition to striations, numerous p-forms, areas that have been eroded by subglacial meltwater under hydraulic head imposed by the glacier, are found on the outcrop.



Figure 2. Striated outcrop at West Hawk Lake showing ice flow towards 230°.

Striations are best preserved under till or glaciolacustrine sediments. Once glacial polish and striations have been exposed to weathering they don't usually last very long.

STOP 2 – WEST HAWK LAKE, TILL SECTION

Till is the material that is directly deposited by the action of glacier ice although there may be considerable influence of subglacial meltwater. It consists of a wide variety of grain sizes from clay to boulders and may be considered as being generally unsorted (Figure 3). Till is generally derived primarily by the comminution of the immediately underlying bedrock with only very small components originating from various up glacial sources. This is the case with the till in the West Hawk Lake area, which is sandy in texture and was derived primarily by the comminution of the underlying volcanic rocks. A small proportion of the till was derived from granitic rocks that outcrop approximately 5 km to the northeast. The till is generally not calcareous, but in places Paleozoic carbonate erratics derived from the Hudson Bay Lowland, 650 kilometres to the

northeast, can be found testifying to long distance glacial transport. Carbonate erratics are however rare, both because of the long glacial transport and the low survival rate of these soft lithologies, but also because of dissolution by near surface weathering in the time since the area was deglaciated. Carbonate erratics, which may be found in the scree were probably ice rafted and subsequently deposited in the glaciolacustrine sediments, which are common in the area. Carbonate erratics are probably not derived from the till at this site.



Figure 3. Section at West Hawk Lake exposing sandy till of northeast provenance.

STOP 3 - WEST HAWK LAKE, METEORITE IMPACT STRUCTURE

West Hawk Lake is almost 4 km wide and nearly circular in shape. It was drilled in the 1960s by the Dominion Observatory and found to be approximately 100 m deep and contain approximately 100 m of sediment overlying the Precambrian basement. The circular shape and great depth of the lake, as well as the presence of shock-metamorphosed quartz and other features indicates the lake was formed by a meteor impact. The oldest sediments in the crater are of Cretaceous age indicating the impact occurred prior to that time, possibly in the Paleozoic.

Because the lake is so deep compared to its diameter, it has been believed for many years that sediment deposited in the lake would be protected from erosion during glaciation. Glacier ice moving over the lake would shear over the top of the lake and not penetrate to the bottom. Previously deposited sediment would therefore be unaffected by glaciation. In addition, the great depth and the fact that there are no major rivers draining the lake means that sediments entering the lake would not be eroded or flushed through the lake. Consequently, the possibility exists that a complete Holocene, glacial and pre-glacial record spanning perhaps millions of years

might be preserved in the sediment in-fill at the bottom of the lake. Jim Teller from the Department of Geology, University of Manitoba, has undertaken coring of the upper 15 m of the sediment in-fill and is planning to core the remaining 75-85 m to elucidate the glacial history, the history of glacial Lake Agassiz and climate variability of the mid continent over possibly the last million years or more.

En route to Stop 4 we drive west on the Trans Canada Highway. Approximately 12 km west of Falcon Lake we leave the area affected by glaciation from Hudson Bay and northwestern Ontario. The ice flow direction changes to southeasterly (145°) and the associated till becomes fine textured and highly calcareous, having been derived by the comminution of Paleozoic carbonate bedrock in the Manitoba Interlake, northwest of Winnipeg. We will have an opportunity to observe diamicton, similar to this till, in the Grunthal pit at Stop 6.

Point of Interest

In some sections of the low boreal forest, the construction of the Trans-Canada Highway had a considerable effect on drainage and the height of the water table. Where the Trans-Canada Highway becomes divided, just west of Falcon Lake, a small stand of eastern white cedars (*Thuja occidentalis*) in the median illustrates the impact of hydrological change on the local vegetation. The growth of these trees began to be affected following highway construction in 1981. Although most of these trees had been growing since the early 1800s, the elevated water table caused their ringwidth and wood density to decline by 50 percent within two to three years. While some cedars were able to survive under the raised water table for several years, the last tree had succumbed to flooding by 1993. Although most are still standing upright, these trees have been dead for 10 to 20 years.

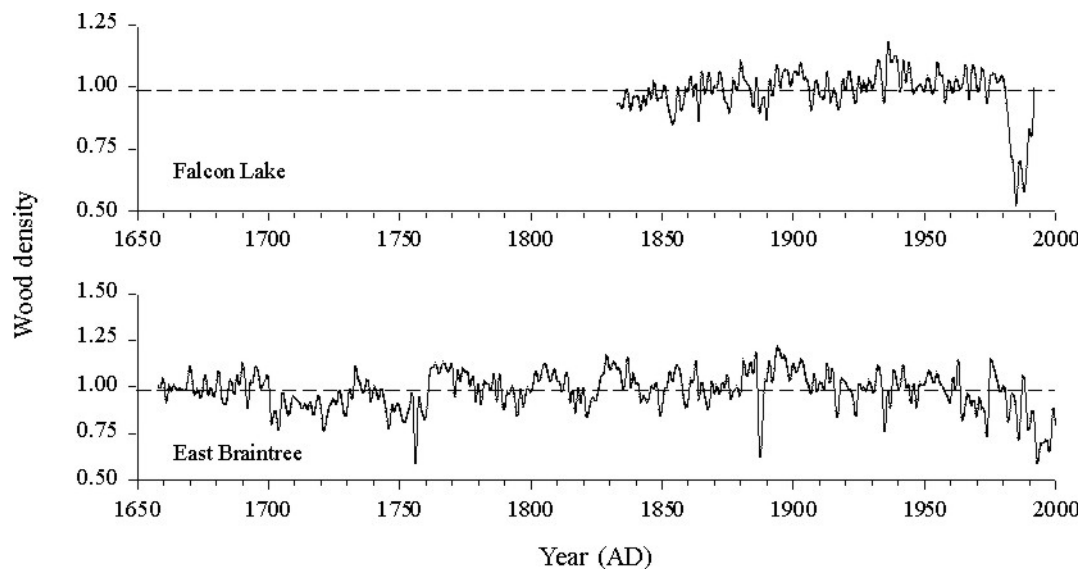


Figure 4. Composite tree-ring density curves for eastern white cedar (*Thuja occidentalis*) from Falcon Lake and East Braintree.

In other areas of southeastern Manitoba, which marks the western limit of cedars, trees growing around undisturbed wetlands can live up to 350 years and possibly longer as is the case around East Braintree. These long-lived cedar trees can potentially provide records of changes in environmental conditions since the mid-17th century and may greatly improve our understanding of the natural variability of climate, forest fire frequency and insect infestations in this region (Figure 4).

STOP 4 - SAPPING CHANNELS (UPPER CAMPBELL BEACH)

The Upper Campbell beach is Lake Agassiz's most prominent strandline and defines the Sandilands Moraine as an island about 9 500 years BP (Figure 1). This phase of Lake Agassiz relates to the final drainage of the lake as progressively lower eastern outlets were opened by glacial retreat until the lake finally completely drained into Hudson Bay. The lunch spot is located on the back or landward side of the Upper Campbell beach, on the shore of a small lake. This small lake is located at the down slope end of what is believed to be a sapping channel. The head of this channel is 5 km to the southeast (Figure 5). This site clearly indicates that the sapping channel is truncated by the Upper Campbell beach, making it older than the beach.

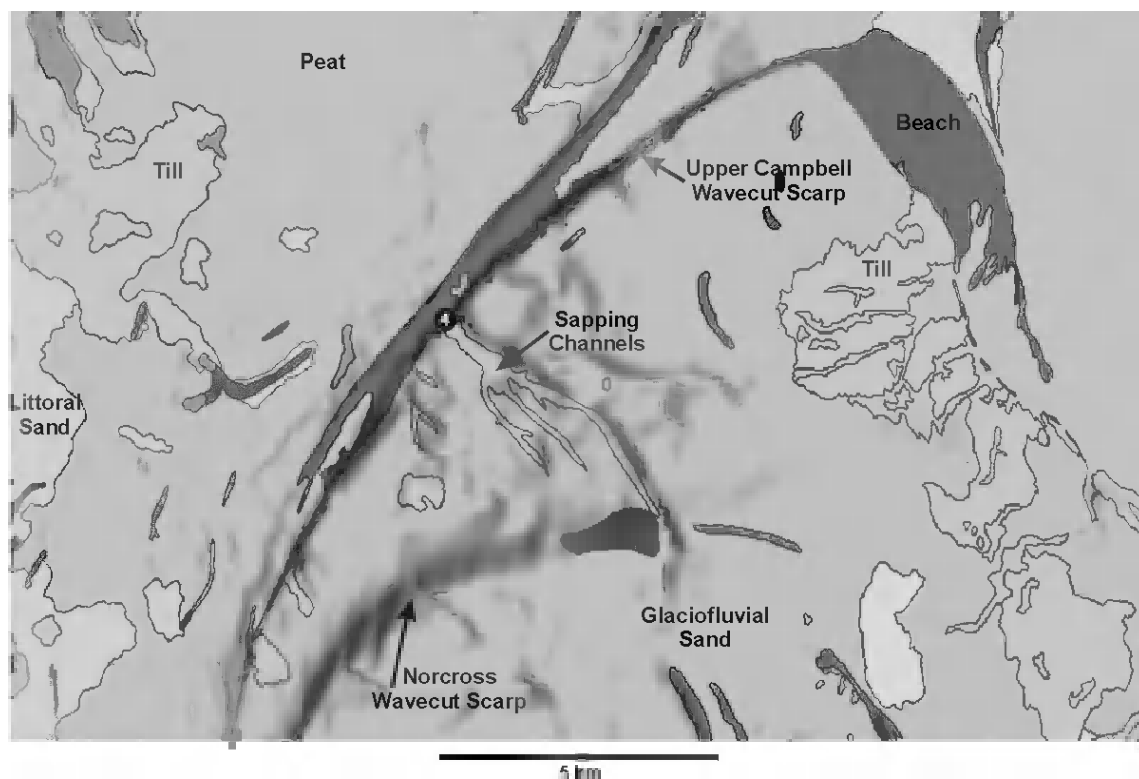


Figure 5. Surficial geological map draped on a Digital Elevation Model of a portion of southeastern Manitoba. Stop 4 is located at the lower end of the sapping channels. The sapping channels are typically infilled with peat. Conical depressions are found above and below the Norcross wavecut scarp.

Sapping channels have only been recognized in the Sandilands area, and are only found above the Upper Campbell beach, in areas where silty sands and fine sands are the predominant

sediments. During times of high lake levels in Lake Agassiz, prior to the formation of the Upper Campbell beach, a high water table would have existed in the Sandilands. With the drop in lake level to the Upper Campbell beach, the water table would have dropped accordingly. This re-equilibration of the water table would have taken place rapidly, perhaps in a decade or less, resulting in high gradients in the local hydrogeologic system. These high gradients made it possible to mobilize silt and transport it from the hydrogeologic system. The surficial expressions of this transport are the sapping channels, created where groundwater discharge occurred.

Numerous conical depressions occur in the Sandilands that are also likely the result of groundwater movement and are believed to be contemporaneous with the sapping channels. These conical depressions occur almost exclusively in silty sands, above and below the Norcross escarpment, 5 km to the southeast. Although the term piping is commonly used to refer to flushing of sediment from beneath a dam in civil engineering terms, piping can occur in natural settings when there is upward movement of groundwater under high gradients in silts and silty sands (Higgins, 1982). The high gradients enable silt to be removed from the sediment matrix and depressions were formed as the remaining sediment collapses under the influence of gravity. Following a drop in the level of Lake Agassiz, groundwater flowing from higher elevations to lower elevations may have become semi-confined as overlying sediments became finer. The resulting upward gradient combined with presence of overlying silty sands suggests that piping is a viable mechanism for forming these conical depressions.

STOP 5 - UPPER CAMPBELL BEACH OF LAKE AGASSIZ

During the Emerson phase of Lake Agassiz the Sandilands Moraine was subjected to a tremendous amount of shoreline erosion. The prevailing winds were from the northwest and Sandilands was an island in the southeast part of the Lake Agassiz basin. As a consequence, the Sandilands Moraine was subjected to waves with a fetch in excess of 300 km. Evidence of this erosion are two 20 m high wave-cut scarps, the Upper Campbell and Norcross scarps, on the northwest flank of the moraine. Large well-developed spits are situated on both ends of these scarps. The largest of these spits is found south of the lower of the two scarps, the Upper Campbell scarp.

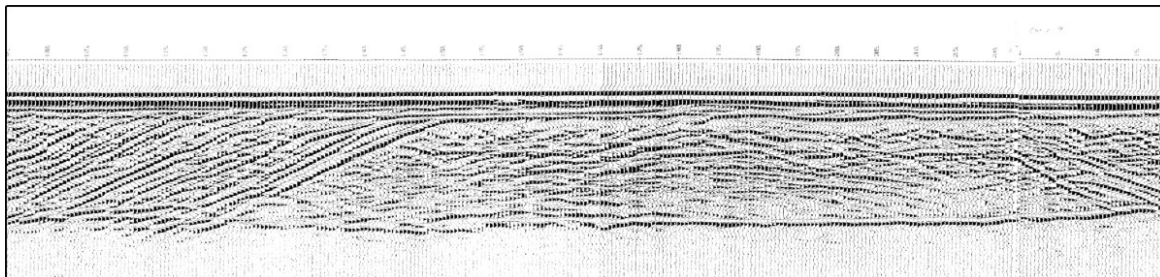


Figure 6. Ground penetrating radar profile across the Upper Campbell spit. This west to east profile is 150 metres wide with 30 metre thick foreset beds and several metre thick topsets. There is fine-grained glaciolacustrine sediment at the base of the foresets.

This stop is located on the crest of the southern spit. The spit is approximately 15 k long, 8 k wide and 30 m thick and composed predominantly of sand with minor amounts of gravel. Ground penetrating radar surveys carried out by the Geological Survey of Canada and the Manitoba Geological Survey show the structure of the spit to be large foreset beds which prograde southward in the core and westward on the west flank (Figure 6). Topset beds are several metres thick.

STOP 6 - INTERGLACIAL SITE AT GRUNTHAL

Although the exposure at the Grunthal pit is poor, it is interesting because musk ox (*Ovibos moschatus*), extinct bison, (possibly *Bison antiquus*) and woolly mammoth (*Mammuthus primigenius*) (Figure 7) bones have been dredged from below the water table. Wood and a variety of organic-rich, fine-textured silt and silty-clay sediments have also been recovered during gravel extraction, but the stratigraphy of the site is speculative.

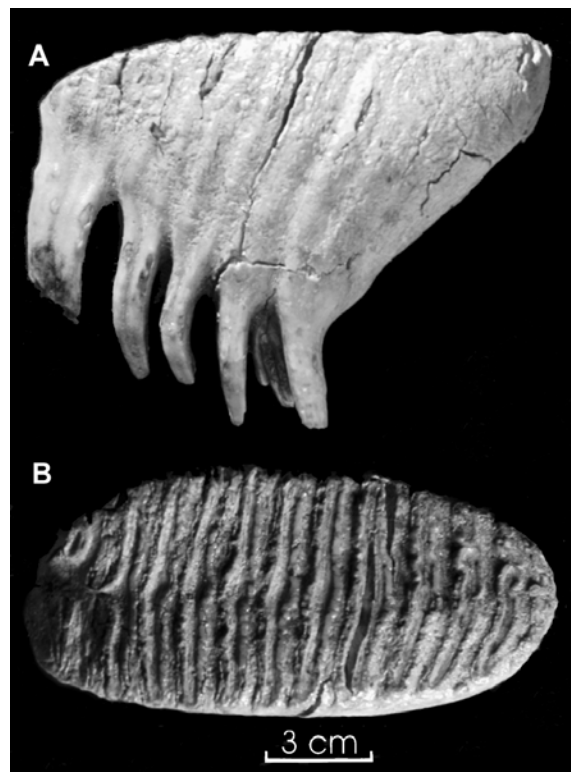


Figure 7. Lower M₁ molar of *Mammuthus primigenius* (V2554) from the Grunthal pit. (A) Lateral aspect. (B) Occlusal aspect.

The sediment above the water table and the sand and gravel extracted by the dredge is interpreted to be late Wisconsinan, ice-proximal, glaciofluvial sediment deposited 11-12 000 years ago, when the last glacier ice to affect the area was waning. These sand and gravel deposits are in part capped by diamicton that may have been deposited as debris flows in a proximal glaciofluvial environment.

Little is known about the sediments underlying the late Pleistocene sediments below the water table. The various bones, wood and the organic-rich sediments dredged from the bottom of the pit suggest the underlying deposits are of mid-Wisconsinan interstadial or possibly Sangamonian Interglacial age. Radiocarbon dating of a wood sample gave a finite age of $44\,020 \pm 1\,030$ years BP (GX-27643) suggesting an interstadial age, although dates in this range are close to the limit of the radiocarbon technique and must be accepted with some trepidation. The presence of bones of *Mammuthus primigenius* and *Bison antiquus* strongly suggest an interglacial age. In addition, a lophar index of 9 (number of lophs per 100 mm of mesiodistal crown length) of an M₁ mammoth molar from the deposit (Graham Young and Ed Dobrzanski, per com 2002) is similar to an M₁ or M₂ molar of Sangamonian age from Bird, Manitoba, (Nielsen et al. 1988) further suggesting an interglacial age for the deposit.

Two samples of organic-rich mud, dredged from below the water table, were submitted to Paleotec Services in Ottawa for macrofossil analysis. The plant macrofossil evidence suggests a forested environment dominated by spruce trees and the presence of sedges, buckbean and mosses further indicates the area was poorly drained. The presence of bark beetles (Scolytidae) agrees with the plant fossil evidence of a forested environment. The insect fossils, specifically rove beetles are in agreement with the plant macrofossil data suggesting a stream or slowly moving water in a poorly drained area possibly a pond or wet depression. The absence of aquatic submergent plants and other typical aquatic faunal elements suggest the pond was temporary rather than permanent. The water-worn bones in association with finer textured organic-rich silt and silty clay suggest the deposit may be in part a point bar. Alternatively, the bones became abraded when they were incorporated into the overlying glaciofluvial sediments.

Interpretation of the floral and faunal macrofossil assemblage indicates the climate at the time of deposition was probably warm. This conclusion is based on the abundant macrofossil remains of spruce along with bark beetles suggesting the climate was at least warm enough for the growth of boreal forest. However, the absence of fossil evidence of other boreal taxa, specifically pine and deciduous trees such as birches and alders is puzzling. The forest, being composed of only spruce, resembles the boreal forests in northern regions. This, along with the presence of fossil rove beetles (*Eucnecosum*) which have distributions restricted to northern boreal, arctic, or alpine areas suggests the climate may have been cooler than today. The macrofossil evidence and the presence of *M. primigenius*, *Bison antiquus* and *Ovibos moschatus* at the site are taken to indicate a northern or boreal steppe or steppe-tundra environment.

All the taxa from the site except the Pleistocene megafauna can be found living in southern Manitoba today, with the rove beetle being at its southern limit. It is therefore concluded from the macrofossil evidence that the deposit at Grunthal is probably of interglacial age, and it is tentatively assigned to the Sangamonian.

Point of interest

If time permits a small detour will be made to the Dawson Trail, which was the first 'road' linking Fort Garry to eastern Canada.

Simon James Dawson, an engineer and land surveyor, was given the task in 1857 of surveying the country between Lake Superior and the Red River valley in Manitoba. Dawson subsequently proposed a route from Port Arthur's Landing, which later became Port Arthur and then Thunder Bay, that would use waterways and roads, to prepare the way for the railroad and thereby forestall northward expansion by aggressive American interests.

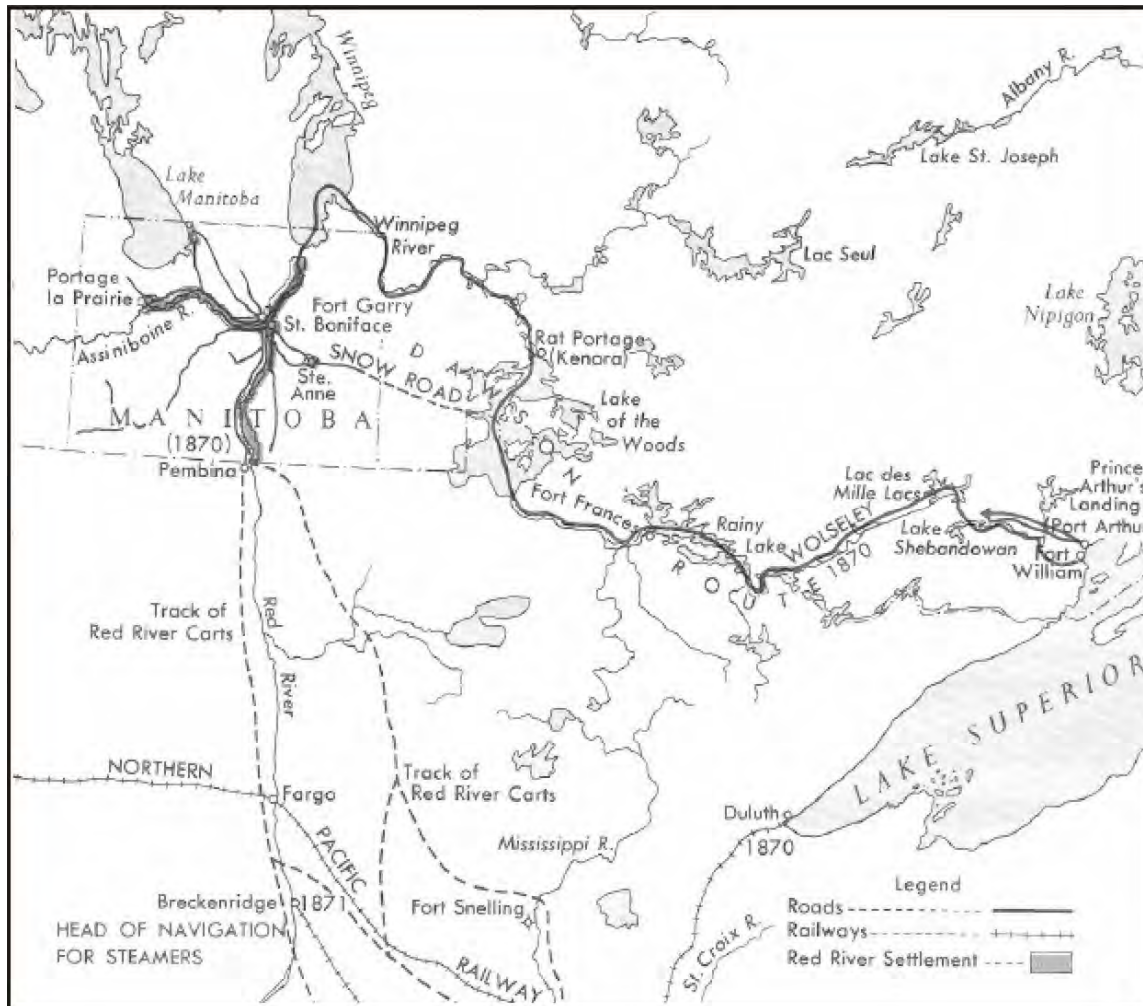


Figure 8. Map showing the Dawson Trail between Port Arthur's Landing (Thunder Bay) and Fort Garry (Winnipeg).

Construction of the Dawson Trail in Manitoba was started in 1868 under the direction of John Allan Snow, as a make-work project after several years of repeated crop failure in the Red River valley, but was then hastened because of potential trouble with the *métis*. The 1200 man army of Colonel Garnet Joseph Wolseley, which was sent west from Upper Canada in 1870 to quell the *métis* uprising led by Louis Riel, was in part employed to help finish the construction of the Dawson Trail (Figure 8). The army worked on the road to the point where it was passable and arrived in the Red River settlement in August of 1870. Interestingly the army traveled from Fort Francis to Fort Garry via Lake of the Woods and the Winnipeg River and did not use the Dawson Trail from the Northwest Angle, and across Sandilands. The trip from Port Arthur's Landing to

Fort Garry lasted approximately one month and was made by approximately 1600 travelers in 1873.

With the completion of the Canadian Pacific Railroad in 1885, the Dawson Trail was quickly forgotten after having been used for only a few years and never really being finished as Dawson originally envisioned it. However, much of the trail is still in use either as bush roads or snowmobile trails. Parts of the Trans-Canada Highway between Richer and Winnipeg also follow the original road. The road is especially well preserved in sections of Sandilands where in some boggy areas the original corduroy can still be found.

ACKNOWLEDGEMENTS

We would like to thank Graham Young and Ed Dobrzanski of the Manitoba Museum of Man and Nature for their analysis of the vertebrate bones from the Grunthal pit and their help in making the Sangamonian age assignment of the deposit. We would also like to thank David Riddle of Manitoba Historic Resources Branch for supplying the Dawson Trail map. Grant Ferguson of the Department of Engineering, University of Manitoba wrote the very eloquent description of the formation of the sapping channels for us.

REFERENCES

- Higgins, Charles G. 1982. Piping and sapping: development of landforms by groundwater outflow. pp. 18-59. In: Groundwater as a Geomorphic Agent. R.G. LaFleur (ed.) 1982. Allen and Unwin, Inc. London, U.K.
- Kerr, D.G.G. 1975. Historical Atlas of Canada. Third revised edition. Thomas Nelson & Sons (Canada) Ltd.
- McAndrews, J.H. 1982. Holocene environment of a fossil bison from Kenora, Ontario. Ontario Archaeology, vol. 37, pp.41-51.
- Nielsen E., Churcher, C.S., and Lammers, G.E. 1988. A woolly mammoth (*Proboscidea, Mammuthus primigenius*) molar from the Hudson Bay Lowland of Manitoba. Canadian Journal of Earth Sciences, vol. 25, pp. 933-938.
- Thorleifson H. 1996. Review of Lake Agassiz History. In, Teller, J.T., Thorleifson, L.H., Matile, G. and Brisbin, W.C. eds. Sedimentology, geomorphology and history of the central Lake Agassiz basin. Geological Association of Canada Field Trip B2, 101p.

Field Trip 3

Structure and Sedimentology of the Seine Conglomerate, Mine Centre Area, Ontario

Dyanna Czeck
*Department of Geology
Oberlin College
52 W. Lorain Street
Oberlin, OH 44074*

Philip Fralick
*Department of Geology
Lakehead University
Thunder Bay, ON P7B 5E1*



Moderately deformed Seine conglomerate containing metavolcanic and granitoid clasts, with clast tiling due to dextral deformation. Hwy 11, 1 km east of Horsecollar Junction.

FOREWORD

This trip will examine sites related to the development and deformational history of a synorogenic sedimentary unit, the Seine Conglomerate. The unit extends across the Canada/United States border in the Rainy Lake region, an area that has sparked interest and controversy for American and Canadian geologists for over a century. The Seine is of significant interest because it preserves important structural and sedimentological clues that may lead us to a better understanding of the tectonic history of the Archean Wabigoon-Quetico subprovincial boundary.

REGIONAL SETTING

Introduction and Tectonic Setting

The central portion of the Superior province is characterized by alternating subprovinces of metavolcanic-plutonic and metasedimentary natures (Fig. 1).

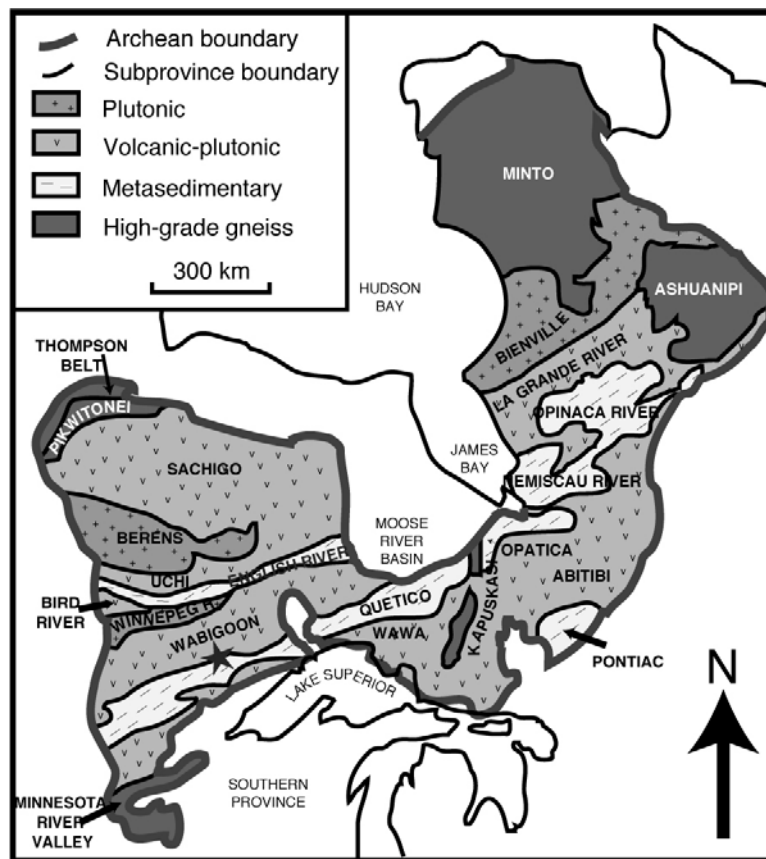


Figure 1. The Superior Province. From Card and Ciesielski (1986).

One popular tectonic interpretation for the central portion of the Superior Province is of repeated island arc, microcontinent collisions. The collisions are evidenced by rocks that can be interpreted as arc sequence subprovinces (metavolcanics) and their corresponding accretionary prism subprovinces (metasediments) (Langford and Morin, 1976; Hoffman, 1989; Percival and

Generalized Geologic Map: Mine Centre Area, Ontario

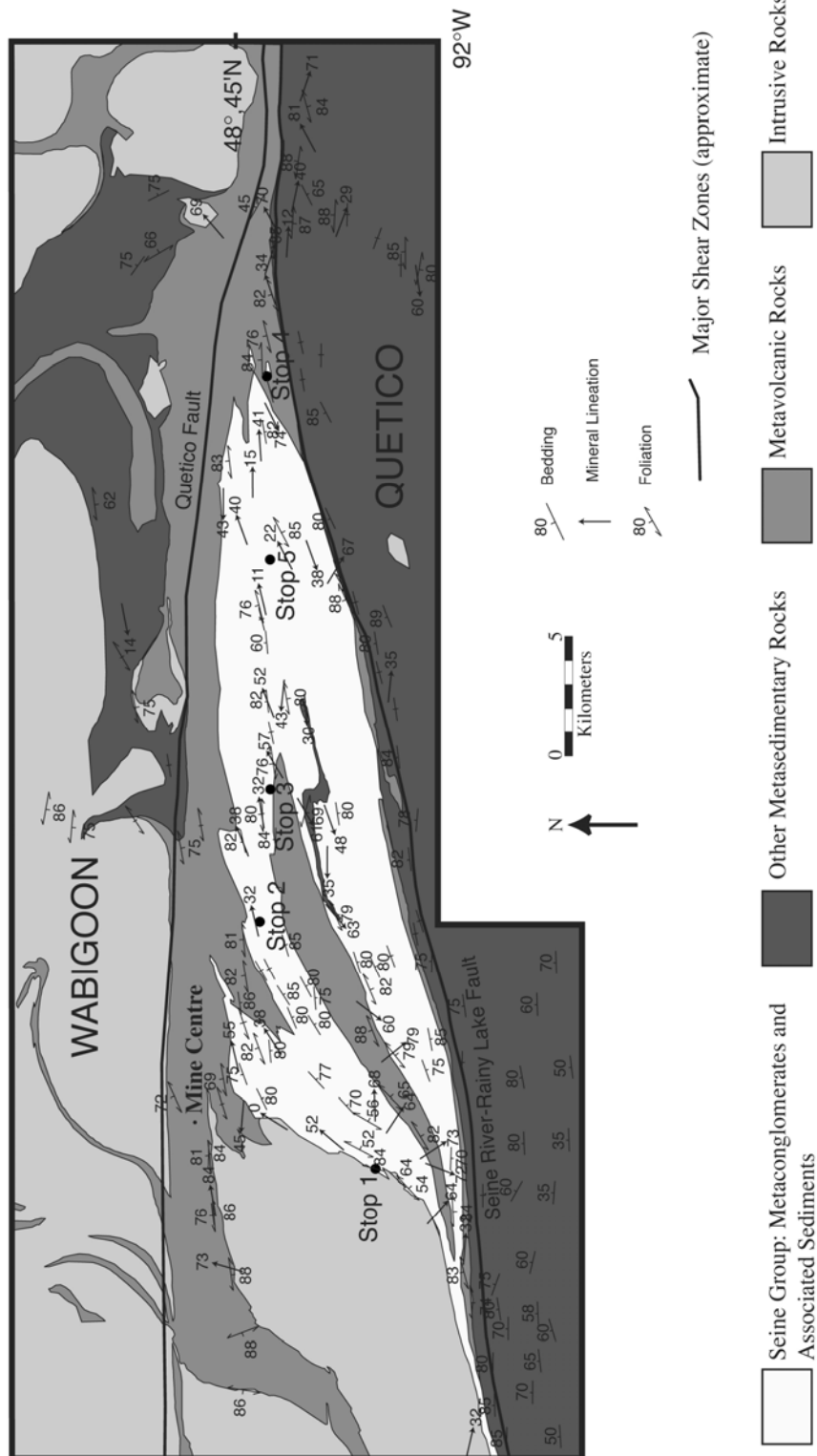


Figure 2. Simplified Geologic Map of Mine Centre area showing the extent of the Seine. Geology compiled from Wood, 1980a & b, Stone, 1998a & b, and Czeck, 2001.

Williams, 1989; Card, 1990; Hoffman, 1990). In general, the ages in the greenstone belts are similar along strike, but differ systematically across strike (Hoffman, 1989). This is consistent with the island-arc accretion model. A history of southward accretion has been proposed to explain the juxtaposition of Superior Province terranes (Langford and Morin, 1976; Percival and Williams, 1989; Card, 1990).

The Seine Conglomerate, located in the Rainy Lake region of the western Superior Province, was deposited along the boundary between the Wabigoon metavolcanic/plutonic subprovince and the Quetico metasedimentary subprovince (Fig. 2). The structural observations along the Wabigoon–Quetico boundary are consistent with an oblique island-arc microplate collision circa 2.7 Ga. In this part of the Superior Province, it seems likely that first the Quetico acted as a subduction prism during accretion of the Wawa to Wabigoon. Then, it was effectively shifted from the subduction prism setting to a back-arc setting, as subduction shifted (Percival and Williams, 1989).

In the Rainy Lake region, a series of lithostratigraphic terranes were assembled together along structurally controlled, stratigraphically discordant boundaries during the collisions. The boundary between the Wabigoon and Quetico Subprovinces in this region is divided into three primary blocks by dextral wrench faults (Poulsen, 1986). Each of the small terranes and sub-terrane may have undergone a somewhat unique history of formation and deformation.

The Quetico Fault forms the northern boundary, separating the granite-greenstone terrain of Wabigoon Subprovince from the Couthiching Group argillites and the Seine Conglomerate. The Seine River-Rainy Lake Fault forms the southern boundary of these sedimentary sequences with the Quetico turbiditic metasediments to the south. The wedge-shaped area lying between the two major fault systems is itself dissected by splays off the major east-west faults, which isolate the lithic units, destroying stratigraphic integrity. This problem has resulted in historical speculation on the lateral equivalency of the Seine and Couthiching sediments (Merritt, 1934) and the Couthiching and Quetico (Lawson, 1913).

Geochronology

Davis et al (1989) used U-Pb, single zircon geochronology to bracket the ages of the Couthiching and Seine between 2704 $\pm$ 3 to 2692 $\pm$ 2 and 2696 $\pm$ 5-3 to 2686 $\pm$ 2-1 respectively. Even though an overlap in age existed, Davis et al (1989) believed that structural considerations indicated that the Couthiching is slightly older than the Seine.

Further detrital zircon geochronology of the Seine was conducted by Davis and reported in Fralick and Davis (1999). Of the two samples analysed one was from the sandstone dominated lithofacies (collected near the Seine River bridge) and the other was from the conglomerate dominated lithofacies (collected near Horsecollar Junction on Highway 17). The detrital zircons in both samples give very consistent ages with the sandstone lithofacies clustering at 2693 $\pm$ 1 (Fig. 3) and the conglomerate lithofacies clustering at 2692 $\pm$ 1 (Fig. 4). These detrital zircon ages are similar to the Bear Pass pluton, a granitic mass which outcrops near the Seine

Conglomerate (Fralick and Davis, 1999). Metamorphic titanite from the pluton gave an age of 2684 $\pm$ 5.

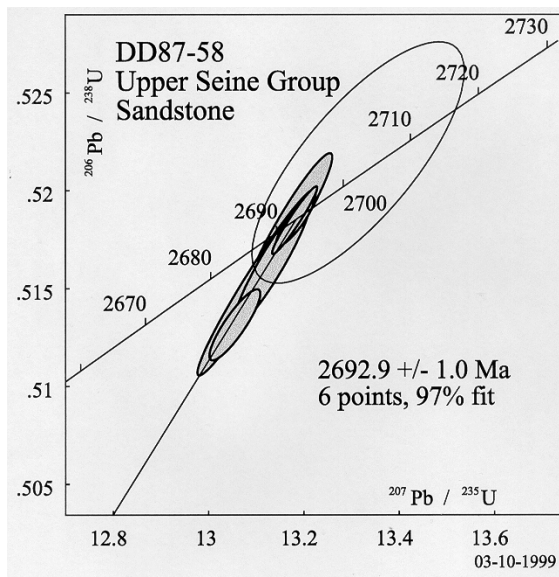


Figure 3. Isochron showing U-Pb detrital zircon ages from the upper Seine Group (supplied by D. Davis).

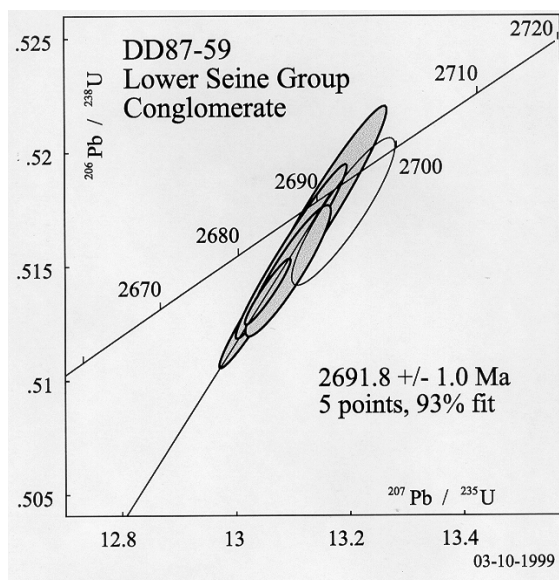


Figure 4. Isochron showing U-Pb detrital zircon ages from the lower Seine Group (supplied by D. Davis).

Detrital zircons from the nearby Quetico and Coutchiching metasediments have an age distribution that is very different than that from the Seine Conglomerate. Their youngest ages are 2699 $\pm$ 1 for the Quetico and 2704 $\pm$ 3 for the Coutchiching with the population in both rock units extending back past 3000Ma. This is in sharp contrast to the Seine zircons which indicate

dominance of a single source. This source may have evolved slightly through time as the age for the upper sandstone is slightly older than the lower conglomerate, though within error. This inverse age stratigraphy may reflect erosive unroofing of slightly older segments of the source igneous body. In any case, the Seine must be 2692 Ma, or younger, and its detritus was derived from a different source than the Quetico and Coutchiching (Fralick and Davis, 1999). The Bear Pass pluton is a good candidate for the source of the sediment except its zircons have lower Th/U ratios than the Seine. The Seine's Th/U ratios of 0.74 to 1.07 are more typical of alkaline igneous rocks (Fralick and Davis, 1999). Alkaline igneous rocks 2692 Ma in age are present to the east of the area in the Shebandowan region.

Metamorphic titanite in the Rice Bay Dome has given an age of 2693-+3 Ma, coeval with or predating the Seine (Davis et al, 1989). The Bear Pass intrusion also predates the Seine and is late-tectonic, probably emplaced into the Rice Bay Dome after the Coutchiching turbidites had been overturned (Fralick and Davis, 1999). Thus, the Seine was deposited after an early period of folding and metamorphism.

What can we learn from the Seine?

The Rainy Lake region has been metamorphosed, generally to greenschist grade, and deformed in response to the Archean microplate collisions. Most of the preserved deformation is of a ductile nature, and thus occurred at significant depth. The Seine itself is metamorphosed and significantly deformed. From the geochronology and sedimentological evidence (to be described below), we know that the Seine was deposited in a dynamic convergent plate setting. From the significant flattening fabrics and structural evidence, we know that the Seine was subsequently buried and deformed at mid-crustal levels. Therefore, the Seine preserves a record of a conglomerate's journey through the crust within a dynamic convergent zone. We can hope to interpret from the Seine a relatively late stage record of the microplate collision history at the Wabigoon- Quetico tectonic boundary through a history of syn-deformational deposition, burial, and deformation. Through analysis of the sedimentology, early structures, and late structures, we can hope to interpret various portions of the conglomerate's path through the crust.

SEDIMENTOLOGY OF THE SEINE

The Seine Conglomerate was interpreted to have been deposited in a fluvial system by Wood (1980). This system undergoes a gradual transition from conglomerate dominated near its base to sandstone dominated near its top. Channels in the lower portion of the section are Scott type (Miall, 1978), with gravel and cobbles forming both longitudinal bars and interbar channels. Through cross-stratified, medium-grained sandstones, representing chute channels, commonly form small lenses in these sequences. The coarse-grained lithofacies association is transitional upwards into successions which contain thicker layers of trough cross-stratified sandstone. This represents a transition from gravelly main channels to channels dominated by the migration of sand dunes. With further fining upwards, the Formation becomes sandstone dominated. The sandstones are organized into stacked, trough cross-stratified lenses, with rarer large-scale, planar cross-stratified layers and conglomeratic horizons. This reflects development of a South Saskatchewan type braided river (Miall, 1978) with dune migration prevalent in the channels and only minor development of sandy transverse and gravelly longitudinal bars. To further clarify the

relationship between the lithofacies present in the rocks and the environments in which the sediment was deposited, the remainder of this section will discuss the types of sediment deposited in the differing sub-environments of gravelly to sandy braided streams.

Braided rivers are multichannel streams with large width to depth ratios that commonly develop in high slope areas, such as alluvial fans and proglacial outwash plains. This type of channel pattern is generally caused by a combination of factors which include: large diurnal and seasonal fluctuations in discharge; high slope, or a rapid increase in slope; high discharge velocities; the dominance of bedload sediment (sand and gravel) in transport; and, meagre vegetation on the floodplain. These factors result in the stream being easily able to erode its banks, spread out laterally and choke its channel with coarse sediment building midchannel islands. The channel morphology of braided rivers is characterised by a series of channels and bars which are occupied at various levels of discharge (Williams and Rust, 1969). During most of the year, with normal to low discharge, one, two or more channels will snake through the assemblage of bars. However, during peak discharge all the previously dry bars and minor channels will be overtopped and the river will develop only one large channel. Flood events, such as this, are the intervals when the coarsest sediment, generally composing the bars, but also flooring the channels in high energy systems, will move. Hammer and Smith (1983) found that bedload sediment transport increases at an exponential rate with river discharge.

As the majority of coarse sediments are transported in bedload during high discharge events, with reduction in discharge the ability of the river to continue transporting this material down gradient is also reduced (Burton, 1989). At this point the largest material in transport stops moving. This produces a low velocity shadow downstream from the sedimented material where more detritus accumulates. This process leads to the formation of gravel bars, termed longitudinal bars, within the river channel. If the channel is in a relatively high slope area, the sand and finer material in transport will only be deposited if it is trapped or carried into the pores between the gravel and sedimented as matrix. Here, the main channel is pebble, cobble or boulder dominated with this detritus arranged into a stacked sequence of commonly irregular lenses. These lenses represent areas of scour and deposition on the bottom of a larger channel. Some gravel lenses may be formed by either migration of coarse-grained dunes or lateral fill into scour pits producing cross-stratification. In less energetic systems trough cross-stratified sand lenses will interbed with the gravel. This represents sand in bedload tractive transport as dunes being deposited and not re-eroded. Further reduction in energy levels of the system will eventually cause the main channel deposits to become a series of stacked, trough cross-stratified sandstone lenses.

In braided streams carrying gravel, longitudinal bars will develop, splitting the flow at low stage (Figs. 5 & 6). These bars are lozenge-shaped mounds of pebbles, cobbles or boulders in clast support with a coarse-grained matrix. They are usually internally massive and nongraded, though occasionally parallel lamination is present. While the bars are submerged during maximum discharge events they are subjected to extremely turbulent flow, during which time they are modified by both erosion and deposition. Such processes result in the head of the bar being continually reworked producing a well sorted and coarser grained deposit (Burton, 1989). A significant decrease in velocity over the length of the bar results in a corresponding decrease in the size of material being deposited.

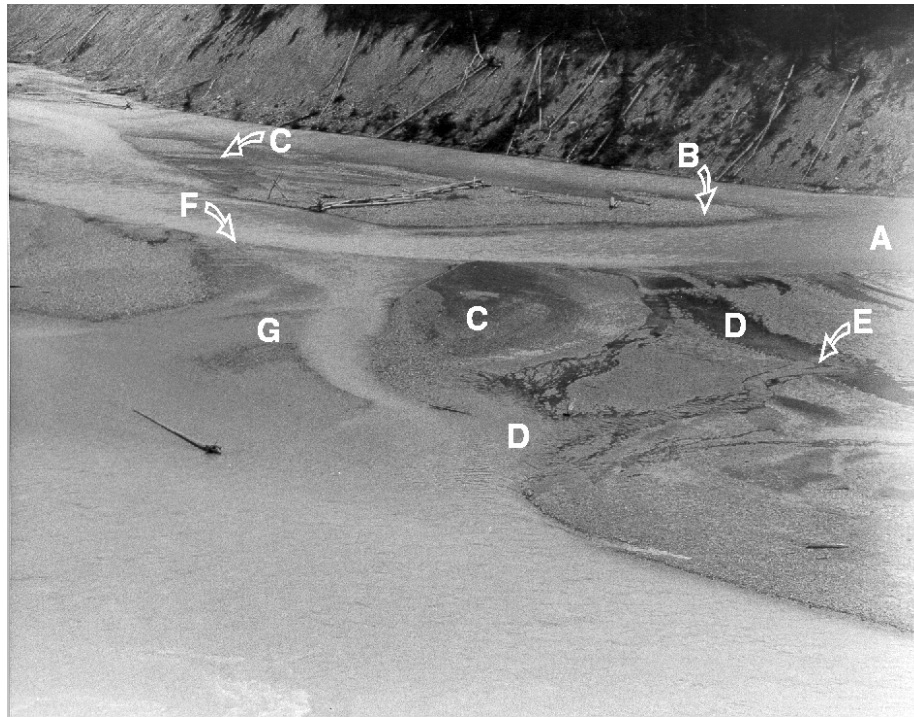


Figure 5. Photograph of the North Saskatchewan River in Alberta. The main channel (A) is cutting around a longitudinal bar which grades from a coarse head (B) to a finer pebble tail with a veneer of darker coloured sand (C). The bar tail in the foreground also has darker sandy areas mantling it (C) and is cut by chute channels (D); one of which is building a chute delta (E). If main channel erosion was not occurring at F this would be the site of a bar edge sand wedge supplied by the nonconfined overbar flow.

During waning flow, the bar tail will be shielded from the main current in the river as the bar top, in the center of the bar, begins to become emergent. This may cause a thin sand sheet, or patches of sand in lower areas, to be deposited over the bar tail. As the flow stage continues to drop small channels will sporadically develop cutting across the upper surface of the bar, from a main channel upstream to another main channel downstream. These are chute channels which commonly fill with trough cross-stratified sand produced by dunes migrating down the channels. They form sand lenses in the gravelly longitudinal bar. Where chute channels rejoin the main channel sediment may accumulate as a large avalanche face building out into the deeper main channel (chute delta). This produces a large-scale, planar cross-stratified sand or gravel deposit banked up against the side of the longitudinal bar. Similar, but laterally extensive, deposits can also be formed by unconfined sheet flow over the only slightly submerged surface of the bar. Again, where this flow enters the deeper main channel a large-scale, planar cross-stratified wedge of sediment will be banked up against the bar. This is called a bar edge sand wedge (Figs. 5 & 6).

All of the above may be present in sand dominated braided systems, but the longitudinal bars will be subordinate and may be absent. The main bar forms in these systems are transverse bars. These are large sand waves, features similar to continuous crested, long wavelength dunes.

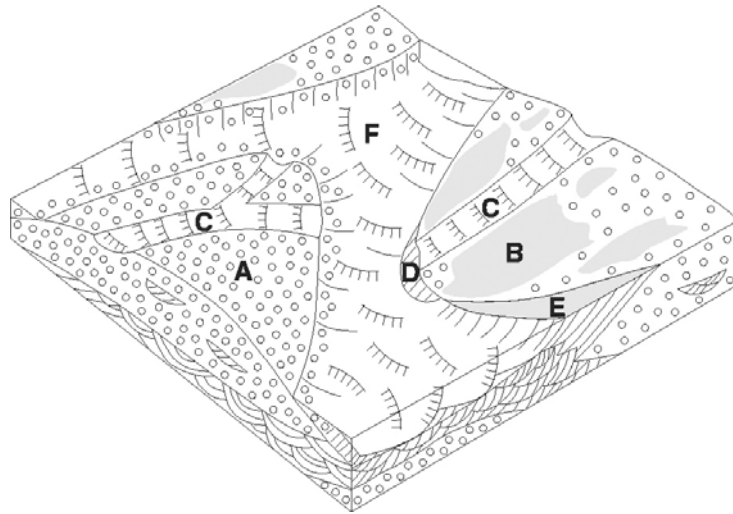


Figure 6. Block diagram of a coarse-grained braided stream schematically showing: coarse bar head (A); finer bar trail with thin sand patches which accumulate in areas shielded from the current during waning flow (B); chute channel with dunes (C); chute delta (D); bar edge sand wedge (E); and main channel with dunes (F). Gravelly braided stream deposits similar to these dominate the lower Seine Conglomerate.

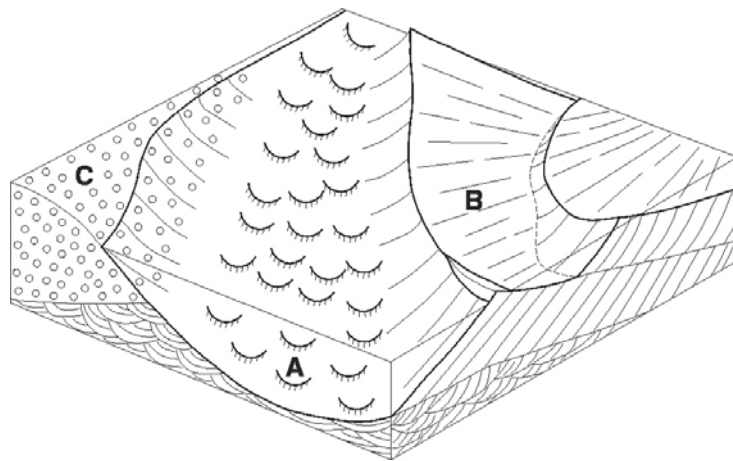


Figure 7. Block diagram of a sand dominated braided stream schematically showing: the main channel with dune migration producing trough cross-stratification (A); transverse bar migration and stacking producing sandflats which are internally planar cross-stratified (B); minor (to no) development of gravelly longitudinal bars (C). Sandy braided stream deposits, and especially the main channel facies, dominate the upper Seine Conglomerate.

Where they are abundant they will pile up next to one another clogging the channel with sand and producing large areas of sand flats (Smith, 1970; Miall, 1985) (Fig. 7). Internally, they are composed of large-scale (commonly >1m thick sets), planar cross-stratification. Transverse bars are quite laterally continuous and are interbedded with other large-scale, planar cross-stratified sand units, in sand flats (downstream accretion macroforms of Miall, 1988), or successions of smaller lenses of trough cross-stratified sand, representing dune migration on the channel floor

(Fig. 7). The transverse bars are mostly active during higher discharge. During low discharge, their tops may become emergent and eroded, and dunes mantle their surface. The next flood event will often result in the bar building in a somewhat different direction. This will result in an apparent change in the angle of the cross-stratification (a reactivation surface). This sloping surface may also show evidence of erosion and contain small lenses of trough cross-stratification.

This completes the general overview of sediment deposits associated with channel sequences in braided streams. Floodplain lithofacies are usually minor to nonexistent in these successions as the fine grained deposits have little preservation potential. Braided streams commonly avulse, changing the position of their channel and combing the floodplain, eroding the fine-grained deposits and forming stacked channel sequences.

The Seine Conglomerate contains lithofacies corresponding to all of the channel sub-environments discussed above. Conglomerate dominated longitudinal bar-channel sequences are the most common in outcrop. However, sandier channel sequences are not rare and gain importance higher in the Formation.

STRUCTURAL GEOLOGY

Deformed primary fabrics

Bedding is often difficult to discern in the Seine. Where it can be identified, it is displayed by variations in grain sizes, often indicated by fine-grained layers interbedded with pebble conglomerates. In some cases, cross bedding can be seen within larger sandy layers. In general, bedding strikes approximately east – west, and is subvertical (Fig. 8). This orientation is similar to bedding attitudes measured throughout much of the Superior Province (Poulsen, 1986; Hudleston et al., 1988; Bauer and Bidwell, 1990; Tabor and Hudleston, 1991; Bauer et al., 1992; Jirsa et al., 1992; Bauer and Hudleston, 1995; Hudleston and Bauer, 1995). Bedding is generally subvertical and subparallel regardless of lithology. However, this fact does not necessarily indicate deformation of a continuous stratigraphic sequence. Based on opposing stratigraphic facing in adjacent rocks, an unconformity between the volcanic units and the base of the Seine conglomerate can be identified (Stop 1) (Lawson, 1913; Poulsen et al., 1980; Poulsen, 2000). There are some exceptions to the general EW, vertical bedding orientation. In the area along Shoal Lake (Stop 1), the bedding strikes more NE/ SW with a shallower (~65°) southeasterly dip. The orientations of the bedding within the Shoal Lake area and adjacent rocks to the north and south combine to create a large, gentle S structure, with shallower dips on the middle section of the S.

Several folds on the scale of hundreds of meters have been identified within the Seine metasediments based on stratigraphic facing (scour beds and cross-beds) and lithologic similarity (Hsu, 1971; Wood et al., 1980a; Wood et al., 1980b; Poulsen, 2000). These folds have vertical limbs and are typically upright and isoclinal. The trends of the hinges are roughly parallel to the foliation (EW). The plunges of the hinges are unknown, and cannot be constructed due to the subparallelism of the limbs. In a few locations (see Stop 5), one can see small scale folds that may display horizontal bedding at the hinges.

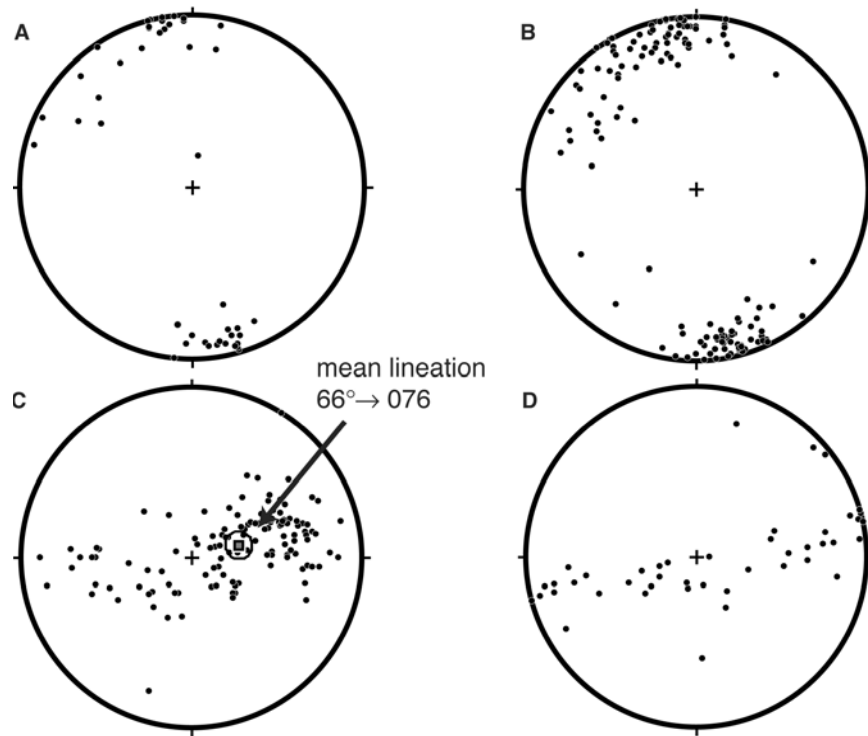


Figure 8. Equal area stereonet showing structural fabric data near Mine Centre, Ontario. A) Poles to bedding. 46 measurements. B) Poles to foliation. 142 measurements. C) Mineral lineations. 123 measurements. D) Intersections between foliation (cleavage) and bedding. 44 measurements. From Czeck (2001).

Ductile deformation

Ductile deformation (as evidenced by rocks with pronounced foliations and mineral lineations) is pervasive throughout the entire Wabigoon–Quetico boundary zone. The overall dominance of the foliation over the lineation creates an S-L type fabric. However, strain is also localized into an anastomosing network of more discrete shear zones, including two main zones of localized shear and displacement. These are the Seine River - Rainy Lake Fault and the Quetico Fault, which diverge to the west and merge to the east (Fig. 2). An anastomosing pattern of smaller shear zones links the major shear zones shown in anastomosing, gentle S-like shapes (Fig. 9). The locations of these smaller shear zones have been determined by linear features observed on electromagnetic anomaly maps or are identified as the discordant boundaries of apparently independent lithostratigraphic terranes (Poulsen, 1986; Poulsen, 2000). Direct observation of these smaller shear zones is difficult because they are typically under water or buried beneath recent sedimentary deposits and not exposed, presumably because they are highly erodable. The presence of discrete shear zones implies some strain partitioning between shortening and wrench components of ductile deformation along the Wabigoon–Quetico boundary. It is probable that the discrete shear zones are zones with relatively high wrench influence. Conversely, it is probable that the wide zones of deformation between the shear zones have undergone deformation with a stronger shortening influence. In some instances, small (on the order of a few meters), secondary shear zones may be seen.

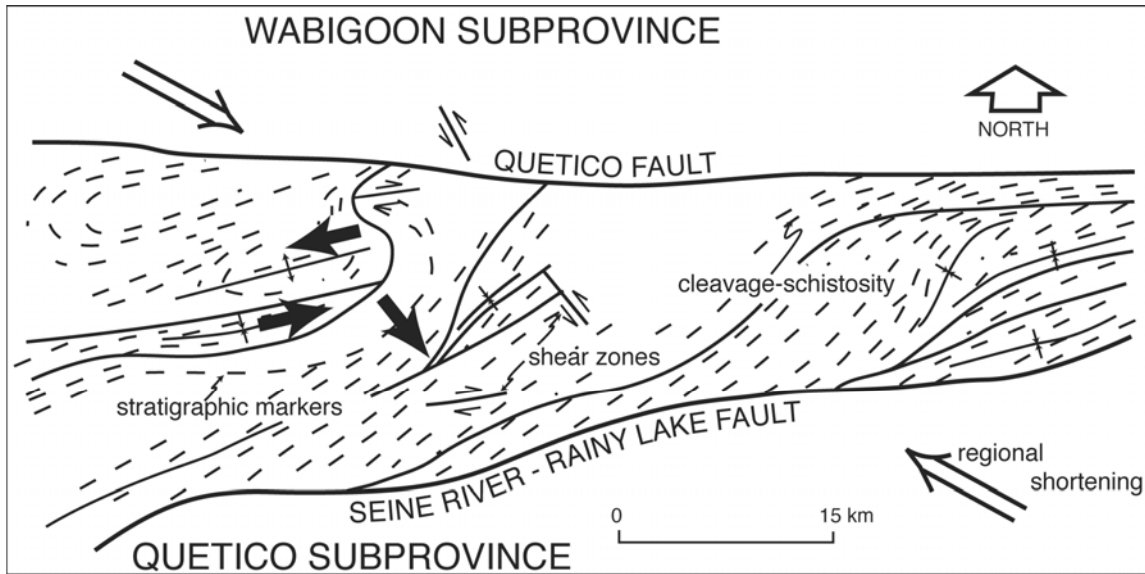


Figure 9. Schematic diagram illustrating structural features of Rainy Lake Wrench Zone. Short solid arrows identify downward facing units. From Poulsen (1986).

Foliation is moderately to well developed in all rocks of the region, with the exception of some late stage plutons. It is especially well developed along the major shear zones and the Seine River – Rainy Lake and Quetico Faults. The foliations are largely subvertical and at a low angle both to bedding (except in the hinge of folds) and to the subprovince boundary (Fig. 8). An exception to the subvertical foliation is in the area along Shoal Lake (Stop 1). Here, like the bedding, the foliation strikes more NE/ SW with a shallower dip ($\sim 65^\circ$). Like the bedding, the combined orientations of the foliations within this Shoal Lake area and adjacent rocks to the north and south create a large, gentle S structure, with shallower dips on the middle section of the S. Unlike the bedding, the cleavage is not folded by the major upright folds. It is, however, affected locally by crenulations.

In general, there is no consistently oriented intersection lineation between bedding and foliation throughout the Seine. Instead, this lineation defines a great circle corresponding roughly to the planes of foliation and bedding. This is to be expected in the situation in which bedding and foliation are subparallel because slight variations in orientation of the two planar features will have a significant effect on the orientation of the intersection lineation.

Typically, chlorite or amphibole forms a mineral lineation, which varies in intensity from weak to strong depending on location. The lineation plunge is highly variable across the Wabigoon–Quetico boundary without any clear systematic change from east to west or from north to south, although there are local domains of similar lineation plunge (Czeck, 2001). The highest concentrations of lineation orientations plunge steeply to the east, and their mean orientation is $66^\circ/076$. However, there are also significant numbers of westward and shallowly plunging lineations. The range of lineation orientations is great enough that the “average lineation” may have little geologic meaning.

The lineation referred to thus far is the mineral lineation, a lineation due to the preferred alignment of mineral grains or clusters of grains. This lineation is present in most rock types along the Wabigoon–Quetico boundary. Within the Seine conglomerate, there are, in fact, two distinct linear elements that can be measured independently: the mineral lineation and that defined by the long axes of the conglomerate clasts. Both can be considered penetrative features of the rock fabric. The long axes of clasts within the conglomerate are generally coincident with the mineral lineation as would be expected if the conglomerate clasts were an accurate recorder of strain and the mineral lineation reflects the stretching direction

Relatively late-stage sinistral and dextral crenulations locally affect the cleavage. These crenulations are fairly small (usually cm scale). They are most abundant in the most highly sheared rocks. This correlation and the relative timing of the crenulations makes it seem likely that they formed during the latest stage of a continuing saga of transpression.

Features of deformed conglomerates

The Seine Group provides an excellent opportunity to observe the effects of competency contrasts on deformation. These natural competency contrasts allow us to obtain structural information that is unavailable in more homogeneous rocks, making the conglomerates are excellent tools for structural analysis and tectonic interpretations.

Within the conglomerates, asymmetric shear sense indicators are prevalent. In general, these are either in the form of asymmetric pressure shadows at the ends of clasts, wrapped foliation indicating rotation of the most rigid clasts, and clast tilting. All of these shear-sense indicators are most evident on the subhorizontal plane, *regardless of lineation orientation*. They indicate dextral sense of shear.

In general, the conglomerate clasts have been strongly flattened, although the degree of flattening is strongly dependent on lithology. The intensity of flattening strain varies greatly through the field area. We will be viewing several degrees of deformation on the various stops of the fieldtrip.

TECTONIC STORY OF THE SEINE METASEDIMENTARY SEQUENCE AND SURROUNDING ROCKS

Plate Collisions and Sediment Deposition

Comparing the zircon populations of sedimentary units in the Rainy River area with other rock groups in the region generates some interesting trends. The zircon populations of turbidites and conglomerates on the northern margin of Wabigoon Subprovince (Savant Group and Ament Bay Formation) exhibit similarities with the Couthiching metasediments (Davis, 1997). The conglomeratic units near the northern margin of Wabigoon Subprovince represent braided fluvial systems (Turner and Walker, 1973; Devaney, 1999). The sediments they were transporting were deposited in the same time bracket (Davis et al, 1988) as some of the sedimentary units near Rainy Lake. If the sedimentary units in the Rainy Lake area represent detritus shed off of upraised blocks during collision-orogeny, as appears to be the case (Davis et al, 1989),

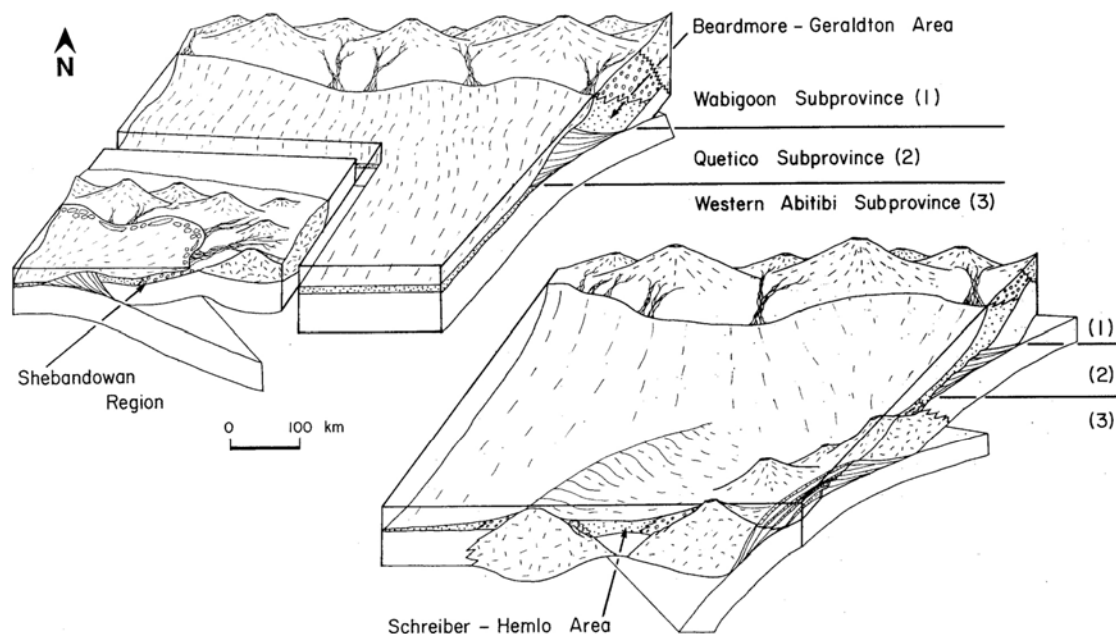


Figure 10. Interpretive sketches showing subduction and plate convergence along the southern margin of Wabigoon Subprovince. The accretionary prism built at 2700 Ma of trench turbidites is represented by the Quetico. Northward subduction in the Schreiber and Shebandowan areas ceased at approximately 2720 Ma, but restarted in the Shebandowan area at 2692 as immanent collision ceased subduction in the Quetico trench. After collision of the Wawa-Abitibi terrain with the Quetico-Wabigoon assemblage, orogenic uplift affected the area. During this interval small basins opened on both sides of the suture zone and accumulated coarse fluvial deposits including the Seine Conglomerate.

understanding the sequencing of sedimentary pulses is key to deciphering the tectonic forces which formed the Seine Basin and uplifted its source area. To understand this sequencing, it is necessary to outline the tectonic history of the region, and the sedimentary response to tectonism, from 2720 Ma to 2685 Ma.

Sedimentary sequences deposited between 2720 and 2685 Ma in, and adjacent to, Wabigoon Subprovince record the final phases of subduction and collision of this area with landmasses to the north and south. Examined basin fill sequences are divisible into three depositional systems tracts. Sediments in the Beardmore-Geraldton area record progradation of braided streams and fan/braid delta complexes from a volcanically active area to the north (Devaney and Fralick, 1985; Devaney, 1987; Devaney and Williams, 1989). The outbuilding sequence fed detritus to a poorly structured, turbidite ramp/fan assemblage in the forearc basin (Barrett and Fralick, 1989), from which it was rerouted into the Quetico trench, via multiple channel systems (Fralick et al., 1992) (Fig. 10). Sediment geochemistry confirms that the calc-alkaline volcanic rocks present in the Onaman-Tashota area, to the immediate north of the forearc basin, were the source of the sediment (Fralick and Kronberg, 1997). Lower Zr and Y values in sandstones from this area compared to analyses of rocks from the western trench (data from Sawyer, 1986) indicate less involvement of older felsic crust as a sediment source. Zircon geochronology (data from D. Davis) demonstrates that the northern Quetico trench received sediment between approximately

2705-2699 Ma, whereas the forearc basic continued to accumulate sediment until at least 2696 Ma. No zircons older than 2828 were found in these sequences. In contrast the zircon population of samples from the western Quetico (Davis et al., 1990) (Fig. 10) contains both 2900 and 3000 Ma zircons, indicating the erosion of older tonalites in this area.

A sedimentary assemblage present to the east of Terrace Bay, in Wawa Subprovince, contains a poorly structured turbidite succession which correlates as the distal equivalent of the Quetico trench deposits (Purdon, 1995) (Fig. 10). The geochemistry of these rocks is very similar to the trench and forearc assemblages to their north, with lower Zr and Y than the trench sandstones to the west. Their geochemistry does not match local sources in the Hemlo and Winston Lake areas. Detrital zircon geochronology matches the Quetico trench sediments to the north, with the exceptions that the main zircon population, which probably reflects age of deposition, is 3 Ma younger, and the sandstones contain a 2900 Ma population. Similar turbidites are present in two other areas of the northern Wawa Subprovince; Shebandowan and Manitouwadge. At the former they are younger than 2700 Ma (F. Corfu, pers. comm.), and at the latter they are younger than 2692 Ma (E. Zaleski, pers. comm.). In the Shebandowan belt, the turbidites are succeeded by a 2692 Ma (Corfu and Stott, 1986), high-Na volcanic assemblage interlayered with near-shore, moderate-to high-slope marine deposits. These are in turn succeeded by <2686 Ma (Corfu and Stott, 1998) braided stream conglomerates eroding crystalline basement.

This depositional system tract records 2709-2693 calc-alkaline arc volcanism on the southern margin of Wabigoon Subprovince and its erosion and transport to the Beardmore-Geraldton forearc basin and Quetico trench at approximately 2700 Ma. A trench-fill state developed at approximately 2696 Ma and the sediment apron expanded to the south covering tholeiitic basalts and a starved clastic-chemical sequence in the area east of Terrace Bay. Similar sequences in Shebandowan and Manitouwadge probably represent overflow in these areas as well. Diachronous overflow younging to the east suggests oblique closure of the arcs comprising northern Wawa Subprovince with the Quetico trench. Deep-marine sediments and volcanic assemblages in the Shebandowan area were upraised at 2692 Ma to surface levels, while deep-marine sedimentation continued in the Manitouwadge area, further indicating west-side-first scissor closure.

The second tract encompasses the English River Subprovince and Warclub Group, on the northern margin of Wabigoon Subprovince. The depositional systems which formed these two units were very similar. They are both primarily composed of unstructured medial to distal turbidite assemblages. The Warclub Group thickens and coarsens upward from a 10m thick basal zone composed of a starved slate-chert assemblage that overlies mafic volcanics. Near its top, minor interbedding with ashes of the Berry River Volcanics occurs. It is sharply overlain by the volcanic unit, which is mostly composed of grainflows of felsic volcanic detritus. The Warclub Group is laterally continuous to the east of Dryden, but does not lithically correlate with sediments in the Minnitaki Lake area. Zircon geochronological patterns (Davis, 1995) for the Warclub Group and English River sediments exhibit a variety of ages. This is in contrast to patterns for sediments on the southern margin of Wabigoon Subprovince, which show a clustering of young ages, and indicates that syndepositional volcanism was not an important sediment source. The youngest detrital zircon age determination for the Warclub Group is 2716 Ma (Davis, 1995), which is in agreement with its stratigraphic position below the 2712 Ma Berry

River Volcanics (Davis, 1995). Volcanics interbedded with the Warclub Group near Vermilion Bay give an age of 2716 Ma (Davis, 1995). The youngest detrital zircon present in the English River assemblage is 2705 Ma (Davis, 1995).

Turbidites of the English River Subprovince and the Warclub Group accumulated in a deep water setting; in the case of the latter, accumulation occurred directly on a mafic assemblage. The turbidites fed from the erosion of local rocks which were upraised, probably tectonically. Deposition of the Warclub Group ceased at 2712 Ma when a felsic volcanic episode effected its basin. English River sediments continued to accumulate until at least 2705 Ma (Davis, 1995). The Warclub Group was most likely deposited in a remnant ocean basin between the Wabigoon and Winnipeg River landmasses. The English River sediments may represent either a remnant ocean basin or a classical trench.

The third depositional systems tract includes the Abram, Minnitaki, Savant, Sturgeon and Conglomerate Lake Groups, and possibly the Crowduck and White Partridge Bay Groups. These sedimentary sequences represent high-slope, fan delta deposits fed into an east-west linear trough which developed south of the north margin of Wabigoon Subprovince. Basal units are dominated by erosion products from the immediately adjacent, underlying lithologies. There is a rapid upward increase in the amount of felsic volcanic detritus, with some sequences almost entirely composed of this material. Reworked sedimentary clasts, representing all fan delta lithofacies, are important constituents of some sequences. Ages of youngest zircons are variable, ranging from post 2707 Ma (Stott and Davis, 1999) for Conglomerate Lake (probably depositional age) to 2699 Ma for Crowduck Lake (D. Davis, pers. comm.). Zircon populations are varied, indicating erosion of older units rather than penecontemporaneous volcanism. The basin system represents proximal foreland basin deposits which were overridden by thrust sheets. Multiple periods of thrusting are indicated by cannibalism, and variation in youngest zircon ages. The Conglomerate Lake assemblage was deposited between 2703 and 2709 Ma; the basal Savant Group at 2704 Ma (Davis, 1995). These ages are similar to ages for cessation of sedimentation in the English River assemblage, and indicate foreland thrusting may be linked to closure of the English River oceanic system.

The three depositional systems tracts are interrelated due to the controlling tectonic processes. Closure of the Warclub remnant ocean initiated development of a foreland thrust belt on the northern margin of Wabigoon Subprovince. During the same period, extensive calc-alkaline volcanism commenced on the southern margin of the subprovince, with commencement of north directed subduction, and fed a systems tract which delivered sediment to two other subprovinces. Probably oblique closure of Wawa arc systems terminated the southern depositional system at 2692 Ma in the west, and resulted in upraising of deep-water environments to shallow depths. By 2686 Ma oceanic deposits, which had formed only 14Ma previously, were being eroded by streams draining the Wawa-Quetico-Wabigoon collision zone.

The depositional environment of the Coutchiching turbidites is consistent with a source-distal, off fan or braid delta setting. Its sedimentology is also consistent with a distal Quetico ramp setting but its position on the northern, source-proximal basin margin makes this scenario unlikely. The Coutchiching most likely was deposited as a submarine apron to the south of fan-deltas fed by thrust-faulting on the northern margin of the Wabigoon subprovince. The age

distribution of zircons from the Coutchiching Group (Davis et al., 1989) is similar to that of coarse-grained metasedimentary sequences present on the northern boundary of the Wabigoon subprovince, all of which have youngest detrital zircons of 2704 Ma, a few m.y. earlier than the Quetico (Davis 1995, Davis 1990). None of these metasediments show the concentration of ages less than 2710 Ma that is characteristic of the Quetico metasediments, suggesting that they are slightly earlier.

The Seine Conglomerate represents the youngest pulse of sedimentation in the evolving collision zone between the Wawa-Abitibi oceanic volcanics, the Quetico trench sediments and the Wabigoon craton. The west side first, scissor closure of the Wawa-Abitibi terrain with the Wabigoon resulted in compression and metamorphism in the Rainy Lake area at 2692 Ma while the Shebandowan area 200 km to the east was just starting to be uplifted and the Manitouwadge area 500km to the east still had an active trench system and subducting ocean floor. Scissor closures such as this denote oblique collision or collision of a promontory. In either circumstance, transpression, or partitioning of oblique deformation into boundary-parallel (wrench) and boundary-perpendicular components (folding or thrust faulting) is likely to result (e. g. Harland, 1971). As blocks slide past one another in wrench settings, strike-slip basins can form as dilation zones open at fault curves, terminations with stepovers, or extensional duplexes. Small rifts can also open due to lateral terrain escape from the compression zone.

There are several late-stage conglomerates similar to the Seine in the Superior Province, many bearing a striking resemblance to one another. They are known as Timiskaming type conglomerates (e. g. Pettijohn, 1943). Based on sedimentological evidence, including the large clast size, relative rarity of cross-bedding in quartzites, and the predominance of relatively immature graywackes interbedded with the conglomerates, Timiskaming type conglomerates have long been recognized as forming in a dynamic, tectonic environment (Pettijohn, 1943). Specifically, researchers have concluded that the conglomerates may have formed synkinematically, possibly in wrench related basins (Poulsen, 1986; Poulsen, 2000). This conclusion is based on the fact that, like the Seine Group conglomerates, other Timiskaming type conglomerates are often found along major wrench zones within the Superior Province. Detailed provenance studies of Timiskaming-type conglomerates have supported the wrench basin interpretation, in that source areas have been located both north and south of the deposition area (Legault and Hattori, 1994). Thus, due to the scissor-closure interpreted from the Seine clasts' provenance and the association of the Seine and other Timiskaming type conglomerates with major wrench zones, it may be appropriate to compare the early structures and stratigraphy in the Seine group to those of more modern strike-slip basins. The aurally limited basin into which the Seine was deposited most likely opened due to some wrench-related process, while the general compression in the area upthrust a possibly yoked source terrain.

Plate collisions and Deformation

In general, the rocks at this boundary show a history of upper crustal stacking and wrenching followed by ductile transpression. The stacking is evidenced by significant amounts of upright bedding and early folds. As deformation continued and rock units became buried, ductile deformation became dominant. This part of the deformation sequence created the dominant S-L

fabrics and was responsible for most of the strain in the rocks. Continued ductile transpression resulted in late-stage crenulations and kinks in the foliation fabric. There is some evidence for minor, brittle structures that formed during the waning moments of deformation.

Along the Wabigoon- Quetico boundary, there are two general *deformational* phases of collision evidenced by the structural field observations. Note that the distinction of two deformational phases is NOT meant to imply that there were two stages of collision, but only that the structural style evolved during the collisional history. The first phase can be interpreted to have included shortening or stacking of strata, frequently coinciding with boundary-parallel motion, in the upper crust. After the first phase and corresponding crustal thickening, the second phase of deformation that created the dominant structural fabric is interpreted to have involved deeper, ductile transpression. The structures preserved in the Seine and surrounding rocks are a result of both their upper-crustal and deeper level deformation.

Structural Evidence of the Tectonic Nature of the Seine Basin

The sedimentological evidence supports the interpretation that the Seine Group was deposited in a dynamic, tectonic environment. The structural evidence supports this conclusion as well. The Seine is the latest of supracrustal rocks to have been deposited at the Wabigoon–Quetico boundary (Poulsen et al., 1980; Davis et al., 1989; Fralick and Davis, 1999). Despite not containing as many folds as its neighboring rock units, the Seine has also undergone deformation that caused the bedding to become vertical. Even though both the Seine and its neighboring rock units are vertically oriented, the reversal in stratigraphic facing between the base of the Seine and the directly adjacent volcanic units (Lawson, 1913; Poulsen et al., 1980; Poulsen, 2000) implies that the earlier strata were tilted, at least in part, prior to Seine group deposition. Therefore, it can be interpreted that the early stacking deformation began before and endured during deposition of the Seine. Thus the Seine group was deposited in a dynamic, tectonic environment, most likely in a basin formed through strike-slip faulting processes that would be expected at an obliquely convergent margin.

The specific type of strike-slip basin (pull-apart, duplex related, fault splay, ...) in which the Seine was deposited remains unclear. However, the geometries of the structures within the Seine Group may provide clues as to the nature of this basin. The dominant vertical nature of the bedding implies that the bedding was probably tilted during the first, upper-crustal stage of deformation by some means (folding, faulting, or both). The few relict folds within the Seine suggest that at least part of the basin was undergoing shortening during basin evolution. This observation leads to the conclusion that the basin was most likely not a simple extensional pull-apart basin (Poulsen, 1986), but rather some other type of wrench-related basin that contained significant areas undergoing shortening during its formation.

If we assume that shear zones form in relatively weaker zones of rocks, the present-day location and orientations of the bounding ductile shear zones may be indicative of the earlier brittle faults. If we follow this logic, the gentle S-shapes of the bounding faults suggest a restraining bend rather than a releasing bend in a dextral strike-slip regime (Fig. 11). This type of restraining bend would likely be associated with thrusting, overturned folding, and localized areas of subsidence and sediment accumulation (Christie-Blick and Biddle, 1985). This scenario seems

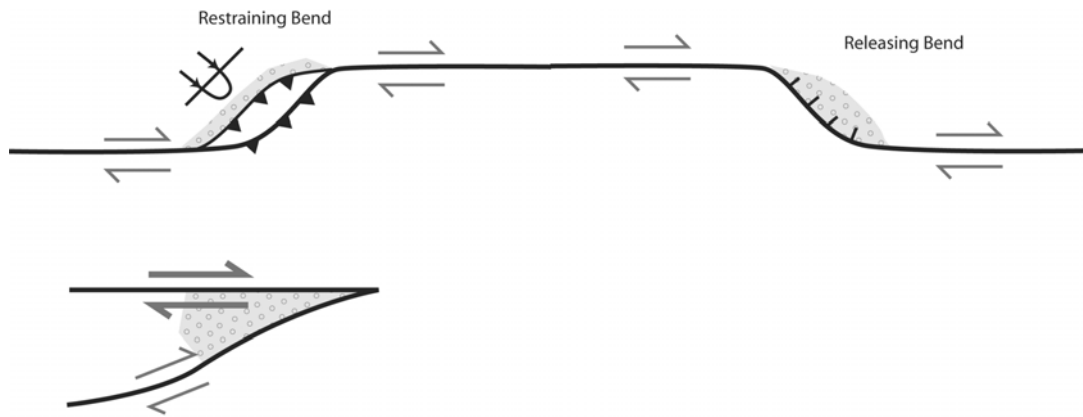


Figure 11. A) Bends in dextral strike-slip fault resulting in either a restraining bend and corresponding thrust faults, overturned folds, and sediment accumulation or a releasing bend and the corresponding normal faulting and pull apart basin. Based on Christie-Blick and Biddle, 1985. B) Possible basin that may have formed if Quetico Fault to the north had relatively more displacement than the Seine River - Rainy Lake Fault to the south.

likely for the Seine basin. Alternatively, one could imagine that both the southern Seine River-Rainy Lake Fault and the northern Quetico Fault were active master-faults and the secondary features (now seen as secondary shear zones) were insignificant in the early history (Fig. 11b). In this scenario, one might expect a basin to form at the fault intersection if the displacement on the Quetico Fault was significantly more than the displacement along the Seine River-Rainy Lake Fault. Alternatively, it is possible, given the scarcity of folds within the Seine, that the Seine could have been deposited in a pull-apart basin; however, this would require that the sense of motion along the faults was sinistral rather than dextral during this early history. There is no evidence for such a change in sense of fault motion, but a switch in motion sense would be possible given that such evidence would likely have been later obliterated by the dominant ductile fabrics. A change in fault sense would require a change in plate motion or the geometry of the boundary. Given the above three scenarios, it may not be possible to prove any one of them, but it seems that the first scenario, that of a basin forming at a restraining bend, is most likely. The original nappe-like nature of the folds and the likelihood of thrusting (see below) support this scenario.

Evidence of Upper Crustal (Brittle) Deformation: Upright bedding as a result of “Stacking”

The major piece of evidence for the first phase of deformation is the ubiquitous steep bedding. One might consider two structural end-members, folding and faulting, that could cause the subvertical tilting of strata. After folding, one would expect to see repetition of stratigraphy and opposing stratigraphic facing directions in adjacent strata. Even in areas with upright, isoclinal folds, one might also expect to see some areas with horizontal bedding corresponding to the fold hinges. After faulting, one would also expect to see repetition of stratigraphy, but not necessarily reversals in stratigraphic facing directions. Within the Seine and surrounding regions, it seems likely that the tilting of bedding was achieved, to some degree, through both faulting and folding, a combination referred to here as “stacking” (Czeck, 2001).

There is significant evidence for folding throughout the Superior Province in general and the Wabigoon–Quetico boundary in particular. Evidence for folding includes visible hinges of some folds and opposing directions of stratigraphic facing (Hooper and Ojakangas, 1971; Bauer, 1985; Poulsen, 1986; Hudleston et al., 1988; Bauer and Bidwell, 1990; Tabor and Hudleston, 1991; Bauer et al., 1992; Jirsa et al., 1992; Bauer and Hudleston, 1995; Hudleston and Bauer, 1995). Several large, upright and isoclinal folds have been identified within the Seine metasediments based on stratigraphic facing (scour beds and cross-beds) and lithologic similarity (Hsu, 1971; Wood et al., 1980a; Wood et al., 1980b; Poulsen, 2000). The present-day upright orientation of folds is consistent with either originally nappe-like or more upright folds. In either case, the second phase of deformation, bulk ductile transpression, would have the effect of rotating the fold limbs from steep to subvertical orientations. However, the combination of several observations including the present-day juxtaposition of adjacent right-way-up and overturned folds (Poulsen et al., 1980; Borradaile, 1982; Poulsen, 2000), suggest that the original orientations of many of the folds were nappe-like.

There is less direct evidence for thrusting, due to a general lack of sedimentary markers that would enable one to recognize duplicated sequences of rock. Instead, the most convincing pieces of evidence for the existence of faults are observations that suggest that all of the vertical bedding could not be a consequence of folding alone. First, within the Seine metasedimentary sequence, folds are much less evident than those reported in other areas, but the dominance of vertical bedding is still the rule. Second, unlike in rocks faulted by brittle mechanisms, folded rocks often leave a record of strain. It has been shown in some areas within the Superior Province that after “unstraining” the folded component of the preserved strain, the strata are still dipping vertically (Schultz-Ela, 1988). Thus, folding alone is insufficient to account for the vertical bedding.

The lack of evidence for faults may indicate that stacking occurred entirely by folding. However, it is also true that if thrust faults were originally present, one would not expect to see evidence of them, other than tilted bedding, after the major fabric-forming deformation (phase 2) took place. Thus, it may be impossible to conclusively determine to what degree the initial stacking event consisted of folds or thrusts. If modern arcs are a suitable analogy to describe the tectonics of the Wabigoon–Quetico boundary, we may consider that while both folding and faulting play a role, faulting appears to be the dominant process at modern arcs (Karig et al., 1979; Karig et al., 1980). Thus, in all likelihood, both thrusts and folds were operational during the stacking phase of deformation at the Wabigoon–Quetico boundary, and it is possible that faulting, although not directly evident, was the dominant process. The relative contributions of faulting and folding to the overall structure may not be equivalent across granite-greenstone terranes, nor even across different portions of the same boundary, such as the Wabigoon–Quetico subprovince boundary. Lack of key exposures and a detailed stratigraphic framework, allied with obfuscation caused by overprinting fabrics from the second phase of deformation, may make it difficult to ascertain the relative contributions of folding and faulting.

The term “transpression” was first introduced by Harland (1971) to describe obliquely convergent motion between two crustal blocks, or motion partitioned into convergent and strike-slip components. Harland, in his original analogue experiments, demonstrated this type of partitioning by generating folds within a deforming medium bounded by two rigid obliquely

convergent plates. In an analogous region of deforming rocks, oblique plate collision may partition motion into strike-slip zones parallel to the boundary and folds and thrusts whose strikes rotate during deformation. The probable contemporaneous history of convergence and strike-slip motions along the Wabigoon–Quetico boundary, as manifested by both faulting/folding (stacking) and wrenching, suggests that Harland-type transpression may have been occurring during the stacking phase of deformation. At least this is likely during the stacking phase that occurred contemporaneously with Seine Group deposition.

It should be noted that the “stacking” in the Seine may or may not be contemporaneous with any of the “stacking” record within adjacent lithologic domains, even within the Quetico and Seine River - Rainy Lake fault-bounded wedge. In fact, the opposite facing directions found between the Seine and a directly adjacent volcanic unit within the wedge reinforces the idea that at least some of the stacking in adjacent units occurred prior to Seine deposition.

Deeper Ductile deformation: Homogeneous Transpression with Variable Extrusion

The second phase of deformation formed the dominant structural fabric in the Seine. It formed the penetrative foliation and lineation fabrics, as well as most of the recorded strain.

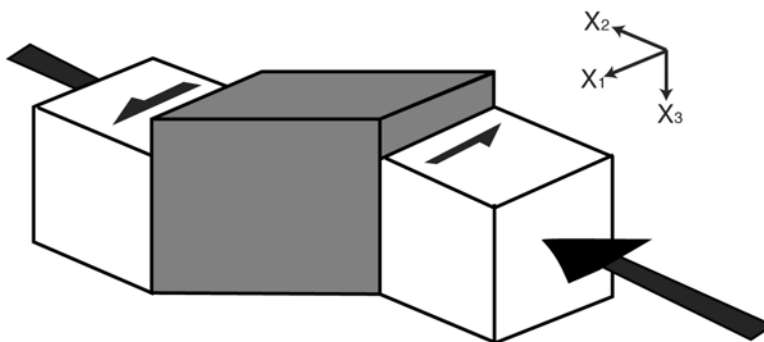


Figure 12. Idealized transpression model according to Sanderson and Marchini (1984)

In general, the foliation is subvertical, and the individual clasts within the Seine conglomerates display a flattening fabric with a subvertical plane of flattening. On subhorizontal planes, the clasts commonly form dextral shear sense indicators, regardless of lineation orientation. Most of these fabric features along the boundary are consistent with a type of ductile transpression first described by Sanderson and Marchini (1984). Sanderson and Marchini (1984) provided a mathematical description of a specialized case of transpression: homogeneous deformation consisting of orthogonal simple shear and pure shear components (Fig. 12). In addition to these two components, their model involves constant volume and confines deformation to a vertically bounded zone. Such an idealized scenario is, perhaps, most likely to correspond to strain in deep, vertical ductile shear zones during oblique convergence. The structural fabrics for this model were predicted by Fossen and Tikoff (1993) and are summarized in Fig. 13. The consistencies of fabrics observed along the Wabigoon–Quetico boundary with the homogeneous transpression model suggest that at least the Wabigoon–Quetico boundary as a whole has undergone quasi homogeneous transpression.

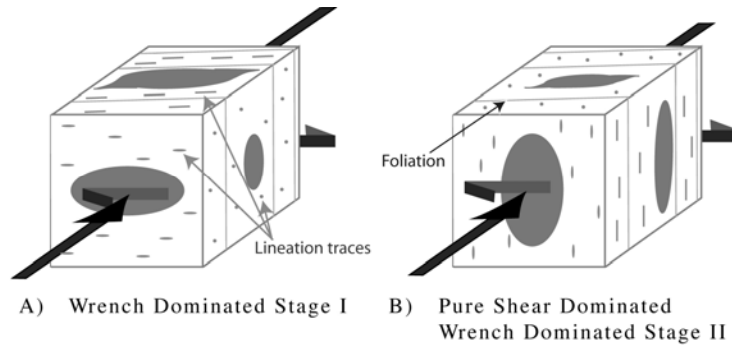


Fig. 13. Generalized transpression. Strain (simple shear and pure shear components) and fabrics (foliation, lineation, conglomerate clast asymmetry) based on Sanderson and Marchini (1984) and Fossen and Tikoff (1993). The front and back sides of the boxes are parallel to the deformation zone boundaries. The mineral fabrics are shown in the general case with fabric oblique to the deformation zone boundaries. As strain accumulates, the foliation becomes progressively closer to subparallel with the deformation zone boundaries. Ellipses (some with “tails”) represent schematic clast traces on each plane. Based on Czeck (2001).

Significantly, the mineral lineations along the Wabigoon–Quetico boundary are neither vertical nor horizontal, as predicted by the Sanderson and Marchini (1984) transpression model; they plunge between 0-90° in both east and west directions (Fig. 8). The most likely way to create variable obliquely plunging lineations of this type is through a combination of Sanderson and Marchini style transpression with nonvertical extrusion (Fig. 14) (Czeck, 2001). In the original

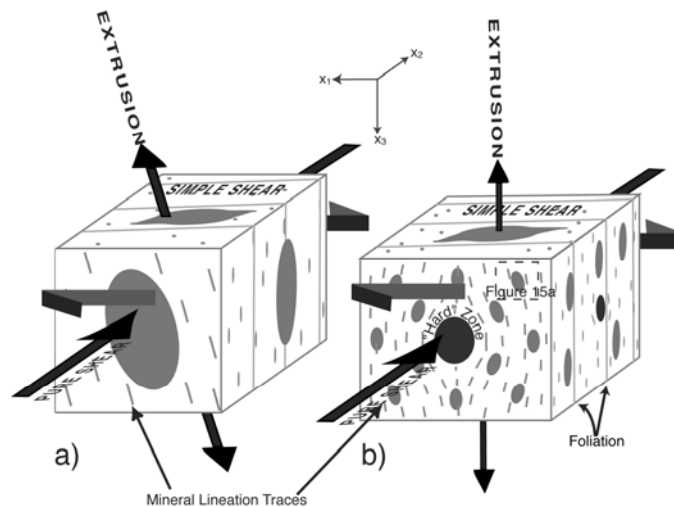


Fig. 14. Schematic view of strain and deformation fabrics for monoclinic transpression with nonvertical extrusion. Light colored ellipses represent schematic clast traces on each plane. (a) Simple view of transpression with nonvertical extrusion. (b) Schematic view of transpression with overall bulk vertical extrusion and localized zones of nonvertical extrusion. Dark colored ellipses represent schematic “hard” zones that influence local extrusion directions. The relative location of Fig. 8a is indicated. Based on Czeck (2001).

Sanderson and Marchini style transpression and subsequent models (Sanderson and Marchini, 1984; Fossen and Tikoff, 1993; Robin and Cruden, 1994; Dutton, 1997; Jones and Holdsworth, 1998; Lin et al., 1998), extrusion of material was assumed to be vertically upwards. This assumption is logical because, in general, one would expect the direction towards the earth's surface to provide the least resistance for material movement. However, rocks at depth may have other boundary conditions that cause local pressure gradients to deviate from this first-order assumption. For many reasons, such as the anastomosing of shear zones and influences of large lithologically diverse bodies, the local pressure gradients at depth may cause rocks to extrude in nonvertical directions. Given this model, the large range of lineation orientations in the Seine is not surprising considering the lithologically diverse nature of the subprovince boundary and the intricately anastomosing shear zones.

As noted by some authors (e. g. Bauer et al., 1992), there may be a final stage of deformation involving amplification of strike-slip motion along wrench zones. This late stage of deformation has often been described as brittle in nature, and thus represents rock exhumation. The presence of brittle faulting of dextral strike-slip motion without contemporaneous thrusting (Kennedy, 1984), may suggest that the latest stage of deformation was almost entirely strike-slip. However, some late-stage brittle faults associated with N-S shortening have been observed (Tabor and Hudleston, 1991). There may also have been an amplification of shortening between the major strike-slip faults, thus creating a more discretely partitioned deformation toward the end of the tectonic history (Tabor and Hudleston, 1991).

Evolution of tectonic styles

The stacking and the homogeneous transpression most likely developed as an evolution of structural styles during different stages of the same oblique collisional event. The presently exposed rocks undoubtedly underwent a voyage through different zones in the crust as evidenced by their deposition at the surface and ductile deformation at some depth. This gradual change in position within the crust is probably responsible for the observed evolution in deformation styles.

It is important to note that the two phases of deformation described here are similar to the commonly discussed "D1" and "D2" described throughout the Superior Province. While specific structural details are different, the general trend of folds overprinted by intense ductile flattening fabrics is common (Poulsen, 1986; Hudleston et al., 1988; Bauer and Bidwell, 1990; Tabor and Hudleston, 1991; Bauer et al., 1992; Jirsa et al., 1992; Bauer and Hudleston, 1995; Hudleston and Bauer, 1995). Locally, rocks at all the Superior Province microplate boundaries may have undergone the same general story of tectonic stacking and wrenching in the upper crust followed by crustal thickening and ductile transpressive flattening as the rocks were deformed at deeper levels. While this general story may be similar, it is important to consider that the regional or even local correlation of these "D1" and "D2" events is probably inappropriate. While the Seine metasedimentary group was forming in a wrench-related basin and surrounding rocks were being stacked, other rocks- even those located along the same microplate boundary or even within the same fault-bounded wedge- may have already reached a deeper level of the crust and began a more ductile, homogeneous phase of transpression. Thus, it is dangerous to correlate exact styles of deformation (e.g. folds) in the Seine with those in either of the adjacent Wabigoon or Quetico subprovinces.

FIELD TRIP STOPS

(Stops are located by UTM co-ordinates based on NAD 83, UTM Zone 15)

Drive to outcrops located on the west side of Shoal Lake Road, south of Mine Centre. (0526600E 5394850N)

STOP 1 - BASAL FACIES OF THE SEINE CONGLOMERATE, EXAMPLE OF LOW DEFORMATION

At this location, we are near the basal contact of the Seine. Based on opposing stratigraphic facing in adjacent rocks, an unconformity between the volcanic units and the base of the Seine conglomerate can be identified (Lawson, 1913; Poulsen et al., 1980; Poulsen, 2000). The clasts within the Seine include more tonalite than is typical further up in the section. A possible saprolite may be observed between the volcanics and the Seine (C. Hemstad, pers. comm.).

Strain at this location is unusually low. Foliation and bedding attitudes are atypical, subparallel with a more NE/SW strike and shallower ($\sim 65^\circ$) southeasterly dip than is typical for the rest of the Seine's area. In addition, the clasts appear to be much more angular and irregularly shaped than the rest of the Seine.

This is a highly unusual outcrop of Seine that poses several interesting questions that are open for discussion. We pose some here with the hope of encouraging some reflection and discussion at the outcrop.

The orientations of the bedding and foliation within the Shoal Lake area and adjacent rocks to the north and south combine to create a large, gentle S structure, with shallower dips here on the middle section of the S. There are several different ways to interpret this sigmoidal map pattern. The various interpretations have bearing on the timing of the geometrical arrangement of structures with respect to the phases of deformation, and therefore will also influence our interpretations of the nature of the Seine basin. Five interpretations are suggested here: 1) The variation in orientation of foliation around the Shoal Lake area may be due to a late stage, gentle folding event. This is suggested by the similar changes in strike and dip of both foliation and bedding. The fold axis of this structure is approximately $55^\circ/077$. 2) As suggested by Poulsen (2000), the faults and small-scale shear zones could be equivalent to those created in fault models of strike-slip systems such as those of Tchalenko (1970), Lowell (1972), and Wilcox et al. (1973). If this were the case, since these models involve Mohr-Coulomb failure, the orientations of the faults would have been determined relatively early in the deformation history, during Harland-type transpression, when the rock would have behaved in Mohr-Coulomb fashion. In this scenario, the Rainy Lake – Seine River fault was the “master fault,” and the Quetico and smaller shear zones formed later as second order conjugate shears. Since there is significant, deeper level, ductile deformation recorded along these same faults, they must have been reactivated during ductile deformation because they were zones of weakness. 3) Alternatively, the orientation of the faults may have been determined during the later ductile transpressive stage of deformation. In this case, the orientation of the major faults and the minor

shear zones would constitute a mega-scale S-C feature creating the sigmoidal pattern seen on the map (Fig. 9). 4) It is also possible that the largest faults were formed by brittle processes, buried and then reactivated as ductile shear zones, with the smaller shear zones being formed later purely by ductile means. 5) Yet another interpretation is possible. It could be that the sigmoidal shape of the foliation is related to lithological contrasts, with foliation wrapping around more rigid bodies. In such a scenario, the rocks to the east of the Bad Vermilion intrusive complex (the large plutonic unit in the west-central portion of Fig. 2) were caught in a large strain shadow region (Borradaile and Dehls, 1993). This hypothesis is consistent with the lower strain found in this area. The apparent “wrapping” of the fabrics around this intrusion seems analogous to the “wrapping” of foliations and lineations around relatively rigid conglomerate clasts at a smaller scale. Not surprisingly, there exists a similar asymmetry in shape between the rigid conglomerate clasts and large rigid units such as the Bad Vermilion intrusive complex.

In addition, the shapes of the clasts here are much more angular than the rest of the Seine clasts. If one were to consider studies that model nonspherical clasts in deformation, we would expect more deformed outcrops of Seine to have barrel or bone shaped deformed clasts (Treagus et. al, 1996; Treagus and Lan, 2000). As we will see at the next outcrops, this is not the case. Why?

Drive East along Hwy 11, right onto Forest Tour Road. (0536650E 5398850N)

STOP 2 - TWO-DIMENSIONAL HORIZONTAL VIEW OF SEINE CONGLOMERATE, SANDY LENS AND DEXTRAL SHEAR INDICATORS

This outcrop allows us to see a large 2D view of the Seine. The deformation here is typical of much of the field area, the granitoid clasts being fairly undeformed while the volcanic clasts reflect significant flattening. Minor amounts of quartzite, BIFs, and other lithologic clast types are also observable. Dextral shear sense indicators are prominent including asymmetric pressure shadows and clast tilings.

Many sandy beds and channels, often with graded bedding, can be located within this outcrop. Is it possible to determine stratigraphic facing here?

Drive East along Hwy 11 to Horsecollar Junction. (0542150E 5398500N)

STOP 3 - THREE-DIMENSIONAL VIEW OF MODERATELY DEFORMED SEINE CONGLOMERATE

This outcrop allows us to see a 3D view of the Seine. The deformation here, as at the last stop, is typical of much of the field area with average strain and dominant flattening fabrics. Here we can observe the subparallel, undulatory nature of bedding and foliation. The lineation plunge here is relatively steep (~78°E). The dextral asymmetric indicators are most prominent on the subhorizontal plane.

Drive East along Hwy 11. (0559500E 5398900N)

STOP 4 - ULTRA DEFORMED SEINE CONGLOMERATE WITH ALTERATION

The conglomerates here are extremely deformed. Both volcanic and plutonic clast types are extremely flattened. Many clasts are flattened beyond recognition, giving the rock a striped appearance. Is it possible to estimate strain in a rock that is this deformed?

The lineation plunge here is typical of the field area (~44°E). While this lineation is “average” stretching lineation for the Seine, it is in no ways representative of the typical deformation due to the wide variance in lineation orientation. The lineation orientation does not vary systematically across the field area and is not directly related to the amount of strain (Czeck, 2001). Again, the dextral asymmetric indicators are most prominent on the subhorizontal plane. This is the case throughout the field area, regardless of lineation orientation, a result that one would not expect in either an ideal strike-slip shear zone or homogeneous transpression. The combination of subhorizontal asymmetric shear indicators and variable lineation orientations makes a deformation model of quasi homogeneous transpression with a variable extrusion direction most likely (Czeck, 2001).

The extensive carbonate alteration in this rock suggests that fluid flow was an important factor during deformation. This implies the possibility of volume loss in these ultra deformed rocks. There was probably a symbiotic relationship between fluid localization and enhanced deformation.

Drive back West along Hwy 11, stop just east of Seine River bridge. (0551850E 5398700N)

STOP 5 - SMALL FOLD IN SEINE

At this stop, we can observe the sandier facies more typical of the upper part of the Seine sequence. Cross beds and localized deposits of gravel can be observed. The cross beds allow us to recognize stratigraphic facing.

The cross beds are deformed, and a good example of a meter-scale fold evident. This fold is asymmetric and upright with its axis oriented 6°/S83W. This subhorizontal fold axis orientation is similar to fold axes orientations described in the Quetico Subprovince and contrasts with the subvertical fold axes described in the Wabigoon subprovince (Borradaile, 1982). Localized prolate strain, atypical of the field area, is evident in the fold hinge. Down the road, just east of this outcrop, another small fold can be observed in the sandy facies. Does this fold have the same subhorizontal fold axis? Is this shallow fold axis typical of larger folds within the Seine where the hinges may not be directly observed?

REFERENCES

Note: Some of the text was previously published in Czeck (2001).

- Barrett, T.J., Fralick, P.W., 1989. Turbidites and iron formations, Beardmore-Geraldton Ontario: application of a combined ramp/fan model to Archean clastic and chemical sedimentation. *Sedimentology* 36, 221-234.
- Bauer, R. L., 1985. Correlation of early recumbent and younger upright folding across the boundary between an Archean gneiss belt and greenstone terrane, northeastern Minnesota. *Geology* 13, 657-660.
- Bauer, R. L., Bidwell, M. E., 1990. Contrasts in the response to dextral transpression across the Quetico-Wawa subprovince boundary in northeastern Minnesota. *Canadian Journal of Earth Sciences* 27, 1521-1535.
- Bauer, R. L., Hudleston, P. J., 1995. Transpression-induced ductile shear in the boundary region of the Quetico and Wawa subprovinces, NE Minnesota; a response to local strain partitioning. In: Ojakangas, R. W., Dickas, A. B., Green, J. C. (Eds.), *Basement Tectonics* 10, pp. 367-377.
- Bauer, R. L., Hudleston, P. J., Southwick, D. L., 1992. Deformation across the western Quetico subprovince and adjacent boundary regions in Minnesota. *Canadian Journal of Earth Sciences* 29, 2087-2103.
- Borradaile, G. J., 1982. Comparison of Archean structural styles in two belts of the Canadian Superior Province. *Precambrian Research* 19, 179-189.
- Borradaile, G. J., Dehls, J. F., 1993. Regional kinematics inferred from magnetic subfabrics in Archean rocks of northern Ontario, Canada. *Journal of Structural Geology* 15, 887-894.
- Burton, J. P., 1989. Constraints on the formation of depositional placer accumulations in coarse alluvial braided river systems. M.Sc. thesis, Lakehead University, Thunder Bay, Ontario, 133p.
- Card, K. D., 1990. A review of the Superior Province of the Canadian Shield, a product of Archean accretion. *Precambrian Research* 48, 99-156.
- Christie-Blick, N., Biddle, K. T., 1985. Deformation and basin formation along strike-slip faults. In: Biddle, K. T. and Christie-Blick, N. (Eds.), *Strike-slip Deformation, Basin Formation, and Sedimentation*, Society of Economic Paleontologists and Mineralogists Special Publication 37, 1-34.
- Corfu, F., Stott, G.M., 1998. The Shebandowan greenstone belt, western Superior Province: U-Pb ages, tectonic implications and correlations. *Bulletin of the Geological Society of America* 110, 1467-1484.
- Corfu, F., Stott, G.M., 1986. U-Pb zircon ages for late magmatism and regional deformation in the Shebandowan belt, Superior Province, Canada. *Canadian Journal of Earth Sciences* 23, 1075-1082.
- Czeck, D. M., 2001. Strain analysis, rheological constraints, and tectonic model for an Archean polymictic conglomerate: Superior province, Ontario, Canada. Ph. D. Thesis, University of Minnesota, 245 p.
- Davis, D.W., 1990. Geological study of the Winnipeg River - Wabigoon subprovince boundary. Report on Energy Mines and Resources Research Agreement 45, 21 p.
- Davis, D.W., 1995. Provenance and depositional age constraints on sedimentation in the western

- Superior transect area from U-Pb ages of zircons. In: Harrap, R. M., Helmstaedt, H. (Eds.), 1995 Western Superior Transect Fifth Annual Workshop 53, pp. 18-23.
- Davis, D.W., 1997. Accretion of the Superior province by collapse of an arc/back-arc/continent margin system: evidence from comparison of U-Pb ages in the Western Superior and Abitibi Lithoprobe transects. In: Harrap, R. M., Helmstaedt, H. (Eds.), 1997 Western Superior Transect Fifth Annual Workshop 63, pp. 18-23.
- Davis, D.W., Pezzutto, F., Ojakangas, R.W., 1990. The age and provenance of sedimentary rocks in the Quetico Subprovince, Ontario, from single zircon analysis: implications for Archean sedimentation and tectonics in the Superior Province. *Earth and Planetary Science Letters* 99, 195-205.
- Davis, D. W., Poulsen, K. H., Kamo, S. L., 1989. New insights into Archean crustal development from geochronology in the Rainy Lake area, Superior Province, Canada. *Journal of Geology* 97, 379-398.
- Davis, D.W., Sutcliffe, R.H., Trowell, N.F., 1988. Geochronological constraints on the tectonic evolution of a Late Archean greenstone belt, Wabigoon Subprovince, northwest Ontario. *Precambrian Research* 39, 171-191.
- Devaney, J.R., 1987. Sedimentology and stratigraphy of the northern and central metasedimentary belts in the Beardmore-Geraldton area of northern Ontario. M.Sc. Thesis, Lakehead University, Thunder Bay, Ontario, 227p.
- Devaney, J.R., 1999. 23. Project Unit 94-04. Stages of volcanism, sedimentation, tectonics and mineralization in the evolution of the Sioux Lookout orogenic belt, western Wabigoon Subprovince. *Ont. Geol. Miscel. Paper* 169, 156-167.
- Devaney, J.R., Fralick, P.W., 1985. Regional sedimentology of the Namewananikan Group, northern Ontario: Archean fluvial fans, braided rivers, deltas and an aquabasin. *Geological Survey of Canada, Current Research, Part B, Paper* 85-1B, 125-132.
- Devaney, J.R., Williams, H.R., 1989. Evolution of an Archean subprovince boundary: a sedimentological and structural study of part of the Wabigoon-Quetico boundary in northern Ontario. *Canadian Journal of Earth Science* 26, 1013-1026.
- Dutton, B. J., 1997. Finite strains in transpression zones with no boundary slip. *Journal of Structural Geology* 19, 1189-1200.
- Fossen, H., Tikoff, B., 1993. The deformation matrix for simultaneous simple shearing, pure shearing and volume change, and its application to transpression-transension tectonics. *Journal of Structural Geology* 15, 413-422.
- Fralick, P., Davis, D., 1999. The Seine-Coutchiching problem revisited: sedimentology, geochronology and geochemistry of sedimentary units in the Rainy Lake and Sioux Lookout Areas. In: Harrap, R. M., Helmstaedt, H. (Eds.), 1999 Western Superior Transect Fifth Annual Workshop 70, pp. 66-75.
- Fralick, P.W., Kronberg, B.I., 1997. Geochemical discrimination of clastic sedimentary rock sources. *Sedimentary Geology* 113 111-124.
- Fralick, P.W., Wu, J., Williams, H.R., 1992. Trench and slope basin deposits in an Archean metasedimentary belt, Superior Province, Canadian Shield. *Canadian Journal of Earth Science* 29, 2551-2557.
- Hammer, K.M., and Smith, N.D., 1983. Sediment production and transport in a proglacial stream: Hilda Glacier, Alberta, Canada. *Boreas* 12, 91-106.
- Harland, W. B., 1971. Tectonic transpression in Caledonian Spitsbergen. *Geological Magazine* 108, 27-42.

- Hoffman, P. F., 1989. Precambrian geology and tectonic history of North America. In: Bally, A. W., Palmer, A. R. (Eds.), *The geology of North America; an overview. The geology of North America A*, pp. 447-512.
- Hoffman, P. F., 1990. On accretion of granite-greenstone terrane. In: Robert, F., Sheahan, P. A., Green, S. B. (Eds.), *Greenstone gold and crustal evolution; NUNA conference volume*, pp. 32-45.
- Hooper, P. R., Ojakangas, R. W., 1971. Multiple deformation in Archean rocks of the Vermilion District, northeastern Minnesota. *Canadian Journal of Earth Sciences* 8, 423-434.
- Hsu, M.-Y., 1971. Analysis of strain, shape, and orientation of the deformed pebbles in the Seine River area, Ontario. Doctoral thesis, McMaster University.
- Hudleston, P. J., Bauer, R. L., 1995. Kinematics of shear zones in the southern Superior Province. In: Ojakangas, R. W., Dickas, A. B., Green, J. C. (Eds.), *Basement Tectonics* 10, pp. 359-366.
- Hudleston, P. J., Schultz-Ela, D. D., Southwick, D. L., 1988. Transpression in an Archean greenstone belt, northern Minnesota. *Canadian Journal of Earth Sciences* 25, 1060-1068.
- Jirsa, M. A., Southwick, D. L., Boerboom, T. J., 1992. Structural evolution of Archean rocks in the western Wawa Subprovince, Minnesota; refolding of precleavage nappes during D₂ transpression. *Canadian Journal of Earth Sciences* 29, 2146-2155.
- Jones, R. R., Holdsworth, R. E., 1998. Oblique simple shear in transpression zones. In: Holdsworth, R. E., Strachan, R. A., Dewey, J. F. (Eds.), *Continental Transpressional and Transtensional Tectonics. Geological Society of London, Special Publications* 135, pp. 35-40.
- Karig, D. E., Lawrence, M. B., Moore, G. F., Curray, J. R., 1980. Structural framework of the fore-arc basin, NW Sumatra. *Journal of the Geological Society of London* 137, 77-91.
- Karig, D. E., Suparka, S., Moore, G. F., Hehanussa, P. E., 1979. Structure and Cenozoic evolution of the Sunda Arc in the central Sumatra region. *Memoir - American Association of Petroleum Geologists* 29, 223-237.
- Kennedy, M. C., 1984. The Quetico Fault in the Superior Province of the southern Canadian Shield. M. S. thesis, Lakehead University.
- Langford, F. F., Morin, J. A., 1976. The development of the Superior Province of northwestern Ontario by merging island arcs. *American Journal of Science* 276, 1023-1034.
- Lawson, A. C., 1913. The Archaean geology of Rainy Lake re-studied. *Memoir - Geological Survey of Canada* 40, 1-115.
- Legault, M. I., Hattori, K., 1994. Provenance of igneous clasts in conglomerates of the Archaean Timiskaming Group, Kirkland Lake area, Abitibi greenstone belt, Canada. *Canadian Journal of Earth Sciences* 31, 1749-1762.
- Lin, S., Jiang, D., Williams, P. F., 1998. Transpression (or transtension) zones of triclinic symmetry: natural example and theoretical modeling. In: Holdsworth, R. E., Strachan, R. A., Dewey, J. F. (Eds.), *Continental Transpressional and Transtensional Tectonics. Geological Society of London, Special Publications* 135, pp. 41-57.

- Lowell, J. D., 1972. Spitsbergen Tertiary orogenic belt and the Spitsbergen fold belt. Geological Society of America Bulletin 83, 3091-3102.
- Merritt, P.I., 1934. Seine-Coutchiching problem. Geol. Soc. Am. Bull. 45, 333-374.
- Miall, A.D., 1978. Fluvial Sedimentology. Can. Soc. of Petrol. Geol., Memoir 5, 859 p.
- Miall, A.D., 1985. Architectural-element analysis: a new model of facies analysis applied to fluvial deposits. Earth Science Reviews 22, 261-308.
- Miall, A.D., 1988. Reservoir heterogeneities in fluvial sandstone: lessons from outcrop studies. Bulletin of the American Association of Petroleum Geologists 72, 682-692.
- Percival, J. A., Williams, H. R., 1989. Late Archean Quetico accretionary complex, Superior province, Canada. Geology 17, 23-25.
- Pettijohn, F. J., 1943. Archean sedimentation. Bulletin of the Geological Society of America 54, 925-972.
- Poulsen, K. H., 1986. Rainy Lake Wrench Zone: An example of an Archean Subprovince boundary in Northwestern Ontario. In: de Wit, M. J., Ashwal, L. D. (Eds.), Tectonic evolution of greenstone belts Technical Report 86-10, pp. 177-179.
- Poulsen, K. H., 2000. Archean metallogeny of the Mine Centre - Fort Frances area. Ontario Geological Survey Report 266, 121.
- Poulsen, K. H., Borradaile, G. J., Kehlenbeck, M. M., 1980. An inverted Archean succession at Rainy Lake, Ontario. Canadian Journal of Earth Sciences 17, 1358-1369.
- Purdon, R.H., 1995. Lithostratigraphy and provenance of the Neoarchean McKellar Harbour sequence, Superior Province Ontario Canada. M.Sc. thesis, Lakehead University, 172 p.
- Robin, P.-Y., Cruden, A. R., 1994. Strain and vorticity patterns in ideally ductile transpression zones. Journal of Structural Geology 16, 447-466.
- Sanderson, D. J., Marchini, W. R. D., 1984. Transpression. Journal of Structural Geology 6, 449-458.
- Sawyer, E.W., 1986. The influence of source rock type, chemical weathering and sorting on the geochemistry of clastic sediments from the Quetico metasedimentary belt, Superior Province, Canada. Chemical Geology 55, 77-95.
- Schultz-Ela, D., 1988. Strain patterns and deformation history of the Vermilion district, northeastern Minnesota. Ph. D. thesis, University of Minnesota.
- Smith, N.D., 1970. The braided stream depositional environment: Comparison of the Platte River with some Silurian clastic rocks, North-Central Appalachians. Bulletin of the Geological Society of America 81, 2993-3014.
- Stone, D., Hallé, J., and Murphy, R. 1997a. Precambrian geology, Mine Centre area; Ontario Geological Survey, Preliminary Map P. 3372, scale 1:50,000.
- Stone, D., Hallé, J., and Murphy, R. 1997b. Precambrian geology, Mine Centre area; Ontario Geological Survey, Preliminary Map P. 3373, scale 1:50,000.
- Stott, G.M., Davis, D.W., 1999. Contributions to the tectonostratigraphic analysis of the Onaman-Tashota greenstone belt, eastern Wabigoon Subprovince. In: Harrap, R. M., Helmstaedt, H. (Eds.), 1999 Western Superior Transect Fifth Annual Workshop 70, pp. 122-123.
- Tabor, J. R., Hudleston, P. J., 1991. Deformation at an Archean subprovince boundary, northern Minnesota. Canadian Journal of Earth Sciences 28, 292-307.
- Tchalenko, J. S., 1970. Similarities between shear zones of different magnitudes. Geological Society of America Bulletin 81, 1625-1640.

- Treagus, S. H., Hudleston, P. J., and Lan, L., 1996. Non-ellipsoidal inclusions as geological strain markers and competence indicators. *Journal of Structural Geology* 18, 1167-1172.
- Treagus, S. H., Lan, L., 2000. Pure shear deformation of square objects, and applications to geological strain analysis. *Journal of Structural Geology* 22, 105-12.
- Turner, C.C., Walker, R.C., 1973. Sedimentology, stratigraphy and crustal evolution of the Archean greenstone belt near Sioux Lookout, Ontario. *Canadian Journal of Earth Sciences* 10, 817-845.
- Wilcox, R. E., Harding, T. P., Seely, D. R., 1973. Basin wrench tectonics. *The American Association of Petroleum Geologists Bulletin* 57, 74-96.
- Williams, P.W., Rust, B.R., 1969. Sedimentology of a braided river. *Journal of Sedimentary Petrology* 39, 649-679.
- Wood, J., 1980. Epiclastic sedimentation and stratigraphy in the North Spirit Lake and Rainy Lake areas; a comparison. *Precambrian Research* 12, 227-255.
- Wood, J., Dekker, J., Jansen, J. G., Keay, J. P., Panagapko, D., 1980a. Mine Centre Area (Eastern Half), District of Rainy River. Ontario Geological Survey Preliminary Map P. 2202, scale 1:15840.
- Wood, J., Dekker, J., Jansen, J. G., Keay, J. P., Panagapko, D., 1980b. Mine Centre Area (Western Half), District of Rainy River. Ontario Geological Survey Preliminary Map P. 2201, scale 1:15840.

Field Trip 4

Industrial Minerals and Paleozoic Geology of Southeastern Manitoba

James D. Bamburak and Ruth K. Bezys
Manitoba Geological Survey
360-1395 Ellice Avenue
Winnipeg, Manitoba R3G 3P2



Interior of the Manitoba Legislative Building, Winnipeg, built in the early 1900s. Decorative dolomitic limestone, the world famous "tapestry stone" with its unique mottled appearance, is still being quarried from the Selkirk Member, Red River Formation in the Garson area.

FOREWORD

Currently, the Province of Manitoba has 18 industrial mineral processing plants and quarries, excluding the production of aggregate (Fig. 1 and Table 1). The 2001 estimated value of industrial mineral production in the province is \$78.1 million, including aggregate production that forms slightly less than half of the total. The \$78.1 million represents 7% of the province's mineral production. Fourteen of Manitoba's industrial mineral processing plants and quarries are situated in southeastern portion of the province.

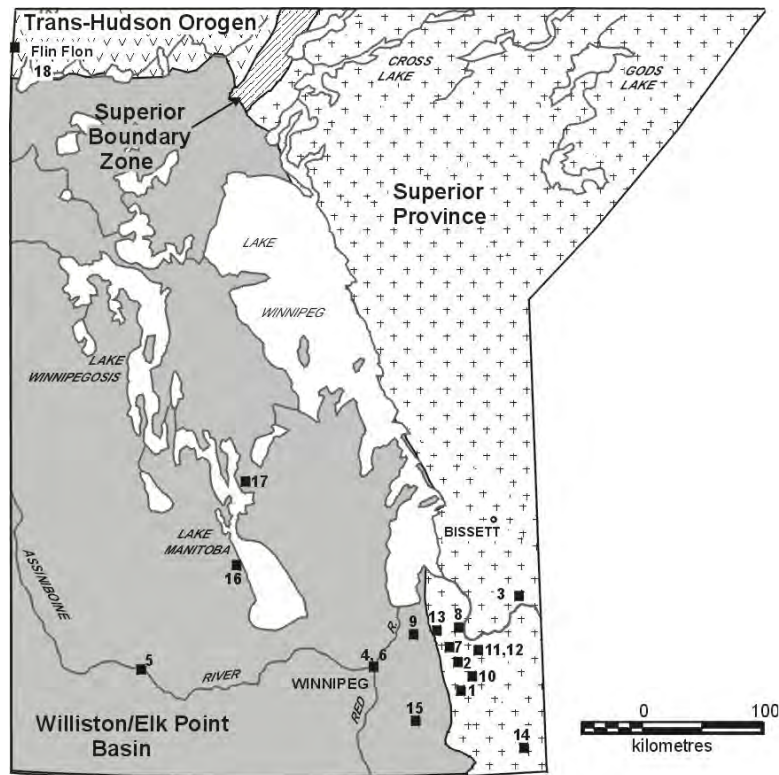


Figure 1. Industrial mineral producing plants and quarries in southern Manitoba

Industrial minerals produced in southeastern Manitoba include lithium, cesium, tantalum, sand, aggregate, dimension stone and peat. Peat is considered as a quarry mineral under the Manitoba Mines and Minerals Act. Lithium, cesium, and tantalum are produced for export from the Tanco mine in the Bernic Lake pegmatite (**Field Trip No. 1, this volume**). Sand and aggregate are quarried for use in local construction. Dimension stone and peat are quarried for local consumption and export. Two companies, Sun Gro Horticulture Canada Ltd., and Premier Horticulture Ltd. extract horticultural quality sphagnum peat. The locations of the peat operations are shown on Figure 1 and listed in Table 1. Five companies, Cold Spring Granite (Canada) Ltd., Gillis Quarries Limited, Carrieres Polycor Inc., Manex Granit Ltd. and Canital Granite Ltd. quarry dimension

Table 1

INDUSTRIAL MINERAL PROCESSING PLANTS AND QUARRIES**2002***

No.	Location	Company	Product
1	Elma (P&Q)	Sun Gro Horticulture Canada Ltd.	Peat moss
2	Whitemouth (Q)	Carrieres Polycor Inc.	Granite, dimension stone
3	Bernic Lake (P&Q)	Tantalum Mining Corporation of Canada Ltd.	Tantalum oxide, spodumene and amblygonite concentrates, cesium and rubidium ores and cesium formate
4	Winnipeg (P)	Westroc Inc.	Gypsum wallboard
5	Brandon	Nexen Inc.	Sodium Chlorate
6	Winnipeg (P)	Canital Granite Ltd.	Granite, dimension stone
7	Moss Spur (Q)	Sun Gro Horticulture Canada Ltd.	Peat moss
8	Lac du Bonnet (P&Q)	Cold Spring Granite (Canada) Ltd.	Granite, dimension stone
9	Garson (P&Q)	Gillis Quarries Limited	Tyndall stone
10	Medika (Q)	Manex Granit Ltd.	Granite, dimension stone
11	Meditation Lake (Q)	Manex Granit Ltd.	Granite, dimension stone
12	PR 307&309 (Q)	Manex Granit Ltd.	Granite, dimension stone
13	Julius North (P&Q)	Sun Gro Horticulture Canada Ltd.	Peat moss
14	Caribou Cluster (Q)	Premier Horticulture Ltd.	Peat moss
15	Giroux (P&Q)	Premier Horticulture Ltd.	Peat moss
16	Harcus (Q)	Westroc Inc.	Gypsum
17	Faulkner (P&Q)	Graymont Western Canada Ltd.	Lime, limestone
18	Flin Flon (P)	Hudson Bay Mining and Smelting Co., Limited	Sulphur

(P) Plant (Q) Quarry

* excludes aggregate producers

stone. Gillis quarries a dolomitic limestone, the renowned "Tyndall Stone", and the other companies quarry granite. Locations of the stone quarries are shown on Figure 2.

INTRODUCTION

This one day field trip is designed to visit three industrial mineral sites, including one Lower Paleozoic site. The sites that will be visited include:

- the sphagnum peat bog harvesting operation and plant of SunGro Horticulture Canada Ltd. near Elma (**Stop 1**);

- the granite dimension stone quarry and plant of Cold Spring Granite (Canada) Ltd. near Lac du Bonnet (**Stop 2**); and,
- the Ordovician Tyndall Stone quarry and plant of Gillis Quarries Limited at Garson (**Stop 3**).

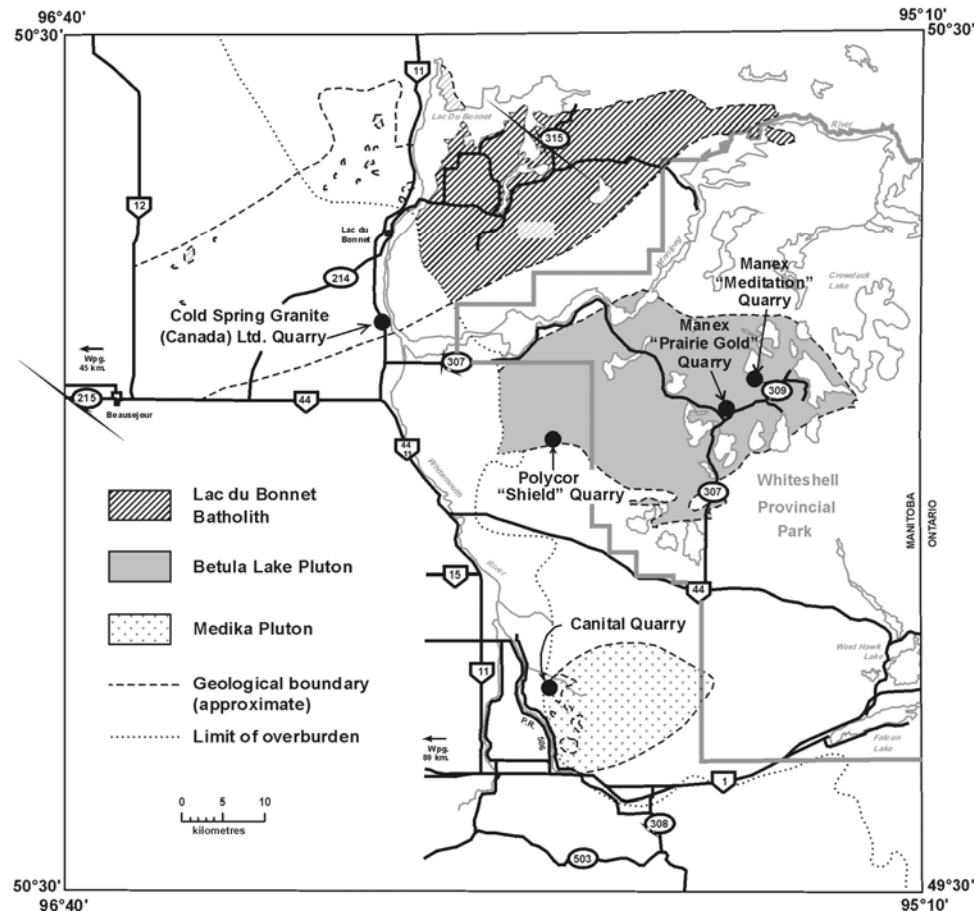


Figure 2. Granitic dimension stone quarries in southeastern Manitoba.

Sphagnum Peat

Canada holds more than a third of the world's peat resources with 1 223 834 km² of peatlands, or 12 percent of the total land mass (Tarnocai et al., 1995). Approximately 40% of Manitoba's surface is covered with peat deposits, many of which are inaccessible and/or of uneconomic thickness and quality to be harvested (Dixon and Stewart, 1988). Nevertheless, Manitoba holds vast reserves of peat suitable for horticultural or energy peat production. Two companies, Sun Gro Horticulture Canada Inc. (**Stop 1**) and Premier Horticulture Inc. harvest 6 bogs in southeastern Manitoba (Fig. 1) for horticultural quality peat. An aerial view of a typical peat extraction area is shown in Figure 3. Peat companies hold almost 4000 hectares of leases in good standing, and 5500 hectares of pending leases in the Interlake and southeastern Manitoba. Peat production in Manitoba

in 2001 was estimated to be worth over \$25 million, and this figure is sure to increase as new companies bring their bogs into production.

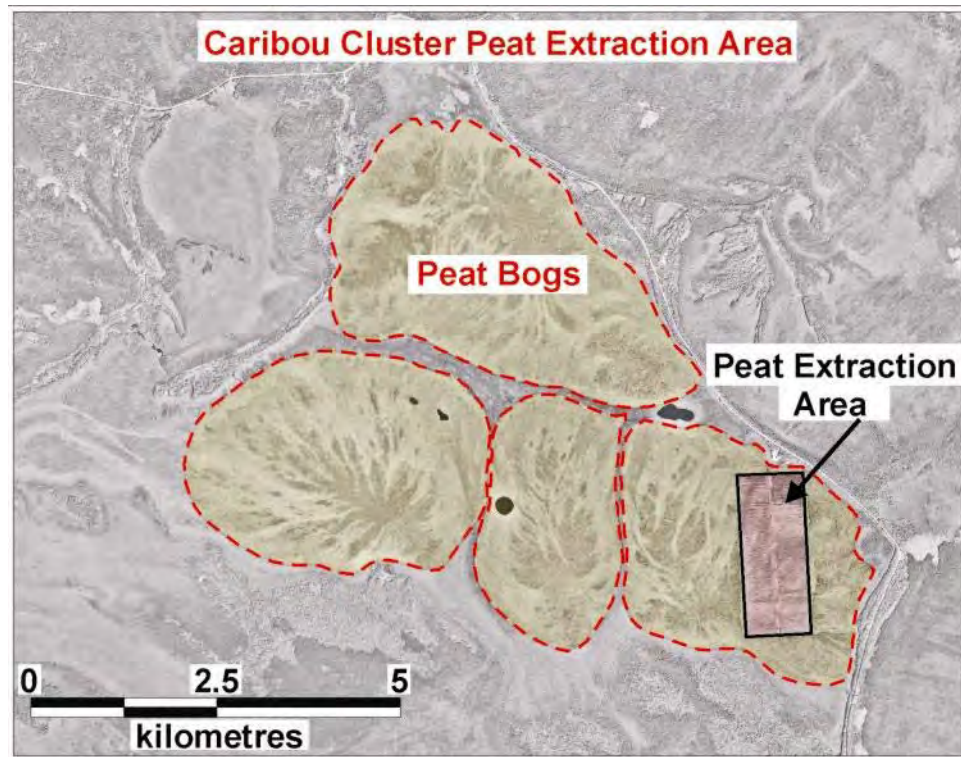


Figure 3. Caribou cluster peat extraction area of Premier Horticulture Inc.

Horticultural quality sphagnum is the preserved, but undecomposed, remains of sphagnum moss plants. Sphagnum deposits accumulate in areas of poor drainage where the rate of atmospheric precipitation exceeds the rate of evapotranspiration, i.e. the low boreal forest climatic zone. The accumulation of sphagnum occurs within an acidic, nutrient poor environment, above the level of the local water table. The characteristics of sphagnum that allow it to survive in this environment are the same characteristics that make it valuable to the horticultural industry as a growing medium and soil conditioner (Schmidtke and Bamburak, 1996). These characteristics are:

1. the ability to absorb approximately 20 times its weight in water;
2. a high capacity for cation exchange;
3. a fibrous structure that introduces volume and pore space to a soil mix;
4. compressibility; and,
5. the ability to resume its precompression volume after compression is released.

Sphagnum moss is composed largely of rigid walled hyaline cells. The function of these cells is to absorb and hold water. Since the sphagnum must get all its nutrients from the

nutrient poor atmospheric precipitation, it is able to absorb approximately 20 times its weight in water and has a high cation exchange capacity. These properties make it a valuable growing medium in places like Texas where the native soil is fine and does not retain moisture. The hyaline cells are compressible and will resume their shape even after being compressed to a 10:1 ratio. The sphagnum moss can be compressed into bales for efficient transport.

These properties are retained after the plant has died and even when it is slightly humified. Since the sphagnum accumulation takes place in an acidic, oxygen poor environment, it is possible for several metres of relatively undecomposed sphagnum to develop. The high quality bogs in southeastern Manitoba accumulated sphagnum to a maximum depth of approximately 2.5 m over a period of 4000 years.

A bog must be prepared before peat extraction occurs. First the trees and roots are removed, ditches are dug, and the bog is drained. It may take two years to prepare a bog for harvesting. Sun dries the surface of the bog, which is then raked using a harrower (or cultivator) to loosen the surface peat. This loose, dry sphagnum peat is lifted from the surface with vacuum harvesters (Fig. 4). The harvesters empty the peat into stock piles, or winrows. The stock piled peat is either moved into the plant for processing or is stored in plastic "silage" tubes for future processing when unfavourable weather prohibits harvesting. (Peat can't be extracted if the weather is too wet or too dry, because quarrying equipment can't operate on a bog that has been saturated by rain or melt water and sparks from equipment can ignite peat dust in hot, dry weather).



Figure 4. Conga line of peat vacuum harvesters on Elma bog of Sun Gro Horticulture Canada Inc.

Once in the plant, the peat is dried (if necessary). Popped perlite is added as a volumizer. The peat is treated with surfactants, which increase absorptive capacity, and fertilizers.

The type and quantity of the chemicals added to the peat are dependent on the intended end use. Specialized mixes are available for several applications, *i.e.* soil mix for violet plants. The peat is baled, shrink-wrapped on pallets and stored in the warehouse before being loaded onto semi trailers.

Some of the peat is sold in local markets, but most goes to nurseries and greenhouses in the southern United States. The peat companies take advantage of backhaul rates by shipping the peat south in trucks that bring produce to Manitoba from the southern United States. Ninety percent of the peat from Sun Gro's Manitoba quarries is exported to Texas. If the Sun Gro operations in Alberta or New Brunswick are unable to produce because of bad weather or labour problems, Manitoba peat is diverted to markets west or east of Texas to cover the shortfall. Both Sun Gro Horticulture and Premier Horticulture operate harvesting operations and plants across Canada (Schmidtke and Bamburak, 1996).

Granitic Dimension Stone

Four companies quarry Precambrian granitic dimension stone at 5 sites in southeastern Manitoba (Fig. 2). They include: Cold Spring Granite (Canada) Ltd., Carrieres Polycor Inc., Manex Granit Ltd. and Canital Granite Ltd. At all sites, the granitic outcrops possess unique physical features that permit the quarrying of large blocks of stone Schmidtke (1993). They include:

1. widely spaced, preferably orthogonal fractures that will allow removal of blocks with a minimum trimmed size of 2.0 m by 1.25 m by 1.25 m;
2. widely spaced, or preferably the absence of, veining;
3. homogeneous, attractive and fashionable colours and textures;
4. the absence of minerals that pluck when polished, or oxidize and cause unsightly rust spots when exposed to the elements;
5. road access;
6. proximity to transportation routes, finishing facilities and markets; and,
7. acceptable strength values that meet ASTM standards (as per Annual Book of ASTM Standards).

Two of the granitic dimension stone cutting and polishing plants are located in southeastern Manitoba (Fig. 1 and Table 1). One plant (**Stop 2**) is adjacent to the quarry near Lac du Bonnet (Cold Spring Granite), and the other plant is situated in Transcona, on the east side of Winnipeg (Canital Granite).

Tyndall Stone

At Garson, Tyndall Stone is quarried by Gillis Quarries Ltd. (Fig. 1 and Table 1), east of the plant. This famous dimension stone, sometimes called “tapestry stone”, occurs in the lower half of the 43 m thick Selkirk Member of the Ordovician Red River Formation. Its unique appearance comes from a matrix of light-coloured limestone, with mottled areas of dark dolomitic limestone distributed uniformly throughout. The horizontal beds are approximately 60 to 100 cm thick, beneath 1 to 6 m of overburden consisting of soil, lake clays and stony glacial till. The upper four beds in the quarry (total thickness 2 to 4 m) have either a buff and golden-brown buff matrix. The fifth layer down has a matrix, which is transitional into the underlying beds that have a steel-gray matrix (Wilkins, 1986; Coniglio, 1999).

After the overburden is stripped, the stone is extracted using two 2.5 m diameter circular saws, drilling and wedging. The 6 to 8 tonne stone blocks are taken into the plant where they are cut and finished using diamond tipped saws or are ground, sheared or split into a variety of products. Finishes available are rubbed (machine smoothed), bushhammered, pointed face, rough cut, sandblasted, split and rustic. Stone is usually marketed as dimension stone, which is cut and shaped to specification or as random ashlar, which are pre-cut into standard or random shapes to be set into mortar (Wilkins, 1986; Coniglio, 1999).

REGIONAL GEOLOGICAL SETTING

The Province of Manitoba is completely underlain by 3.0 to 1.7 billion year old Precambrian rock, which is overlain in the southwest and northeast by younger (less than 570 million years old) Phanerozoic sedimentary rocks (Fig. 5). Pleistocene and Holocene deposits, younger than 2 million years in age cover most of these earlier rocks. Industrial minerals in Manitoba range, in age and form, from Precambrian dimension stone to Holocene peat deposits.

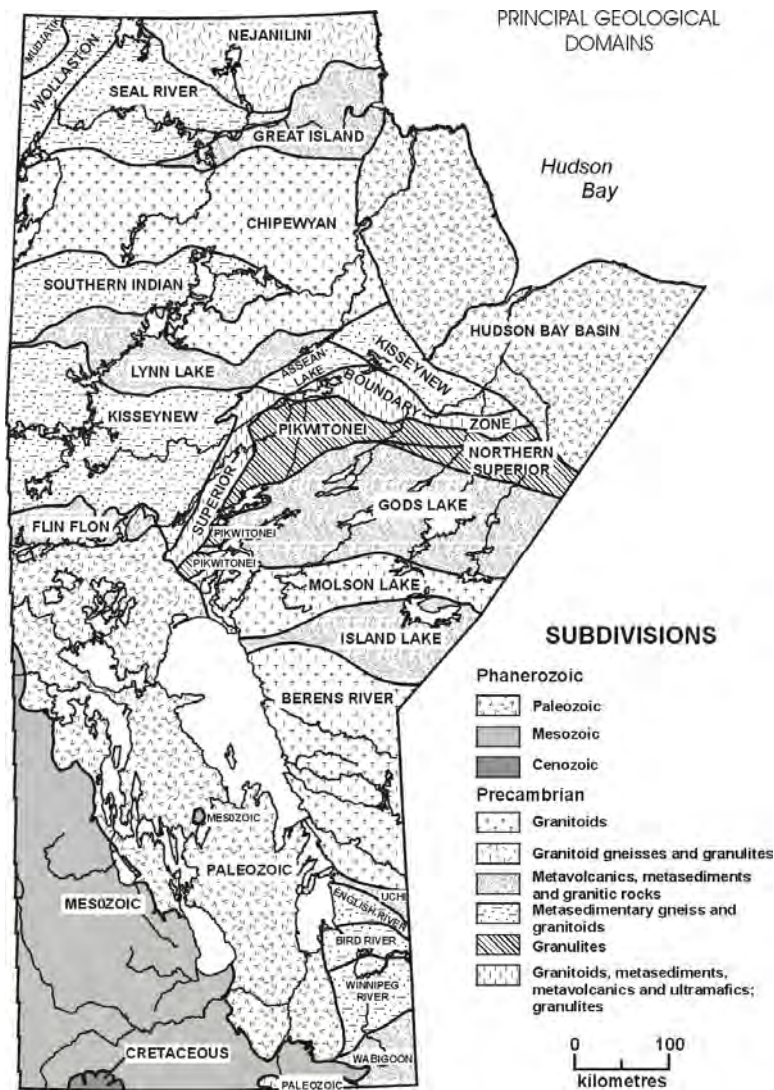


Figure 5. Principal geological domains of Manitoba

Within southeastern Manitoba, the Precambrian surface is exposed in the east half of the area and is known as the Precambrian Shield. The surface dips to the west (Fig. 6), where it is covered by an increasing thickness of Lower Paleozoic strata which also dip gently to the southwest at approximately 2.8 m per km (Fig. 7). The eastern edge of the Paleozoic outcrop belt represents the Manitoba Lowland or First Prairie Level, which is

bounded on the east by the Precambrian Shield, and on the west by the Manitoba Escarpment.

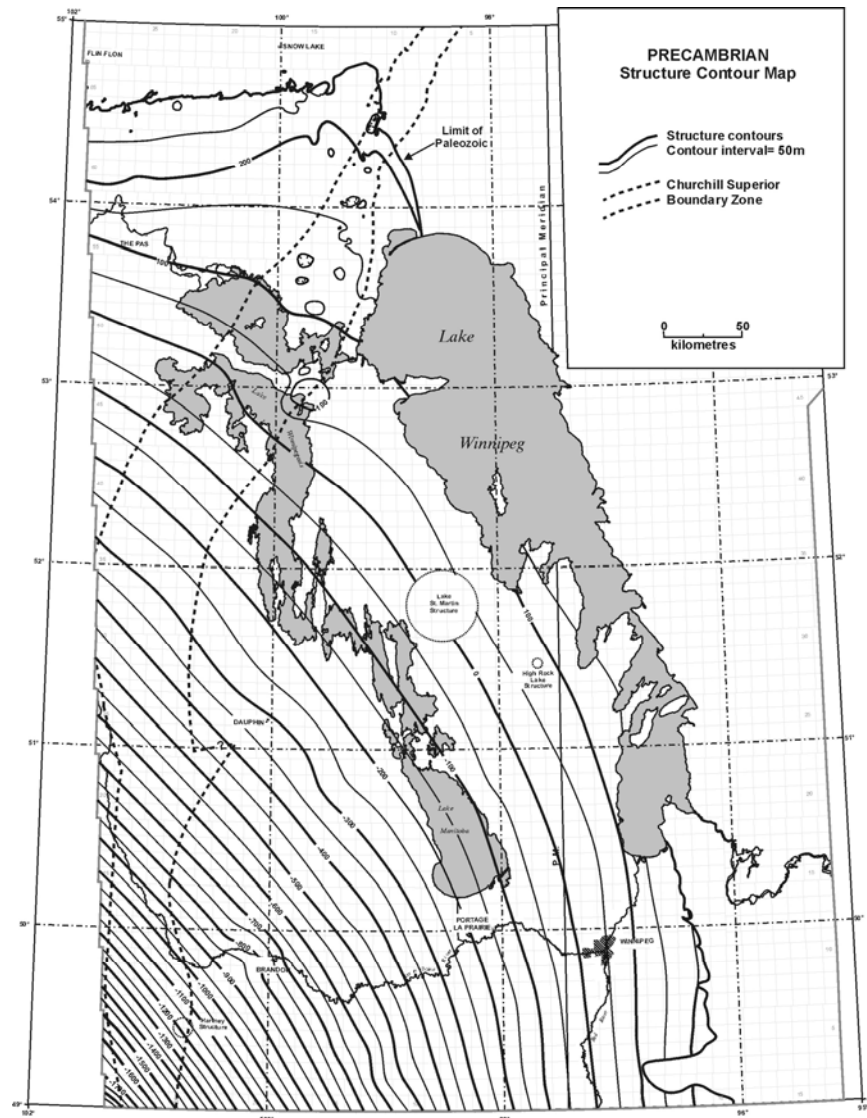


Figure 6. Precambrian structure contour map.

The Manitoba Escarpment forms the eastern edge of the Second Prairie Level, which is underlain by Cretaceous strata dipping gently to the southwest at 1.5 to 1.9 m per km. The actual Escarpment is composed of soft, easily eroded sands and shales in the lower part of the Cretaceous, underlying a resistant shale cap (Odanah Member of the Pierre Shale).

In southeastern Manitoba, industrial minerals are mined from Precambrian, Lower Paleozoic and Holocene localities. Granite quarries (Fig. 2) are situated within late tectonic granitic batholiths and plutons on the western edge of the Archean Superior Province. The Ordovician Tyndall Stone quarry (Gillis Quarry, Fig. 1) occurs within the eastern edge of the Paleozoic outcrop belt. The harvested sphagnum peat bogs (Fig.1)

are located in areas of thick glacio-lacustrine sediments that overlie Archean terrane or Ordovician strata.

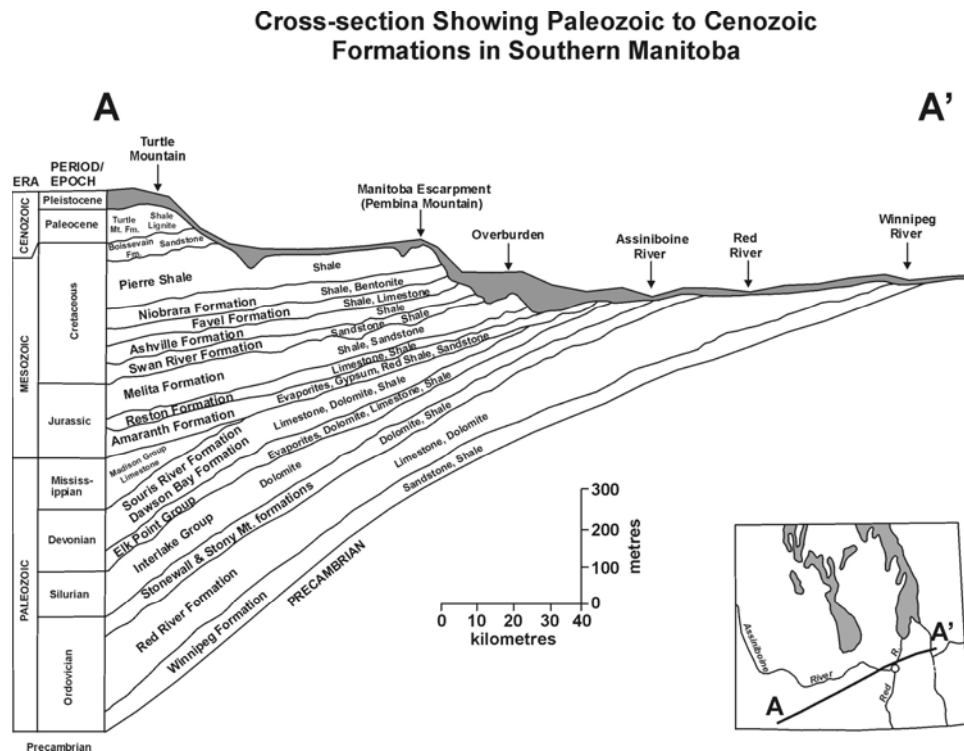


Figure 7. Structure cross section, southern Manitoba.

Precambrian Basement

The Precambrian of southeastern Manitoba is comprised of younger Archean granitic batholiths or plutons that have intruded the older greenstone, sedimentary and gneissic formations of the Wabigoon, Winnipeg River, Bird River and English River domains of the Superior Province (Fig. 5). The structure contours on the buried Precambrian surface are shown in Figure 6.

All granitic dimension stone production to date has been derived from the Winnipeg River and Bird River domains. The Medika and Betula Lake plutons are situated within the Winnipeg River Domain. The Lac du Bonnet Batholith (LDBB), located to the northwest, lies within the Bird River Domain. For the purpose of the visit to Cold Spring's Lac du Bonnet Quarry (**Stop 1**), the following will focus on the latter.

The LDBB (outlined on Fig. 2) is the youngest intrusion in the Winnipeg River area (Tammemagi et al., 1980). The batholith is a predominantly pink granite that extends over approximately 1000 km² from Pointe du Bois southwestward beneath Paleozoic cover. The largest exposures of the batholith occur east of the town of Lac du Bonnet, but isolated outcrops are found as far west as the farmlands directly north of Beausejour. Many of the outcrops of Lac du Bonnet granite have widely spaced fractures, which makes them potential sources of dimension stone (Schmidtke, 1993).

The geology of the Lac du Bonnet Batholith (LDBB) has been the subject of intensive study by Atomic Energy of Canada Ltd. (AECL) as a research site for geological, geotechnical and hydrogeological studies to determine the potential for storing nuclear waste at depth in granite. The regional geology has been described, in detail, by Tammemagi et al. (1980) and McCrank (1985).

Lower Paleozoic Stratigraphy

The Lower Paleozoic beds (Table. 2) exposed in southeastern Manitoba form part of the Manitoba outcrop belt that is located on the northeastern edge of the Western Canada Sedimentary Basin (WCSB). The WCSB is a composite feature which includes both the Elk Point Basin (Fig. 8), centered in south-central Saskatchewan (which controlled Devonian deposition), and the Williston Basin, centered in northwestern North Dakota (which controlled the depositional patterns throughout the remainder of post-Cambrian time). Since the Manitoba outcrop belt appears to be situated on the northeastern edge of the sedimentary basin, and roughly parallels the regional structure contours, one might surmise that the strata comprising the outcrop belt would be relatively uniform in lithology. The outcrop would also represent marginal shelf-type deposits relative to the thicker, more basinal sedimentary sequence found to the southwest in the subsurface. However, this is not the case for most Paleozoic formation in southwest Manitoba. The outcrop belts, particularly the Ordovician and Devonian, show marked changes in both thickness and lithology, indicating a complex and varied tectonic and depositional framework (Bezys and McCabe, 1996).

The outcrop succession is not marginal to the depositional basin, but rather exposes a series of dip sections of the basin, which show the maximum possible isopach and lithofacies variation. As well, the directions of the dip sections are opposite: basinal Ordovician outcrops occur at the southern end of the outcrop belt, whereas basinal Devonian outcrops occur at the northern (or northwestern) end of the outcrop belt.

Regional strike of the Paleozoic strata is approximately north-south, and regional dip increases gradually and uniformly from about 2.6 m/km in the eastern part of southeastern Manitoba to 4.2 m/km in the western part. Despite the regional structural dip to the southwest, isopachs of the Winnipeg and Red River formations all trend east-west and thicken to the south at up to 0.3 m/km (Fig. 9B and 10B, respectively). This indicates a major change in tectonic framework subsequent to early Paleozoic time, as mentioned previously. The present north-south structural trend probably developed during late Paleozoic to early Mesozoic, due to uplift with associated erosion and eventual exposure of Precambrian bedrock in southeastern Manitoba.

A detailed discussion outlining: the evolution of the complex pattern of structural trends in the Lower Paleozoic; a regional tectonic control for apparent anomalies in facies trends; and other related structural and stratigraphic anomalies are described in Bezys and McCabe (1996).

AGE Millions of years before present	ERA	PERIOD	EPOCH	FORMATION	MEMBER	MAX. THICK (m)	BASIC LITHOLOGY	
50	CENOZOIC	QUATER- NARY	RECENT				TOP SOIL AND DUNE SANDS.	
			PLEISTO- CENE	GLACIAL DRIFT		140	CLAY, SAND, GRAVEL, BOULDERS AND PEAT.	
		TERTIARY	Pliocene					
			Miocene					
			OLIGOCENE Eocene					
65	MESOZOIC	CRETACEOUS	PALEO- CENE	TURTLE MOUNTAIN	PEACE GARDEN GOODLANDS	120	SHALE, CLAY, SAND, LIGNITE BEDS. LOCATED ONLY IN TURTLE MOUNTAIN.	
UPPER			BOISSEVAIN		30	SAND AND SANDSTONE, GREENISH-GREY. LOCATED ONLY IN TURTLE MOUNTAIN.		
			PIERRE SHALE	COULTER			SHALES, GREY, NON-CALCAREOUS, LOCAL IRONSTONE, BENTONITE NEAR BASE, GAS SHOW.	
				DOONAN				
				MILLWOOD				
				PERMENA				
NIORARA			GRAMMON FERRUGINOUS	75	SHALE, GREY SPECKLED, CALCAREOUS, BENTONITIC, SLIGHTLY PETROLIFEROUS.			
MORDEN SHALE				55	SHALE, DARK GREY, NON-CALCAREOUS, RARE IRONSTONE CONCRETIONS, LOCAL SAND AND SILT.			
FAVEL			ASSINBOINE			SHALE, GREY WITH HEAVY CALCAREOUS SPECKS, LIMESTONE BANDS AND BENTONITE.		
			KELD		40			
		WESTGATE						
LOWER		ASHVILLE	NEWCASTLE (ASHVILLE) SAND CREEK	115	SHALE, DARK GREY, NON-CALCAREOUS, FINE-GRAINED QUARTZ SANDSTONE OR SAND "ZONE".			
		SWAN RIVER		75	SANDSTONE AND SAND, FINE-GRAINED WITH SILTS AND GREY, NON-CALCAREOUS CLAYS, PYRITIC, GLAUCONITIC.			
150		JURASSIC	UPPER	WASKADA		200	BANDED, GREEN BENTONITIC SHALE AND CALCAREOUS, GLAUCONITIC SANDSTONE.	
MELITA				UPPER LOWER		BANDS OF SANDY LIMESTONE, VARI-COLOURED SHALE AND SANDSTONE.		
RESTON					45			
MIDDLE				AMARANTH	UPPER: EVAPORITE	45	ANHYDRITE AND/OR GYPSUM, WHITE AND BANDED DOLOMITE AND SHALE.	
			LOWER: RED BEDS		40	SHALE, RED TO SILTSTONE, DOLOMITIC.		
200			TRIASSIC	(?)	ST. MARTIN COMPLEX		300	CARBONATE BRECCIA AND TRACHYANDESITE (CRYPTO-EXPLOSION STRUCTURE).
250						PERMIAN PENNSYL- VANIAN	MISSISSIPPIAN	MADISON GROUP
MISSION CANYON			120	LIMESTONE, LIGHT BUFF, OOLITIC, FOSSILIFEROUS, FRAGMENTAL, CHERTY, BANDS OF SHALE AND ANHYDRITE.				
	LODGEPOLE		FLOSSIE LAKE WHITEWATER LAKE VIRIDEN SCALLION REDOUTLEDGE	185	LIMESTONE AND ARGILLACEOUS LIMESTONE, LIGHT BROWN AND REDDISH MOTTLED, SHALEY ZONES, OOLITIC, CRINOIDAL AND CHERTY.			
			BAKKEN	UPPER MIDDLE LOWER	20	TWO BLACK SHALE ZONES SEPARATED BY SILTSTONE.		
DEVONIAN		SASK- GROUP MAIN GROUP ELK POINT GROUP		THREE FORKS		35		
	BIRDBEAR				40	LIMESTONE AND DOLOMITE, YELLOW-GREY, FOSSILIFEROUS, POROUS, SOME ANHYDRITE.		
	DUPEROW			170	LIMESTONE AND DOLOMITE, ARGILLACEOUS AND ANHYDRITIC IN PLACES.			
	SOURIS RIVER (FIRST RED)			120	CYCLICAL SHALE, LIMESTONE, DOLOMITE AND ANHYDRITE.			
	DAWSON BAY (SECOND RED)			65	LIMESTONE AND DOLOMITE, ANHYDRITIC. LOCAL RED AND GREEN SHALE.			
	PRAIRIE		EVAP.	120	HALITE, POTASH, ANHYDRITE AND DOLOMITE INTERBEDDED.			
	WINNIPEGOSIS		UPPER (REEF)	75	DOLOMITE, LIGHT YELLOWISH-BROWN, REEF-OLD.			
	ELM POINT		LOWER (PLATFORM)		LIMESTONE, FOSSILIFEROUS, HIGH-CALCIUM			
	ASHERN			12	DOLOMITE AND SHALE, BRICK RED TO VARIGATED GREEN.			
	400		SILURIAN	INTERLAKE GROUP		135	DOLOMITE, YELLOWISH-ORANGE TO GREYISH-YELLOW FOSSILIFEROUS, SILTY ZONES.	
STONEWALL	UPPER LOWER WILLIAMS	20			DOLOMITE, GREYISH-YELLOW, BEDDED.			
450	ORDOVICIAN	STONY MOUNTAIN		25	DOLOMITE, YELLOWISH-GREY, SHALY.			
			PENITENTIARY		20	DOLOMITE, DUSKY-YELLOW FOSSILIFEROUS.		
			GUNN		20	SHALE, RED-GREEN, FOSSILIFEROUS LIMESTONE INTERBEDS.		
			FOXY HARRY BELKIRK CAT HEAD DOG HEAD		170	DOLOMITIC LIMESTONE, MOTTLED AND MOTTLED DOLOMITE.		
			WINNIPEG	UPPER SHALE LOWER SANDSTONE	60	SHALE, GREEN, WAXY, AND INTERBEDDED SANDSTONE.		
500	CAMBRIAN	DEADWOOD		60	SAND AND SANDSTONE, QUARTZOSE.			
			60	SAND, BLACK TO GREEN-GREY, WAXY, GLAUCONITIC SILTSTONE AND SHALE, GREEN- GREY TO BLACK, LOCATED ONLY IN EXTREME SOUTHWEST CORNER OF MANTOBA.				
550	PRECAMBRIAN						ACID AND BASIC CRYSTALLINES AND METAMORPHICS.	

Table 2. Geological formations in Manitoba.

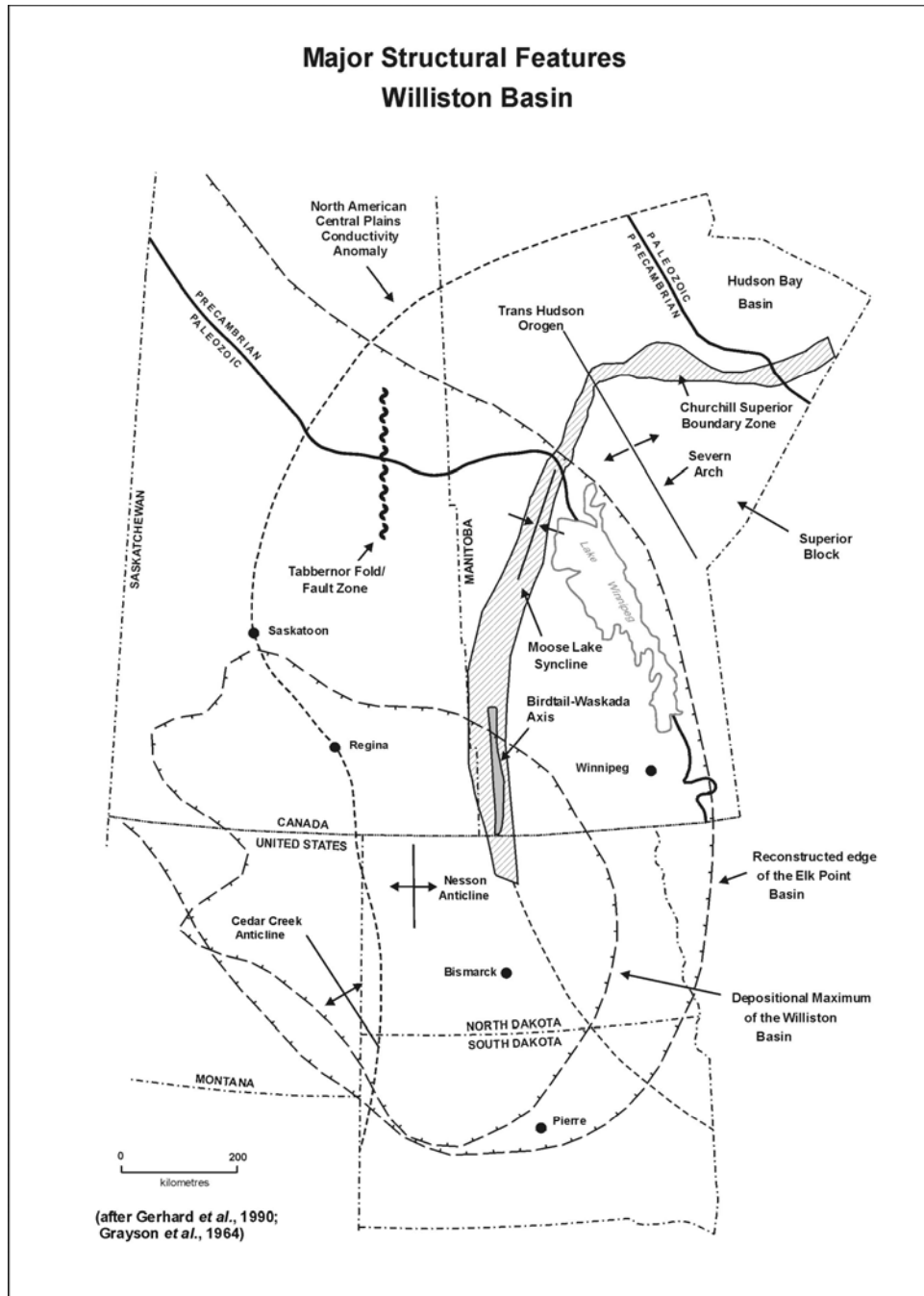


Figure 8. Major structural features of the Elk Point and Williston basins.

Ordovician

Winnipeg Formation

The Winnipeg Formation, a quartzose sandstone interbedded by green, waxy shale with sand and silt interbeds, is exposed in outcrop east at the northeast end of the southeastern Manitoba area, on Black Island and near Seymourville. Structure contours and isopachs

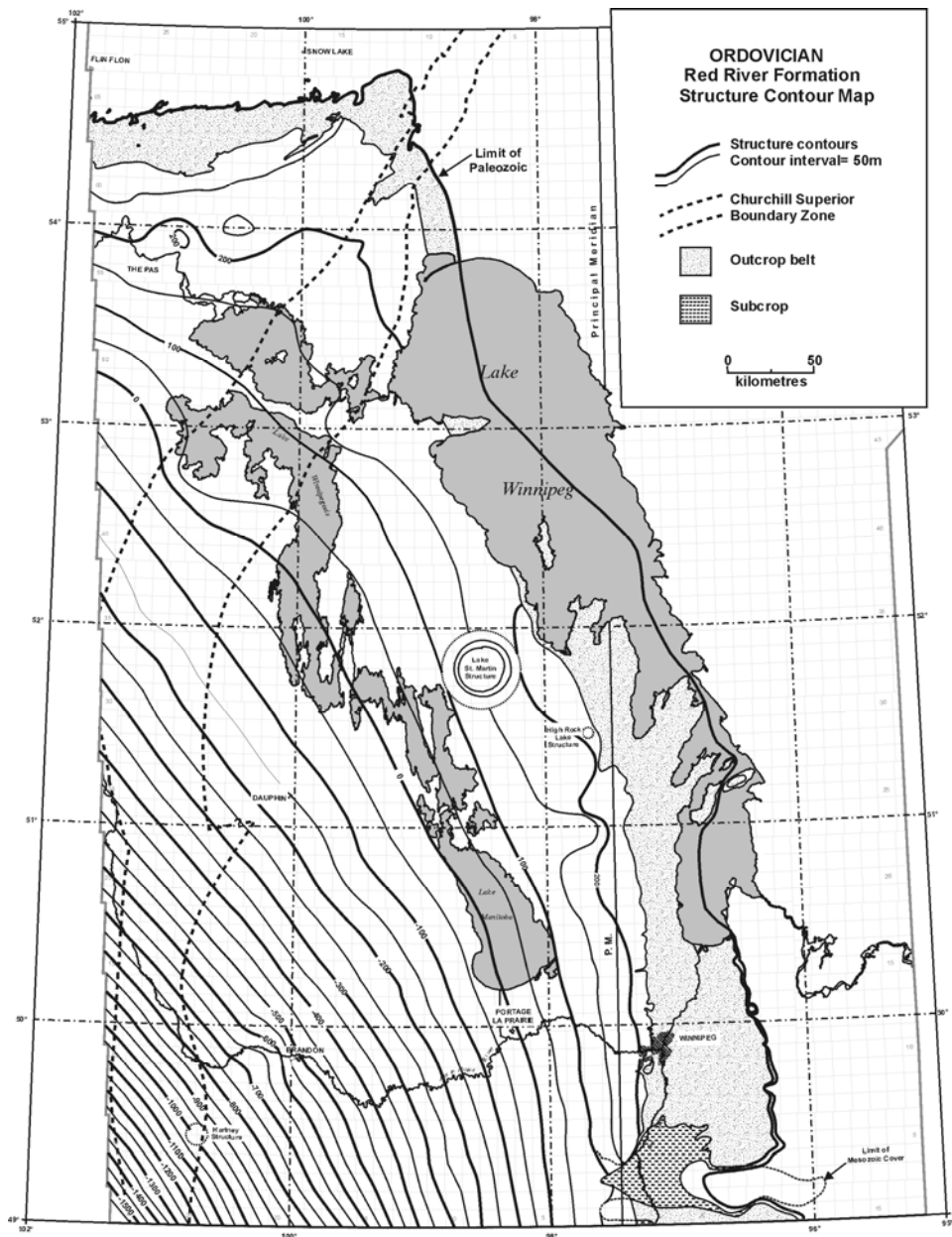


Figure 9A. Winnipeg Formation structure contour map.

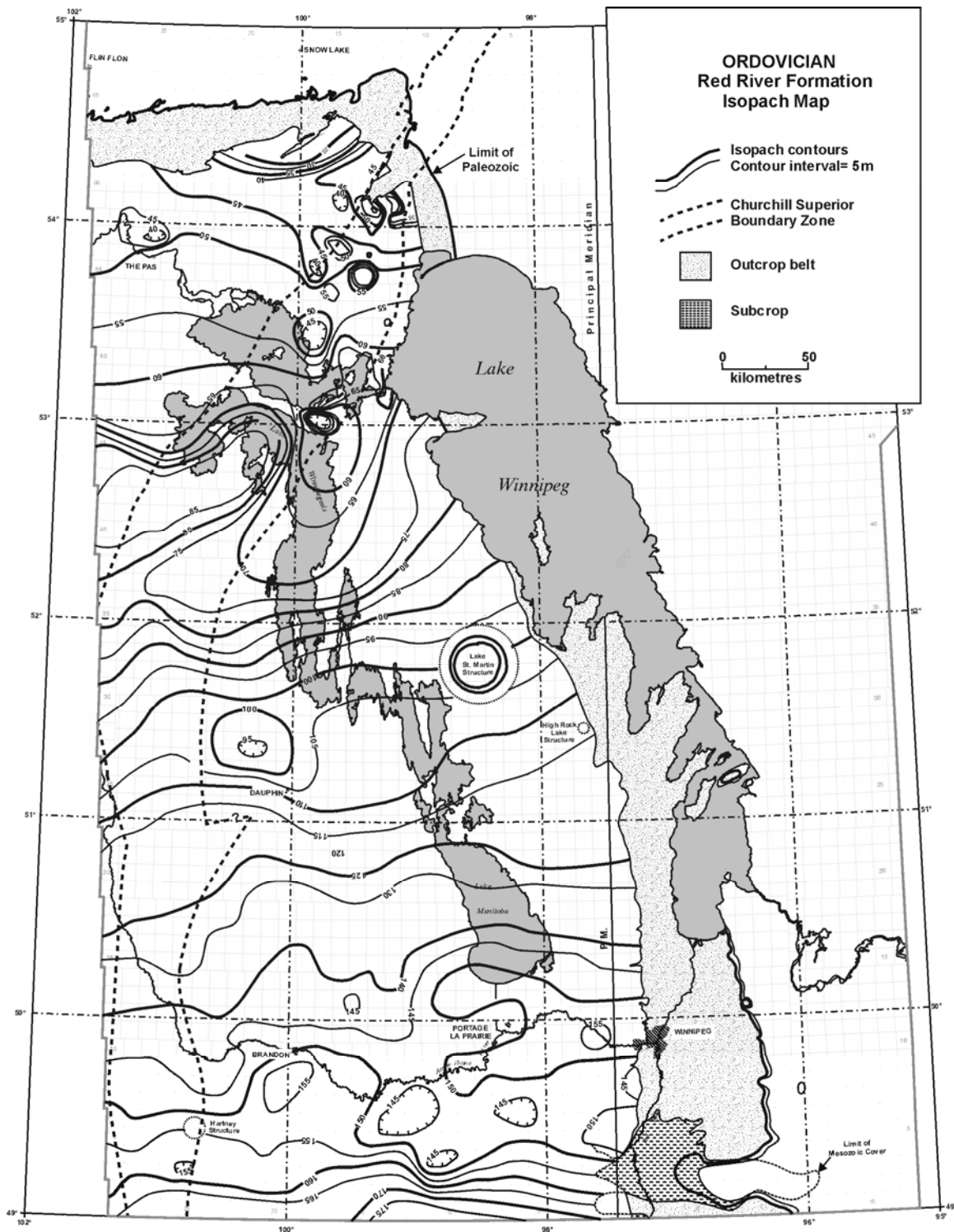


Figure 9B. Winnipeg Formation isopach map.

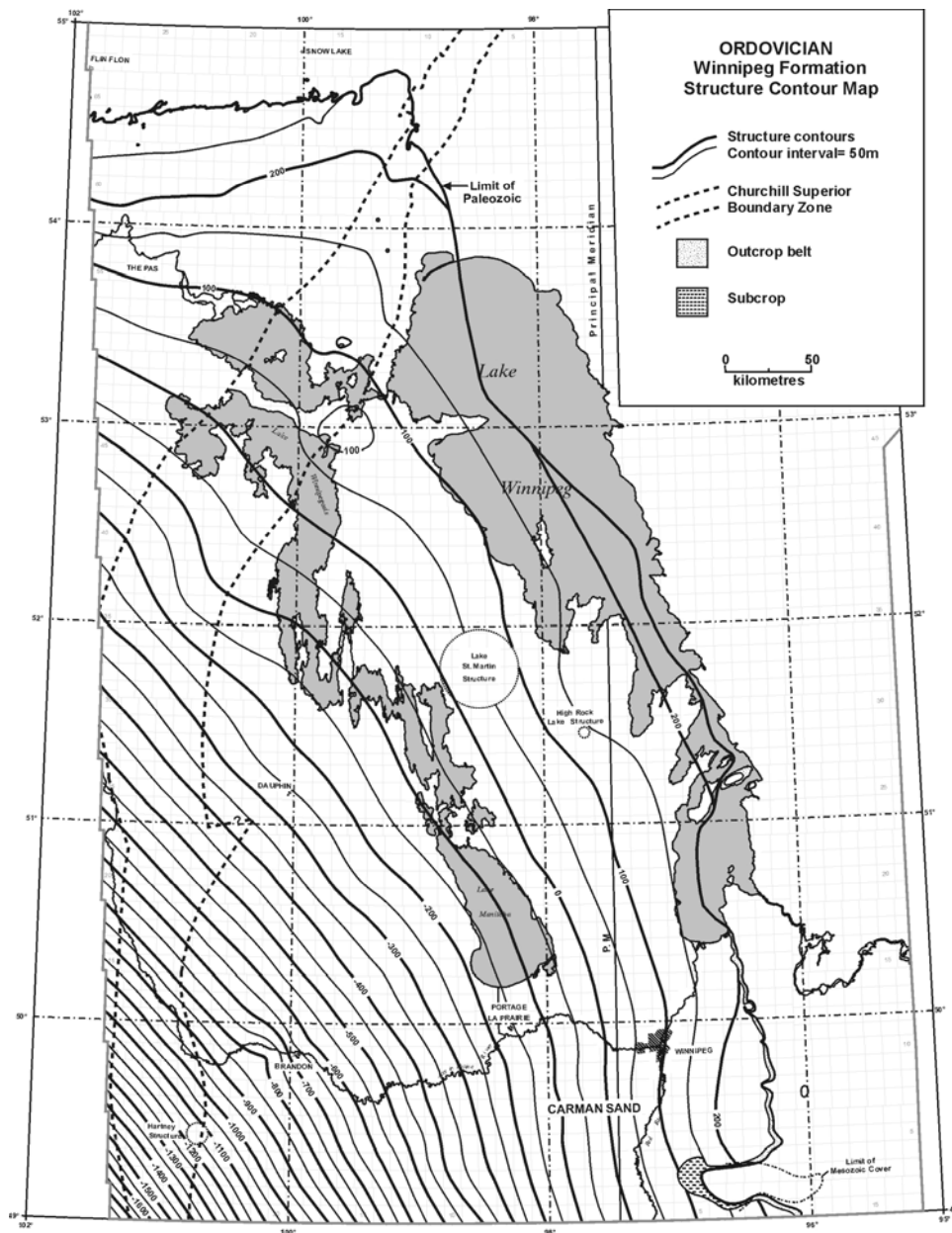


Figure 10A. Red River Formation structure contour map.

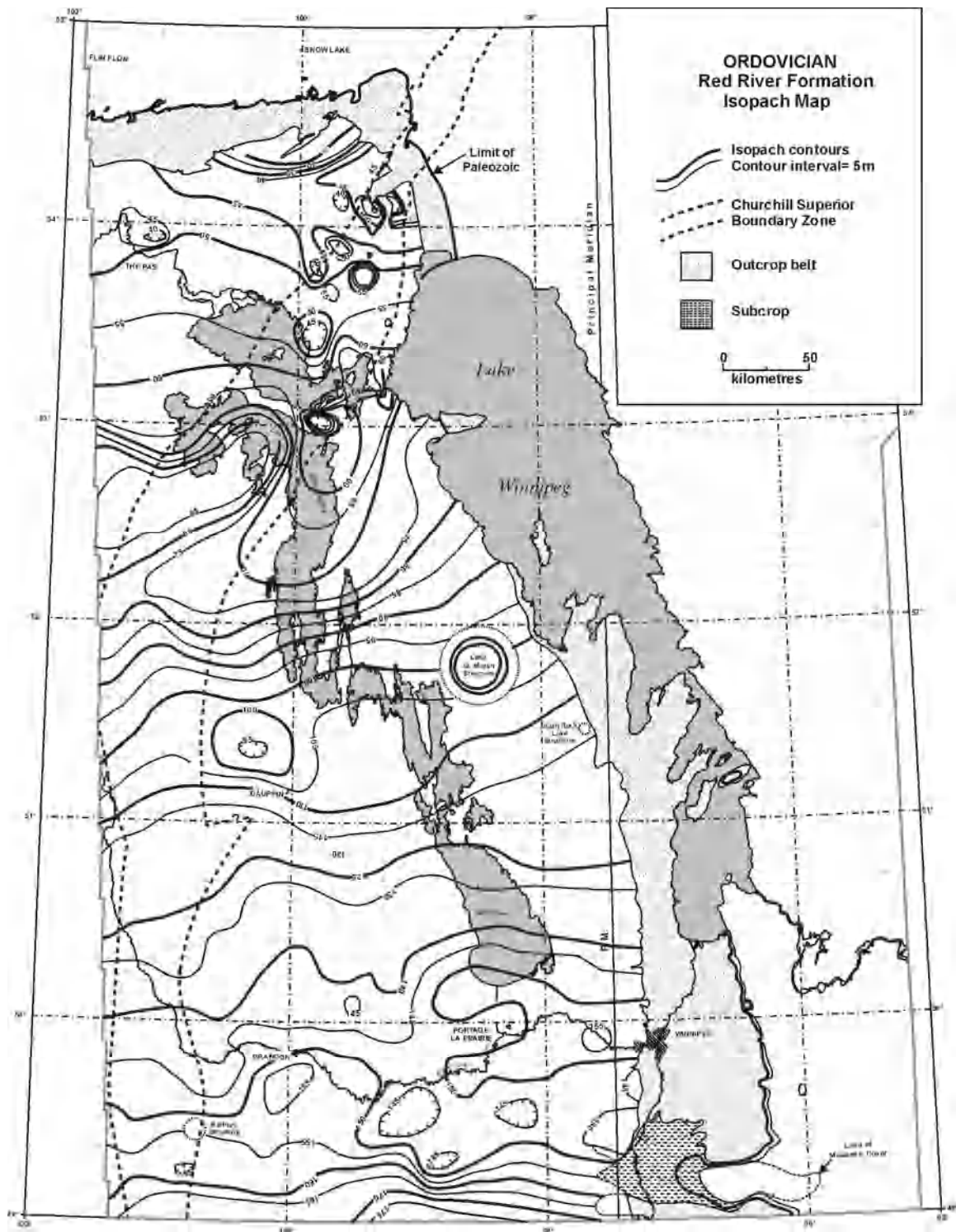


Figure 10B. Red River Formation isopach map.

for the Winnipeg Formation are shown in Figures 9A and B, respectively. The formation was described, in detail, by McCabe (1978).

Red River Formation

The Red River Formation consists of two principal subunits, the lower Red River and upper Red River strata (Table 2). In the vicinity of the south basin of Lake Winnipeg, the lower Red River (Baillie, 1952) can be subdivided into three mappable members: a lower Dog Head Member, a medial Cat Head Member, and an upper Selkirk Member (=Tyndall Stone). Lower Red River strata consist of light grey to yellowish- and brownish-buff, prominently mottled, fossiliferous, commonly cherty, dolomitic limestones. The upper Red River strata consist of dolomite and argillaceous cherty dolomite, designated as the Fort Garry Member. A thin, high calcium limestone bed occurs locally at the top of the Fort Garry Member.

Structure contours and isopachs for the Red River Formation are shown in Figures 10A and B, respectively.

At Garson, Gillis Quarries Limited (**Stop 3**) is actively quarrying the Red River Formation (Selkirk Member) for its dimension stone (Tyndall Stone).

Stony Mountain Formation

The Stony Mountain Formation is subdivided into three members, in ascending order: the Gunn, Penitentiary, and Gunton (Table 2). The Williams Member was once included within the Stony Mountain Formation; however, standardized correlations established for the new Atlas of the Western Canada Sedimentary Basin (Norford et al., 1994) have placed the Williams into the overlying Stonewall Formation (Bezys and McCabe, 1996).

The Gunn Member consists of greyish-red to purplish-grey, fossiliferous, calcareous shale with interbeds of relatively clean, fossiliferous limestone. The Penitentiary Member consists of yellowish- to reddish-grey, fossiliferous, argillaceous dolomite. These two members together comprise the lower Stony Mountain. The upper Stony Mountain (Gunton Member) consists of a buff, finely crystalline, sparsely fossiliferous, nodular-bedded dolomite that is relatively uniform in thickness and lithology.

All three members are exposed in the Mariash Quarry and abandoned City of Winnipeg quarries at Stony Mountain, an erosional outlier of the Stony Mountain Formation, located 7 km southwest of the Town of Stonewall, near the western edge of the southeastern Manitoba area. The Gunton Member acts as a cap rock for a shallowly buried, east-facing, north-trending escarpment (Gunton Escarpment), 4 km east of the Town of Stonewall.

The Gunton Member is extensively used for crushed stone, extracted from quarries in the Stony Mountain and Stonewall areas. The stone has also been used to construct buildings in Winnipeg, Stony Mountain (including the Federal Penitentiary) and in Stonewall.

Ordovician/Silurian

Stonewall Formation

The Williams Member, is the basal unit of the Stonewall Formation (Bezys and McCabe, 1996). It represents the oldest of a series of so-called “para-time-stratigraphic” markers; thin sandy and/or argillaceous beds that can be traced for many hundreds of kilometres throughout most of the Williston Basin (Table 2, Fig. 8). These marker beds provide the primary means for stratigraphic subdivision of Upper Ordovician and Silurian strata and probably represent deposits related to brief periods of shoaling or even slight uplift and erosion (*i.e.* non-sequences) (Porter and Fuller, 1959). The Williams Member consists of buff to grey to red, sublithographic dolomudstone.

The lower Stonewall beds, above the Williams Member, consist of pale yellowish-grey to yellowish-brown, faintly mottled, medium- to thin-bedded, finely crystalline dolomite with sparse, poorly preserved fossils. A sandy argillaceous marker bed, the “t-marker” or “t-zone”, separates the lower Stonewall Formation from the upper Stonewall Formation. The upper Stonewall Formation consists of light brown to grey, laminated to thin-bedded, sparsely fossiliferous microcrystalline dolomite, which is capped by a grey to buff dolomudstone marker bed, the Upper Stonewall Marker. According to Bezys and McCabe (1996), the t-marker within the upper part of the Stonewall Formation, also marks the position of the Ordovician-Silurian boundary in the Williston Basin. This was confirmed in biostratigraphic studies, based upon outcrop and subsurface investigations.

The formation was previously quarried in the Town of Stonewall for lime and aggregate production.

Silurian

Interlake Group

The Interlake Group, consisting of the Fisher Branch, Moose Lake, Atikameg, East Arm and Cedar Lake formations (in ascending stratigraphic sequence), is exposed near the western margin of southeastern Manitoba area. In the subsurface, the group consists of yellow-orange to grey, fossiliferous, oolitic, stromatolitic dolomite, interrupted by sandy, argillaceous marker beds.

Jurassic and Cretaceous

South of the City of Winnipeg, within the Manitoba Lowland, a large area of Jurassic sediment infills a major pre-Mesozoic channel in the Paleozoic erosion surface. Also, many small Cretaceous outliers have been noted in karst features penetrated by water wells (Bannatyne, 1988).

Recent

Six peat quarries (Fig.1) are located in areas of thick glacio-lacustrine sediments that overlie Archean terrane or Ordovician strata. Over the past 4000 years, sphagnum plants have contributed organic matter that has accumulated to a maximum depth of approximately 2.5 m.

Near Elma, Sun Gro Horticulture Ltd. (**Stop 1**) harvests sphagnum peat from spring to fall from a drained bog. Sphagnum peat is also produced on a seasonal basis at 5 other sites, on a seasonal basis, by Sun Gro Horticulture Canada Inc. and Premier Horticulture Inc.

FIELD TRIP STOPS

Leave Kenora, on Trans Canada Hwy, travel west for 110 km to Prawd, at junction of Trans Canada Hwy and PR 506. Continue on Trans Canada Hwy (west) to Hwy 11 (11 km), turn right (north) to Sun Gro Horticulture entrance road (12 km), turn left (west), park in visitor's parking area.

STOP 1 – SUNGRO HORTICULTURE SPHAGNUM PEAT BOG AND PLANT

The Elma bog (Fig. 1 and Table 1), quarried by Sun Gro Horticulture Canada Ltd., is approximately 3000 acres (12.14 km²) in area and has been in production since 1969. The on site plant was completed in 1972. Peat is quarried using the vacuum harvesting method described above. The bales are loaded at the plant into semitrailers and shipped to the southern United States. A small percentage of the peat is sold for local consumption at retail stores in Manitoba. Reserve estimates have not been published by the company.

Leave Sun Gro parking area, travel east on exit road back to Hwy 11, turn left (north) for 50 km to Cold Spring Granite entrance road, turn left (west), park in visitor's parking area.

STOP 2 – COLD SPRING GRANITE DIMENSION STONE QUARRY AND PLANT

The quarry and plant of Cold Spring Granite (Canada) Ltd. (Fig. 2) are located in the south central area of the LDBB on a 1220 m long 6 to 8 m high ridge approximately 10 km south of the Town of Lac du Bonnet (Fig. 2). The quarry is accessed via Highway 11.

The Precambrian monadnock (Bezys et al., 2001) was first quarried from 1933 to 1949 by a local, Ivor Peterson, for tombstones. An American company, Cold Spring Granite Ltd., reopened the quarry in 1959 and has produced stone from the ridge to the present time.

The product is a fine grained pale rose granite sold under a variety of trade names including Lac du Bonnet, Canyon Rose, Colonial Rose and Canadian Mist. Even grained rock is used for monuments and building stone, textured or variegated rock is used for tiles and countertops. The plant at Lac du Bonnet is equipped to make grave markers, countertops, paving and landscaping material and structural panels. Blocks are shipped to the Minnesota plant for finishing into headstones, mausoleums, monuments, columbariums, structural panels, tiles, custom design industrial work, paving and landscaping material. Fine grained, even textured Lac du Bonnet granite is prized for grave markers, monuments and headstones, because sandblasted letters and designs stand out well. It is also a preferred rock for precision industrial applications because it takes a very tight smooth polish, i.e. precision milling surfaces. Rock is sold locally from the Lac du Bonnet quarry, and internationally through Cold Spring Granite's office in Cold Spring, Minnesota.



Figure 11. Granite dimension stone blocks being removed from Cold Spring Quarry in 1982.

Prior to 1987, rock was removed from the quarry with wire saws and moved into the plant using hoists (Fig. 11). Since 1987, blocks have been removed by drilling and blasting. Sections of the outcrop are drilled off with portable, track-mounted, hydraulic drills. The drilled sections are then separated from the outcrop by blasting. The blast must move the section of rock without shattering it or inducing microfractures. The sections of rock are then drilled and wedged into smaller blocks that are moved to the plant with a 988 Cat loader. The plant has a 10 wire slab saw, a Salvatore 16 head polishing machine, a JB 110 granite milling machine, a 24" diamond saw and 6', 2', and 1' hydraulic splitters. Blocks are cut into slabs with the wire saw. The slabs are cut and polished with the diamond saw and the polishing machine for use as structural stone. Polished slabs are also manufactured into paving stone and grave markers with the hydraulic splitters and into countertops and furniture with the milling machine. Raw blocks are shipped to plants in Montreal for manufacture into granite tile and to the plant in Cold Spring, Minnesota to be processed for all other applications.

Leave Cold Spring parking area, travel east on exit road back to Hwy 11, turn right (south) to PTH 44, turn right (west) to Garson (total 55 km) arrive Gillis Quarries, park in visitor's parking area.

STOP 3 – GILLIS TYNDALL STONE QUARRY AND PLANT

Gillis Quarries Limited quarries an 8 m thick section of pale yellowish brown, dolomite mottled, burrowed, fossiliferous micrite of the Selkirk Member of the Ordovician Red River Formation at Garson (Fig. 1 and Table 1). In the quarry, the well known "Tyndall Stone", is extracted using two 2.5 m diameter tungsten carbide-toothed circular saws,

(Fig. 12), followed by wedging of the blocks along the bedding planes. The stone is finished in the plant, as described earlier. Three colours of stone are produced from various parts of the quarry – buff (a light creamy beige with pastel brown mottles) and golden buff (possibly due to ground water) from the upper beds. And, gray (a pale bluish grey with gray-brown mottles) from the lower beds (Wilkins, 1986; Coniglio, 1999).



Figure 12. Carbide toothed circular saw in Gillis Tyndall Stone Quarry.

The quarry is noted for its well-preserved fauna of large cephalopods, gastropods, corals, stromatoporoids, bryozoans, crinoids, trilobites, brachiopods, bivalves and calcareous algae, etc. A waste pile is available to hunt for fossils.

Gillis Quarries Limited has been a family-owned business since 1915 when August Gillis and his son, Charles, acquired a quarry property in Garson. The stone was finished in Winnipeg, until 1968 when the Garson plant was built. Gillis Quarries has owned all the quarry property in Garson since 1973. The company estimated that based on the 1986 production rate, it had at least 100 to 125 years of stone in reserve (Garson and District History Book Committee, 1990).

References: Corehole M-3-69 (internal government core logs) (Garson Quarry, 15-3-13-6EPM).

Go east on Hwy 44, 7 km to Hwy 12, turn right (south) and continue 38 km to the Trans Canada Hwy. Turn left (east) and continue to Kenora (175 km).

REFERENCES

- Baillie, A. D. 1952. Ordovician geology of Lake Winnipeg and adjacent areas, Manitoba. Manitoba Mines Branch Publication 51-6, 64 p.
- Bannatyne, B.B., 1980. Sphagnum bogs in southern Manitoba and their identification by remote sensing; Manitoba Energy and Mines, Economic Geology Report ER79-7, 103p.
- Bannatyne, B.B., 1988. Dolomite resources of southern Manitoba; Manitoba Energy and Mines, Economic Geology Report ER85-1, 4 maps, 39p.
- Betcher, R. N., McCabe, H. R., and Render, F. W. 1993. The Fort Garry aquifer in Manitoba. Manitoba Energy and Mines, Geological Report GR93-1, 15 p.
- Bezys, R.K. and McCabe, H.R. 1996. Lower to Middle Paleozoic stratigraphy of southwestern Manitoba – Field Trip Guidebook B4: Geological Association of Canada/Mineralogical Association of Canada Annual Meeting, Winnipeg, Manitoba, May 27-29, 1996.
- Bezys, R.K., Matile, G.L.D. and Keller, G.R. 2001. Investigation of Precambrian monadnocks (NTS 62I/1 and 62/8); *in* Report of Activities 2001, Manitoba Industry, Trade and Mines, Manitoba Geological Survey, p. 133-137.
- Coniglio, M. 1999. Manitoba's Tyndall Stone; *in* Wat on Earth; University of Waterloo, Department of Earth Sciences, Spring 1999, pp. 15-18.
- Dixon R.J. and Stewart, J., 1988. Peatland inventory of Manitoba: III- Interlake region using LANDSAT thematic mapper; Manitoba Department of Mines and Natural Resources, Surveys and Mapping Branch, 21p.
- Garson and District History Book Committee 1990. Garson, then and now 1890-1990; Derksen Printers Ltd., pp. 14-26.
- McCabe, H.R., 1978. Reservoir potential of the Deadwood and Winnipeg Formations, southwestern Manitoba, Manitoba Energy and Mines, Geological Paper GP 78-3, 54p.
- McCrack, G.F.D., 1985. A geological survey of the Lac du Bonnet Batholith, Manitoba; Atomic Energy of Canada Limited, Report AECL-7816, 63p.
- Norford, B.S., Haidl, F.M., Bezys, R.K., Cecile, M.P., McCabe, H.R., and Paterson, D.F. 1994. Middle Ordovician to Lower Devonian strata of the Western Canada Sedimentary Basin, *in* Geological Atlas of the Western Canada Sedimentary Basin, G.D. Mossop and I. Shetsen (compilers), Calgary, Canadian Society of Petroleum Geologists and Alberta Research Council, p. 109-127.
- Porter, J.W. and Fuller, J.G.C.M. 1959. Lower Paleozoic rocks of the northern Williston Basin and adjacent areas. American Association of Petroleum Geologists Bulletin, Vol. 43, No. 1, pp. 124-189.
- Schmidtke, B.E., 1993. Granitic dimension stone potential of southeast Manitoba; Manitoba Energy and Mines Economic Geology Report ER93-1, 52p.

- Schmidtke, B.E. and Bamburak, J.D., 1996. Industrial minerals of southeast Manitoba – Field Trip Guidebook B7, Geological Association of Canada/Mineralogical Association of Canada Annual Meeting, Winnipeg, Manitoba, May 27-29. 1996.
- Tammemagi, H.Y., Kerford, P.S., Requeima, J. and Temple, C.A., 1980. A geological reconnaissance of the Lac du Bonnet Batholith; Atomic Energy of Canada Limited, Report 6439, 68p.
- Tarnocai, C., Kettles, I.M., Ballard, M., 1995. Peatlands of Canada; Geological Survey of Canada, Open File 3152. 1:6 000 000 map with marginal notes.
- Wilkins, C., 1986. Manitoba's magnificent limestone graces Canada's finest buildings; Canadian Geographic, v. 106, no. 1, pp. 28-37.

Field Trip 5

Separation Rapids Rare-Element Pegmatite Field, Ontario

Charles Blackburn
Blackburn Geological Services
Site 130, Comp. 21
Kenora, Ontario P9N 3W

Don Bubar
President and CEO
Avalon Ventures Ltd.
1116-1111 Richmond Street West
Toronto, Ontario M5H 2G4

Carey Galeschuck
Project Geologist
Tantalum Mining Corporation
of Canada Limited
Box 2000
Lac du Bonnet, Manitoba R0E 1A0

Alasdair Mowatt
President
Emerald Fields Resources Corporation
1546 Pine Portage Road
Kenora, Ontario P9N 2K2

Chris Pederson
Consulting Geologist
Karen Rees
General Manager
Avalon Ventures Ltd.
777 Red River Road
Thunder Bay, Ontario P7B 1J9

Tony Pryslak
A.P. Pryslak Geological Services
15 Hunterspoint Rd.
Winnipeg, Manitoba R3R 3B6



Aerial view of the Big Whopper pegmatite, from the southeast

FOREWORD

Separation Lake and surrounding area has in recent years emerged as, if not the most, certainly among the most, important host to rare-element pegmatites in Ontario. The Separation Rapids pegmatite field (Figure 1), located where the English River forest access road crosses the English River near Separation Rapids, was first discovered in the 1993 field season by Fred Breaks of the Ontario Geological Survey (OGS).

However, the presence of beryl-bearing pegmatites had been known long before roads were pushed into this region, since at least the 1930s, when a Geological Survey of Canada field crew working its way along the lakes and waterways of the English River noted beryl "in a large pegmatite dyke cutting volcanics on the east shore of English River 2 miles northwest of Separation rapids" (Stockwell 1932). Access in those days was difficult, and so possibilities of exploitation lay dormant for 50 years. Separation Lake and the surrounding area was included in a 37 000 km² reconnaissance survey of the present English River and Winnipeg River subprovinces in the 1970s (Breaks and Bond 1993), and although other previously known rare-metal pegmatites were examined in some detail, little attention was paid to the pegmatites at Separation Lake. Then, in the 1980s, Carmen Storey of the OGS, as part of a broad evaluation of the industrial mineral potential of a large part of northwest Ontario, sampled what was possibly the same dike as Stockwell had examined and noted accessory red garnet and apatite. He also found lithium and beryllium assay values in other pegmatites recently exposed along the newly opened right-of-way for the English River road (Storey 1990).

It was not until late in the field season of 1993, when Fred Breaks, following a long summer of investigation of the Raleigh lake pegmatites, and taking the opportunity to visit the OGS field camp of Charlie Blackburn at Separation Rapids, knowing of the beryl mineralization and suspecting that the pegmatites there might show some further characteristics of the prized rare-element group, that the real potential began to emerge (Breaks 1993). Blackburn was completing the second year of a broad geological survey of the never-before-mapped Separation Lake greenstone belt. He and Jeff Young (Blackburn and Young 1993) had become involved in the possibilities of base metal potential in the belt, at that time being explored by Champion Bear Resources Ltd., and had not realised that other more exciting and exotic metals lay beneath their feet. Tony Pryslak, working for Champion Bear, had also encountered beryl-bearing pegmatites in their base metal exploration program.

A half-day of fieldwork convinced Breaks that he was on to something, and in the next few days he laid the foundation for what was to eventually develop over the next 5 field seasons into the discovery of the Big Whopper and Big Mac pegmatites and numerous other bodies. Breaks (1993) was quick to realise that the Separation Rapids pluton, exposed on islands and along the shoreline of the English River, bears striking similarity in size, constituent granitic units and mineral content to the peraluminous Greer Lake pluton of the Winnipeg River Pegmatite District in Manitoba, the location of the Tanco Mine. He related the pegmatites, that had up to that time only been discovered on the

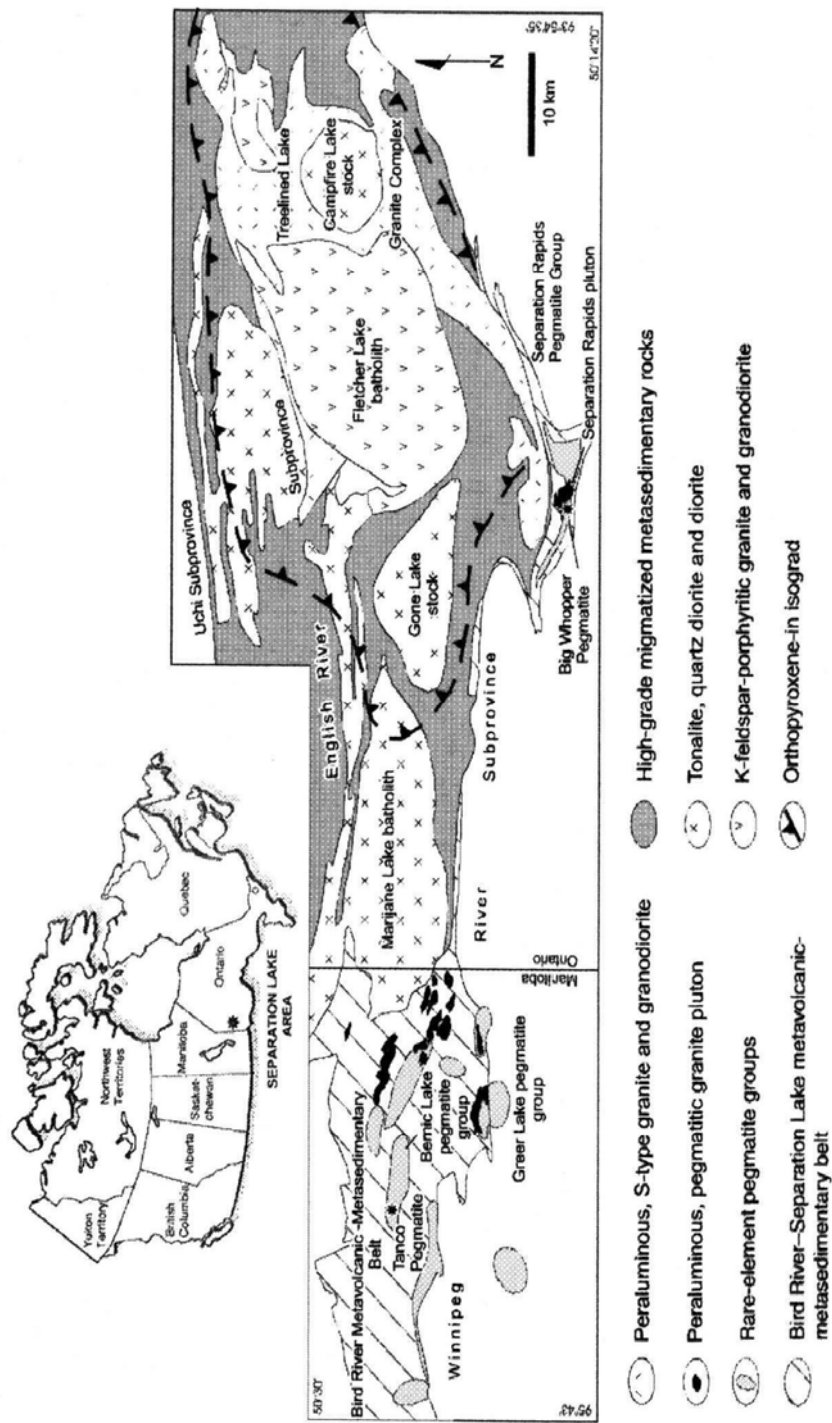


Figure 1. General geology and distribution of rare-element groups in the Bird River-Separation Lake metasedimentary-metavolcanic belt, southeast Manitoba and northwest Ontario. Orthopyroxene-in isograd outlines the Umfreville-Conifer lakes granulite zone. Figure taken from Figure 1 in Breaks and Tindle (2002).

east side of the river, to the pluton, and called the complete package the Separation Rapids Pegmatite Field.

In the following field season Breaks began what was to become a detailed investigation of the area around Separation Rapids, in partnership with colleagues Andy Tindle (Breaks and Tindle 1994) and Yuanming Pan (Breaks and Pan 1995). Thanks to painstaking work, discovery of the Big Whopper pegmatite was made by Breaks and Tindle in 1996 on the west side of the English River (Breaks and Tindle 1996, 1997).

Following announcement in 1996 of the discovery, the Big Whopper was staked by local prospectors Bob Fairservice and Jim Willis. Further expansion of the Separation Rapids pegmatite field was made to the west. Discovery of the Big Mack was made in 1998 by two other local prospectors, Al Mowatt and Phil Thorgrimson. Meanwhile, Tantalum Mining Corporation of Canada Ltd. (Tanco) geologists Carey Galeschuk and Peter Vanstone were further exploring the numerous pegmatites on ground earlier investigated by Champion Bear to the east of the river. Tanco continues to explore under a joint venture agreement with Gossan Resources Ltd. Other companies that became major stakeholders included Avalon Ventures Ltd. (Big Whopper), Emerald Fields Resources Corp. (Big Mack) and Champion Bear Resources Ltd. (Marko's Pegmatite). Most recently Tony Pryslak and Seymour Sears, working for Champion Bear Resources, enabled further expansion of the field to a minimum 6.5 km strike length, with their discovery of a number of rare metal pegmatites (e.g. the Glitter Zone) further to the west.

INTRODUCTION

Breaks and Tindle (1997) have pointed out that:

"Rare-metal class pegmatites of the complex-type and petalite-subtype represent the most desirable target for tantalum, cesium, rubidium and ceramic quality petalite in Archean terrain settings.....Current economic interest is focussed upon the petalite potential.....The widest part of the Big Whopper Pegmatite averages 37% petalite over 60 m which is comparable to the world's premiere petalite deposit at the Bikita Pegmatite of southern Zimbabwe. The tantalum potential is also considered significant as wodginite, the chief ore mineral for Ta at the Tanco Mine of southeastern Manitoba, is not only widespread in the Separation Lake area, but also exhibits compositional variation unlike any other pegmatite group on a global scale. Cesium.....also has high exploration potential as pollucite, the only ore mineral for the metal, has ...been verified in the area."

So-called "fertile" granite/pegmatite systems are typically peraluminous and of an S-type heritage (Breaks and Tindle 1997). The 4 km² Separation Rapids pluton represents a classic example of a fertile granite. It has generated a rare-element pegmatite field with a minimum presently known east-west dimension of 12 km that is 3 km at its widest. The pluton compares in size and constituent granitic units with the Greer Lake pluton (Cerny et al 1981) 55 km to the northwest in the Winnipeg River Pegmatite District of southeast Manitoba (Figure 1). Similarities include presence of cordierite, beryl, cassiterite and the common presence of primary layering between pegmatitic leucogranite, sodic aplite,

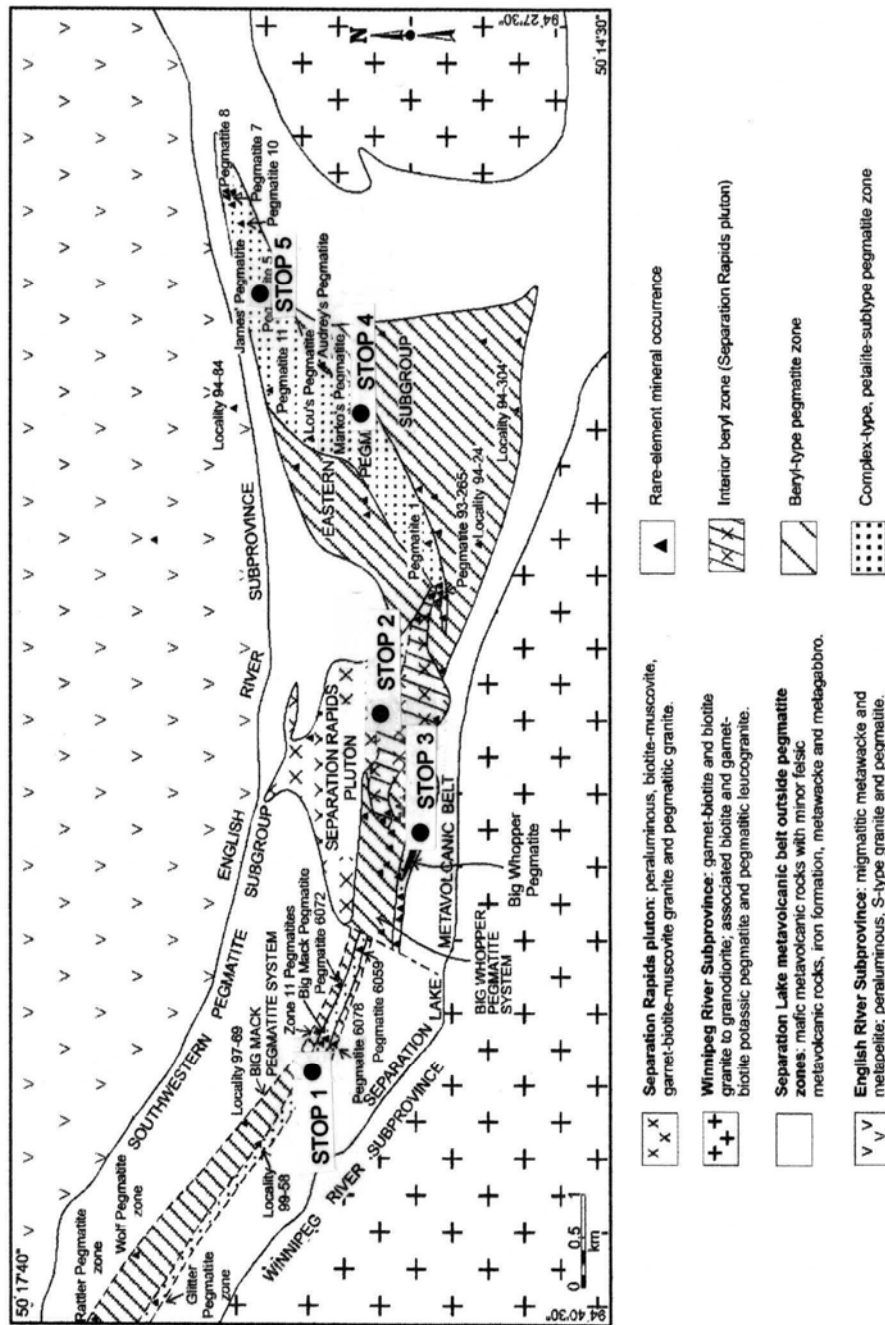


Figure 2. Distribution of rare-element pegmatite mineralization in the Separation Rapids pegmatite group, and location of field trip stops 1 through 5. Modified from Figure 3 in Breaks and Tindle (2002).

potassic pegmatite and coarse grained granite. Beryl has been found at numerous places that constitute a zone in the southern portion of the pluton, either as a primary phase, or secondary with garnet, muscovite and biotite after cordierite.

The pegmatites have recently (Breaks and Tindle 2002) been grouped into an eastern and a western subgroup, based on their position relative to the Separation Rapids pluton. However, both subgroups exhibit a beryl zone and a complex, petalite-bearing zone. The Big Whopper, Big Mack and Glitter Zone pegmatites are located within the petalite subzone in the western subgroup, and the Marko's and James' pegmatites are in the complementary subzone in the eastern subgroup. Audrey's pegmatite lies within the beryl zone, just outside the petalite zone.

REGIONAL GEOLOGICAL SETTING

The Separation Rapids pegmatite field is set in the heart of the Separation Lake greenstone belt (Figures 1 and 2). Metavolcanic and subordinate metasedimentary rocks occur discontinuously along the English River-Winnipeg River subprovincial boundary from the Ontario-Manitoba border in the west to western Lac Seul in the east, a distance of about 100 km. They represent the eastern extension of the Bird River greenstone belt in Manitoba (Cerny et al. 1981) (Figure 1).

The Separation Lake greenstone belt (Figure 1 and 2; Blackburn and Young 2000; Blackburn et al 1994a,b) is the largest segment, extending from the east shore of Umfreville Lake to Helder Lake, a distance of 45 km, and with a maximum width of 5 km. It consists predominantly of a lower sequence of mafic metavolcanic rocks, with intercalated magnetite-bearing iron formations, a single discontinuous clastic metasedimentary unit, and overlying subordinate felsic metavolcanic rocks. Gabbro sills intrude the mafic metavolcanic sequence. A thin unit of polymictic conglomerate and sandstone lies along the northern margin of the belt. Along the length of the belt the volcano-sedimentary assemblage faces predominantly to the north. However, the lower sequence is folded about the westerly plunging Separation Narrows anticline, while in the west folding has been about the easterly plunging Paterson Lake antiform. Metamorphic grade is amphibolite throughout the belt. Breaks and Tindle (2002) suggest on the basis of geochronology done in the Bird River portion in Manitoba that the belt has an age range of >2844 Ma to 2740 Ma, while the Separation Rapids pluton has been dated at 2646 $\pm$ 2 Ma (Larbi et al 1999).

The English River Subprovince, extending north from the Separation Lake belt to the Uchi Subprovince, is comprised of metasedimentary migmatites (50%), and felsic to intermediate plutonic rocks comprised of a tonalitic suite in the west and a granodiorite to granite suite in the east (Breaks 1991). Metamorphic grade varies from amphibolite to granulite, and has affected all rocks except

those of a peraluminous suite (Breaks 1991).

The Winnipeg River Subprovince, south of the Separation Lake belt, is comprised of felsic to intermediate plutonic rocks ascribed to two suites, an early tonalitic suite in the north and a later granitic suite in the south by Beakhouse (1991). Rocks of the tonalitic suite in the subprovince are metamorphosed to medium to high grade, while granitic suite rocks were either synchronous with or postdated regional metamorphism (Beakhouse 1991).

GEOLOGY OF THE PEGMATITE FIELD

The Separation Rapids pluton and the Separation Rapids rare-element pegmatite field lie entirely within the greenstone belt (Figure 2). There appears to be little direct relationship between the pegmatite field and the stratigraphy of the greenstone belt. However, deformation events could have provided convenient structural traps into which the pluton and the pegmatites were emplaced.

A major folding event, represented by folding about the Separation Narrows anticline, preceded emplacement of the cross cutting Separation narrows pluton, dated at 2646 $\pm$ 2 Ma, as noted above. De la Fuente (1998), in a study done for Tanco, interpreted three deformation phases, such that D1 and D2 predated emplacement of the Separation Narrows pluton. He interprets the pluton to therefore be parent to pegmatites that are only weakly deformed, such as the Marko's pegmatite. In his interpretation, the Separation Narrows pluton cannot be parental to the Big Whopper and Big Mack pegmatites, both of which are complexly folded. He suggests that the source of the Separation Narrows pluton may be at depth either within the greenstone belt or "within the mainly undeformed Winnipeg River subprovincelate granites outcropping to the south" (de la Fuente 1998). His analysis that the Treelined Lake granite was involved in D2 and D3 deformation is consistent with this granite being a possible source of the Big Whopper, Big Mack, James and other complexly deformed pegmatites.

These structurally based interpretations of relative timing of emplacement of various pegmatites and granitic bodies differ from the interpretation of Fred Breaks and colleagues (eg. Breaks and Pan 1995; Tindle and Breaks 2000; Breaks and Tindle 2002), made on mineralogical and geochemical arguments, that there is a consistent evolutionary trend from the Treelined Lake granite complex through the Separation Narrows pluton, to the various pegmatite groups.

Detailed discussion of all other aspects of the Precambrian geology of the Separation Lake area, such as lithology, stratigraphy, metamorphism and mineral deposits, other than those associated with the rare metal pegmatites, has been made by Blackburn and Young (2000).

Breaks and Tindle (2002) have recently presented a detailed account of the Separation Narrows pegmatite field, from which much of the rest of this section is paraphrased or quoted in parentheses.

Treelined Lake Granite Complex

The Treelined Lake granite complex is a "peraluminous granite mass situated in the adjacent English River subprovince. This granite mass is an irregular-shaped, 3 to 23 by 63 kilometer mass situated mostly in the core of the Umfreville-Conifer lakes granulite centre." (Figure 1). There is an abrupt regional metamorphic discontinuity at the boundary between the English River subprovince and the Separation Lake greenstone belt, jumping from upper amphibolite in the greenstones to granulite in the migmatized clastic metasedimentary rocks to the north. Although not a field trip stop in the present guide, the boundary is described in detail as Stop 1-6 in the Western Superior Province Fieldtrip Guidebook for Precambrian '95 (Beakhouse et al 1995). Rocks of the Treelined Lake granite complex characteristically contain the metamorphic minerals garnet, orthopyroxene, cordierite, while the "southwestern apophysis consists mainly of garnet-biotite and muscovite-biotite granite with local, in situ pegmatite zones that contain rare-element-enriched mineralogy." Breaks and Tindle (2002) discuss such a pegmatite that occurs very close to the boundary adjacent to the Umfreville Road that contains "tourmaline, topaz, cassiterite, gahnite, fluorapatite,.....microlite, manganocolumbite and manganotantalite."

Separation Rapids Pluton

The Separation Rapids pluton (Figures 2) has a "core of coarse-grained, potassium-feldspar-porphyritic, garnet-biotite-muscovite granite that is enveloped by a larger area composed of various pegmatitic granite units." Variable textural and mineralogical features include: wide range in grain size, from aplite to potassic pegmatite and pegmatitic leucogranite (with potassic megacrysts up to one meter in diameter); graphic, plumose, radial, and unidirectional solidification textures; layering among units; a peraluminous mineralogy of cordierite, primary muscovite, biotite, garnet and schorl tourmaline; and metasomatic rare-element-rich biotite and muscovite along contacts with mafic metavolcanic host-rocks and enclaves. "Rare-element minerals.....are largely confined to...the southeastern part of the pluton. These comprise occurrences of green and white beryl, columbite-tantalite group minerals and cassiterite in potassic pegmatite, various sodium-rare-element-enriched pods and layers (albitite, albite trondhjemitite and muscovite-quartz-cleavelandite pods) and more rarely in fine-grained leucogranite." Rocks of the pluton are conveniently exposed on the shore-lines and islands of the English River.

Eastern Subgroup Pegmatites

The eastern subgroup of pegmatites (Figure 2) covers a 7.5 km² area to the east of the English River. It "comprises a narrow, 0.5 by 5 kilometre, central axis of 11 complex type, petalite subtype pegmatites that is almost completely enveloped by zones of beryl-type pegmatites." "The beryl zone contains dikes of pegmatitic leucogranite, potassic pegmatite and minor sodic aplite.....Green and white beryl.....is the most widespread rare-element mineral. Cassiterite, ferrocolumbite and gahnite represent widespread accessory

minerals. (In the beryl zone) Wodginite.....has only been documented in Audrey's pegmatite." Topaz has been found in four dikes in the beryl zone.

The petalite zone pegmatites characteristically, in addition to petalite, contain a diverse population of oxide minerals, in particular wodginite. The 8 by 130 metre Marko's pegmatite in particular contains a diversity of wodginite species (viz. titanowodginite, ferrowodginite, ferrotitanowodginite, and tungsten-rich wodginite). Marko's pegmatite is notable also for its zonation, containing four primary zones and two replacement units. Features of the primary zones are dominated by megacrysts of petalite and of potassium feldspar. In the replacement zones: spodumene-quartz intergrowths (the SQUI so common at Tanco) occur within petalite megacrysts; lepidolite replaces muscovite; and oxide minerals are especially conspicuous.

Southwestern Subgroup Pegmatites

The southwestern pegmatite subgroup of pegmatites (Figure 2) occupies a 0.3 to 0.8 by 6.5 kilometre area to the west of the English River. It is divisible into two zones, a beryl type and a petalite subtype zone. The beryl zone contains numerous small and large pegmatites with major mineralogy similar to those of the eastern subgroup.

The petalite zone contains nine relatively larger, deformed pegmatite lenses, the largest of which in surface outcrop are the 56 by 650 metre Big Whopper and the 30 by 100 metre Big Mack. "The initial resource estimate of Avalon Ventures Limited....revealed the Big Whopper pegmatite to contain 7.1 million tonnes with an average of 1.285% Li₂O, 0.346%Rb₂O and 0.007% Ta₂O₅ over a strike-length of 600 metres and to a depth of 200 metres." At the Big Mack, "a preliminary estimate of 300 000 tonnes averaging 30.5% petalite to a 65 metre depth has been indicated by the initial diamond drilling program." "Petalite content of the core of the Big Whopper and Big Mack pegmatites ranges from 30 - 60%.....Petalite is of optimum quality for use as a direct feedstock in the lithium glass and ceramic industry." Extremely low iron contents, a deleterious metal in the glass-making industry, are indicated in samples taken by Breaks and Tindle that analyzed at <5 to 123 ppm Fe. "Furthermore, Li₂O contents (4.6 - 4.7 %) are somewhat higher than the 4.3% average of six Li₂O analyses compiled from the literature."

"Other phases in the petalite zone pegmatites include garnet....., cordierite, lepidolite, cookeite, spodumene, eucryptite, bikitaite, holmquistite, topaz and chrysoberyl. Oxide phases include cassiterite, gahnite, ferrowadginite, ferrotapiolite, ferrocolumbite, manganocolumbite, ferrotantalite, struverite, and yttrio- and yttrian pyrochlore (Tindle and Breaks 2000).

Potassium and sodium feldspar minerals, of high purity, represent potential valuable by-products of the exploitation of petalite pegmatites in the area. Potassium feldspar from the southwestern subgroup also reveals a significant variation in Rb content.....(Those) from the Big Whopper pegmatite indicate a rubidium content mainly in the 1.5 to 2.0 wt. % range with a maximum value of 3.0 wt %."

FRACTIONATION TRENDS IN RARE ELEMENT PEGMATITES

Oxide "minerals of the columbite-tantalite group are the most common Nb-Ta species in rare element pegmatites" (Tindle and Breaks 2000). Following Cerny and Ercit (1985), Tindle and Breaks (2000) have used the columbite-tantalite quadrilateral (Fig. 3) to

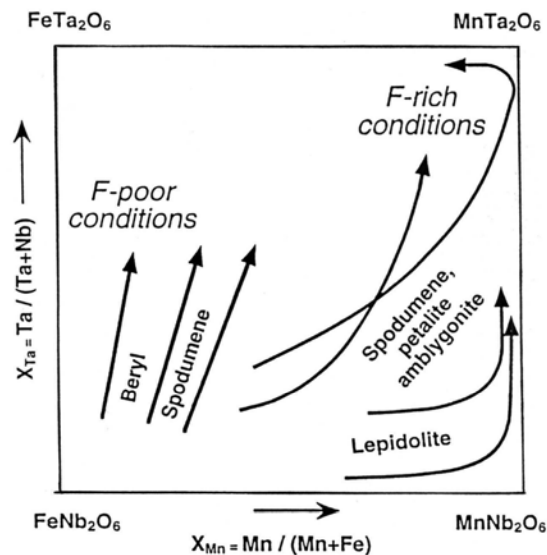


Figure 3. Columbite-tantalite quadrilateral. Vectors describe variation trends in beryl-type and complex-type pegmatites. From Fig. 9, Tindle and Breaks (2000).

analyse fractionation trends in both beryl-type and complex-type pegmatites of the Separation Narrows rare element pegmatite field. Fractionation trend may be strongly influenced by the activity of fluorine, as indicated in the evolution paths shown in the quadrilateral (Fig. 3). Changes in bulk chemistry, increase in temperature and decrease in pressure result in the formation of petalite, lepidolite and amblygonite subtype pegmatites, all noted for their high fluorine activity.

Tindle and Breaks (2000) have subdivided the Separation Rapids pegmatites into Fe-suites and Mn-suites on the basis of columbite-tantalite (oxide mineral) compositions. Figures 4, 5, and 6 demonstrate the use of this classification for the four pegmatites to be visited on the field trip. Data for those of the southwest sub-group complex-type pegmatites are shown on Fig. 4, and for the eastern sub-group complex-type pegmatites on Figs. 5 and 6. Data for a number of other pegmatites are also included on the diagrams, taken from Tindle and Breaks (2000). For clarity, envelopes have been added around the data for the Big Mack, Big Whopper and lepidolite unit of the Big Whopper (Fig. 4), Marko's pegmatite petalite core and outer layer (Fig. 5) and James' pegmatite (Fig. 6).

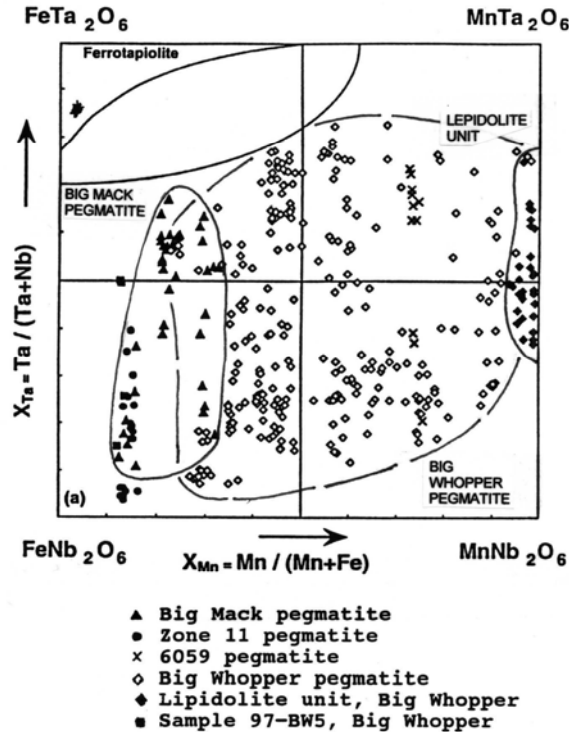


Figure 4. Columbite-tantalite quadrilateral: major SW subgroup petalite pegmatites. Modified from Fig. 13a, Tindle and Breaks (2000).

In Fig. 4, the Big Mack pegmatite data clearly fall in the Fe-suite, as do most of the pegmatites of the southwest sub-group. However, data for the Big Whopper pegmatite are spread over a large area of the quadrilateral, while data for the lepidolite unit show extreme fractionation along the high Mn side of the quadrilateral. It is suggested that the apparent randomness of Big Whopper data reflect the complex folding this pegmatite has undergone.

The Marko's pegmatite (Fig. 5) is the only Mn-suite petalite-subtype in the eastern subgroup. According to Tindle and Breaks (2000), the fractionation trend is from the outer, earlier crystallizing, layered pegmatite-aplite unit toward the late crystallizing petalite rich core.

In Fig. 6, the James' pegmatite data fall in the Fe-suite. The differentiation trend is subvertical in the diagram, indicating fluorine-poor conditions. However, the pegmatite is more evolved than the primitive dikes #9 and #10 (same diagram) and equivalent to approximately 50% of the samples from the Big Whopper (Fig. 4).

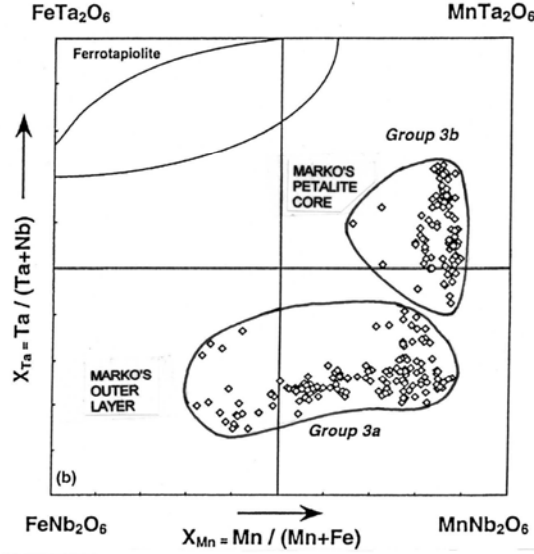


Figure 5. Columbite-tantalite quadrilateral: eastern subgroup, manganese suite petalite pegmatite. Modified from Fig. 12b, Tindle and Breaks (2000).

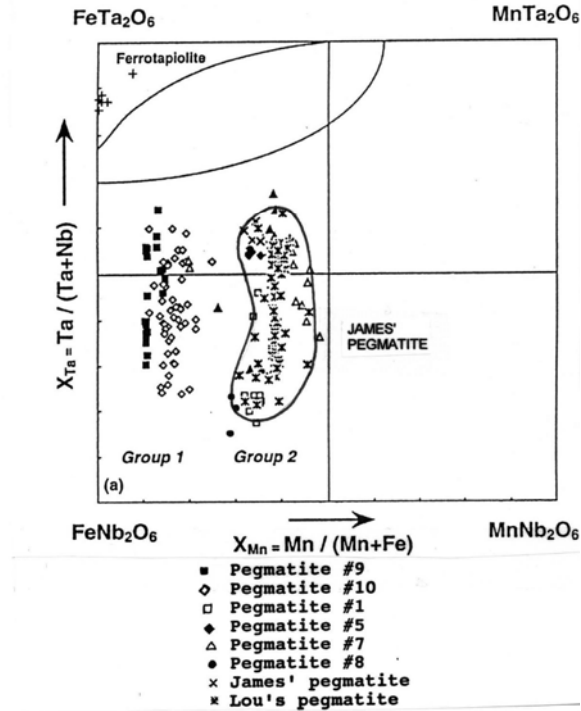


Figure 6. Columbite-tantalite quadrilateral: eastern subgroup Fe suite petalite pegmatites. Modified from Fig. 12a, Tindle and Breaks (2000).

THE FIELD TRIP

The trip commences in Kenora. Proceed north on Highway 659 to the turn-off on to English River Road, just south of Redditt. Take the English River Road to the turn-off on to the Sand Lake Road, about 7 km south of the Separation Narrows bridge. Proceed along the Sand Lake Road to the Emerald Fields Resources access road, to the Big Mack pegmatite (Fig. 2).

STOP 1 - BIG MACK PEGMATITE

The Big Mack pegmatite (Fig. 7) is complexly folded and compressed into a 35 m x 100 m lens with several prominent apophyses tapering to the south, southeast and west. These apophyses consist of non-petalite bearing sodic aplites, blocky potassic pegmatite and holmquistite bearing granitic units.

Several units will be observed within the Big Mack:

- A) Wall zone of medium blocky quartz+plagioclase+muscovite+garnet+biotite. Cordierite is common in this unit and in the apophyses. It is generally altered to garnet+mica+holmquistite rich simplectites that give the unit and several metres of the interior petalite zone a spotted appearance.
- B) Petalite rich, medium to coarse blocky phase of quartz+plagioclase+K-spar+muscovite+petalite. The petalite varies up to 60% in this unit and is identified by light brown weathering.
- C) Chrysoberyl bearing petalite pegmatite. This unit is restricted to a lens at the south end of the trench. It is grey due to the dominance of biotite over muscovite. Petalite content is generally lower than in unit B (15-20%), and it is generally finer grained but still blocky in nature and contains sporadic lime green 1-15 m chrysoberyl crystals.
- D) Primary aplite layered with petalite pegmatite. Folds are defined by this unit.
- E) Replacement albitic unit seen as white weathering layers and pods of muscovite+garnet+albite+quartz+K-spar. This unit is best observed enveloping the mafic metavolcanic screens.
- F) Post deformation, fracture controlled vein like features include bikitaite, holmquistite and eucryptite. The eucryptite can be recognized by its grey, recessive weathering, capped by a lacy network of quartz veining.

Massive to pillowed mafic flows can be observed on the hill north of the parking area.

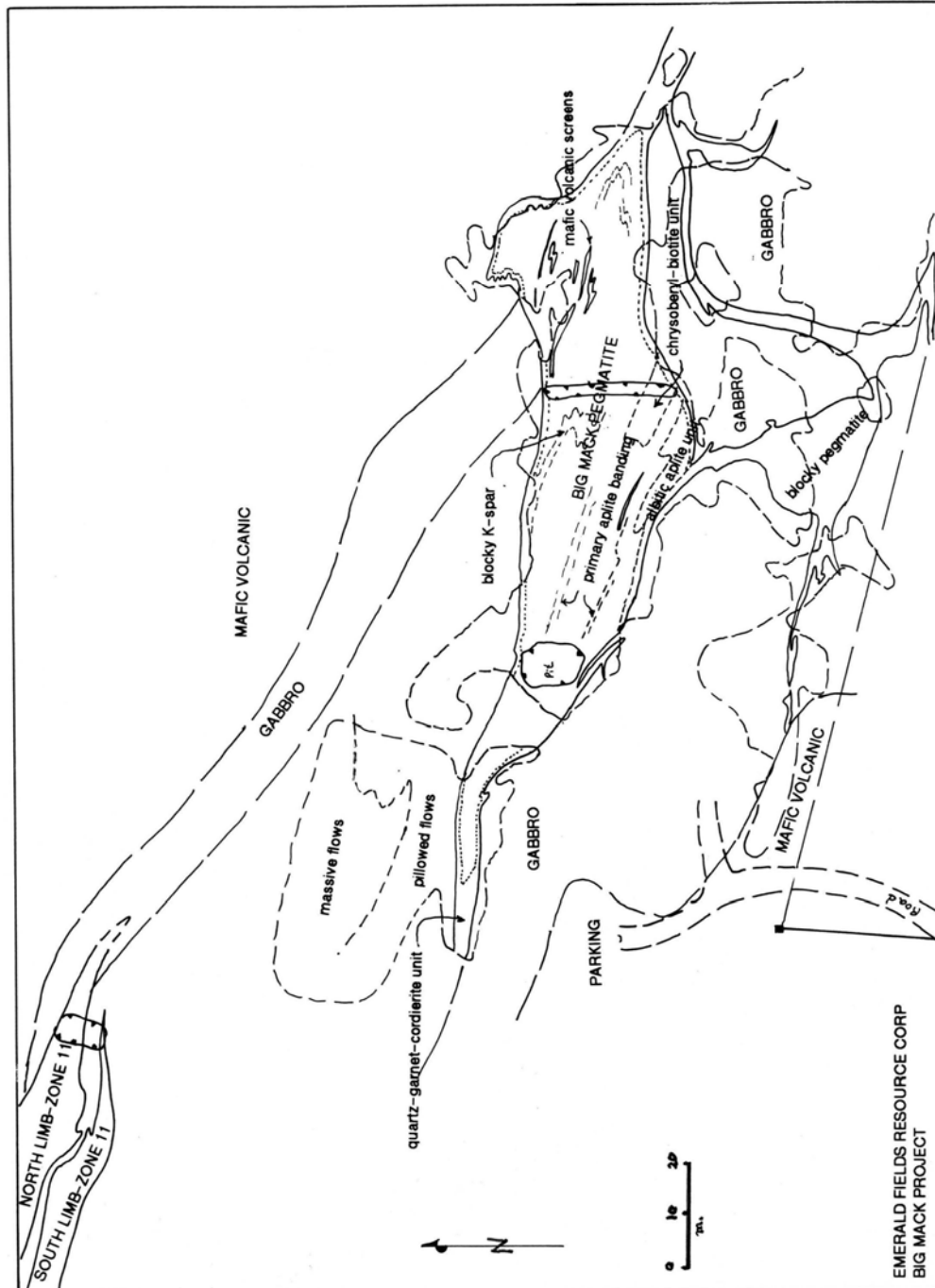


Figure 7. The Big Mack pegmatite, showing location of units discussed in the text.

Return to the Sand Lake Road, and then to the Separation Narrows bridge. Board boats and travel down stream, passing through Separation Rapids, to Heart Island on the Separation River (Fig. 2).

STOP 2 - SEPARATION RAPIDS PLUTON

The Separation Rapids Pluton is interpreted by Tanco geologists to be a flat lying, sheet-like, layered, very fractionated pegmatitic granite. The interpretation of the pluton being a sheet rather than a stock-like body is based on an aeromagnetic survey flown for Tanco (Assessment Files, Ministry of Northern Development and Mines, Kenora) that shows a magnetic pattern of similar continuity, amplitude and intensity as in the surrounding volcanic rocks extending beneath the Separation Rapids Pluton.

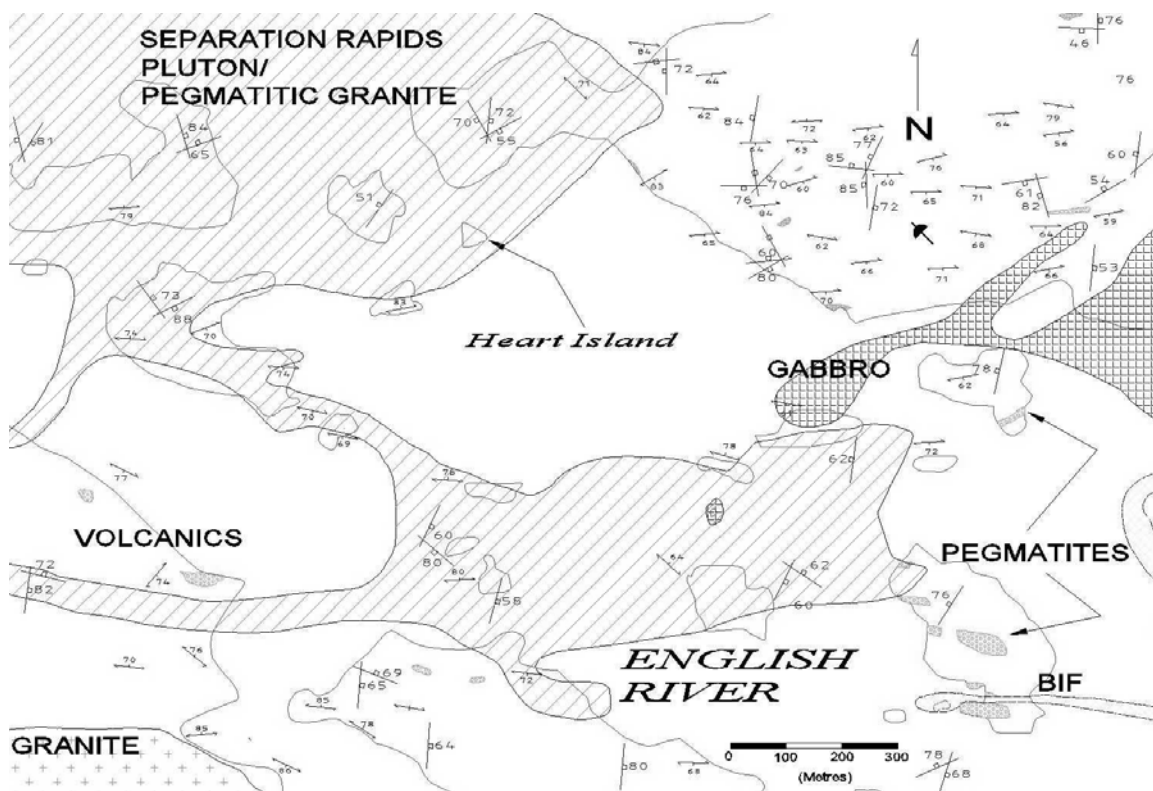


Figure 8. Location of Heart Island in the Separation Rapids pluton.

Heart Island (Fig. 8) displays classic pegmatitic granite features such as “bird’s-foot mica”, megacrystic potash feldspars, pegmatitic vugs, and aplite banding.

If time permits, Red Handed Island, the larger island to the west of Heart island, will be visited. This island features a flat lying lepidolite-bearing pegmatitic granite that postdates D1 and D2 deformation phases. It is affected by D3 phase open folds with E-W

axes gently plunging to the west. It may represent an external facies of the Separation Rapids pluton.

Proceed by boat from Heart Island to Avalon Ventures Ltd.'s boat landing on the west shore of the river. A short walk inland leads to the Big Whopper pegmatite (Fig. 2).

STOP 3 - BIG WHOPPER PEGMATITE

Introduction

Following staking of ground over the Big Whopper by local prospectors Bob Fairservice and James Willis in 1996, the 560 acre property (since expanded to 4480 acres) was optioned to Avalon Ventures Ltd. which has earned a 100% interest, subject to a 2% NSR royalty interest retained by the vendors.

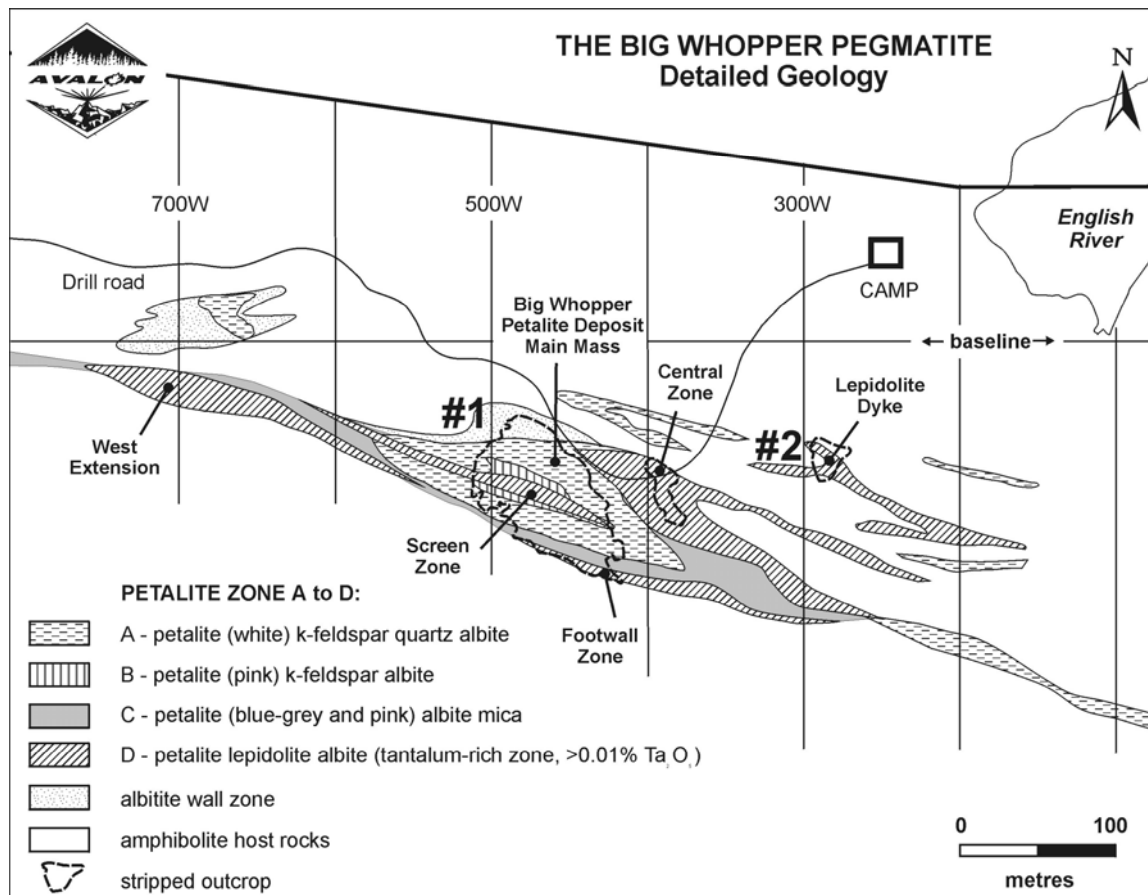


Figure 9. Big Whopper pegmatite. Areas 1 and 2 of the field trip stop are indicated.

In 1997 and 1998, Avalon Ventures Ltd. began exploring the property by conducting linecutting, ground magnetic, geological and geochemical surveys, overburden stripping, trenching, mineralogical studies and diamond drilling totalling 8,751 metres in 57 holes. This work delineated the Big Whopper (Fig. 9) over a strike length of 1.5 km with widths

ranging from 10 m to 80 m and to a vertical depth of 250 metres where it remains open. Total indicated and inferred petalite resources are estimated at 11.6 million tonnes grading 1.34% Li₂O, 0.30% Rb₂O and 0.007% Ta₂O₅. In 1999, a pre-feasibility study was completed on the deposit by Micon International Ltd. which concluded that development of the deposit as a producer of petalite plus feldspars, mica and tantalum, was economically viable and recommended proceeding with a bulk sampling program and full feasibility study. This work has not yet begun. In 2001, in response to higher tantalum prices, Avalon conducted a program of 1,401 metres of diamond drilling in 12 holes, channel sampling, mineralogical and metallurgical studies to better define tantalum distribution within the Big Whopper pegmatite system.

The dominant economic minerals in the deposit are petalite and columbite-tantalite, the ore mineral of tantalum. The deposit also contains significant quantities of rubidium-potash feldspar, albite, lepidolite, and cassiterite.

At the Big Whopper, which is hosted entirely within amphibolites, a north-directed compressional tectonic event produced flattening and a strong vertically oriented regional schistosity striking west-northwest. This schistosity is folded about a sub-vertical axis, with minor folds commonly observed both in the pegmatite and the amphibolite host rocks. The Big Whopper itself exhibits tight s-fold geometry, with the thickened central portion of the pegmatite coinciding with the hinge zone, and attenuated limbs extending to the east and west. Fold axes exhibit vertical to sub-vertical orientations. Parallel mineral lineations indicate a strong vertical stretching component, with aspect ratios in the order of 5:1 to 10:1. Small pegmatites flanking the Big Whopper commonly exhibit boudinage structures indicative of a high-strain environment.

Mineralogy and Zonation

Mineralogical zoning observed in the Big Whopper is characteristic of highly evolved rare metal pegmatites, with well-developed wall zones and internal intermediate zones classified according to their dominant constituent minerals (Figure X). Metallogenic zoning is closely related to mineralogical zoning. The predominant mineralogical zones of the Big Whopper are as follows:

1. Wall Zone (predominantly albitite)
2. Megacrystic Feldspar and Quartz-Mica marginal Zones
3. Petalite (intermediate) Zone

1. The Wall Zone is a narrow 1 to 10 metre wide endocontact zone of albitite consisting essentially of saccharoidal to aplitic albite with accessory K-feldspar, muscovite, quartz, and Mn-rich garnet (spessartine). Proximal dykes and stringers exhibit the same mineralogy as the Wall Zone albitite. Cassiterite and tantalum oxides are commonly associated with the albitite, along with rare gahnite (a zinc spinel). Albitite characteristic of the Wall Zone commonly occurs in intimate association with the Megacrystic Feldspar Zone and these zones together with the Quartz Mica Zone, likely reflect early, more primary phases of pegmatite development.

2. The Megacrystic Feldspar Zone is confined to the eastern and western internal margins of the Big Whopper pegmatite and resembles pegmatitic granite. It consists predominantly of orange-pink to grey-white, coarse to megacrystic K-feldspar and coarse silvery mica aggregates in an albitic matrix. Highly elevated whole rock rubidium values averaging in excess of 0.3% Rb_2O are attributed to Rb-K-feldspar as an essential mineral in the pegmatite. The Quartz Mica Zone occurs in intimate association with the Megacrystic Feldspar Zone, and is generally enveloped by or interdigitated with it. It contains 50% quartz, 30% muscovite, and 20% K-feldspar. Elevated whole rock lithium values in this zone (up to 0.5% Li_2O) are attributed to the presence of micas of the lithian muscovite to lepidolite series.

3. The Petalite Zone is an intermediate zone of the Big Whopper pegmatite and is the largest defined to date, comprising approximately 80% of its volume. The essential mineralogy consists of petalite, Rb-K-feldspar, albite, quartz and mica. A crude but distinct petalite zoning can be identified within the Big Whopper pegmatite as tightly folded layers with progressive fractionation increasing eastward. Ribbon-like, white petalite displaying schlieren-like habit (Type A) grades to coarse pink and pink-white petalite (Type B), and to blue-grey to pink-grey petalite (Type C). A fourth sub-zone (Type D) is recognized based on the presence of the purple mica lepidolite and occurs peripheral to Types A-C, mainly to the south and east. This zone is enriched in tantalum, typically assaying greater than 0.01% Ta_2O_5 . Type C is a very fine-grained, equivalent of Types B and A, which is very highly foliated, mica-rich unit and commonly occurs interlayered as coarse-grained bands and lenses within Types B and A. Petalite in this unit tends to be partially altered to spodumene-quartz intergrowth ("SQUI") exhibiting a net texture.

Mineralization

The main economic minerals of the Big Whopper deposit are petalite, Rb-K-feldspar, albite, lepidolite and columbite-tantalite. The Big Whopper pegmatite system is characterized by unusually high purity end-member compositions of the constituent minerals, a feature reflecting the highly evolved chemistry of the system.

Petalite ($\text{LiAlSi}_4\text{O}_{10}$) is almost stoichiometrically pure, averaging close to the theoretical maximum lithium content of 4.8% Li_2O , with only traces of soda, potash, and iron. It averages about 25% of the ore, and varies from white to pale pink in colour.

Albite averages 11% soda, 0.10% potash, 0.35% lime, 0.01% iron oxide (Fe_2O_3). It makes up 40% of the ore, and on average ranges from white to bluish-white in colour.

Rb-K-feldspar constitutes 10 to 15% of the ore. Although known in other pegmatites where it generally exhibits perthitic intergrowth, the Big Whopper variety carries only 0.3-0.4% Na_2O along with 2.8% Rb_2O , 15-16% K_2O and. It is generally grey-white in colour and typically occurs as large megacrysts in the petalite ore.

Lepidolite ($\text{K Rb}(\text{Li,Al})_{2-3}(\text{AlSi}_3\text{O}_{10})(\text{O,OH,F})_2$) is a distinct purple-coloured mica that occurs in marginal zones of the Big Whopper and in separate flanking dykes. The mineral is an ore of rubidium, containing up to 4% Rb_2O , and can comprise up to 15% of the ore.

Columbite-tantalite (Mn,Fe)(Nb,Ta)O₆ Manganocolumbite and manganotantalite predominate with rare microlite and ferrocolumbite, all occurring as fine-grained dark brown opaques. Tantalum is well distributed through the deposit but is typically enriched to levels exceeding 0.01% Ta₂O₅ in marginal lepidolite-rich petalite zones and albitite dykes.

Other potentially valuable industrial minerals include muscovite mica (some with elevated lithia) which may comprise up to 15% of the ore, spodumene averaging 3-5% occurring as SQUI replacement rims on petalite, cassiterite, pale pink spessartine garnet and high-purity quartz.

Minor accessory minerals include apatite, zircon, gahnite, monazite, xenotime, rare sulphides, sulphosalts, and thorite.

Field Stop Descriptions

Area #1: Big Whopper Petalite Deposit Main Mass

The large stripped exposure of the Big Whopper main mass reveals all of its major mineralogical zones and sub-zones. The Wall Zone and feldspathic zones are exposed on the northwest side of the outcrop. The coarse white and pink petalite zone (Type B) is well exposed in the trench in the central part of the outcrop. It is flanked by Type A and C petalite mineralization with Type D (lepidolite rich) occurring on the south side and in a separate exposure to the east. The surface trench along the top of the Whopper averages 1.58% Li₂O, 0.33% Rb₂O and 0.007% Ta₂O₅ across 58.90 metres.

Amphibolite screens occur within and at the margins of the Big Whopper. These screens are commonly disjointed with mullioned terminations, but are continuous to depth. Narrow 2 to 5 cm wide albitic haloes characteristically rim most of these screens, and show remarkably little variation in width regardless of the size of the amphibolite screen. These rims are interpreted as reaction fronts or depletion haloes, in which are concentrated lithophile elements (specifically Li, Rb, and Cs) forming mica-rich (glimmerite) selvages to the amphibolite screens. The white albitic rims are depleted in these elements, but commonly exhibit elevated tantalum values of up to 0.049% Ta₂O₅.

Area #2: Lepidolite Dike

Lepidolite-rich petalite pegmatite dikes occur flanking the Main Mass of the Big Whopper pegmatite system mainly to the east. These dikes tend to be enriched in tantalum relative to the Main Mass of the Big Whopper reflecting the greater abundance of more high-evolved tantalum minerals such as microlite and wodginite in the Lepidolite Dyke. Channel sampling of this outcrop has produced an average of 0.023% Ta₂O₅ over 3.15 metres, with individual assays up to 0.031% Ta₂O₅. Dark blue fluor-apatite is a common accessory mineral

Return to Avalon's landing on the Winnipeg River, and by boat to the Separation Narrows bridge. Proceed north on the English River Road about 3 km to the Umfreville

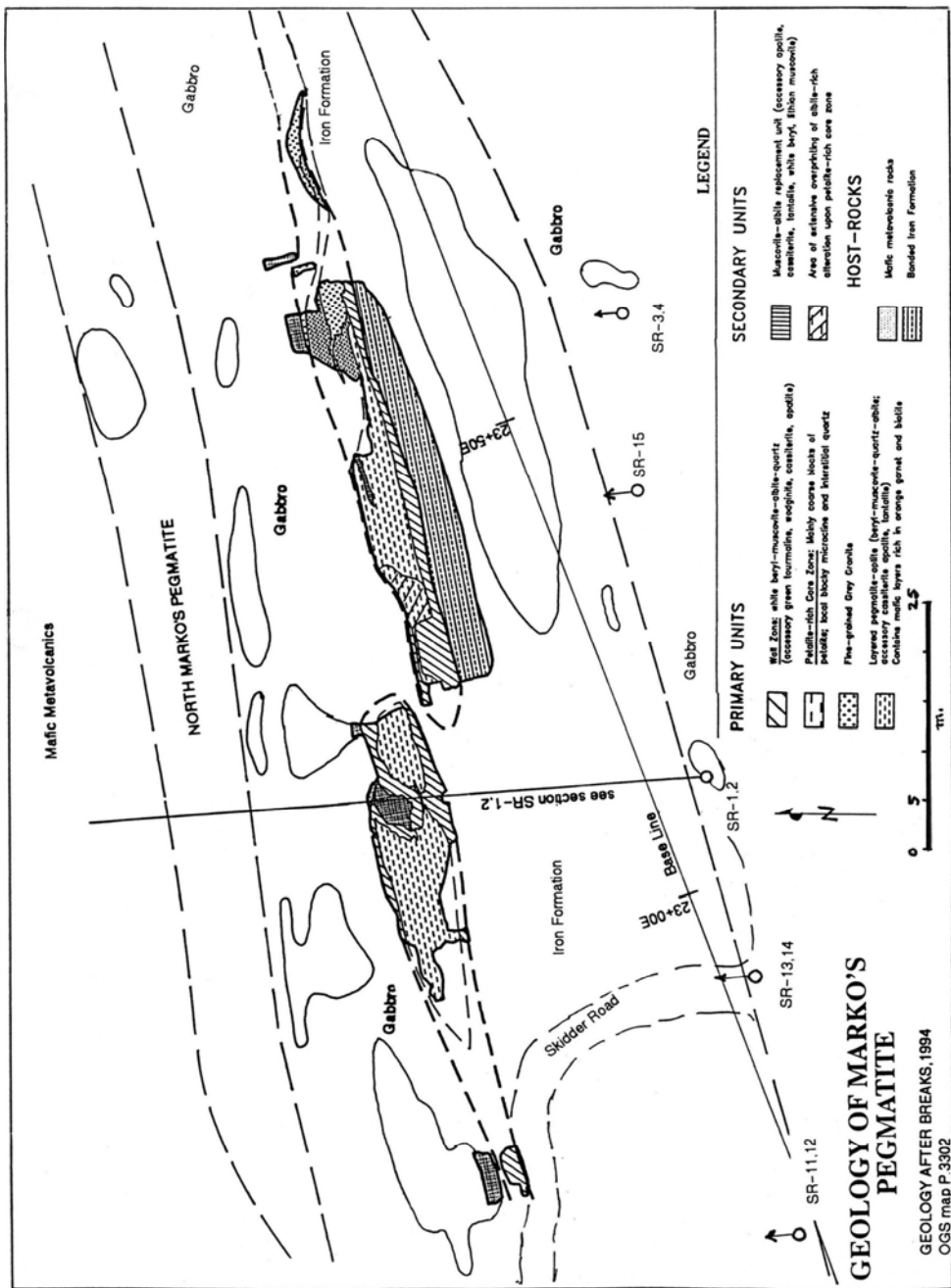


Figure 10. Marko's pegmatite, showing location of zones discussed in the text.

Road turn off. A skidder trail leads from the Umfreville Road to Marko's pegmatite (Fig. 2).

STOP 4 - MARKO'S PEGMATITE

Marko's pegmatite (Fig. 10) extends along strike for a distance of 190 m in an east-west direction. It has a shallow dip to the south and is discordant to the near vertical dip of the iron formation that is its host rock. The pegmatite has a maximum thickness of 15 m and a maximum down dip extension of 30 m. Drill intersections indicate in cross section that Marko's pegmatite occupies a tension fracture that extends from the gabbro/iron formation contact at surface and progresses south across the iron formation at a relatively shallow angle but near normal to the primary layering in the iron formation. In longitudinal section Marko's pegmatite plunges 5-10° to the west.

A second pegmatite, the North Marko's pegmatite, lies along the gabbro/mafic metavolcanic contact at surface, 20 m to the north of Marko's pegmatite. Diamond drilling shows that the pegmatite extends to a depth of 40 m as a single, near vertically dipping sheet and then splits into north and south dipping sections. The south limb increases in size and degree of differentiation in the down dip and easterly directions. The North Marko's pegmatite is essentially barren at surface, but drill results show that mineralogy and geochemistry changes abruptly with depth and association with either a roll or flattening of the dike. This is likely due to the entrapment of fluorine rich fluids along these structural features.

Both pegmatites are pristine and undeformed by the folding events that affected the Big Mack and Big Whopper pegmatites. Marko's pegmatite is exposed as two lenses at surface (Fig. 10). This is due to a sigmoidal roll in the moderate dip of the intrusion to the south. The internal zones can be readily traced and differentiation trends established with confidence along the surface exposures and in drill core.

Zones of Marko's pegmatite to be examined are as follows:

- A) Wall zone comprised of quartz+albite+muscovite+beryl. Accessory minerals include black oxides (cassiterite, wodginite), green tourmaline and apatite.
- B) Petalite rich core zone, containing up to 95% petalite. The amount of petalite is locally variable, as seen in the westernmost part of the outcrop which consists essentially of coarse blocks of K-spar up to 2 m across, with interstitial petalite. This represents the crest of the pegmatite.
- C) Layered pegmatite-aplite. Quartz+garnet+biotite aplite is interlayered with a coarser muscovite+beryl granite. Fine grained black oxide minerals are common in the albite rich unit. A 1.6 m channel sample assayed 0.165% Ta₂O₅ and 0.10% Sn.
- D) Grey, fine grained granite with minor muscovite and fine grained black oxides.

E) Muscovite replacement unit of K-spar.

F) Albitization of the petalite core.

North Marko's pegmatite will also be examined. It has a simple assemblage at surface of quartz+K-spar+albite+mica with minor bands of aplite.

Return to the Umfreville Road/English River Road intersection. Proceed north on the English River Road to a 75 m trail on the left leading to James' pegmatite (Fig. 2).

STOP 5 - JAMES' PEGMATITE

This highly fractionated pegmatite (Fig. 11), intruded into mafic metavolcanics, is strongly deformed and folded. De la Fuente (1998) has described it as an example of pre D2 deformation phase pegmatite. The Treelined Lake Granite, which shows the same deformation, is suggested (de la Fuente 1998) to be source granite for pre D2 pegmatites and pegmatitic granites

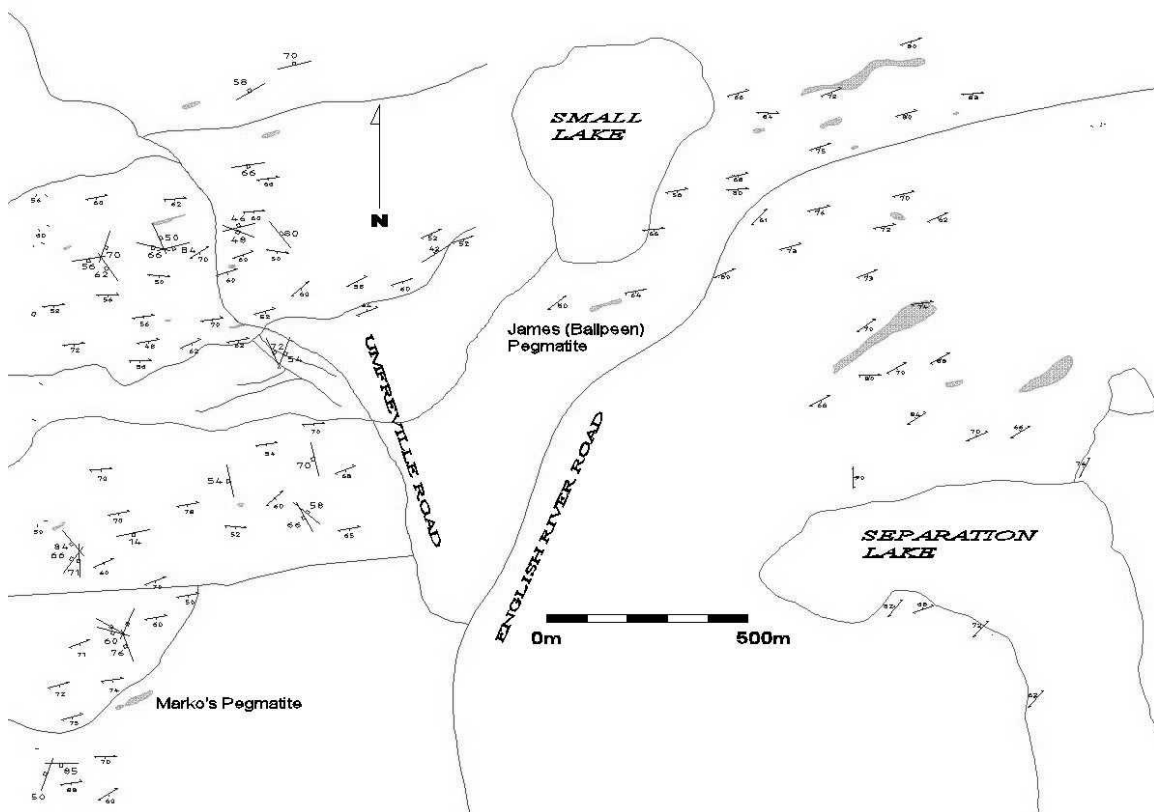


Figure 11. Location of James' pegmatite

In addition to quartz and feldspars, minerals present include green beryl, lithiophilite, petalite, spodumene blades, abundant black tourmaline, curvilinear mica ("ballpeen

mica”), which is assumed to be lithium rich, and possibly zinnwaldite. Ferrowodginite has been identified in this pegmatite (Fred Breaks, personal communication).

This zoned pegmatite is approximately 30 metres by 2 metres. The joint venture of Tanco and Gossan Resources Ltd. drilled the dike in 1996. The best Ta_2O_5 grades obtained were 0.035% in drill core and 0.026% at surface. The pegmatite dips to the southwest at about 60° and appears to widen at depth.

End of field trip stops.

REFERENCES

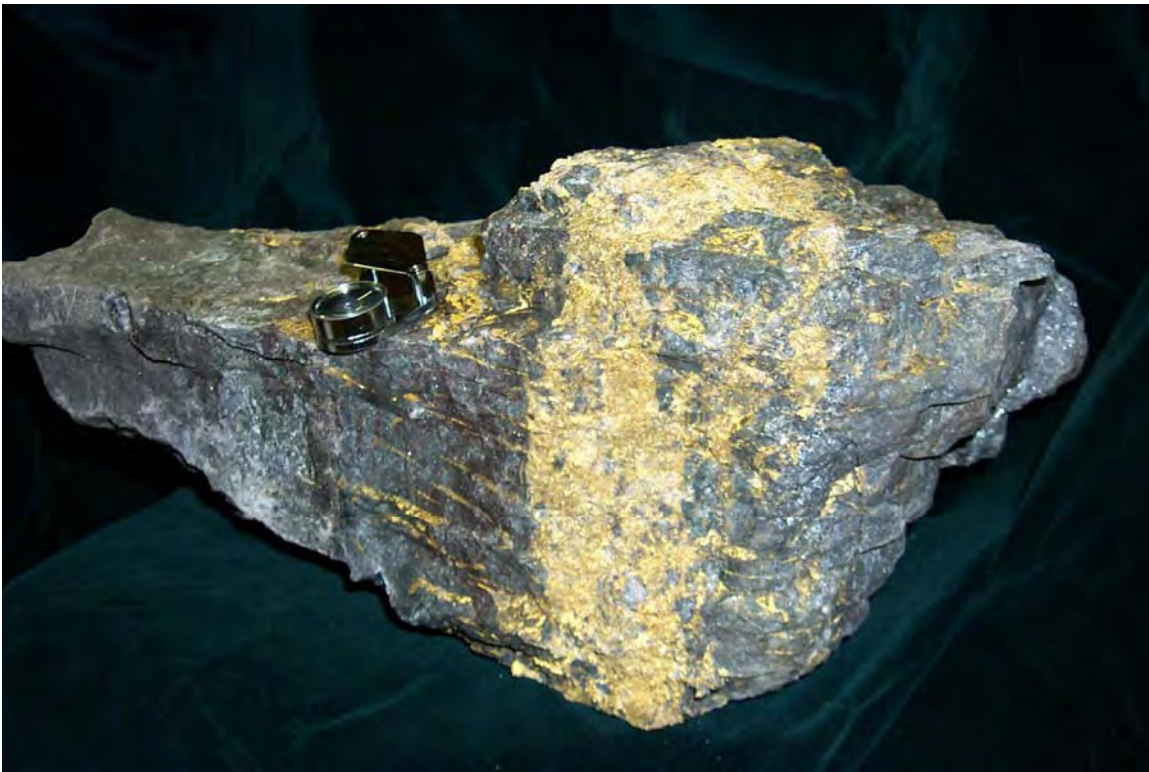
- Beakhouse, G.P. 1991. Winnipeg River Subprovince; in Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.279-301.
- Beakhouse, G.P., Blackburn, C.E., Breaks, F.W., Ayer, J., Stone, D. and Stott, G.M. 1995. Western Superior Province Fieldtrip Guidebook, Precambrian '95; Ontario Geological Survey, Open File Report 5924, XXp.
- Blackburn, C.E. and Young, J.B. 1993. Geology of the Separation Lake greenstone belt; in Summary of Field Work and Other Activities 1993, Ontario Geological Survey, Miscellaneous Paper 162, p.68-73.
- Blackburn, C.E. and Young, J.B. 2000. Precambrian geology of the Separation Lake area, northwestern Ontario; Ontario Geological Survey, Open File Report 6001, 94 p.
- Blackburn, C.E., Young, J.B., Searcy, T.O. and Donohue, K. 1994a. Precambrian geology of the Separation Lake greenstone belt, west part; Ontario Geological Survey, Open File Map 241, scale 1:20 000.
- Blackburn, C.E., Young, J.B., Searcy, T.O. and Donohue, K. 1994b. Precambrian geology of the Separation Lake greenstone belt, east part; Ontario Geological Survey, Open File Map 242, scale 1:20 000.
- Breaks, F.W. 1991. English River Subprovince; in Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.239-277.
- Breaks, F.W. 1993. Granite-related mineralization in northwestern Ontario: I. Raleigh Lake and Separation Rapids (English River) rare-element pegmatite fields; in Summary of Field Work and Other Activities 1993, Ontario Geological Survey, Miscellaneous Paper 162, p.104-110.
- Breaks, F.W. and Bond, W.D. 1993. The English River Subprovince – an Archean gneiss belt: geology, geochemistry and associated mineralization; Ontario Geological Survey, Open File Report 5846, v. 1 and 2, 884 p.
- Breaks, F.W. and Pan, Y. 1995. Granite-related mineralization in northwestern Ontario: III. Relationship of granulite metamorphism to rare-element mineralization in the Separation Lake area of the English River Subprovince in Summary of Field Work and Other Activities 1995, Ontario Geological Survey, Miscellaneous Paper 164, p. 79-81.
- Breaks, F.W. and Tindle, A.G. 1994. Granite-related mineralization in northwestern Ontario: II. Detailed examination of the Separation Narrows (English River) rare-element group in Summary of Field Work and Other

- Activities 1994, Ontario Geological Survey, Miscellaneous Paper 163, p. 109-112.
- Breaks, F.W, and Tindle, A.G. 1996. New discovery of rare-element pegmatite mineralization, Separation Lake area, northwestern Ontario; Ontario Geological Survey, Open File Report 5946, 9p.
- Breaks, F.W. and Tindle, A.G. 1997. Rare-metal exploration potential of the Separation Lake area: an emerging target for Bikita-type mineralization in the Superior Province of NW Ontario; Ontario Geological Survey, Open File Report 5966, 27p.
- Breaks, F.W. and Tindle, A.G. 2002. Rare-metal mineralization of the Separation Lake area, northwest Ontario: characteristics of a new discovery of complex-type, petalite-subtype, Li-Rb-Cs-Ta pegmatite in Industrial Minerals in Canada, CIM Special Volume 53, p. 159-178.
- Cerny, P. and Ercit, T.S. 1985. Some recent advances in the mineralogy and geochemistry of Nb and Ta in rare-element granitic pegmatites; Bulletin Mineralogie, v. 108, p. 499-532.
- Cerny, P., Trueman, D.L., Ziehlke, D.V., Goad, B.E. and Paul, B.J. 1981. The Cat Lake-Winnipeg River and the Wekusko Lake pegmatite fields, Manitoba; Manitoba Department of Energy and Mines, Economic Geology Report ER80-1, 216p.
- de la Fuente, F. 1998. Structural analysis of the Tanco's Separation Lake property, western Ontario, Canada; report for Tantalum Mining Corporation of Canada Limited, 29 p.
- Larbi, Y., Stevenson, R., Breaks, F.W., Machado, N. and Gariépy, C. 1999. Age and isotopic composition of Late Archean leucogranites: implications for continental collision in the western Superior Province; Canadian Journal of earth Sciences, Vol. 36, p. 495-510.
- Stockwell, C.H. 1932. Beryllium deposits; p.126 in Geology and mineral deposits of a part of southeastern Manitoba, by J.F. Wright; Geological Survey of Canada. Memoir 169, 150p.
- Storey, C.C. 1990. An evaluation of the industrial mineral potential of parts of the districts of Kenora and Rainy River; Ontario Geological Survey, Open File Report 5718, 259p.
- Tindle, A.G. and Breaks, F.W. 2000. Tantalum mineralogy of rare-element granitic pegmatites from the Separation Lake area, northwestern Ontario; Ontario Geological Survey, Open File Report 6022, 387p.

Field Trip 6

Geology of the Red Lake Camp, Ontario

Andreas Lichtblau and Carmen Storey
Ontario Geological Survey
Ministry of Northern Development and Mines
227 Howey Street, Box 324
Red Lake, Ontario
P0V 2M0



Example of late gold vein stockwork forming part of the High Grade Zone, 32 Level, Red Lake Mine. Estimated contained gold in sample: 298 ounces (at 7,284 ounces gold per ton). Photo courtesy of Goldcorp Inc.

REGIONAL GEOLOGY

The Red Lake District (Fig. 1) is underlain by Archean rocks of the Superior Province of the Canadian Shield. Rocks of four subprovinces are found in the Red Lake District:

1. Uchi Subprovince rocks in the Red Lake District comprise the Red Lake and Birch-Confederated Lake greenstone belts in which the bulk of exploration and mining activity has taken place. The supracrustal rocks of the Red Lake greenstone belt can be subdivided into several assemblages with ages ranging from ca. 2990 Ma to ca. 2700 Ma (Table 1). Major granitoid intrusions show a range from ca. 2734 Ma to 2699 Ma (Table 2).
2. English River Subprovince rocks, south of the Uchi Subprovince, are predominantly metasedimentary and host minor intrusive rocks similar to those in the Quetico Subprovince.
3. To the north, the Berens River Subprovince formed the core of a microcontinent. This area is underlain by ca. 2750-2690 Ma felsic plutonic rocks interpreted as a magmatic arc formed at an Andean-style margin that culminated in the Kenoran orogeny. These plutonic rocks intruded an older substratum (North Caribou terrane) on which Mesoarchean volcanic rocks of the Red Lake belt are also interpreted to have formed.
4. The Sachigo Subprovince comprises crustal blocks ranging from Paleoarchean (>3.4 Ga) to Neoarchean (ca. 2.7 Ga) in age.

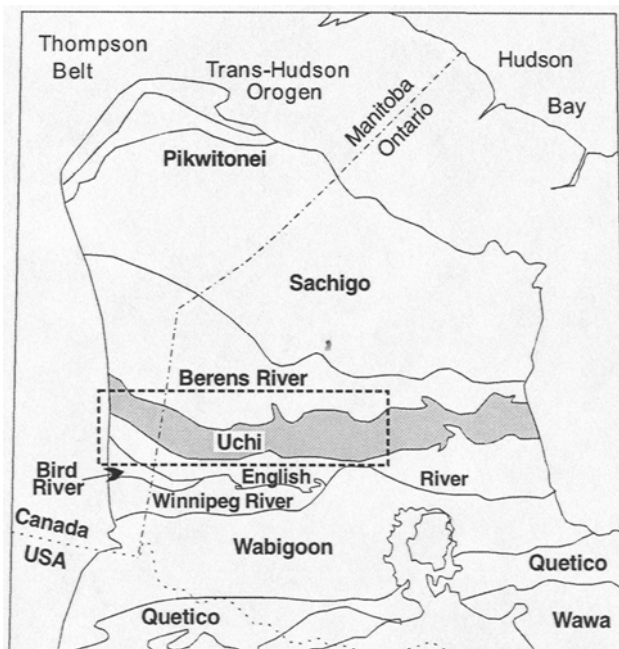
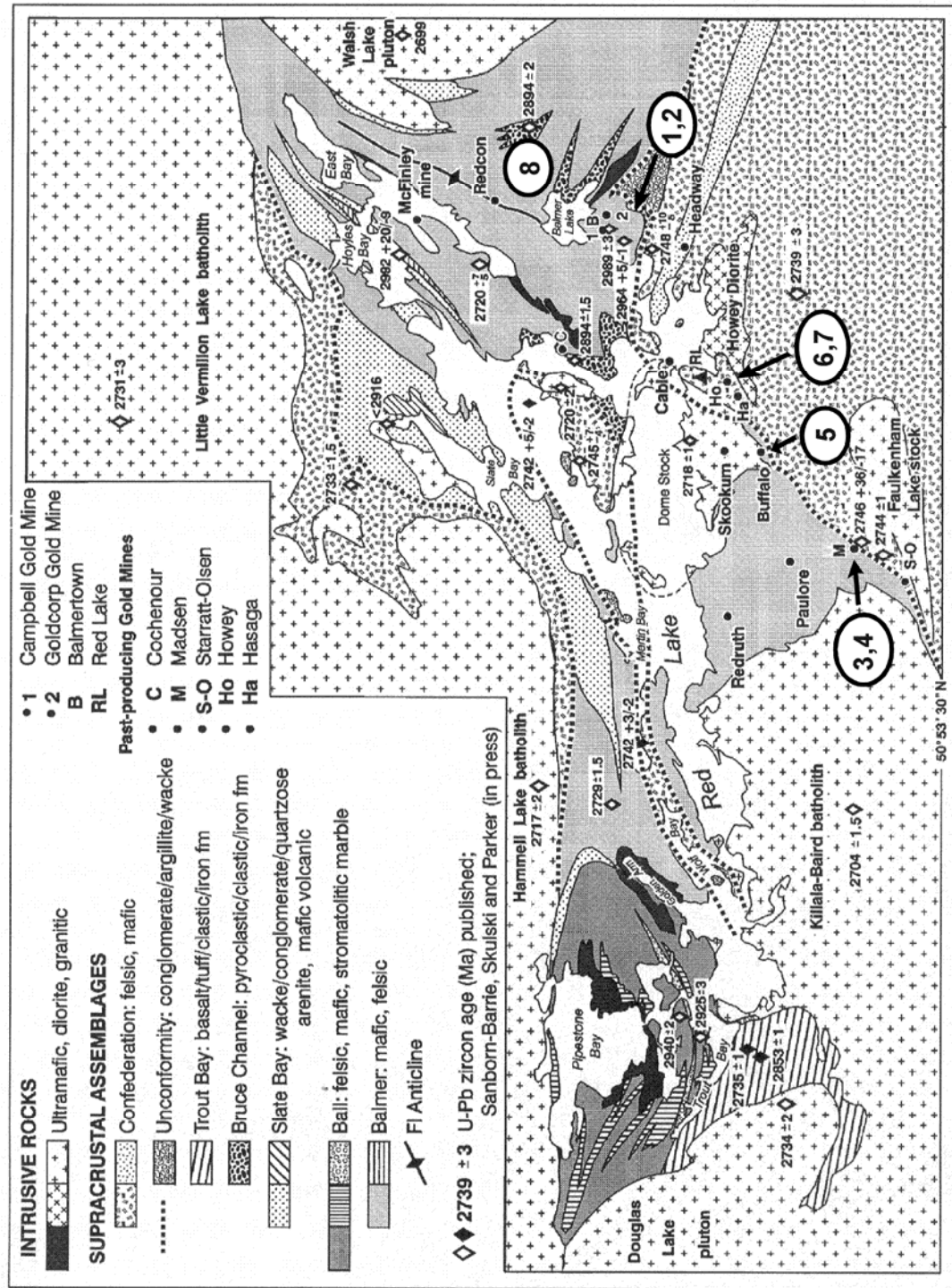


Figure 1. Western Uchi Subprovince (modified from Percival et al. 2000)



GEOLOGY OF THE RED LAKE BELT (*adapted from Sanborn-Barrie et al. 2001*)

The Red Lake greenstone belt (Fig. 2) is dominated by the (ca. 2990 Ma) mafic-ultramafic Balmer assemblage, an oceanic plain sequence; minor calc-alkalic volcanic rocks of arc-like affinity terminate the assemblage. The majority of lode gold deposits in the camp are hosted by the basal mafic-ultramafic sequence. A later diverse lithologic association, the Ball assemblage, appears to represent a shallow marine, volcanic edifice built upon the Balmer substrate.

Table 1. Summary of supracrustal lithologies and radiometric ages in the Red Lake greenstone belt (*modified from Parker 2000; with new ages from Sanborn-Barrie et al. 2001 and Skulski et al. 2001; final error estimates are not cited for the new unpublished ages of T. Skulski*).

Supracrustal assemblage	U-Pb Age (Ma)	Rock types and descriptions	References
English River ?	<2700±6	Polymictic pebble conglomerate. Thought to correlate with the Austin tuff, host to the Madsen gold deposit.	Sanborn-Barrie et al. 2001
Confederation-Graves (north Red Lake)	2733±1.5	Strongly calc-alkaline rocks. Andesitic to dacitic pyroclastic rocks	Corfu and Andrews 1987
Huston (Cemetery)	≤2743	Well-bedded argillite and turbiditic wacke; polymictic conglomerate.	Skulski et al. 2001
Confederation-Heyson (southeast Red Lake)	2748+10/-5 to 2739±3	Basal sequence is commonly tholeiitic to calc-alkaline with lobe-hyaloclastite rhyolite flows; intermediate pyroclastic rocks; basalt; and feldspar-phyric andesite. Calc-alkaline rocks are more abundant at higher stratigraphic levels.	Corfu and Wallace 1986
Confederation-McNeely (central and SE Red Lake)	2742; 2748+10/-5	Dominated by calc-alkaline, intermediate lapilli-tuff breccia and lapilli tuff	Sanborn-Barrie et al. 2001
Trout Bay	2853	Lower tholeiitic basalt sequence with associated gabbroic rocks overlain by fine-grained clastic metasedimentary rocks (wacke, argillite) interlayered with subordinate intermediate pyroclastic rocks and chert-magnetite iron formation. Overlain by tholeiitic, pillowed basalts.	Sanborn-Barrie et al. 2001
Bruce Channel	2894±1.5; 2894±2	Strongly calc-alkaline intermediate pyroclastic rocks overlain by pebble conglomerate, thinly bedded wacke and capped by chert-magnetite iron formation	Corfu and Wallace 1986; Corfu and Andrews 1987
Slate Bay	≤2916	Interlayered, feldspathic wacke, lithic wacke and argillite; lenses of pebble and cobble conglomerates and quartz-rich pebble conglomerate and quartz arenite.	Corfu et al. 1998
Ball	2940±2; 2925±3	Typically calc-alkaline intermediate pyroclastic rocks and rhyolite flows; komatiitic to tholeiitic	Corfu and Wallace 1986

		basalt; overlain by chert-magnetite iron formation and dolomitic marble which contains stromatolites.	
Balmer	2992+20/-9; 2989±3; 2964+5/-1	Tholeiitic basalt, basaltic komatiite and komatiite interlayered with subordinate chert-magnetite iron formation; minor clastic metasedimentary rocks; minor intermediate to felsic pyroclastic rocks; and rhyolite.	Corfu and Andrews 1987

Table 2. Summary of lithologies and radiometric ages for major granitoid intrusions in the Red Lake greenstone belt (*modified from* Parker 2000; new ages cited in Sanborn-Barrie et al. 2001 and elsewhere do not have final error estimates assigned, as this U-Pb data is not yet published).

Granitoid intrusion	U-Pb Age (Ma)	Rock types and descriptions	References
Cat Island pluton	2699	Potassium feldspar granodiorite	Sanborn-Barrie et al. 2001
Walsh Lake pluton	2699	Potassium feldspar- and quartz-phyric monzogranite; xenolith-rich, diorite or granodiorite; possible oxidized phase at Ranger Lake with broad magnetic anomaly	Noble 1989
Killala-Baird batholith	2704±1.5	Potassium feldspar- and quartz-phyric monzogranite; xenolith-rich, diorite or granodiorite, diorite or granodiorite; oxidized, magnetite-bearing marginal phase.	Corfu and Andrews 1987
Hammel Lake batholith	2717±2	Potassium feldspar and quartz porphyritic monzogranite; associated anorthositic intrusion.	McMaster 1987
Dome stock	2718±1	Granodiorite and augite porphyritic diorite/gabbro.	Corfu and Andrews 1987
McKenzie stock	2720±2	Augite porphyritic diorite-gabbro; some ultramafic rocks; granodiorite	Corfu and Andrews 1987
Red Crest stock	2729±1.5	Augite porphyritic diorite-gabbro	Corfu and Andrews 1987
Little Vermilion batholith	2731±3	Hornblende tonalite-granodiorite	Corfu and Andrews 1987
Douglas Lake pluton	2734±2	Biotite tonalite	Corfu and Stone 1998

Widespread ca. 2894 Ma calc-alkaline volcanism is represented in Red Lake by the Bruce Channel assemblage. Overlying this is the ca. 2850 Ma Trout Bay assemblage which includes substantial basaltic and gabbroic rocks in western Red Lake which are prospective for PGE mineralization, and which includes minor intermediate pyroclastic rocks throughout central Red Lake. The Trout Bay assemblage may correlate with Woman assemblage rocks of the Confederation Lake belt.

A regional angular unconformity is interpreted to separate the Mesoarchean assemblages from the Neoarchean Confederation assemblages. Volcanogenic massive sulphide mineralization is associated with the younger sequence. A significant number of felsic

units are classed as FII and FIII type rhyolites, considered highly prospective for large (Kidd Creek/Noranda type) massive sulphide deposits (Parker 1999).

A newly recognized component of the Neoarchean supracrustal package is the Huston sedimentary assemblage that includes polymictic cobble- to pebble-conglomerate and argillite; clasts include jasperoidal chert iron formation, massive sulfide pebbles, and mafic flow (?) rocks, as well as well-bedded, graded turbiditic wacke and argillite. The U-Pb age of detrital zircons give single age peaks of 2743 and 2746 Ma at the cemetery and Madsen sites respectively (Skulski et al. 2001), indicating erosion of pre-existing Confederation age rocks, and deposition after ca. 2743 Ma.

Recent age dating (Skulski et al. 2001) has also yielded multiple ages of detrital zircons from a fragmental unit thought to correlate with the Austin "tuff" ore zone at the former Madsen mine. Most of the Meso- and Neoarchean assemblages exposed in Red Lake are represented in this unit. Maximum age of deposition is consequently $\leq 2700 \pm 6$ Ma.

DEFORMATION (*adapted from Sanborn-Barrie et al. 2001*)

The Red Lake greenstone belt has undergone at least three phases of deformation:

- 1) D₀, a non-penetrative, early (pre-2748 Ma) event involving overturning of the Balmer assemblage;
- 2) D₁, (bracketed between 2733-2742 Ma) resulted in a north trending foliation that is axial planar to F1 folds and involved east-west shortening; and
- 3) D₂, (ca. 2720-2700 Ma) resulted in a dominantly east- to northeast-striking foliation that refolds F1 folds. A local 'deflection' of S₂ around the McKenzie stock created an east-southeast striking corridor of heterogeneous strain forming the "Mine Trend", from Cochenour through the Balmertown area, hosting the major gold deposits of the camp.

HYDROTHERMAL ALTERATION (*adapted from Parker 2000*)

The Red Lake greenstone belt has been affected by a large-scale (10's of kilometres) hydrothermal alteration system, resulting in approximately contemporaneous a) strong to intense, distal calcite carbonatization that affects rocks of all ages; and b) less extensive (kilometres), proximal, strong to intense ferroan-dolomite and potassic alteration, found in almost all areas hosting gold mineralization. Carbonate alteration affects both the Dome (2718 $\pm$ 1 Ma) and McKenzie (2720 $\pm$ 2 Ma) stocks and is overprinted by calc-silicate, skarn-like alteration formed during the intrusion of the Killala-Baird batholith (2704 $\pm$ 1.5 Ma) and the Walsh Lake pluton (2699 Ma). The significant carbonate alteration event is therefore bracketed between 2718 and 2704 Ma, during D₂.

The main macroscopic features of carbonate alteration are pervasive replacement of rock matrix, open-space filling/replacement of primary porosity (vesicles, pillow selvages, hyaloclastite matrix), filling of extension veins with massive, colloform, crustiform and cockade breccia textures, networks of variably oriented veins and "jigsaw puzzle" breccia veins.

Multiple stages of carbonate alteration and veining have been recognized, indicating continuous carbonatization during D₂ deformation.

Potassic metasomatism takes the form of sericite/muscovite alteration in greenschist-facies rocks; in ferroan-dolomite altered ultramafic rocks fuchsite occurs instead of sericite. Potassic alteration in amphibolite-facies mafic and ultramafic rocks takes the form of pervasive biotite ± muscovite. Centimetre- to metre-wide, strong to intense, biotite ± calcite ± ferroan-dolomite ± disseminated pyrite alteration halos often enclose ferroan-dolomite veins in amphibolite-facies mafic rocks.

Biotite altered zones in amphibolite-facies rocks are characterized by a diverse assemblage of aluminosilicate minerals such as andalusite, staurolite and cordierite, with garnet, chloritoid, cummingtonite and anthophyllite.

Barren, pervasive silicification within proximal alteration zones may be due to release and remobilization of silica during periods of pervasive carbonatization. The majority of gold deposits in the Red Lake belt are quartz and arsenopyrite rich selective replacement zones of colloform-crustiform ferroan-dolomite veins and breccia.

GEOLOGY OF THE CAMPBELL-RED LAKE GOLD DEPOSIT (*adapted from Dubé et al. 2002*)

Gold has been continuously produced from the Campbell-Red Lake (formerly known as the Campbell-Dickenson) deposit since 1948: current production levels and reserves are given in Table 3. Historical production figures for the Red Lake greenstone belt are shown in Table 4.

Table 3. Current gold production and reserves, Red Lake greenstone belt

Mine	Production to end of 2000		Production in 2001		Reserves at end of 2001	
	Tonnage Grade	@ Total Commodity	Tonnage @ Grade	Total Commodity	Tonnage	Grade
Goldcorp Inc. Red Lake Mine	74 148 tons @ 1.57 ounces per ton	85 115 ounces Au	246 618 tons @ 2.26 opt Au (223 728 tonnes @77.50 g/t)	503 385 ounces Au	3 208 000 tons (2 910 000 tonnes) (1)	1.34 opt Au (46.04 g/t)
Placer Dome (CLA) Ltd. Campbell Mine	473 000 tonnes @ 15.7 g/t Au	229 408 ounces Au	438 000 tonnes @13.3 g/t (482 800 tons @ 0.388 opt Au)	178 139 ounces Au	1 941 000 tonnes (2 139 600 tons) (2)	16.7 g/t Au (0.487 opt Au)

(1) News release, Goldcorp Inc. February 7, 2002

(2) News release, Placer Dome (CLA) Ltd. February 14, 2002

Table 4. Historical gold production, Red Lake greenstone belt

<u>GOLD PRODUCTION IN THE RED LAKE GREENSTONE BELT</u> <u>to December 31, 2001</u>					
MINE	YEARS PRODUCTION	OF	ORE MILLED (SHORT TONS)	GOLD PRODUCED	
				TROY OUNCES	OUNCES PER TON
CAMPBELL RED LAKE	1949 - PRESENT ⁽¹⁾		17,979,851	10,335,248	0.575
GOLDCORP (DICKENSON)	1948 - PRESENT ^(1,2)		8,619,008	3,736,704	0.434 ⁽³⁾
MADSEN	1938 - 1976, 1997 ⁽⁴⁾ - 1999		8,678,143	2,452,388	0.283 ⁽⁵⁾
COCHENOUR-WILLANS	1939 - 1971		2,311,165	1,244,279	0.538 ⁽⁶⁾
MCKENZIE RED LAKE	1935 - 1966		2,353,833	651,156	0.277
HOWEY	1930 - 1941, 1957 ⁽⁷⁾		4,630,779	421,592	0.091 ⁽⁸⁾
HASAGA	1938 - 1952		1,515,282	218,213	0.144
STARRATT OLSEN	1948 - 1956		907,813	163,990	0.181
H.G. YOUNG	1960 - 1963		288,179	55,244	0.192
MCMARMAC	1940 - 1948		152,978	45,246	0.296
GOLD EAGLE	1937 - 1941		180,095	40,204	0.223
RED LAKE GOLD SHORE	1936 - 1938		86,333	21,100	0.244
BUFFALO	1981 - 1982		31,986	1,656	0.052
ABINO	1985 - 1986		2,733	1,397	0.511
LAKE ROWAN	1986 - 1988		13,023	1,298	0.100
RED SUMMIT	1935 - 1936		591	277	0.469
MOUNT JAMIE	1976		552	265	0.480
TOTAL			47,752,344	19,390,257	0.406

NOTES: (1) Includes final production figures for 2001.

(2) For 1997, 1998 and 1999 no production due to strike by unionised employees.

(3) From 1970, includes production from Robin Red Lake.

(4) Includes clean up ore and materials from the mine site.

(5) Historic grade, actual grade for 1999 was 0.14 ounce per ton gold.

(6) Includes production from Annco and Wilmar properties.

(7) Continuous production 1930 to 1941; includes 268 ounces recovered from clean up in 1957.

(8) The ore mined at Howey, before sorting totalled 5,158,376 tons.

The average production from run-of-mine ore was therefore 0.0817 ounce per ton gold.

Alteration facies in the High Grade Zone at Goldcorp Inc.'s Red Lake Mine have been described by Dubé et al. 2002:

1. an outer, metre-wide, garnet-chlorite-magnetite alteration with chlorite-amphibole-andalusite and locally associated centimetre- to metre-wide 'bleached zone' containing andalusite-muscovite-quartz-ilmenite ...;
2. a proximal, centimetre- to metre-wide, massive to laminated, reddish-brown, biotite-carbonate alteration with disseminated pyrite (3-5%) and carbonate veinlets in well foliated basalt; and
3. a gold-rich, strongly foliated, silicified zone with abundant fine-grained arsenopyrite, sericite, and rutile, and lesser amounts of pyrite, pyrrhotite, magnetite, and stibnite ($\leq 15\%$).

This third alteration facies is adjacent to the silicified auriferous carbonate veins and replaces the biotite-carbonate-rich alteration.

The chronology of gold-rich replacement textures suggests a syn-D₂ mineralizing event, dominated by silicification of carbonate veins, contemporaneous with boudinage of the veins. The silicified carbonate veins are hosted mainly by basalt; areas of high-grade gold mineralization are controlled by F₂ fold hinges deforming the basalt-ultramafic contact. Multiple periods of silicification and gold deposition overprint and replace the carbonatization in these lower pressure hinge zones.

The extremely high grade ore (>2.0 oz/t Au) currently mined at Goldcorp Inc.'s Red Lake Mine, is possibly due to a combination of factors, including the presence of a low-permeability ultramafic cap, allowing the build-up of very high fluid pressure in the footwall basalt; the high iron content of the tholeiitic basalt, creating a chemical, as well as structural, trap for the auriferous fluids; multiple D₂ strain events; repeated episodes of gold deposition and remobilization into a low pressure F₂ fold hinge hosting the High Grade Zone.

SUMMARY OF STOPS, SURFACE FIELD TRIP, RED LAKE BELT

The first outcrops after the underground tours will traverse both the proximal-distal alteration facies and the Neo–Mesoarchean boundary.

- *The tour then continues to the south-central portion of the Red Lake greenstone belt, within the metamorphic aureole of the Killala-Baird batholith.*
- *Outcrops at the interface of Meso- and Neoarchean assemblages expose rock units similar to those mined at the past producing Madsen mine, a high temperature, disseminated, stratabound gold deposit, quite dissimilar to deposits in the 'Mine Trend';*
- *this is followed by a visit to the Dome stock, a mineralized granodiorite intruded into the volcanics in the central portion of the belt;*
- *followed by stops in the town of Red Lake to view the site of the Howey mine, and to examine intensely deformed rocks within the purported Howey Bay – Flat Lake deformation zone;*
- *the last stops will be within strongly altered and veined Balmer rocks in the northeast portion of the belt.*

STOP 1 - MESO-NEOARCHEAN CONTACT

Woodland Cemetery Road and Hwy. 125 (Fig. 2)

These outcrops show altered relatively low-strain pillowed basaltic komatiite flows of the Balmer Assemblage unconformably overlain by polymictic conglomerate of the Huston assemblage. The exposures are in the transition from calcite carbonatization (distal alteration) to ferroan-dolomite (proximal) alteration.

The pillowed and minor massive flows show extensive iron carbonate alteration as well as iron carbonate and quartz veins. Fuchsite is present in the central part of the outcrops on the west side of the highway (cemetery side). The Campbell Mine is approximately 1.5 km to the north

While the mafic flows have not been directly dated at this locality, they are typically variolitic, and show a geochemical similarity with known Balmer age rocks elsewhere; the massive and pillowed flows here can be traced to Balmertown, where an intercalated rhyolite at the Campbell mine was dated at 2989 ± 3 (Corfu and Andrews 1987).

Variolitic flows occur in the northern part of the outcrops on the east side of the highway. However, they are unconformably overlain by Huston polymictic conglomerate further south along the outcrop. The conglomerate contains a large proportion of rounded cherty, jasperoidal and pyritic fragments. It represents an apron of Confederation assemblage (McNeely age-2743 Ma) detritus deposited at the break in the paleoslope between the Confederation volcanic centre and its Balmer age substrate.

STOP 2 - CALCITE CARBONATIZED PILLOWED FLOWS: DISTAL CARBONATE ALTERATION FACIES

Outcrops on west side of Hwy. 125 and Sandy Bay Road (Fig. 2)

Slightly deformed pillows of the Balmer assemblage show pervasive calcite carbonatization, calcite veins and pods. Amygdules are also filled (replaced?) with calcite. Jig-saw puzzle breccias (created by fluid overpressure at depth) are cemented by calcite. This represents the distal, outer halo of carbonate alteration.

STOP 3 - CONTACT BETWEEN CONFEDERATION AND BALMER ASSEMBLAGES

Suffel Lake Road and Hwy. 618 (Figs. 2 and 3)

Exposures on the south side of the highway are part of the lowermost units of the Neoarchean Confederation assemblage. The outcrops here are amphibolite-facies

tholeiitic, quartz-feldspar-porphyrific lapilli-crystal tuff, with thin, dark grey, collapsed pumice fragments; occasional lapilli sized lithic clasts are also observed. Strike of the rocks is generally northeast, facing and dipping steeply southeast. A sample from this unit, 800 m northeast of the intersection, gave an age of 2744 ± 1 Ma (Corfu and Andrews 1987).

The north side of the road exposes highly altered tholeiitic, mafic volcanoclastic rocks of the Balmer assemblage. Abundant garnet and biotite rims clasts; minor andalusite is present. This outcrop, barren at this locality, forms part of the Austin "tuff" ore zone, described further below.

STOP 4 - MADSEN DEPOSIT, POWER LINE OUTCROPS (Figs. 2 and 3)

Time limitations of the tour do not permit a complete visit of the Madsen deposit; a brief description of the deposit follows:

Geology of the Madsen Deposit (*adapted from Dubé et al. 2000*)

Madsen is a stratabound, replacement-style, disseminated gold deposit, exhibiting two alteration facies, the mineralogy of which is now represented by two amphibolite-facies zones:

- 1) a pervasive aluminous, metre- to tens-of-metres-wide, low-strain, outer zone, containing andalusite-garnet-biotite-staurolite-amphibole; metre-wide stockwork amphibole veins and veinlets alternate with the pervasive alteration. Timing of this alteration is pre- to syn- D_1 , but its relationship to gold mineralization is not yet known; indeed, it could be classified as the amphibolite-facies equivalent of volcanogenic massive sulfide (VMS) type alteration, related to a Confederation age syn-volcanic hydrothermal alteration system;
- 2) an inner zone comprising a banded-laminated texture, characterized by bands of actinolite-hornblende-microcline-calcite-tourmaline, alternating with biotite-rich bands. The amphibole is commonly randomly oriented. Diopside locally forms disseminated crystals up to 7-8 cm long, or veinlets.

Ore zones occur within the inner alteration zone, and comprise finely layered, sulfide-rich lenses up to a few metres wide. Sulfides (8-10%) comprise pyrrhotite, pyrite and/or arsenopyrite with trace chalcopyrite, and are found as disseminations or veinlets parallel to lamination/foliation. Gold occurs in the native state as inclusions in silicate minerals and locally as coatings on sulfide minerals. Highest grade is found in areas of most intense alteration, represented by quartz-biotite-muscovite-microcline assemblage in mm-cm bands or layers.

Crenulation of alteration bands, sulfides and calcite veinlets by S_2 as well as the large-scale deformation and folding of Austin ore lenses by F_2 folds are consistent with pre- to early D_2 timing of gold mineralization. A minimum age on the deposit is 2699 ± 4 Ma (Corfu and Andrews 1987), the age of a cross-cutting post-ore granodiorite dyke.

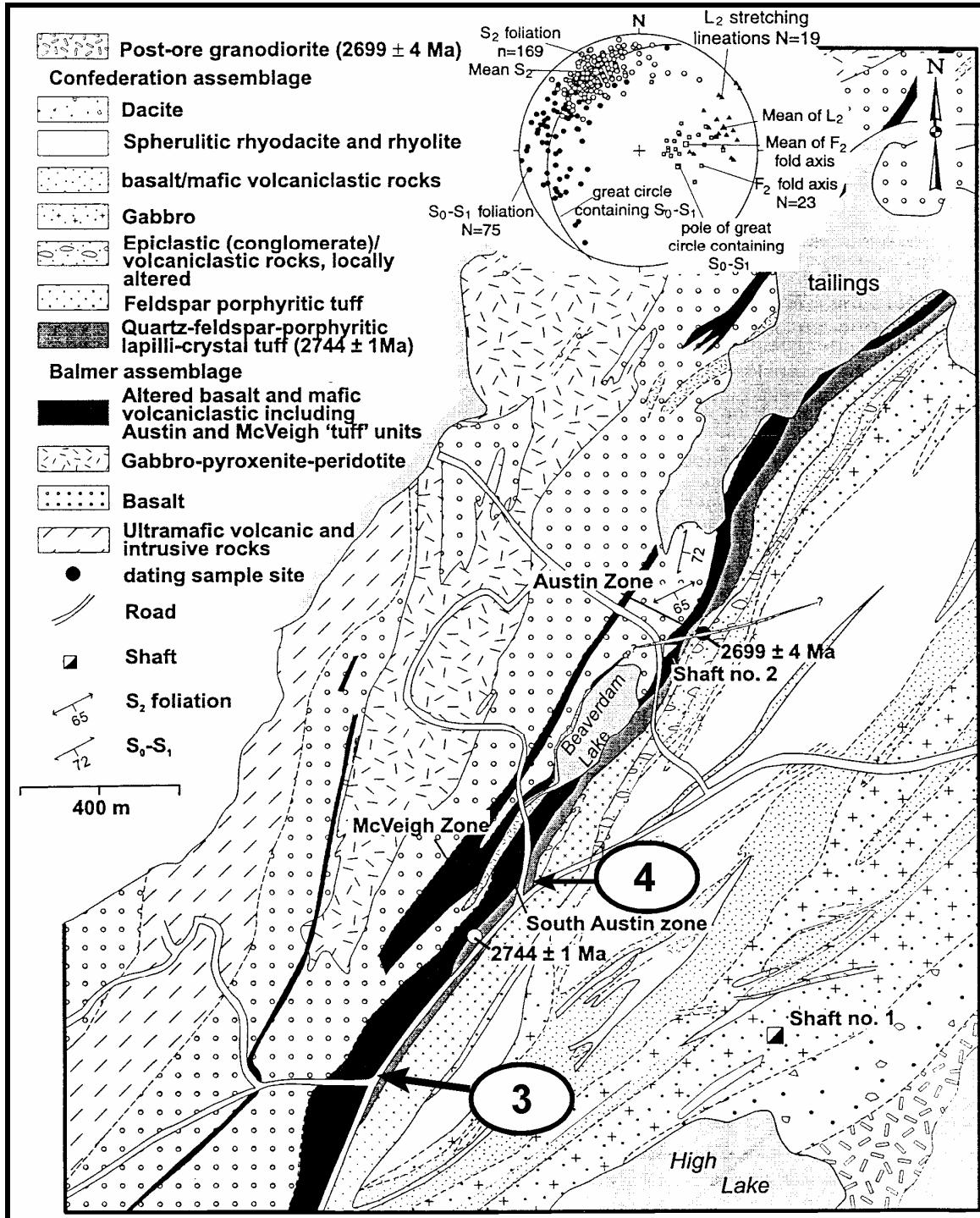


Figure 3. Geology of the Madsen mine area (modified from Dubé et al. 2000)

Proximal alteration and style of mineralization may indicate the Madsen deposit to be related to higher temperature (400°-600°C) gold deposits and gold-skarn deposits hosted by mafic volcanics (Parker 2000).

South Austin Zone – Powerline Section

The base of this series of poorly exposed outcrops is a well banded/layered example of Austin "tuff", from which the bulk of the 2.5 million ounces gold of the Madsen deposit were mined between 1938-1976 (Table 4). At this locality the Austin is a strongly altered (biotite, amphibole, garnet) mafic volcanoclastic/epiclastic rock, with wacke and conglomerate clasts, occupying the position of the unconformity between Balmer and Confederation assemblages.

Further up the hill the Confederation age quartz-feldspar porphyritic lapilli tuff unit from Stop 1 forms the structural and stratigraphic hangingwall of the deposit and marks the beginning of Confederation time. Overlying this unit is an altered (biotite, garnet) polymictic conglomerate outcrop, part of the Huston assemblage, that yielded a single peak in detrital U-Pb zircon ages of ≤ 2746 Ma (Sanborn et al. 2001a). At the top of the hill, feldspar phyric tuff of the Confederation assemblage is exposed.

STOP 5 - BUFFALO DEPOSIT - DOME STOCK MINERALIZATION (Fig. 2)

The approximately 7 km diameter hornblende-biotite granodiorite stock (Table 2) has been dated at 2718 ± 1 Ma (Corfu and Andrews 1987) and is interpreted to have been emplaced during D₂ (Sanborn-Barrie et al. 2001). The stock is variably iron-carbonate, sericite, and chlorite altered and deformed. Exposures to be visited (Figure 4) are at its southern contact; here it intrudes, and contains xenoliths of, foliated Balmer assemblage mafic volcanic rocks (Figure 4).

The stock hosts several gold occurrences and two past-producing mines: the Red Lake Gold Shore produced 21,100 ounces gold, and the Buffalo Mine produced 1656 ounces gold. The Buffalo prospect was discovered in 1925 and explored several times since then. Note the adit reopened by Claude Resources Ltd. in October 1998 to further explore the Buffalo deposit.

Gold is hosted within two sets of quartz-tourmaline-pyrite-calcite veins in conjugate orientation (centimetre-wide NE veins: 239°/73° N, and decimetre-wide NW veins: 119°/76° S; Pettigrew 1999). Their orientation may be as a result of the intersection of two previously interpreted (Durocher and Hugon 1983) deformation zones (St. Paul Bay-Martin Bay and Flat Lake-Howey Bay Deformation Zones). The dominant vein set strikes NW; primary quartz vein fill was replaced by tourmaline, concomitant with bleached pink metasomatic halos developing around tourmaline-rich portions of the veins. Gold is concentrated in the calcite-albite-sulfide halos, in particular at its outer fringe, where chalcopyrite and tellurides were deposited. A second stage of gold

mineralization is associated with Bi-tellurides in fractures and cavity fillings in quartz and late fracture-filling pyrite, hosted within the qtz-tourmaline-pyrite-calcite veins.

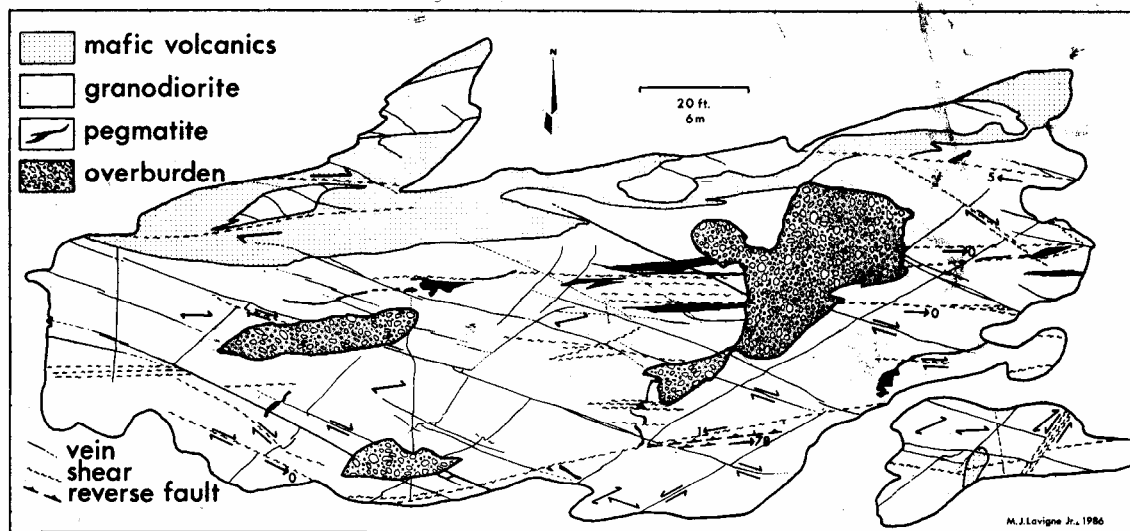


Figure 4. Detailed geology of south side of Buffalo Pit (from Lavigne et al. 1986)

STOP 6 - HOWEY MINE (Fenced in pit - drive by: Fig. 2)

On the north side of Hammell Road a cement foundation marks the site the former Howey mine. Behind the fenced off area is the site of the crown pillar mined out in the final stages of the mine. The Howey Mine was the first producer (1930-1941) in the Red Lake camp and remains the lowest grade profitable gold mine in Canadian mining history (final average grade 0.08 opt Au, having produced 422 000 ounces gold). The Howey (and adjacent Hasaga) ore bodies occur in a boudinaged, variably sericitized and silicified quartz-feldspar porphyry dyke trending approximately $065^{\circ}/80^{\circ}\text{S}$. Centimetre-wide, auriferous quartz veinlets trend 080° , making an angle of 15° with the contacts of the dyke and dip 80°S . Gold-bearing quartz veinlets formed as the last of three episodes of quartz veining. Gold is associated with pyrite-sphalerite-galena-tourmaline $\pm$ tellurides.

Small flat outcrops between the highway and the fence are highly deformed intermediate rocks of the Howey Mine hanging wall. This site lies within the northeast trending Howey Bay – Flat Lake deformation zone and comprises Confederation age rocks.

STOP 7 - HOWEY BAY-FLAT LAKE DEFORMATION ZONE (Fig. 2)

The Howey Bay – Flat Lake deformation zone was defined by Durocher and Hugon (1983), and was interpreted to be part of a belt-wide system of transcurrent shear zones hosting most of the major gold deposits. Recent detailed work has led to a reevaluation of this concept (Sanborn-Barrie et al. 2000).

This stop is approximately 750 m southwest of the Howey mine. Intense deformation at this stop has destroyed most primary textures that might be used to identify the rocks. The dominant rock type is mylonitized intermediate tuff. Pink felsic dikes that cut the intermediate rock are also mylonitized. Iron-carbonate veins are boudinaged and transposed into the shear direction. The far western extremity of the outcrops exposes deformed quartz-feldspar dyke (similar in appearance to the Dome stock) containing mafic xenoliths and quartz-tourmaline veinlets.

STOP 8 - REDCON CARBONATE ZONE: Proximal ferroan-carbonate alteration; carbonate veining

West and east sides of Nungesser Road (Fig. 2)

This area is approximately 4 km north of the Campbell–Red Lake deposit, still within the proximal, ferroan-carbonate alteration facies. The outcrops are weakly foliated (145°), dominantly massive to pillowed Balmer assemblage basalts, occurring within the amphibolite-facies metamorphic aureole of the Walsh Lake pluton.

The stripped area on the east side of the Nungesser road was mapped in detail (Figure 5) by Redcon Gold Mines in 1981 (assessment files) and now forms part of Goldcorp Inc.'s holdings. Here, a 1-2 m wide carbonate vein is exposed near its southeastern termination. The vein can be traced in outcrop and drilling for approximately 750 m to the west-northwest and will be seen at the next stop on the west side of the road. Gold occurs in north-northwest trending, irregular, centimetre-thick quartz-actinolite stringers within the carbonate vein.

After an initial, pervasive biotite alteration event, cross-cutting relationships suggest the following sequence of formation (*from* Lavigne et al. 1986):

1. amphibole-quartz-calcite cross-fractures
2. quartz-calcite veins
3. ferroan-dolomite veins
4. mafic dyke
5. auriferous quartz veins

Silicification evident in the pillowed flow on the northern half of the outcrop is barren and apparently not related to the gold-rich silicification event, rather, it may be due to local silica dumping following pervasive carbonate metasomatism.

A "black line" fault occurs in the northern wall rocks of the main carbonate vein. A mafic (or lamprophyre) dyke (unit 4, above) cuts the vein, but is itself cut by late quartz-actinolite-gold stringers.

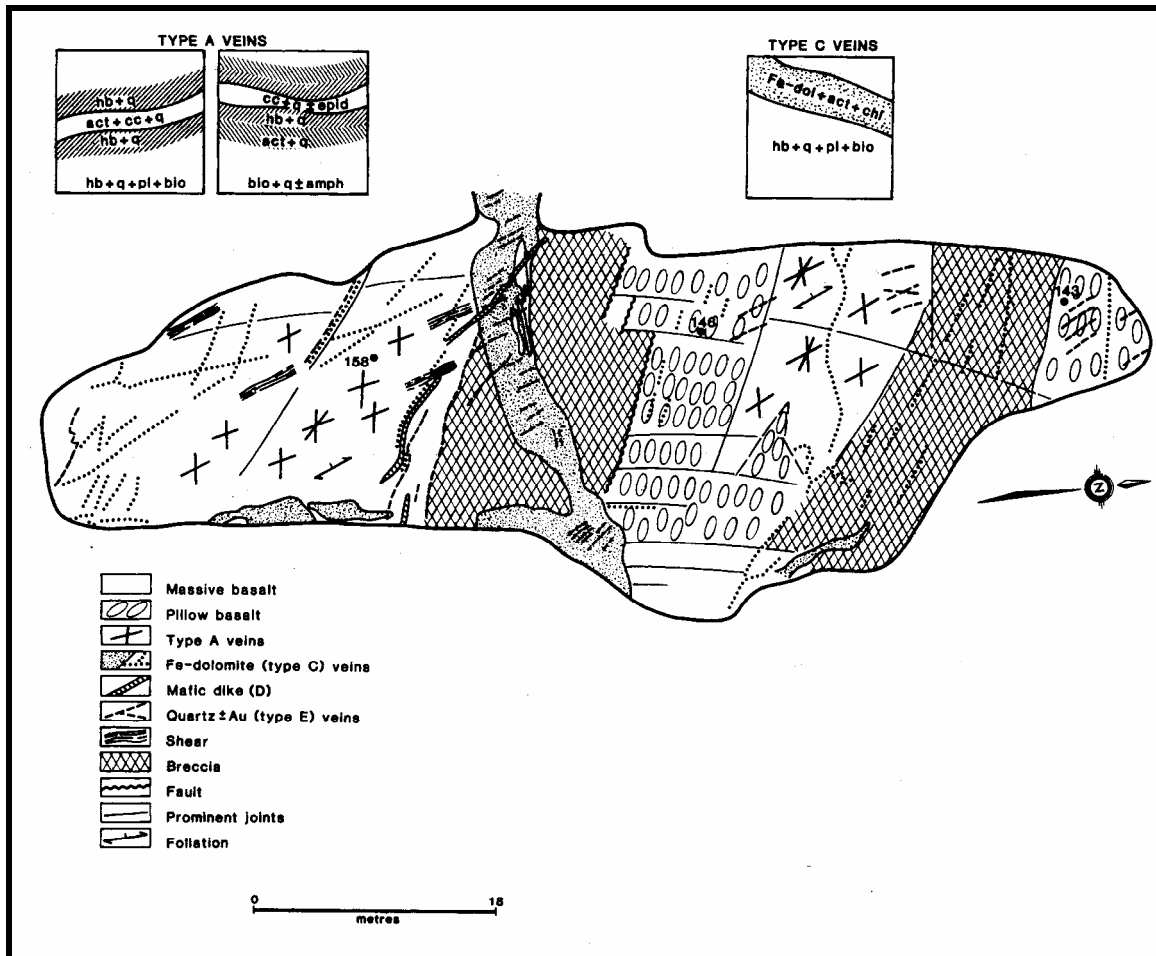


Figure 5. Detailed geology of the Redcon prospect (*modified from Lavigne et al. 1986*)

The western outcrops are approximately 300 m west-northwest of the previous exposures.

Things to note on the western series of outcrops:

- differing colours of cross-cutting carbonate veins
- colloform/crustiform textures in carbonate veins
- andalusite-garnet-biotite alteration of pillows cut by calc-silicate veins (diopside ± calcite, quartz, tourmaline; retrograding to epidote, tremolite, actinolite/hornblende, magnetite)
- calc-silicate veins cross-cut by carbonate veins
- folding of carbonate veins by the "Mine trend" S_2

REFERENCES AND BIBLIOGRAPHY OF RECENT RESEARCH

- Chi, G., Dubé, B. and Williamson, K. 2002. Preliminary fluid-inclusion microthermometry study of fluid evolution and temperature-pressure conditions in the Goldcorp High-Grade zone, Red Lake mine, Ontario, *in* Current Research 2002-C27, geological Survey of Canada, 14p.
- Dubé, B., Balmer, W., Sanborn-Barrie, M., Skulski, T. and Parker, J. 2000. A preliminary report on amphibolite-facies, disseminated-replacement-style mineralization at the Madsen gold mine, Red Lake, Ontario; *in* Current Research 2000-C17, Geological Survey of Canada, 12p.
- Dubé, B., Williamson, K., and Malo, M. 2001. Preliminary Report on the Geology and Controlling Parameters of the Goldcorp Inc. High Grade Zone, Red Lake Mine, Ontario; Geological Survey of Canada, Current Research 2001-C18, 13 p.
- Dubé, B., Williamson, K., and Malo, M. 2002. Geology of the Goldcorp Inc. High Grade zone, Red Lake mine, Ontario: an update, *in* Current Research 2002-C26, Geological Survey of Canada, 15p.
- Durocher, M.E. and Hugon, H., 1983. Structural geology and hydrothermal alteration in the Flat Lake-Howey Bay deformation zone, Red Lake area, *in* Summary of Field Work, 1983, Ontario Geological Survey, Miscellaneous Paper 116, p. 216 to p. 219.
- Gulson, B.L., Mizon, K.J. and Atkinson, B.T. 1993. Source and timing of gold and other mineralization in the Red Lake area, northwestern Ontario, based on lead-isotope investigations, *Canadian Journal of Earth Science* v. 30, pp. 2366-2379.
- Horwood, H.C., 1940. Geology and mineral deposits of the Red Lake area, *in* Forty-ninth Annual Report of the Ontario Dept. of Mines, vol. XLIX, Pt. II, 231p.
- Lavigne Jr., M.J., Hugon, H., Andrews, A.J. and Durocher, M.E. 1986. Gold deposits of the Red Lake District, Relationships of gold mineralization to regional deformation and alteration in the Red Lake greenstone belt, Ontario, *in* Gold '86, Excursion Guidebook, ed. Pirie, J. and Downes, M.J., p.167 to p.211.
- Parker, J.R. 1999. Exploration potential for volcanogenic massive sulphide (VMS) mineralization in the Red Lake greenstone belt; *in* Summary of Field Work and Other Activities 1999, Ontario Geological Survey, Open File Report 6000, p.19-1 to 22-26.
- Parker, J.R. 2000. Gold mineralization and wall rock alteration in the Red Lake greenstone belt: a regional perspective; *in* Summary of Field Work and Other Activities 2000, Ontario Geological Survey, Open File Report 6032, p.22-1 to 22-27.

- Parker, J.R. 2001. Intermediate to Felsic Plutons in the Red Lake Greenstone Belt: Relationship to Deformation and Gold Mineralization; *in* Summary of Field Work and Other Activities 2001, Ontario Geological Survey, Open File Report 6070, p. 19-1 to 19-10.
- Penczak, R.S., and Mason, R. 1999. Characteristics and origin of Archean premetamorphic hydrothermal alteration at the Campbell Gold Mine, Northwestern Ontario, Canada, *Economic Geology*, v. 94. pp. 507-528.
- Penczak, R.S., and Mason, R. 1997. Metamorphosed Archean epithermal Au-As-Sb-Zn-(Hg) vein mineralization at the Campbell Mine, Northwestern Ontario, *Economic Geology*, v.92, pp 696-719.
- Percival, J.A., Bailes, A.H., Corkery, M.T., Dubé, B., Harris, J.R., McNicoll, V., Panagapko, D., Parker, J.R., Rogers, N., Sanborn-Barrie, M., Skulski, T., Stone, D., Stott, G.M., Thurston, P.C., Tomlinson, K.Y., Whalen, J.B., and Young, M.D. 2000. An integrated view of Western Superior crustal evolution: highlights of 2000 NATMAP studies, *in* Summary of Field Work and Other Activities 2000, Ontario Geological Survey, Open File Report 6032, p.13-1 to p.13-17.
- Pettigrew, N., 1999. Structural and alteration history of the Buffalo Gold Deposit, Red Lake, Ontario; B.Sc. Thesis, University of New Brunswick, 154p.
- Pirie, J. and Downes, M.J., eds., 1986. Gold '86 Excursion Guidebook.
- Sanborn-Barrie, M., Skulski, T., and Parker, J. 2001. Three hundred million years of tectonic history recorded by the Red Lake greenstone belt, Ontario, *in* Current Research 2001-C19, Geological Survey of Canada, 32p.
- Sanborn-Barrie, M., Skulski, T., Parker, J. and Dubé, B., 2000. Integrated regional analysis of the Red Lake greenstone belt and its mineral deposits, western Superior Province, Ontario, *in* Current Research 2000-C18, Geological Survey of Canada, 16p.
- Skulski, T., Sanborn-Barrie, M. and Sanborn, N., 2001. New U-Pb geochronology in the Red Lake greenstone belt, Western Superior NATMAP, unpublished poster.
- Stone, D. and Hallé, J. 2000. Geology of the Blackbear, Yelling and Stull Lake areas, Northern Superior Province, Ontario, *in* Summary of Field Work and Other Activities 2000, Ontario Geological Survey, Open File Report 6032, p. 15-1 to 15-9.