APPLIED QUATERNARY GEOLOGY AND TILL GEOCHEMISTRY OF THE LOCH LOMOND REGION, CAPE BRETON ISLAND, NOVA SCOTIA

by

FENTON MURDOCH ISENOR

Thesis
submitted in partial fulfillment of the requirements for
the degree of Master of Science (Geology)

Acadia University
Fall Convocation 2000

0-612-54529-6

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ACKNOWLEDGMENTS

This late-in-life graduate degree was possible with the support and encouragement of many colleagues, professors, friends and family. It was first suggested by Dean Stephen Manley of the University College of Cape Breton. His recommendation for support from the University, continued by his successor, Hubert Chiasson, is appreciated. The professors of Acadia University have been patient and understanding. Ian Spooner accepted the challenge of being principle advisor. He has seen through the eyes of his student, just as the student has seen through the eyes of the mentor, and both have reaped rewards along the journey. Beth McClenaghan, from the Geological Survey of Canada, supported this project with analyses and technical data. In addition to giving encouragement, some friends were even willing to take on field work, including Jim Marten, Mike LeBlanc, John MacInnis, Al MacQuarrie, Brad Langille Wayne Nichols and Peter Graves. My son, David, mastered the skill of locating our position on aerial photographs at the age of seven. The Munsell colour determinations and acid tests were completed under the observant eye of my daughter, Merrill. Maps were prepared by Steve Bailk of the Geological Survey of Canada. Additional figures were drawn by Karen Johnston and Paul Barker at Acadia University. The University College of Cape Breton provided financial support in the form of research and professional development grants (Robert Morgan, Robert Campbell, Stephen Manley and Hubert Chiasson). NSERC grant fund assistance for field expenses came from Dr. Spooner. Additional financial support came from my parents and my sisters, Janice, Margaret and Adelia.

I am truly indebted to Ian Spooner for his advice and counsel. However, it is his sense of dedication to his students that is foremost in my mind. I thank you Ian and your family for your extra time.

I cannot express enough thanks for the support I received from my wife, Gayle. I believe marriage is trust, and with that there should be no fear of being taken for granted.

During the tenure of this thesis I lost a brother-in-law, Robert Trenchard, in May, 1998, and a good friend, Al MacQuarrie , in May, 2000. Both were problem solvers who would never allow a problem to get the best of them. I salute both of you and dedicate this thesis to your memories.

"We hauled the big rock....Dave and I landed her."

-Ernest Buckler, The Mountain and the Valley

ABSTRACT

Southeastern Cape Breton Island is host to several former industrial mineral and base metal mines discovered by traditional prospecting methods, but present exploration is hampered by a complex glacial history. Late Wisconsinan ice advances resulted in the deposition of five distinct tills. The basal grey till (LL-1) is a compact, fine-grained till found in local depressions. The regional red till contains 10-30% clasts and 20-30% clay and was deposited by an eastward ice advance (LL-2). Northward (LL-3) and southward (LL-4) ice flows were responsible for two hybrid tills that formed in part through inheritance and overprinting. The local stony till was formed by a southeasterly ice-flow event (LL-5) and contains 35-75% angular local clasts and less than 10% clay. The southern half of the study area is dominated by 50 m high bedrock-cored till ridges. Inter-ridge areas are overlain by organic deposits and glaciofluvial sediments which provide anomalous geochemical values. Samples were collected at 3-5 km spacing and the <0.063 mm fraction was analyzed. Till geochemical patterns are complex as a result of lithological repetition, complex glacial history and numerous mineralization types. Detailed analysis of sedimentology resulted in the recognition of individual tills at geochemical sample sites. Till pebbles could be used to help delineate bedrock boundaries. Additional sampling of the regional red till could be conducted in the Loch Lomond valley for as yet undetected mineralization located west of the study area. Complex Ba patterns require a subtle sampling strategy for future exploration. The local stony tills in the Mira Hills are recommended as the best stratigraphic target to delineate Cu (Au) values in rocks of the Stirling Group.

CHAPTER 1

INTRODUCTION

1.1 Purpose

Several industrial mineral and base metal deposits occur in southeastern Cape Breton Island, Nova Scotia, all of which were discovered by traditional prospecting methods. Mineral exploration has been hampered by thick overburden, which limits outcrop exposures, and a complex glacial history. A precise interpretation of the glacial stratigraphy is crucial to the delineation of dispersal trains and fans, and to the determination of the provenance of geochemical anomalies. This information can be derived from the study of till geochemistry, clast lithology, glacial striae, till pebble fabric analysis and aerial photographic interpretation. Geologists from the Geological Survey of Canada (GSC) have collected this information from the northern portion of southeastern Cape Breton Island, and their work established a benchmark for this study (McClenaghan *et al.*, 1992; McClenaghan and DiLabio, 1994; 1996). The purpose of this study is to add to the geological database of an area directly west of the original GSC work (Figure 1). These new data are important because they provide information which aids in the search for additional mineral deposits in areas covered by glacial sediments. Specifically, this study provides: (1) a description of the Quaternary stratigraphy and geology of the Loch Lomond area; (2) an investigation of till-clast lithologies as a method of determining ice-flow directions; (3) information as an aid in the interpretation of the till geochemistry.

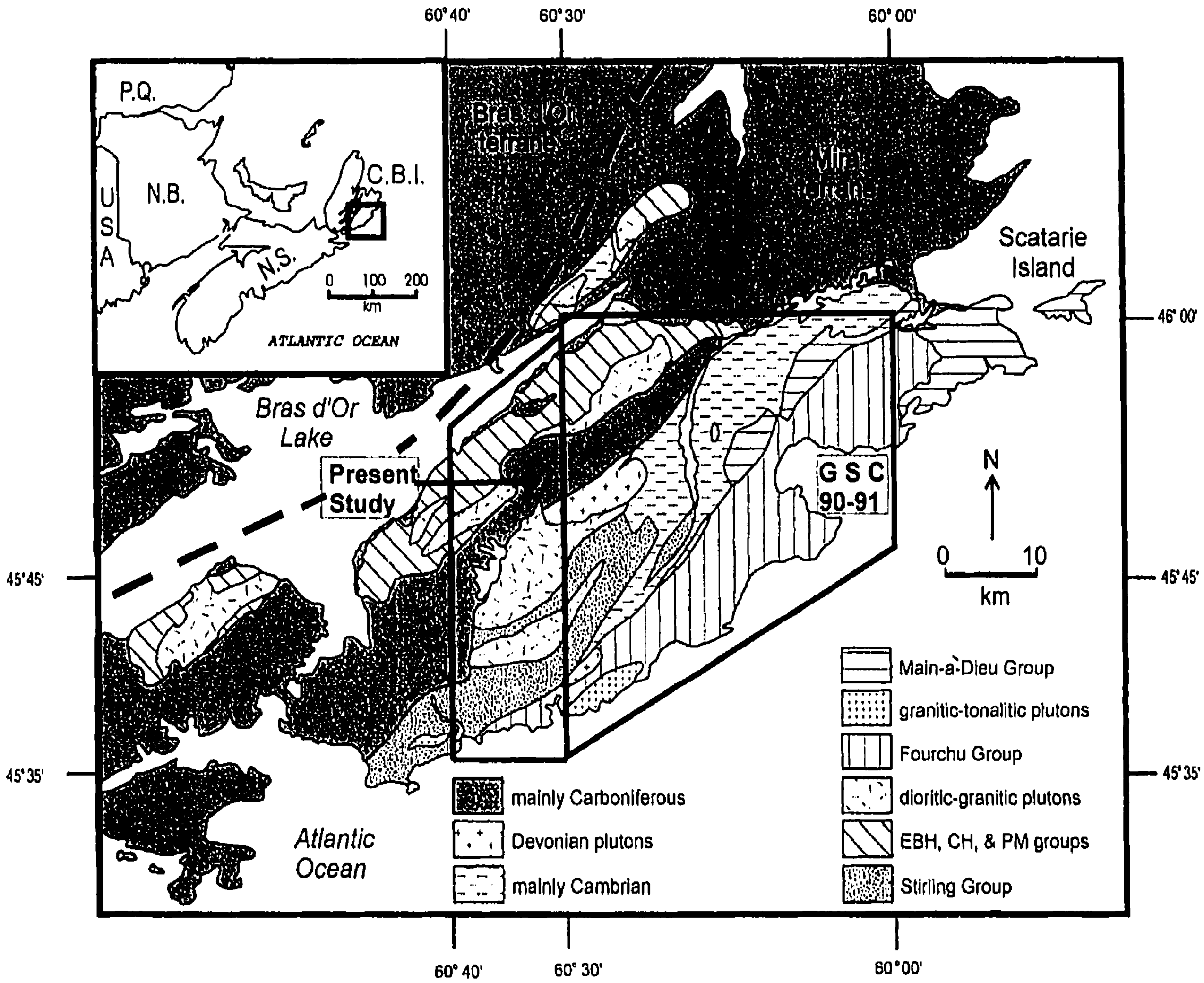


Figure 1: Location map showing Loch Lomond study area and G.S.C. study area(1990-91) superimposed on the regional geology of southeastern Cape Breton Island.
Bedrock geology modified from Barr et al.(1996).

1.2 Location and access

The Loch Lomond study area is located in southeastern Cape Breton Island, Nova Scotia, 45 km southwest of Sydney, between latitudes 45°35' N and 45°57' N, and longitudes 60°30' W and 60°40' W. It is bounded by the East Bay of the Bras d'Or Lake on the northwest and the Atlantic Ocean on the southeast (Figure 1). The area includes parts of Cape Breton and Richmond Counties, and comprises approximately 400 km^2. Parts of National Topographic Series (NTS) map sheets 11F-10 (St. Peters) and 11F-15 (Grand Narrows) cover the study region. Lake Uist and Loch Lomond, the largest freshwater lakes of southeastern Cape Breton Island, drain southward to the Atlantic Ocean via Grand River. Villages in the vicinity include Big Pond, Irish Cove, Loch Lomond and Grand River (Figure 2). Paved highways in the area include Highway No. 4 and the Fleur-de-Lis Trail which parallel the northern and southern boundaries, respectively. Numerous unpaved secondary roads and logging roads provided access to the remaining area. An all-terrain vehicle (ATV) was used to gain access to several sites in the East Bay Hills. Coastal exposures were reached by foot.

1. 3 Geological setting and previous work

Introduction

Cape Breton Island is part of the northern Appalachian orogen and has generally been considered as part of the Avalon terrane of eastern Newfoundland (Williams, 1979). Barr and Raeside (1986, 1989) have proposed that Cape Breton Island can be divided into four tectonostratigraphic terranes, primarily on the basis of pre-Carboniferous geology. More recently, only the southeastern part of Cape Breton Island has been considered part

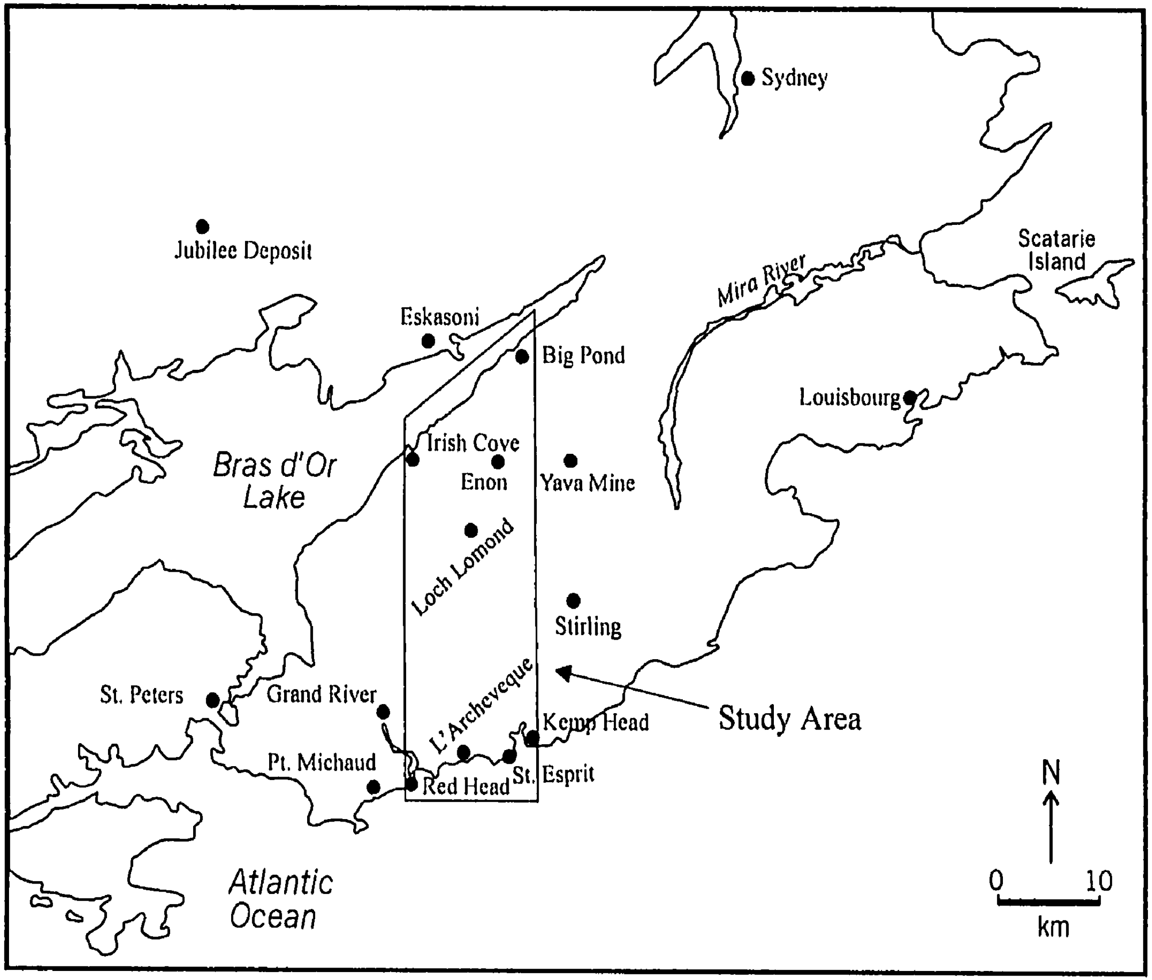


Figure 2: Some regional place names referred to in text. For geochemical sample sites locations, refer to Figure 8.

of the Avalon terrane (Barr *et al.*, 1998). Southeastern Cape Breton (Figures 3 and 4) consists of volcanic, sedimentary and plutonic rocks of Late Precambrian age, fossiliferous Cambrian strata and Devonian plutons (Weeks, 1954; Bevier *et al.*, 1993; Barr *et al.*, 1996). The northeast-trending belts of Precambrian rocks are separated from each other by clastic and chemical sedimentary rocks which were deposited in faulted grabens and half-grabens and which are part of the Carboniferous Maritimes Basin (Boehner and Prime, 1985, 1993; Calder, 1998). Cape Breton Island was assigned to the Mira terrane (Barr and Raeside, 1989; Barr *et al.*, 1998) and is considered part of the Avalon terrane of eastern Newfoundland. Barr *et al.* (1998) suggested that the Avalon terrane *sensu stricto* could itself be considered a Neoproterozoic composite terrane.

Barr *et al.* (1996) mapped the pre-Carboniferous rocks in southeastern Cape Breton Island which had not been systematically mapped since the late 1940s (Weeks, 1954). They assigned the various volcanic, sedimentary, and plutonic rocks of Late Precambrian age to five separate belts. These blocks include the Coastal belt, the Stirling belt, East Bay Hills belt, Coxheath Hills belt and the Sporting Mountain belt (Figures 3 and 4). The first three belts occur in the study area and are discussed in this thesis. A schematic diagram (Figure 5) provides a summary of the geological history of these belts, relating the order of tectonic events in geological time.

The Carboniferous rocks in the study area have been mapped by Boehner and Prime (1993) and White and Barr (1998). The Horton Group is represented by the Clam Harbour River Formation (White and Barr, 1998) which consists mainly of quartz arenite and related clastic units. These rocks outcrop in the southwestern portion of the study area. Rocks of the Windsor and Canso groups form a major portion of the Loch

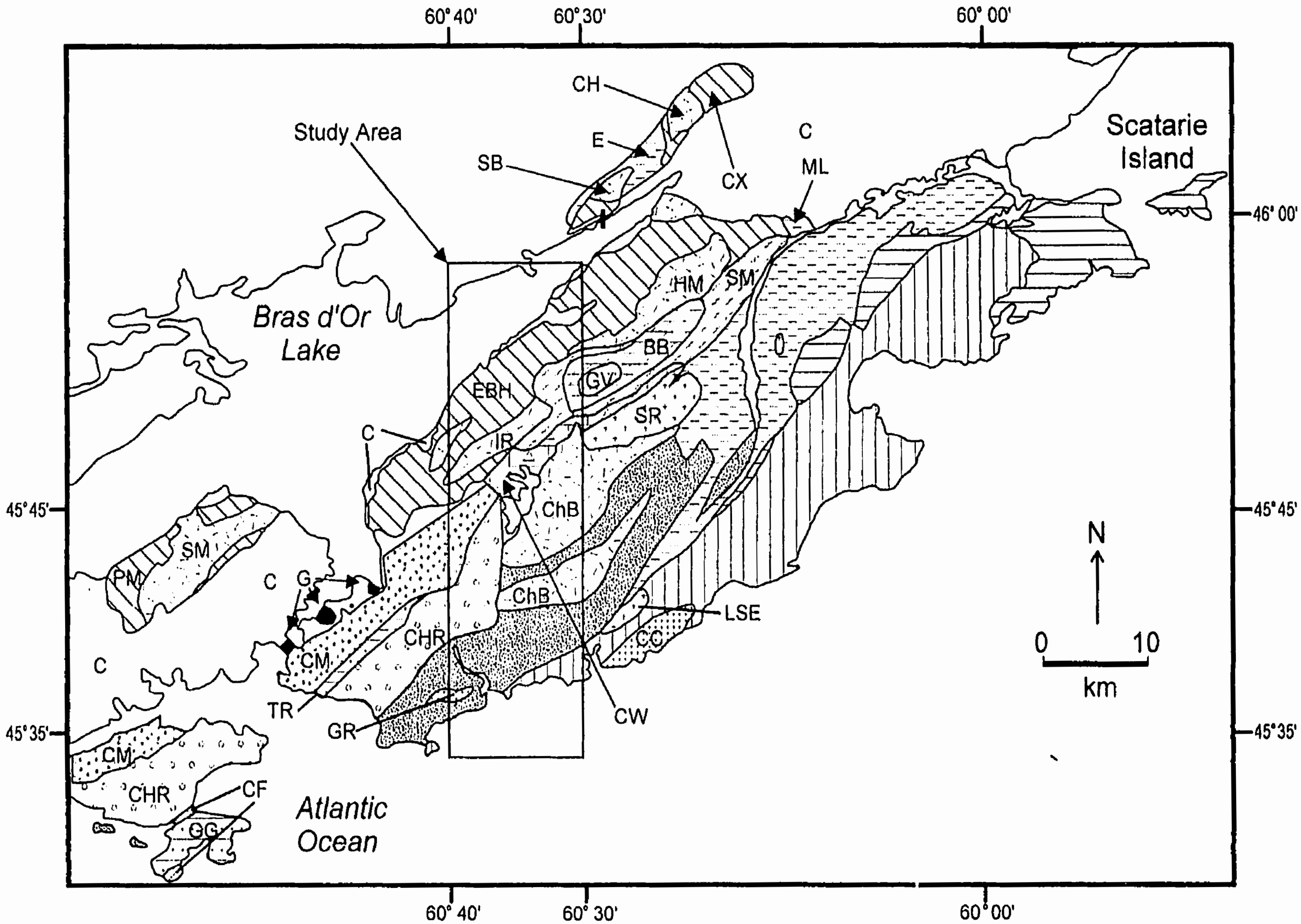


Figure 3: Detailed bedrock geology map of southeastern Cape Breton Island. See Figure 4 for legend.

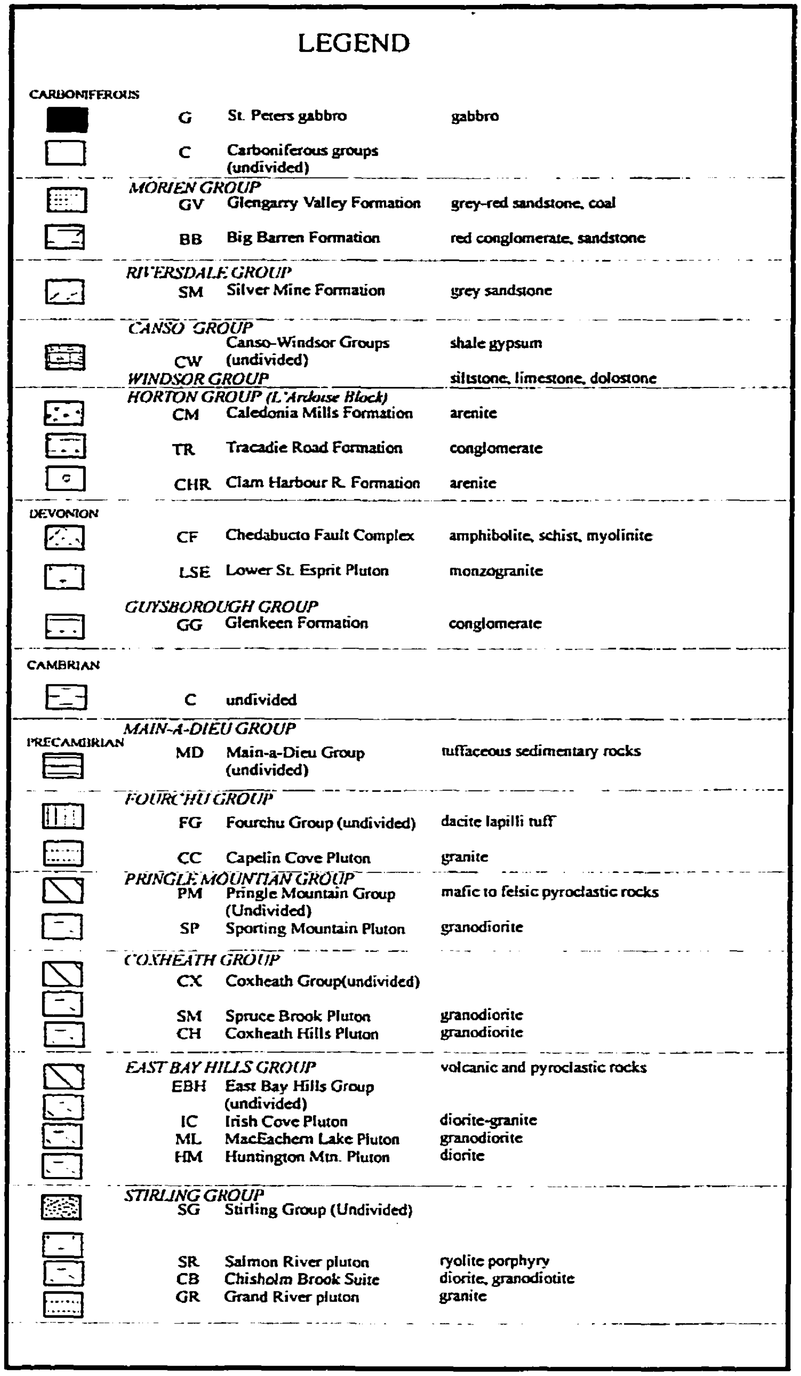


Figure 4: Legend of stratigraphic units in map 3.

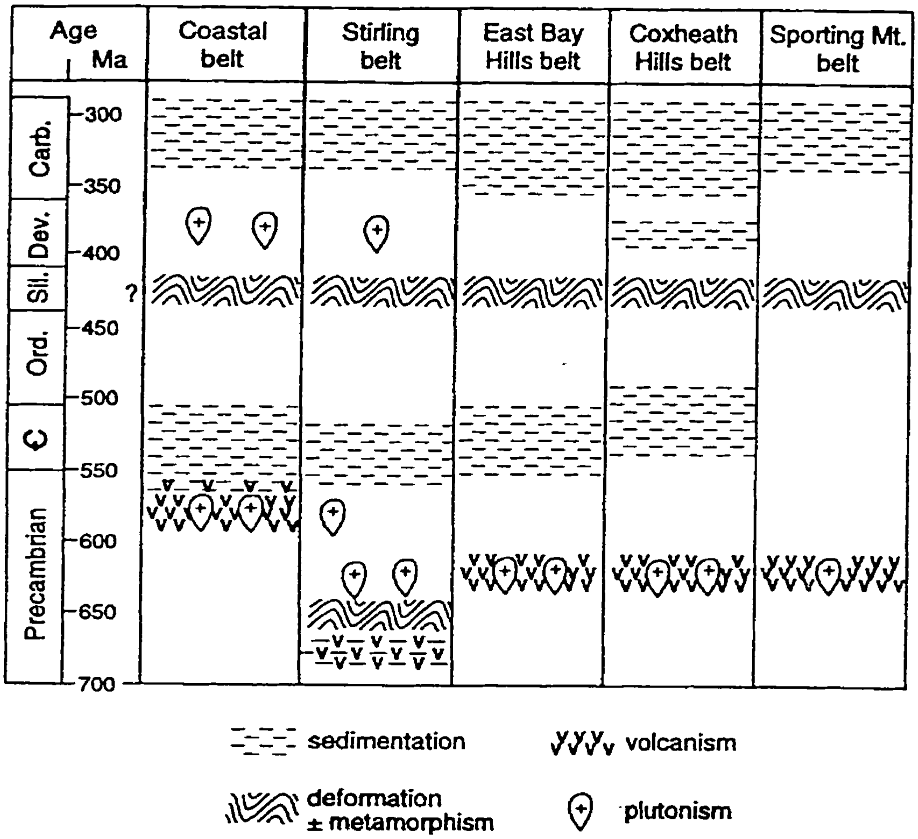


Figure 5: Schematic diagram summarizing the Precambrian-Carboniferous geological history of southeastern Cape Breton Island. Diagram from Barr et al., (1996).

Lomond Basin, with a stratigraphic thickness up to 2000 m of continental and marine sedimentary rocks. Upper Carboniferous rocks include the Cumberland Group which consists of the Silver Mine Formation (sandstone), Big Barren Formation (red conglomerate) and the Glengarry Valley Formation (coal-bearing sandstone and mudstone) as described by Boehner and Prime (1993). These units outcrop in the northeastern quadrant of the study area (Figure 6).

In southeastern Cape Breton Island, several Wisconsinan ice-flow phases left several main till sheets of differing colour, texture, lithology and provenance, superimposed drumlins with fluting, and crosscutting striations (MacDonald *et al.*, 1991; McClenaghan *et al.*, 1992; Grant, 1994; McClenaghan and DiLabio, 1994, 1996). Local highland areas (East Bay Hills) are partly covered with glacial sediment, whereas lowlands and valleys are covered with a thick complex surficial stratigraphy (Grant, 1994).

Precambrian volcanogenetic polymetallic deposits have been mined east of the study area at Stirling (Macdonald, 1989; Barr *et al.*, 1996). Individual celestite, barite and galena deposits occur along a major nonconformity between the pre-Carboniferous basement and the Carboniferous marine and terrestrial sedimentary rocks (Forgeron, 1977; Felderhof, 1978; Macdonald, 1989; Boehner and Prime, 1993).

Late Precambrian volcanic and sedimentary rocks

Dawson (1855) made the first recorded geological observations in eastern Cape Breton Island. He considered the sedimentary pre-Carboniferous rocks as Devonian or Upper Silurian and reported the presence of "syenite (granite) and porphyry." Fletcher

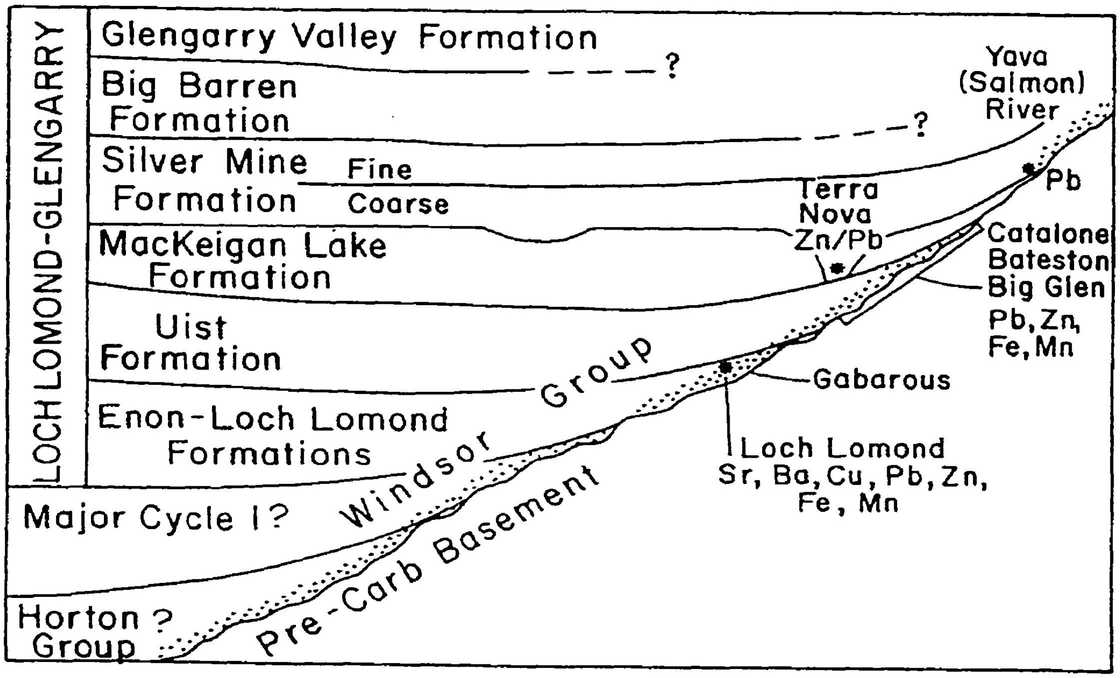


Figure 6: Schematic diagram (Boehner and Prime, 1993) indicating the distribution of mineral deposits in the Carboniferous basins of southeastern Cape Breton Island.

(1877, 1878, 1884a, 1884b) conducted the first systematic mapping of southeastern Cape Breton Island and produced several natural history maps at a scale of 1 in = 1 mi. These maps are still useful today when trying to locate significant outcrops. He suggested a pre-Silurian group to include all volcanic (felsites) and intrusive rocks, and reasoned that these rocks were the oldest units of the area. Fletcher then considered all younger sedimentary rocks to be Lower Silurian in age.

Gilpin (1886) compiled the first geological map of Cape Breton Island based on the surveys of Fletcher (1877, 1878, 1884). Later, Matthew (1903) ascribed a Cambrian age to Fletcher's "Lower Silurian" strata and inferred that the felsite (volcanic rocks) and syenites (granites) are Precambrian in age. To the north of this study area, Bell and Goranson (1938) mapped the Sydney and Glace Bay area (NTS map sheets 11K-1 and 11J-4), and assigned a Precambrian age to the igneous intrusions and volcanic rocks that outcrop on Scatari Island and in the Coxheath Hills.

Weeks (1954) mapped southeastern Cape Breton Island and proposed the name Fourchu Group to describe a group of variously metamorphosed volcanic and sedimentary rocks that lie beneath the Lower Cambrian Morrison River Formation. He divided the Fourchu Group into four belts which included the "coastal belt," "south side of East Bay," "north side of East Bay" and "Sporting Mountain" based on the separation from each other by Carboniferous sedimentary basins and East Bay of the Bras d'Or Lake. Hutchinson (1952) determined that the Bourinot Group (lava flows, pyroclastic rocks, shale, tuffaceous shale and siltstone, and volcanic breccia) are Middle Cambrian. However, Weeks (1954) had correlated the Bourinot Group in the Boisdale Hills (Hutchinson, 1952) with his Mira-L'Ardoise belt of sedimentary-volcanic rocks. Weeks

(1954) recognized there were differences between the Mira-L'Ardoise Belt and his Fourchu Group rocks, but he did not attempt any further subdivision of his noted variations of lithology.

Smith (1978) re-mapped a group of volcanic and sedimentary rocks located west of the Mira River which were part of the Bourinot Group of Weeks (1954). He re-assigned them to his Giant Lake Complex, equivalent to the Fourchu Group of Weeks (1954). Keppie (1979) included the Giant Lake Complex with the Fourchu Group. Murphy (1977) divided the Fourchu Group in the Louisbourg area into six members but his work did not extend as far south as this study area. Donohoe (1981) suggested that lithological subdivisions were possible in the Fourchu Group. Macdonald (1989) conducted a metallogenic study of southeastern Cape Breton Island and recognized lithological differences in the Fourchu Group. Macdonald (1989) also suggested that further detailed study of Stirling-type pyritic showings was required.

Barr *et al.* (1992, 1996) revised the work of Weeks (1954) with additional mapping and U-Pb age dating (Bevier *et al.*, 1993). Their work divided the Fourchu Group (Weeks, 1954) into the East Bay Hills, Coxheath Hills and Pringle Mountain groups (620 Ma), and the coastal belt (Weeks, 1954) into a redefined Fourchu Group (575 Ma) and a younger Main-à-Dieu sequence (563 Ma) (Figure 5). The East Bay Hills Group occurs in the East Bay Hills and is composed of andesitic to dacitic lapilli tuff, with crystal and lithic fragments, and is considered to have formed in a subaerial environment. These rocks exhibit sub-greenschist to lower greenschist metamorphism but display an intense cleavage that parallels the northeasterly trend of the belt. In the Stirling belt, part of the Middle Cambrian Bourinot Group of Weeks (1954) and Giant

Lake Complex of Smith (1978) was reassigned to the Precambrian based on a ca. 680 Ma age from a rhyolite unit (Bevier *et al.*, 1993). Barr *et al.* (1996) renamed this unit the Stirling Group. The Stirling Group is dominated by andesitic to basaltic lapilli tuff and tuffaceous litharenite and siltstone sequences as well as basaltic flows and breccia, rhyolitic crystal-rich lapilli tuff and rhyolitic quartz-feldspar porphyry (Barr *et al.*, 1993). This work identified the Stirling Group as the oldest rocks of the Mira Terrane (Bevier *et al.*, 1993). These rocks are host to exhalative volcano-sedimentary polysulfide mineralization at Stirling (Macdonald, 1989).

Plutonic rocks

Weeks (1954) briefly described the plutons in southeastern Cape Breton Island as mainly Devonian. Radiometric dating by Cormier (1972) and Keppie and Smith (1978) indicated that many are Cambrian or older. Many of the names assigned to these plutons by O'Reilly (1977) were retained by Barr *et al.* (1996). O'Reilly (1977) proposed the name Loch Lomond Complex for the largest pluton in the Stirling belt, to include a rhyolite unit and granitic and gabbroic units which were first mentioned by Weeks (1954). McMullin (1984) renamed the rhyolitic part the Salmon River rhyolite porphyry and the granitic part the Chisholm Brook Suite. Barr *et al.* (1984) suggested that the northeastern rhyolitic part is Devonian and the southwestern parts are Late Precambrian to Early Cambrian. This Late Precambrian age was confirmed with U-Pb (zircon) dating which yielded an age of 620 +3/-2 Ma (Barr *et al.*, 1990). Other plutons in the Stirling belt include the Grand River pluton (leucogranite) which is considered to be ca. 575 Ma because it is similar in lithology to the dated Capelin Cove Pluton (Barr *et al.*, 1996).

In the Coastal belt, the Capelin Cove Pluton (leucocratic monzogranite) (574±3 Ma) outcrops on the eastern edge of the study area (Barr *et al.,* 1996). The Devonian Lower St. Esprit pluton (hornblende-biotite monzogranite) outcrops to the east of the study area (Figure 3) and is northwest of the Caplin Cove pluton. In the East Bay Hills belt, the Irish Cove pluton (monzogranite) (ca. 620 Ma) represents late Precambrian calc-alkalic intrusive activity in this study area (Barr *et al.*, 1996). The Huntington Mountain Pluton (syenogranite to diorite) is situated northeast of the study area (Barr *et al.*, 1996). Barr *et al.* (1994) determined that the St. Peters gabbroic plutons west of this study area are Carboniferous, with an U-Pb age of ca. 340 Ma.

Cambrian-Ordovician sedimentary rocks

Hutchinson (1952) and Weeks (1954) divided the post-Fourchu Group and pre-Carboniferous sedimentary rocks of southeastern Cape Breton Island into several groups and formations as summarized in Table 1. The lower-most Early Cambrian unit was originally called the Morrison River Formation, and consists of red clastic sedimentary rock, shale and a white quartzite member. The Morrison River Formation is overlain conformably by fossiliferous strata of the MacCodrum Formation and the Trout Brook Formation (Table 1). Barr *et al.* (1996) redefined the Morrison River Formation as the Kelvin Glen Group (west of Mira River), the name which Smith (1978) had originally suggested to include all of the Early and Middle Cambrian formations. The rocks located east and north of the Mira River were renamed the Bengal Road Formation (quartz pebble conglomerate) and Sgadan Lake Formation (quartz arenite) by Barr *et al.* (1996). The remaining Early Cambrian units, the MacCodrum Formation (green shale) and the Canoe

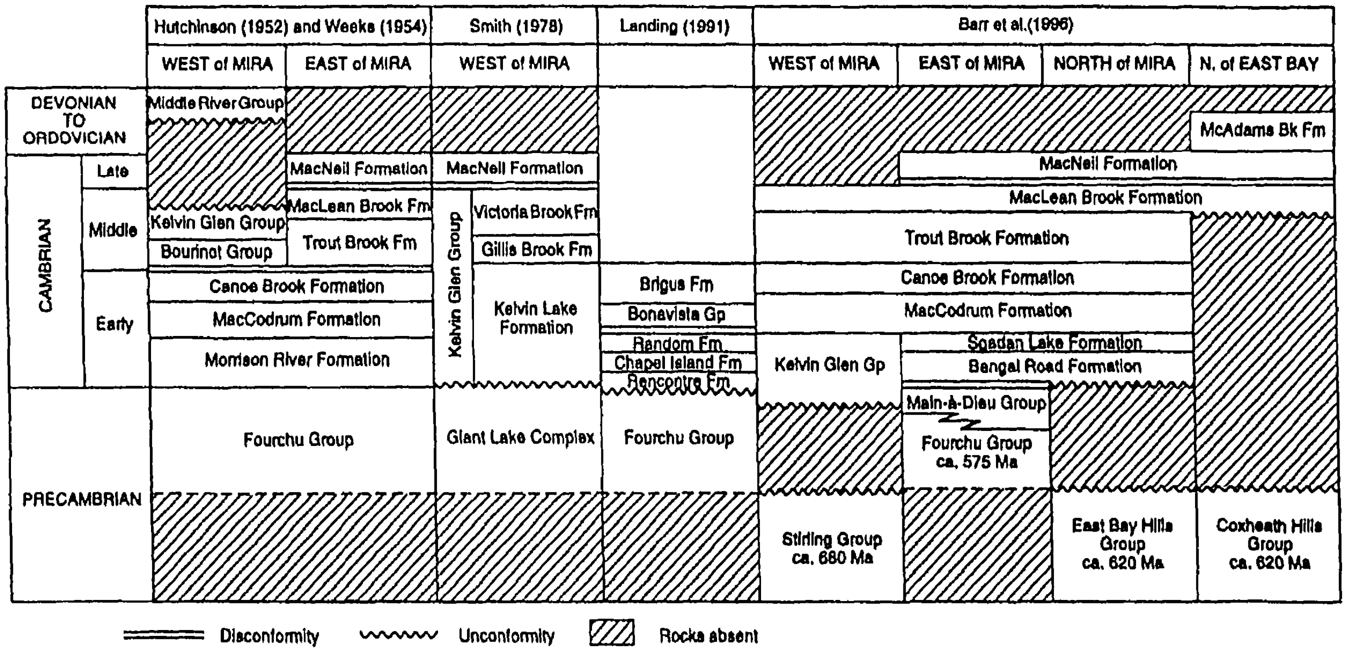


Table 1: Chart showing previous stratigraphic interpretations and units for southeastern Cape Breton Island including the recent work of Barr et al., (1996).

Brook Formation (red to green claystone) as defined by Weeks (1954) were retained by Barr *et al.* (1996). The Middle Cambrian units, Trout Brook Formation (grey to black shale) and MacLean Brook Formation (siltstone and shale) defined by Weeks (1954) were also retained by Barr *et al.* (1996) in the areas west, east and north of the Mira River and also north of East Bay for the MacLean Brook Formation. The Late Cambrian MacNeil Formation, consisting of black shale and limestone (Hutchinson, 1952; Weeks, 1954) east and north of the Mira River and also north of East Bay, was also retained by Barr *et al.* (1996). The Ordovician MacAdams Brook Formation (Barr *et al.*, 1996) occurs only north of East Bay.

These Cambrian-Silurian rocks do not outcrop in the study area, but their descriptions have been included to provide a complete geological history of southeastern Cape Breton Island. They are important constituents in the pebble counts of McClenaghan *et al.* (1992) but were not a factor in this study.

Carboniferous geology

The Loch Lomond Basin and the Glengarry Half Graben are small structural elements of an extensive basin system in Atlantic Canada containing Carboniferous rocks. This collection of basins was called the Fundy Basin (Bell, 1958) and the Maritimes Basin (Boehner *et al.*, 1988). Locally, these two basins in southeastern Cape Breton Island are grouped with the Central Cape Breton Carboniferous Basin (Calder, 1998). Boehner and Prime (1993) recognized that these two basins are genetically related and spatially connected but used separate names to differentiate between the two. Carboniferous sedimentary rocks infilled these rift-formed basins which separate the

Precambrian East Bay Hills from the Precambrian Stirling belt and the Cambro-Ordovician sedimentary units of the Mira River area.

Early geological observations in the area were reported by Dawson (1868). Fletcher (1878, 1884a, 1884b) carefully located coal, gypsum and limestone outcrops, as well as showings of barite at Pine Brook in the two basins. Weeks (1954) reported on the Mississippian and Pennsylvanian rocks of this region in the St. Peters and Grand Narrows map sheets (NTS 11F-10 and 11F-15). Shea and Murray (1967) described the limestone and dolomite deposits of the area, as well as providing detailed chemical analyses. Exploration and mining geologists have added detail through their unpublished maps and reports (e.g., Crowell, 1971; Forgeron, 1977). Boehner and Prime (1993) referred to many other detailed exploration reports and theses which describe the Yava deposit located northeast of this study area. The most detailed report on the Carboniferous rocks of this area was compiled by Boehner and Prime (1993). They formalized many of the lithological units of the area from drill core logs, as most of these formations do not outcrop in the Loch Lomond basin area (Figures 3 and 6).

The Devono-Carboniferous allochthonous L'Ardoise Block underlies the southwestern edge of the study area (Weeks, 1954; Boehner and Prime, 1993). White and Barr (1998) divided the L'Ardoise Block into the Clam Harbour River, Tracadie Road, and Caledonia Mills formations of the Horton Group, along with the Macumber Formation of the Windsor Group (Figure 3). These units consist of coarse terrestrial sediments (Horton Group) and grey laminated limestone (Macumber Formation). The Loch Lomond Basin contains up to 500 m of marine evaporites, carbonates and continental redbeds of the Windsor Group (Boehner and Prime, 1993). The Windsor

Group has been subdivided into three formations (Figure 6): Enon Formation, Loch Lomond Formation and Uist Formation (Crowell, 1971; Forgeron, 1977; Boehner and Prime, 1985, 1993). Siltstone, mudstone and evaporite of the Mabou (Canso) Group are represented in the study area by the MacKeigan Lake Formation but do not outcrop in the Loch Lomond Basin. A disconformity exists between the Mabou Group and Cumberland Group. The only formation of the Cumberland Group present in the Loch Lomond Basin is the Silver Mine Formation, consisting of sandstone, shale, conglomerate and coal.

The Glengarry Half Graben, a contiguous but distinct structural basin, is comprised of the Uist Formation through to the Silver Mine Formation. The younger Big Barren Formation (conglomerate) and Glengarry Valley Formation (grey and red sandstone, mudrock, minor coal) complete this sequence (Boehner and Prime, 1993).

Quaternary geology

No conclusive evidence of pre-Wisconsinan glacial deposits occurs on Cape Breton Island (Grant, 1994). However, a suite of littoral and organic beds at Northside East Bay and Eskasoni represents remnants of the Sangamonian inter-glaciation period between 126-47 ka BP (Grant, 1994). Late Wisconsinan glaciers covered Cape Breton Island from 62-47 ka BP until the last retreat from the Cape Breton Highlands 8-9 ka (Grant, 1994). Today, many highland areas, including the East Bay Hills, are only partially covered with Quaternary sediments. Several ice-flow phases deposited three till sheets of different colour, texture and lithology along the Atlantic Coast lowlands and the Loch Lomond Valley, forming a thick complex surficial stratigraphy. Extensive glacial deposits, cross-cutting striae and distinctive landforms indicate that Cape Breton Island was affected by eight major ice-flow events during the Late Wisconsinan (Grant, 1988, 1994). Southeastern Cape Breton Island was affected by at least three of these ice-flow events (McClenaghan *et al.*, 1992; McClenaghan and DiLabio, 1994, 1996).

Early work

Fletcher (1877, 1878, 1884) made some of the earliest observations on ice-flow directions on Cape Breton Island and reported northeasterly striae north of this study area. At East Bay on the Bras d'Or Lake, he recorded striae trending 244°. The conclusions of Honeyman (1890) that the grooves on beach outcrops in southwestern Cape Breton Island "..showed that an impulse was communicated from beyond Nova Scotia and Cape Breton, and that the glaciers of both are only members of a great glacier system which comprehended both Nova Scotia and Cape Breton" was the beginning of the insight on glaciers that we appreciate today.

Cann *et al.* (1963) produced the earliest soil maps for agricultural purposes. They classified the parent materials as mainly sandy-loam and stony sandy-loam till for most of this study area, and clay-loam and gravelly clay-loam till in the vicinity of the Loch Lomond valley lakes. Cameron (1961), having had access to the preliminary work of Cann *et al.* (1963), recognized "...that the effects of continental and local glaciation were relatively slight and that transportation over long distances of large amounts of material derived from the weathered bedrock did not take place.". Wright (1985) mapped Cape Breton Island for aggregate resources which concentrated on outwash and ice-contact deposits. He identified several of these gravel deposits along the East Bay shore and on the Salmon River Road in this study area as potential sources of construction aggregate. Forgeron (1977) observed local glacial features in and around the Kaiser Celestite properties at Lake Enon in the Loch Lomond Valley. He described the till in the Loch Lomond Valley as structureless, and locally up to 200 ft thick.

Recent work

The surficial geology of the Loch Lomond study area (Big Pond to Grand River) was mapped by Grant (1988; 1994) at a scale of 1:250 000 as a part of the regional surficial mapping of Cape Breton Island. Grant (1988, 1994) recognized up to eight successive ice-flow patterns and suggested that his B, C2, D, E1 and G flow patterns affected southeastern Cape Breton Island (Table 2).

Grant (1988, 1994) grouped tills together and classified them according to thickness and extent (Table 3). His till blanket (map unit 2a), defined as a mantle more than 5 m thick, is relatively fine grained and occurs in two main phases. One is a single sheet of till, chiefly composed of comminuted Carboniferous redbeds; the other comprises layers of different tills, produced by successive advances of the last glaciation. Examples of till blanket (unit 2a) in this study area include the drumlins of the East Bay Hills which were carved from pre-existing stratified sediments, and the giant till ridges near Grand River which range up to 50 m high, 1 km wide and 30 km long. The till veneer (map unit 2b) and discontinuous till veneer (map unit 2c) are sandy-stony tills which were generally locally derived from the more resistant crystalline rocks. They are 2-4 m thick and less than 2 m thick, respectively.

Table 2: Comparison of till characteristics, distribution, and flow orientation by early authors. The azimuths refer to the direction the glacier was moving. Letters, Roman numerals and numbers are the designations used by the authors. GTR= giant till ridge, SE CBI = southeastern Cape Breton Island, [1] Grant and King, 1984; Stea, 1984; Stea et al., 1985.

Grant (1994) **Cape Breton Island**	**McClenaghan and DiLabio (1996) Southeastern CBI**	**Stea (1994)** **Mainland Nova Scotia**
H Highlands: radial flow		
G Bras d'Or: radial flow 160°	**V** sandy till 165° - 180°	**4** **Chignecto Phase** southeast
E1 Bras d'Or: radial flow 050°		
D locally derived grey till 340° - 030°	**IV** sandy till 000° - 030°	**3** **Scotian Phase** northward
C2 not contiguous 140° fluting in GTR	**?** not observed	**2 ?** **Escuminac Phase** southward
B red silty till 070° - 115° formed GTR	**III** red silty till 080° - 110°	**1(B) ?** red silty till
	II grey till 095° - 110°	**1** early eastward
A Highlands ? in SE CBI	**I** orange - red till 120° -150°	**1** **Caledonia Phase** eastward Early Wisconsinan [1]

Table 3: Legend describing the stratigraphic record and associated unit designations as presented by Grant (1994).

UNIT	DEPOSIT
8	Organic deposits
7a-7b-7c	Colluvial deposits
6	Marine and Lacustrine deposits
5a-5b	Fluvial deposits
4	Glaciolacustrine deposits
3a-3b	Glaciofluvial deposits
2a-2b-2c	Till: blanket - veneer - discontinuous veneer
1	Residuum and regolith
Ra-Rb-Rc	Consolidated rock

Grant (1988, 1994) described glaciofluvial deposits (map units 3a and 3b) at only three locations in the study area. The deposits consist of ice-contact stratified drift (kames) composed of sandy-cobble gravel, and outwash plains and fans composed of sandy-coarse gravel. The former were identified in the Breac Brook area in the northeastern part of the study area, and along Highway No. 4 at Big Pond. Outwash was also mapped at the intersection of the Loch Lomond and Stirling roads. No glaciolacustrine deposits (map unit 4) were mapped in this study area. Fluvial deposits were mapped as postglacial and paraglacial alluvial terraces (map unit 5a), and as modern flood plains (map unit 5B) which consisted of sandy pebble alluvium. Both types are found west of Loch Lomond near the Irish Cove-Loch Lomond Road intersection while the upper Grand River flood plain is the most extensive example of modern fluvial deposits. Marine deposits (map unit 6), consisting of beaches, barriers, spits and the upper Grand River flood plain is the most extensive example of modern fluvial deposits. Marine deposits (map unit 6), consisting of beaches, barriers, spits and tombolos, are common on the Atlantic coast of the study area and to a lesser degree on the Bras d'Or Lake shore. Recent organic deposits (map unit 8) found in bogs, fens, swamps and coastal salt marshes are prevalent in the central eastern edge of the study area and locally in the East Bay Hills.

Grant (1988, 1994) stated that the first major glacial event after the formation of an ice cap on the highland plateau (A) was a strong west-to-east movement (B: 070°-115°) (Table 2) across the southern lowlands which introduced massive quantities of foreign red till from the west and formed the giant till ridges. Next, ice overlapped southward (C_2: 140°) on to the eastern part of the island from the direction of the Laurentian Channel. Grant (1994) suggested that there was a period of ice retreat because of iron staining on the glaciated surfaces as a result of the oxidation of iron by atmospheric oxygen. Finally, a strong flow (D) moved northward from the Scotian Shelf. Grant (1994) realized that an ice centre that occurred in the Atlantic Ocean and affected a positive land mass (Cape Breton Island) is not an easy concept to comprehend because glacial theory dictates that glacial ice flows down gradient from a highland source to a lower region. Grant (1994) suggested three possible explanations: (1) Cape Breton Island could have been affected by the northern component of radial flow from a large ice sheet on the outer shelf; (2) There may have been a floating ice shelf that grounded on the Canso bank and developed an ice dome which, when further nourished, developed a northward flow; (3) Possible calving of ice in the Gulf of St. Lawrence may have affected the glacio-isostatic loading, causing sea level to rise.

McClenaghan *et al.* (1992) described the geochemistry of till over the Framboise (11F-9) and Mira (11F-16) map areas and identified several locations with anomalous Pb, Cu-Zn, Cu-Mo and Ba trace element concentrations. Till-clast sampling and evaluation suggested that local sources were common and a short transport distance was implied. The striation record indicated that an ice-flow movement to the east was common (McClenaghan and DiLabio, 1994). McClenaghan and DiLabio (1996) concluded that three major ice-flow directions affected the area east of this study area. They also recognized four till units based on till colour, fabric and texture as noted at their Fox Cove section (Table 2). MacDonald *et al.* (1991) and MacDonald and Boner (1993) reported glacial, geological and multi-media geochemical studies near the Yava sandstone-hosted Pb deposit, located several kilometres east of this study area. Overburden drilling as part of their study revealed that several local drumlins have a core of moderately compacted silty till and an underlying silty sandy facies which they interpreted as being deposited by a northeasterly ice flow. The entire area is blanketed with an upper sandy till sheet deposited by a north-northeasterly ice flow. They referred to these two units as 2a and 2b, respectively, to correspond to glacial units of Grant (1988, 1994) (Table 2). Limited fabric analysis also supported their ice flow directions.

Economic geology

Southeastern Cape Breton Island has had the most active and diversified mineral production record of any area in Nova Scotia. It is still recognized as one of the most favourable exploration targets in the province. The area is a composite of geological environments favourable to several mineralization models. Precambrian rocks of the area host a polymetallic, volcano-sedimentary, massive sulfide deposit known as the Mindamar Mine at Stirling (Macdonald, 1989; Patterson, 1993; Barr *et al.*, 1996). Locally, Carboniferous rocks host economic deposits of celestite, barite, galena and pyrolusite (Bishop and Wright, 1974; Forgeron, 1977; Felderhof,1978; Fowler, 1984; Patterson, 1993). The nonconformity between Carboniferous rocks and pre-Carboniferous basement has been recognized as host to Sr and Ba deposits and locally carries Cu-Pb-Zn-Fe-Mn accessory minerals. Independent Cu-Pb-Zn mineralization is also found in similar settings in southeastern Cape Breton Island (Figure 6). Metallurgical limestone was quarried at Irish Cove. Coal and gypsum are also present in the Central Cape Breton Basin (Calder, 1998) but are not economic to date.

Fletcher (1884) was the first to report "barytes" at Pine Brook, celestite at Sydney River, and pyrolusite at McCuish Brook. At the end of the nineteenth century, prospectors discovered sulfide mineralization in Copper Brook at Stirling. Between 1915 and 1956, mining "produced 1.06 million tonnes of ore grading 6.3% Zn, 1.5% Pb, 0.8% Cu, 74 g/t Ag and 1.1 g/t Au" (Patterson, 1993). Exploration activity in the search for similar deposits has continued in the area to the present date. The Horton-Windsor contact, Windsor-pre-Carboniferous contact and the Horton-pre-Carboniferous contact have also been promoted as prospecting targets for many years (Fletcher, 1878; Messervey, 1930; Kelly, 1961) (Figure 6).

Celestite

Avard Hudgins (per. comm., 1999) collected a heavy bluish rock on a brook near Lake Enon in the early 1960s. The sample was thought to be barite and sat on a desk for two years before a chance analysis indicated that it was high in strontium. This led to the staking of the area by the Laura Corporation and the subsequent purchase of the deposit by the Kaiser Corporation. From 1970 to 1976, a total of 325,000 tons of approximately 60% grade celestite ($SrSO_4$) was mined from four open pits and an experimental room and pillar operation at Lake Enon by Kaiser Celestite Limited (Forgeron, 1979). Mining operations ceased in 1976 as a result of marketing problems. It is interesting to note that the closure parallels the end of the Vietnam War in 1975 (strontium is the key ingredient in flares and tracer bullets). Galena is commonly associated with these deposits and locally the celestite ore at the MacRae open pit contained 0.5% Pb (Boehner and Prime, 1993). The mineralization has been described as a stratabound deposit ("manto"), possibly formed by the "sabkha" model, with the celestite depositing at the edge of paleotopographic highs of basement granite which protruded from the Windsor seas as islands (Forgeron, 1979). Boehner (1981) has also speculated on an unconformity-related karst process involving dissolution and hydration of evaporates in an up-dip position. Forgeron (1979) stressed that Mississippian rocks of the lower Windsor Group are host to almost 95% of all the mineral showings in the Loch Lomond Basin and that all celestite showings are invariably found in the lower Windsor Group sedimentary rocks. Felderhof (1978) and Forgeron (1979) estimated total strontium resources in the Enon-Loch Lomond area to be approximately 1.9 million short tons, with a representative composition in the range of 30-60% SrO.

Barite

Novex Mining and Exploration Co. Ltd. produced barite from the Pine Brook

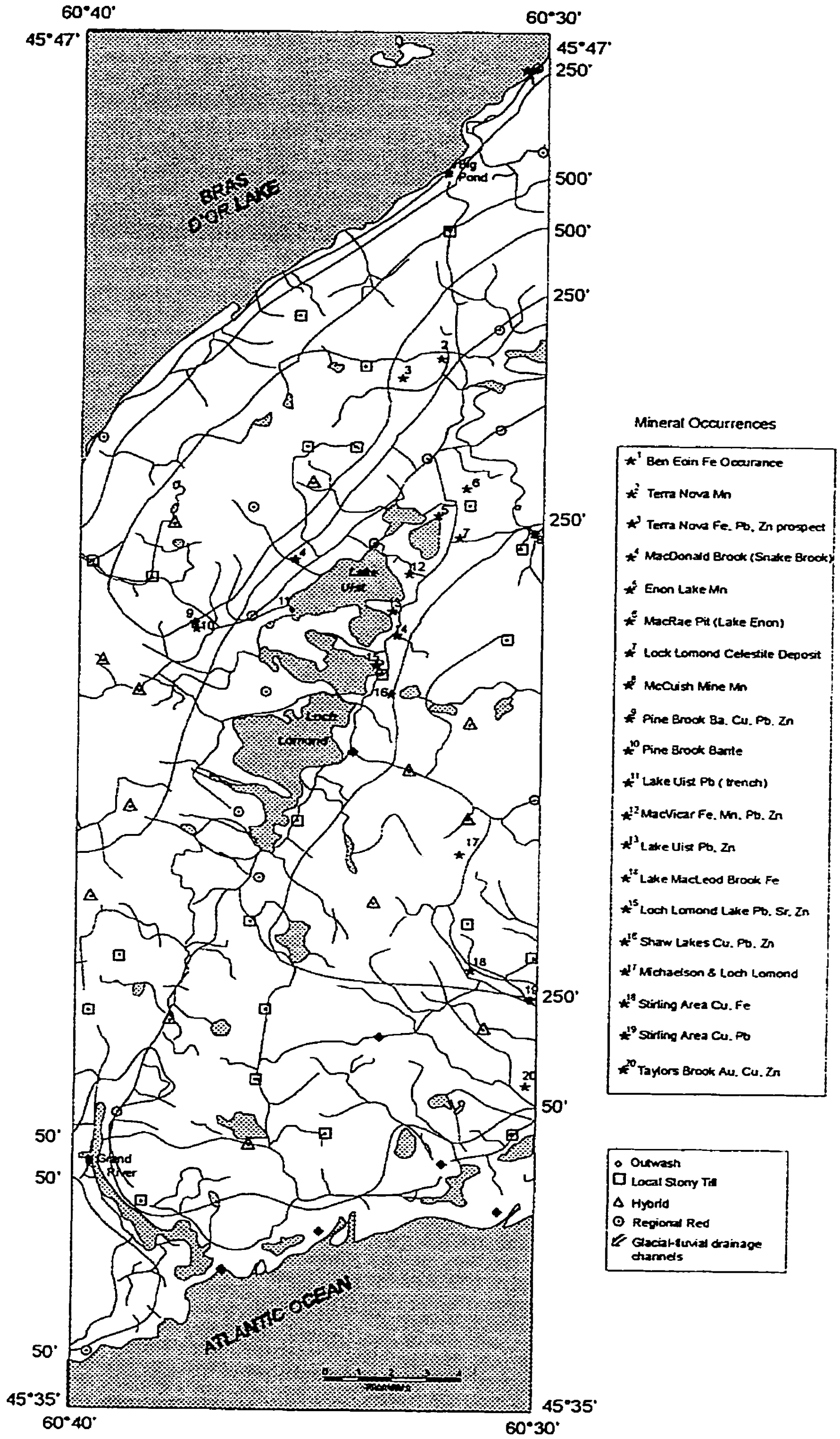


Figure 7: Mineral occurrence map for the study area with sample sites and some elevation contours. See Appendix 10 for exact co-ordinates and details.

deposit in 1983 (Fowler, 1984; Boehner and Prime, 1993). This mineralization is considered to be a stratabound replacement deposit, occurring in the basal Windsor Group conglomerate (Grantmire Formation). Chalcopyrite is also found as an accessory mineral with this occurrence. Felderhof (1978) reported that brick-red cryptocrystalline barite forms the cement in a conglomerate outcrop found on the Salmon River Road, approximately 0.5 km east of Lake Enon (Figures 2and 7).

Galena

Another significant ore deposit exists 7 km east of this study area at the Yava Mine (Figure 2). The Salmon River-Yava Pb deposit is a sandstone-hosted base metal deposit. Between 1979 and 1981, 388,000 tonnes at a mill-head grade of 4.69% Pb were mined by the trackless room and pillar method (Patterson, 1993). Drill core yielded 5.9% Pb with 0.36% Zn and 5.8 ppm Ag. The mine closed due to market conditions but the mineralization zone has been actively explored since 1989 for possible *in situ* leaching potential. Patterson (1993) has suggested a possible down-dip Zn enrichment at Yava, similar to the Laisvall zinc mine in Sweden.

Other minerals

Scotia Limestone Limited (Sydney Steel Co.) quarried metallurgical limestone at Irish Cove from mid-1960 to mid-1970 (Figure 2). Adams (1991) indicated that gypsum exposures are rare in the Loch Lomond Basin due to the thick cover of surficial deposits. Gypsum and anhydrite are present in the subsurface and are not as prevalent near-surface because they are subject to karstic collapse (Boehner and Prime, 1993). Mineral occurrences such as hematite at the McVicar prospect (Wright, 1975; Gilpin, 1901) and manganese at the McCuish (Moseley) mine (Bishop and Wright, 1974) were explored in the late 1800s and re-investigated in the twentieth century, but no economic activity took place as a result. Local residents believe that gold is present in streams north of Loch Lomond.

Geochemical surveys

Early workers in this region performed limited orientation geochemical surveys in the search for mineral deposits. Regional stream sediment sampling (Rogers, 1983) and lake-bottom gyttja sampling (Rogers and MacDonald, 1984, 1986) were completed in southeastern Cape Breton Island as part of a province-wide survey. The goal was to establish a characteristic "fingerprint" of various elements for selected deposits, and to re-calculate the threshold values with respect to principal catchment-area lithologies. Forgeron (1977) determined that the biogeochemical sampling of spruce and fir needles and twigs was more effective than B-horizon soil samples (Pb-Zn analysis) in the search for the strontium mineral celestite in the Lake Uist area. However, he utilized Pb as a soil-pathfinder element due to the almost invariable association with celestite locally.

A detailed, multi-media geochemical orientation survey consisting of balsam fir twigs, A1 horizon (organic humus) soil, and C-horizon till at each site, as well as stream sediment sampling, was carried out over the Yava Pb deposit (MacDonald *et al.*, 1991; MacDonald and Boner, 1993). MacDonald and Boner (1993) reported till geochemistry to be effective for detectomg ribbon-shaped Pb and Zn anomalies in the Glengarry Half Graben (Boehner and Prime, 1985, 1993). Heavy mineral concentrates from till mirrored these anomalous findings but were expensive to carry out. Humus geochemistry was not recommended but MacDonald *et al.* (1991) concluded that balsam fir was the most cost-efficient and geochemically effective medium. A reconnaissance biogeochemical survey of southeastern Cape Breton using black spruce bark and balsam fir twigs was carried out in 1991 (Dunn *et al.*, 1992, 1994). Dunn *et al.* (1992) reported Ni enrichment between the Stirling and Yava deposits and Ni-Co enrichment southwest of Loch Lomond in black spruce bark. McClenaghan *et al.* (1992) carried out regional and detailed orientation till-geochemical and clast-lithologies surveys in 1990 and 1991 on glacial deposits to the immediate east of this study area (Figure 1). As a result of anomalous Au, Pb, Zn and Cu levels in till occurring up to 1 km east and southeast of the Stirling mine, they concluded that the dominant glacial transport event was eastward.

CHAPTER 2

METHODOLOGY

2.1 Introduction

The following chapter outlines why the study area is appropriate and relevant for this thesis project. The sampling protocols used in this study were similar to those used in other studies, and procedures were developed to select relevant samples for analysis. In this study, two analytical methods were used to determine the geochemistry of the till matrix. Pebble counts were completed to help resolve provenance and the direction of glacial flow movement. The determination of the direction of glacial flow was assisted by till fabric analysis on coastal exposures and by the interpretation of glacial striae on outcrops. Data evaluation was carried out with statistical and plotting software.

2.2 Site selection

The thesis area was selected for several related reasons. First, this area is host to deposits of celestite and barite along with their respective accessory minerals, galena and chalcopyrite. The Yava Pb and the Mindamar Stirling Cu-Pb-Zn-Ag-Au deposits were former producers just east of the study area. Second, the area contains a cross-section of geological environments and physiographical terrains on southeastern Cape Breton Island (Figure 3). Finally, the study area is adjacent to a site where a similar study was carried out by the Geological Survey of Canada (McClenaghan *et al.*, 1992; McClenaghan and DiLabio, 1994, 1996). This is an excellent area in which to test mineral exploration techniques in a complex Quaternary geological environment (Figure 1).

Forty-eight 3 km x 3 km cells, based on the Universal Transverse Mercator

(UTM) grid, were outlined on 1:50 000 topographic maps. The intent of this grid was to select unbiased sampling locations. Although sampling protocol dictated that one sample be secured at the center of each cell, road access dictated the final sampling location within the cell. A total of 60 till samples were taken from 56 sample pits. This was equivalent to at least one till geochemical sample being taken every 9 km^2. The only deviation from this approach was when the sampling point was interpreted as an outwash environment and a replacement sampling site was substituted. The cells were numbered and cross-referenced with 1:10 000 colour aerial photographs, and this information was recorded on field data sheets. This system permitted efficient field retrieval of sample location data.

Sample sites were plotted on 1:50 000 topographical maps. The UTM co-ordinates were recorded (Appendix 1). Sample sites were also recorded on mylar overlays of aerial photographs. A Global Positioning System (GPS) unit assisted in determining some of the sample locations, especially where forestry roads were constructed after the aerial photographs were taken. However, at the time one could not be reassured of a location closer than 100-300 m with the available GPS technology. The sampling code was assigned by the Geological Survey of Canada. It consists of the sampling year, GSC scientist code and a sequential number beginning at 6601 (e.g., 96-MPB-6622). Future reference to sample sites will be indicated simply by the four-digit number (e.g., 6622) (Figure 8).

2.3 Field sampling

Once a suitable sample site was located, a pit (0.5-1.0 m deep) was dug by hand

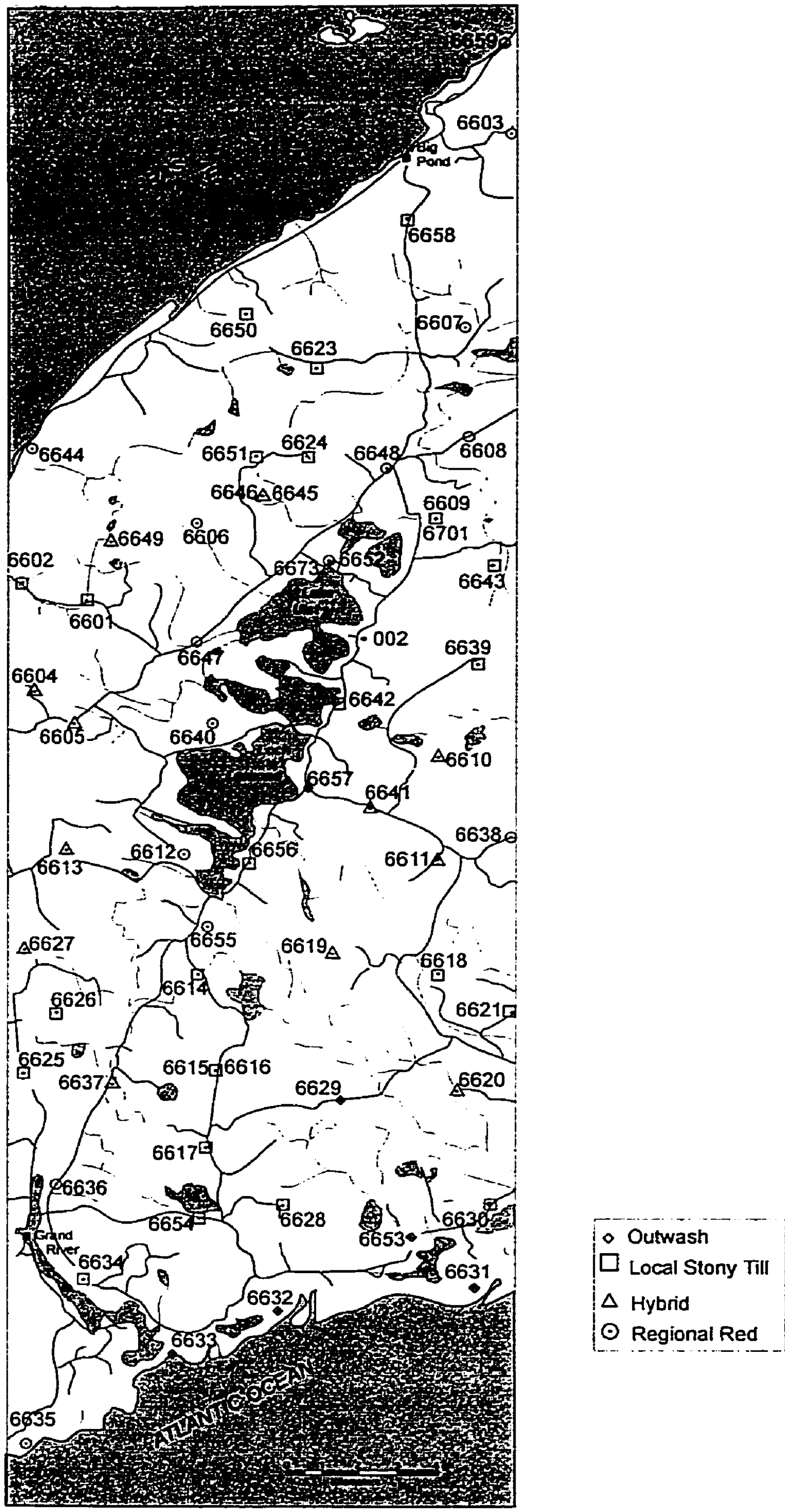


Figure 8: Sample location map for till samples. Numbers (6622) are equivalent to Geological Survey of Canada sample codes (96-MPB-6622).

to sample the upper C-horizon (Plate 1). These methods were used to collect till samples by McClenaghan *et al.* (1992) on the adjacent map sheets. At each site, a photograph was taken and field data describing the site and sample were recorded (Appendix 1) for archival purposes for the Geological Survey of Canada. Till characteristics were recorded which included texture, unit thickness, slope direction, vegetation type, site type, depth of samples, pebble and cobble lithologies, and soil horizon thicknesses (Appendix 1).

Till geochemical samples

A stainless steel blade was use to collect till from the pit and a hard plastic garden trowel or scoop was used to recover approximately 2 kg of pebble-free material which was then sealed in a labeled plastic sample bag. McClenaghan and DiLabio (1994) reported that the <0.063 mm fraction is the cost-effective fraction to use for regional geochemical surveys because relatively small samples (2 kg) are required, they are collected quickly, and it provides an adequate contrast between background and elevated trace element concentrations. Strict attention to potential contamination was followed, including the removal of hand jewelry while in the field. On average, five samples were collected per day.

Individual representative samples (25 g) also were collected for determinations of Munsell colour (moist) and reaction to dilute HCl. A total of 60 till samples, including two field duplicates (6615, 6616 and 6645, 6646) and two multiple horizons(6652, 6673 and 6609, 6701), were collected from 56 locations in the study area. Sample 6622 was later rejected as it was interpreted to be glaciofluvial sediment, not till, and therefore not suitable for the regional geochemical survey.

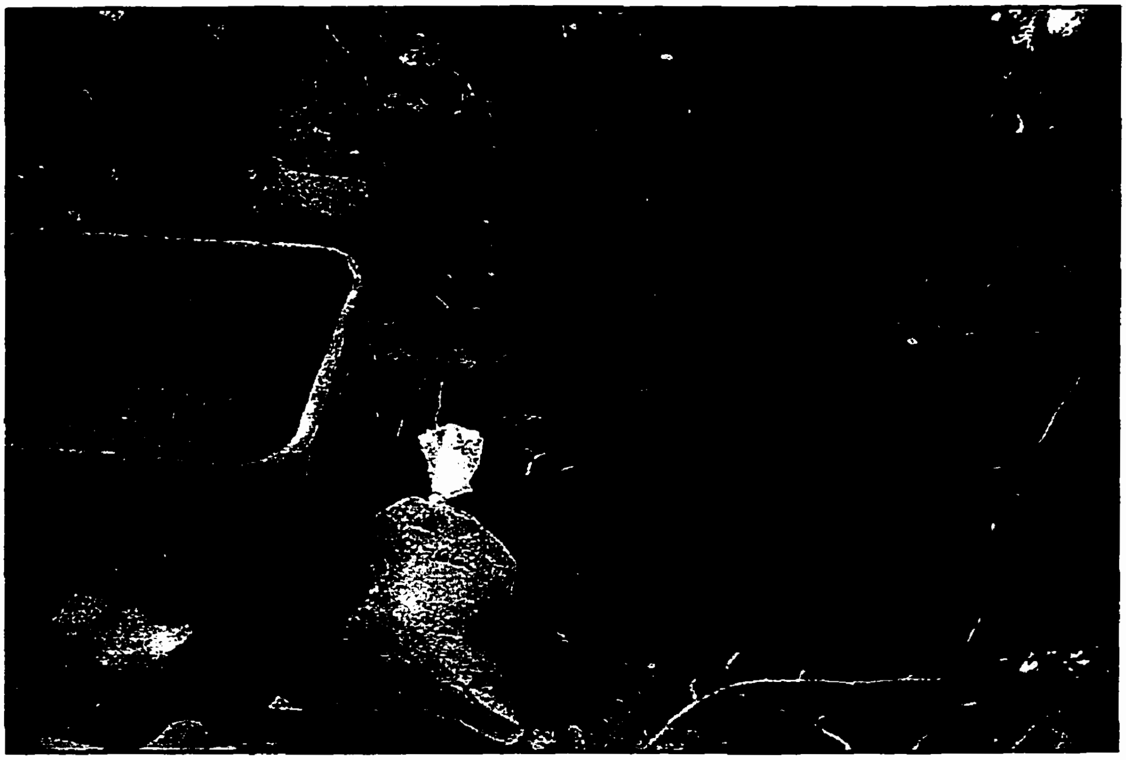


Plate 1: Typical pit used to recover till geochemical sample as shown in the bag marked as sample 96-MPB-6623. Note as well the plastic container fitted with a 1.5 cm (5/8 in.) stainless steel screen used to separate pebbles and cobbles from the till for pebble counts.

Field duplicates

The value of geochemical data is dependent on proper sample preparation as well as accurate and precise analytical methods. The inclusion of quality control samples with field samples is essential to evaluate the precision and accuracy of the laboratory procedures and methods. Two field duplicates, unknown to the sample preparation lab, were collected to test these procedures. These paired samples were 6615-6616 and 6645-6646 and were selected on a random basis in the field.

Till pebble lithology samples

Pebbles (1.6-6.4 cm) were collected from till at each of the 56 sample locations using a 1.6 cm (5/8 in.) stainless steel screen set in a plastic container (Plate 1). The objective was to collect 200-300 pebbles at each site. The average number of pebbles collected at the sites was 190, with a range of 11-465. The collected pebbles were then stored in labeled 20-liter pails for subsequent lithological identification and counting.

2.4 Geochemical analysis

Geochemical sample preparation

A total of 60 till samples were shipped to the Sedimentology Lab of the Geological Survey of Canada in Ottawa. Samples were divided into three portions. The first portion was air dried and then dry sieved with stainless steel sieves to recover the <0.063 mm fraction for geochemical analysis. The second 200 g portion was used for grain-size analysis of the <2.0 mm fraction. The third portion was a 500 g sample retained by the Geological Survey of Canada for archival purposes.

Geochemical analytical methods

Two identical packages containing representative portions of the <0.063 mm sieved material from each sample were prepared. The <0.063 mm till fractions were analyzed for major, minor and trace elements using two multi-element analytical methods: aqua regia/inductively coupled plasma-emission spectrometry (ICP-ES) by Bondar-Clegg and Company Limited of Ottawa, Ontario; and instrumental neutron activation analysis (INAA) by Activation Laboratories Ltd. of Ancaster, Ontario.

Inductively coupled plasma-emission spectrometry

This technique relies on placing a weighed 0.100 g sample in a glass test tube and digesting the sample in 2 ml of aqua regia (HCl :HNO_{3-}, 3:1) for two hours in a water bath at 90° C. This method essentially achieves a near-total digestion of most elements, especially Ag, Bi, Cd, Pb and Sb. The sample solution was brought up to a final volume of 10 ml with distilled water and then shaken on a vortex mixer. The solutions were then introduced into a radio frequency excited plasma (8000° K). Each element in solution produces a characteristic spectrum. The intensity of the spectral lines are directly proportional to the quantity of the element present in the sample. The final result was calculated based on the initial sample weight. Major elements were reported as percentages (%) and the minor and trace elements were reported as parts per million (ppm). The only exception was Hg. It was analyzed by cold vapor-atomic absorption spectrometry (CV-AAS) and was reported as parts per billion (ppb). The CV-AAS method is a single element determination based on the absorption of radiation at 253.7 nm by mercury vapor. The mercury was reduced to the elemental state and aerated from solution in a closed system. This was necessary because mercury will vaporize and will escape during a high temperature event such as used for ICP-ES.

The following 35 elements were determined by aqua regia - ICP-ES: **Al, Bi, Ca, Cu, Hg, K, Li, Mg, Mn, Mo, Nb, Ni, Pb, Sr, V, Y, Zn, Zr,** Ag, As, Ba, Cd, Co, Cr, Fe, Ga, La, Na, Sb, Sc, Sn, Ta, Te, Ti and W. However, only the first 18 elements are included in Appendix 2-A. The last 17 were omitted because concentrations were at or near the lower detection limit or because the element is best determined by INAA.

Instrumental neutron activation analysis

The INAA analytical technique is dependent on measuring the primary gamma radiation which is emitted by radioactive isotopes produced by the irradiation of samples in a nuclear reactor. Each element, when activated, emits a "fingerprint" of gamma radiation which is measured and quantified. The "Au+34" (with enhanced detection limits) commercial analysis package was selected because it is popular for soil, lake sediment and stream sediment samples, and is cost effective. An average sample mass of 24 g (range from 16-37 g) of <0.063 mm material was encapsulated, irradiated and measured. The final calculation of concentration was based on the sample's mass. Major elements were reported as percentages (%), Au and Ir were reported in parts per billion (ppb), and all other elements were reported in parts per million (ppm).

The following 35 elements were determined by INAA: **As, Au, Ba, Br, Ce, Co, Cr, Cs, Eu, Fe, Hf, La, Lu, Na, Nd, Rb, Sb, Sc, Sm, Ta, Tb, Th, U, Yb, Zn,** Ag, Ca, Hg, Ir, Mo, Ni, Se, Sn, Sr and W. The first 25 elements are reported in Appendix 3-A. The latter 10 elements are omitted from this report because the concentrations were at or below the lower detection limits or they are best determined by aqua regia-ICP-ES.

Analytical quality control

Analytical quality control was monitored using Geological Survey of Canada "in house" standard (TCA-8010) inserted into analytical batches at regular intervals (approximately every 15 samples). The TCA-8010 standard is a bulk till sample collected from the Geraldton area of Ontario.

Both accuracy and precision, two components of analytical quality control, are essential in exploration and environmental geochemistry. These parameters are used to check on the laboratory methods and procedures. Accuracy is the proximity of the results to the ultimate truth where the total amount of a metal or compound is being determined. The only way of monitoring accuracy is by the inclusion of reference materials (Sinclair, 1986). Ideally, several reference samples should be used but in this case the batch was relatively small (60) and a Control Reference (CR) TCA-8010 from the Geological Survey of Canada was inserted seven times for a frequency of 10%. In the case of ICP-ES analysis, which uses a partial aqua regia extraction, absolute accuracy has less meaning than when a total extraction method such as hydrofluoric acid attack or fusion extraction is used. In these latter two methods, the total sample, including silicate minerals, is put into solution, thereby releasing the total amount of the elements for chemical detection. Because a partial extraction does not release 100% of the element into the solution for analysis, it is impossible to test for absolute accuracy.

The precision of an analysis is a measure of the repeatability of the determination. For surficial material surveys, precision is of more concern than accuracy. It is monitored by submitting duplicate samples from those prepared in the lab. In this case, eight duplicates were randomly inserted among the samples submitted for analysis by staff at the Sample Preparation Lab of the Geological Survey of Canada. Two field duplicates were also inserted in order to check on sample preparation, analytical procedures and field representativeness.

If gold values are erratic and most other elements show good precision, then the erratic gold values are usually attributed to the nugget effect. This is one of the most difficult parameters to assess in field geochemistry. Gold and platinum group metals (PGE) may commonly be dispersed through a geochemical sample as discrete grains, and frequently it is difficult to reproduce values in the subsequent analyses. The confidence of these gold values is somewhat suspect, and little reliance is placed on them. This does not affect the confidence with the remaining elements if their precision is demonstrated.

2.5 Pebble lithology identification and counting

An average of 190 pebbles (range from 11-465) were collected from each of the 56 sample sites. An additional pebble sample (97-DS-002) was also collected from an excavation near Loch Lomond. All samples were hand-washed with a brush and a hose to remove matrix material in order to facilitate classification. In the laboratory, the pebbles were separated into 14 different lithological categories by visual inspection of external weathered properties, or by hand-lens inspection after being broken by hammer blows on an iron plate (Plate 2). The 14 rock categories included: mafic volcanic, felsic volcanic, mafic porphyry, rhyolite porphyry, granite, Grand River granite, diorite, quartz arenite, vein quartz, red-green-brown sedimentary rock, grey-black sedimentary rock,

Plate 2: Sizing tool set for maximum (6.5 cm) and minimum (1.5 cm) with a pebble and a cobble which were of the required size criteria for the pebble counts.

mafic intrusive, limestone and other. The "other" category includes rocks that could not be identified or lithologies that could not be placed in the other 13 categories. Data are presented in actual count (Appendix 4-A) and frequency percentages (Appendix 4-B). Where possible, attempts have been made to correlate the 14 lithological categories with formation names.

2.6 Till fabric analysis

Till fabric data were collected at three Atlantic coastal sites in the study area. One advantage of these sites is that the slumped material has been washed away by the ocean waves resulting in fresh till exposures. The disadvantage of these sites was the difficulty in finding exposures of till that contained suitably shaped clasts for fabric analysis. It was noted that many till exposures found near bedrock outcroppings usually contained angular rocky cobbles and boulders composed of local lithologies. Sixty pebbles were measured at Kemps Point, and 50 pebbles were measured just east of Point Michaud Beach and Red Head . A suitable looking pebble (Plate 3) was removed from the till and its A-B-C axes were examined. If the C-A axis ratio was greater than 3:1, then an aluminum knitting needle was inserted in the till to parallel the orientation and dip of the C-axis of the pebble (Plate 4). Approximately 15 needles were inserted for 15 different pebbles at a time before azimuth measurements were taken (Plate 5). The azimuth and the dip of the pebbles were measured using a Brunton compass, and the readings were recorded. The process was repeated until a suitable number of readings were acquired. The Stereo and Rose programs from RockWare Utilities 3.0, a statistical software package, were used to produce stereonet plots for the fabric data.

Plate 3: Five cobbles show the range of shapes possible and relative usefulness for all fabric analyses. The cobble on the left is considered excellent for these measurements, while the cobble on the right is the least useful due to the approximately equal dimensions shown.

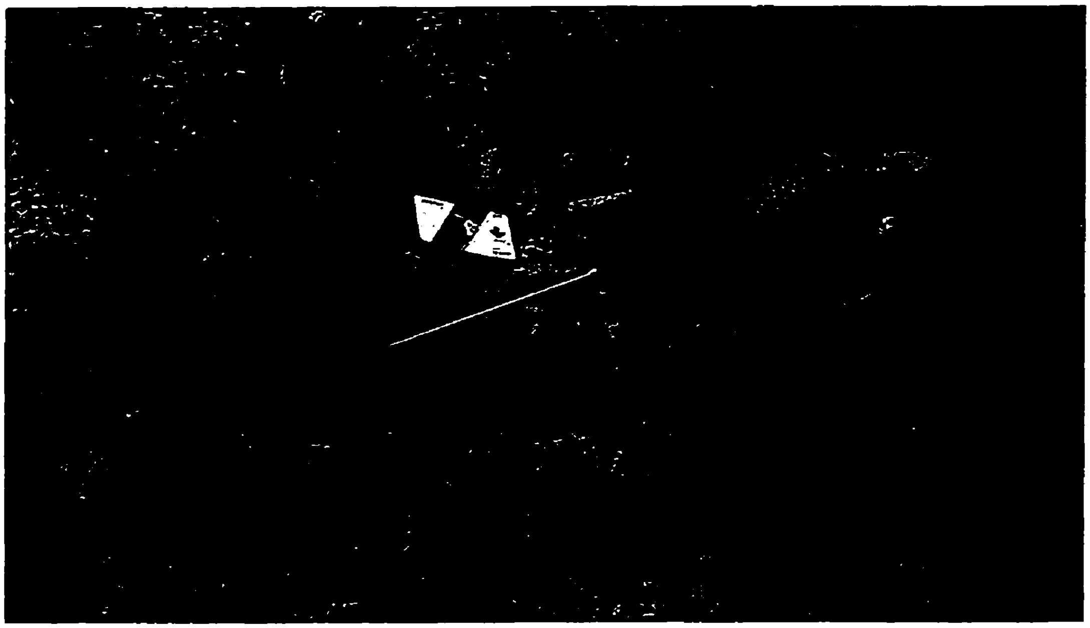


Plate 4: Fabric determination in practice. A knitting needle has been oriented in the void left by the cobble which has been removed by the Quaternary geologist. Note the angle of plunge from the horizontal (approximately 30 degrees).

Plate 5: Aluminium knitting needles are used to mark the orientation of a number of cobbles in till at Kempt Head. The knitting needle marks the dip direction and the angle of inclination for each cobble. These are measured with a compass and a clinometer, recorded and later plotted for analysis

2.7 Grain size analysis

Textural analyses were completed at the GSC Sedimentology Lab. The grain-size characteristics (% clay, silt, and sand) of the <2.0 mm fraction of the till were determined using dry sieving and pipette methods. The textural description of each sample, listed in Appendix 5, was determined using the % clay (<0.002 mm), % silt (0.002-0.063 mm), and % sand (0.063-2.0 mm) as shown in Figure 9.

2.8 Heavy mineral sample processing

Two bulk samples of till (10 kg +) were collected for heavy mineral analysis at sample locations 6609 and 6617. These samples were processed by Overburden Drilling Management Ltd. (ODM), Nepean, Ontario, to recover heavy mineral concentrates for geochemical analysis and to examine any gold grains microscopically. Weights for each fraction produced during the processing procedure are reported in Appendix 9. The <1.7 mm fraction was processed using a combination of tabling and heavy liquid separation methods. First the samples were passed over a Wifley shaking table to obtain a pre-concentrate which was panned to recover gold and sulfide grains. The gold and sulfide grains were counted, described and returned to the sample. Gold grains were classified using the three morphologic categories of DiLabio (1990) that reflect increasing distance of glacial transport: (1) pristine, (2) modified and (3) reshaped. The Wifley table separated the sand-size mineral concentrates into heavy and light mineral fractions. The heavy mineral concentrate was then further refined in the heavy liquid methylene iodide (MI) which has a specific gravity of 3.3 g/cm^3. Estimated gold assays for each sample were calculated by ODM based on the abundance and size of the gold grains

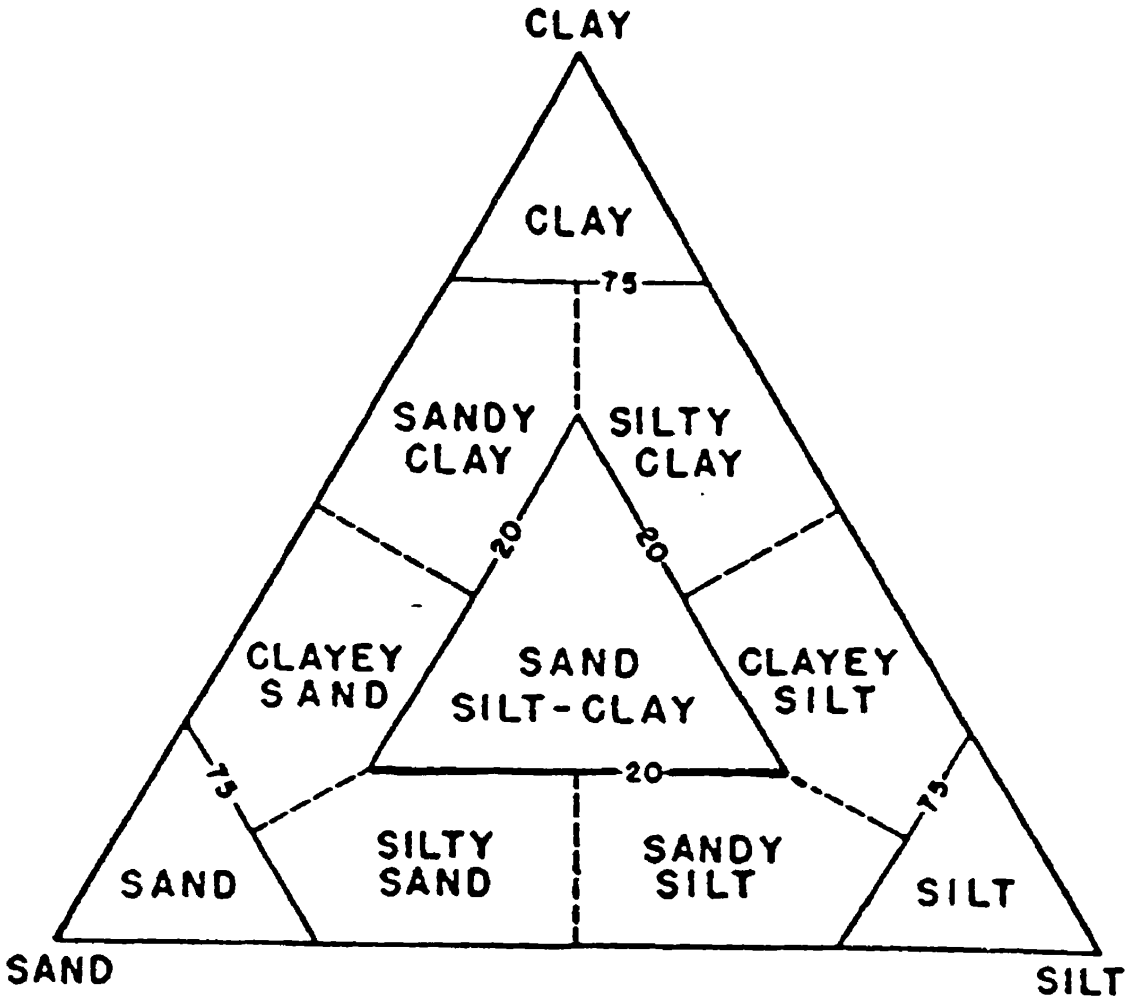


Figure 9: Ternary graph and nomenclature used to classify glacial sediments in the study area (Shepard, 1954).

recovered. The ferromagnetic minerals were removed from the remaining heavy mineral fraction (S.G.>3.3) using a hand magnet (leaving the <1.7 mm non-magnetic fraction for mineralogical examination).

2.9 Glacial flow indicators

Striae

Striae are thin grooves on bedrock formed as a result of asperities in rock particles entrained in the base of a glacier being dragged over bedrock or clasts (Benn and Evans, 1998). While striae appear continuous to the naked eye, in actual fact the striation is formed by a series of jerky steps (Drewry, 1986) producing numerous crescent-shaped fractures, each marking a discrete failure event. Striae are most pronounced when the overriding clasts were much harder than the bed and when the force pressing the clast against the bed was greatest. Other factors include the velocity of the clast relative to the bed, the rate of removal of the wear products and the availability of the basal debris (Benn and Evans, 1998).

The azimuth of the striation is measured with a compass and recorded as two possible and opposite directions of ice flow (e.g., 090° and 270°). It may then be possible to determine the sense of direction of the ice movement from other observations such as an abraded stoss face and a quarried lee face on the outcrop. Rat-tail striations may also prove useful for determining ice-flow directions. For this study, the "sense" of direction was recorded when it could be determined. Where outcrops of bedrock display two or more sets of striae displaying cross-cutting relationships, it may be possible to determine the order of ice-flow events that produced the striae. The age and orientation of striations were recorded in the field data forms, as well as on field topographic maps.

2.10 Data evaluation

Till geochemical values reported as less than the lower detection limit were reassigned values of one half the detection limit for calculation of summary statistics and plotting proportional symbol maps. Univariate statistics and frequency histograms for the till geochemical data and selected pebble lithology groups were calculated using the MacIntosh computer program StatViewIV and are listed in Appendix 6. Pebble lithology maps are found as figures in Chapter 3. Visualization of geochemical data on maps was accomplished by using a series of dot diameters which were proportional to concentrations at approximately 25, 50, 75, 90, 95, 99 and 100 percentile (Bjorklund and Gustavsson, 1987). Data manipulation and plotting were carried out by Terrain Sciences Division of the Geological Survey of Canada, Ottawa. Forty-seven proportional symbol maps of till geochemistry were generated. They included 22 ICP-ES maps (Ag, Al, Ba, Bi, Ca, Cd, Cr, Cu, Hg, K, Li, Mo, Mg, Mn, Ni, Nb, Pb, Sr, V, Y, Zn, Zr) and 25 INAA maps (As, Au, Ba, Br, Ce, Co, Cr, Cs, Eu, Fe, Hf, La, Lu, Na, Nd, Rb, Sb, Sc, Sm, Ta, Tb, Th, U, Yb, Zn). Only selected maps are discussed in Chapter 4 and presented in Appendix 6.

Eight till pebble lithology maps were also plotted using proportional symbols. They include felsic volcanic rock, mafic volcanic rock, granite, diorite, L'Ardoise quartz arenite, red/green/brown sedimentary rocks, grey/black sedimentary rocks and the Salmon River rhyolite porphyry and are included in the till pebble lithology section of Chapter 3.

2.11 Age determinations

One C^{14} age determination was obtained from an organic sample collected beneath gravels at Big Pond Beach. The sample was wrapped in tin foil and submitted to Geochron Laboratories in Cambridge, Massachusetts, for radiocarbon age determination. The sample was given the reference number GX-22226 at Geochron. At the lab, the sample was cleaned of dirt or other foreign material and was split into small pieces. It was then treated with hot dilute HCl to remove any carbonates, and with hot dilute NaOH to remove humic acids and other organic contaminants. After washing and drying, it was combusted to recover carbon dioxide for the analysis. The date reported was based upon the Libby half life (5570 years) for ^{14}C. The error stated is $\pm 1\sigma$ as judged by the analytical data alone. The modern standard used was 95% of the activity of N.B.S. Oxalic Acid. The age is referenced to the year A.D. 1950. The report of analytical work is found in Appendix 7.

CHAPTER 3

QUATERNARY GEOLOGY

3.1 Introduction

This chapter describes the Quaternary geology of the study area with a focus on the Late Wisconsinan glacial history. The area is part of the Bras d'Or Lowlands and includes the Salmon River Lowland which is located between the East Bay Hills and the Mira Hills (Grant, 1994). The Quaternary geology of Cape Breton Island has been regionally mapped by Grant (1988, 1994). Other investigators have mapped and studied the local stratigraphy of adjacent areas of southeastern Cape Breton Island (McClenaghan *et al.*, 1992; MacDonald *et al.*, 1991). The regional geomorphology is characterised by till ridges, drumlins, outwash and kame deposits, beaches and organic deposits. This study recognizes three distinct diamictons and two composite diamictons in the field on the basis of colour, texture and induration. The relative ages of ice-flow patterns have been determined by the till deposition record and a variety of erosional rock-inscribed markings. The latter indicators are judged to be more definitive because the features are widespread, better preserved, and commonly present in multiple sets. These erosional features include striae, grooves, roche moutonnées and miniature crag-and-tail forms. While most of these markings are ubiquitous on all rock types, these features are better preserved and more pronounced on outcrops of aphanitic silicic rocks. Pebble lithology counts also provide useful and definitive information on the Late Wisconsinan glacial ice-flow history of the area. This information is contained in the following Quaternary geology map which displays the mapped glacial features and deposits which are described in detail in the following chapter (Figure 10).

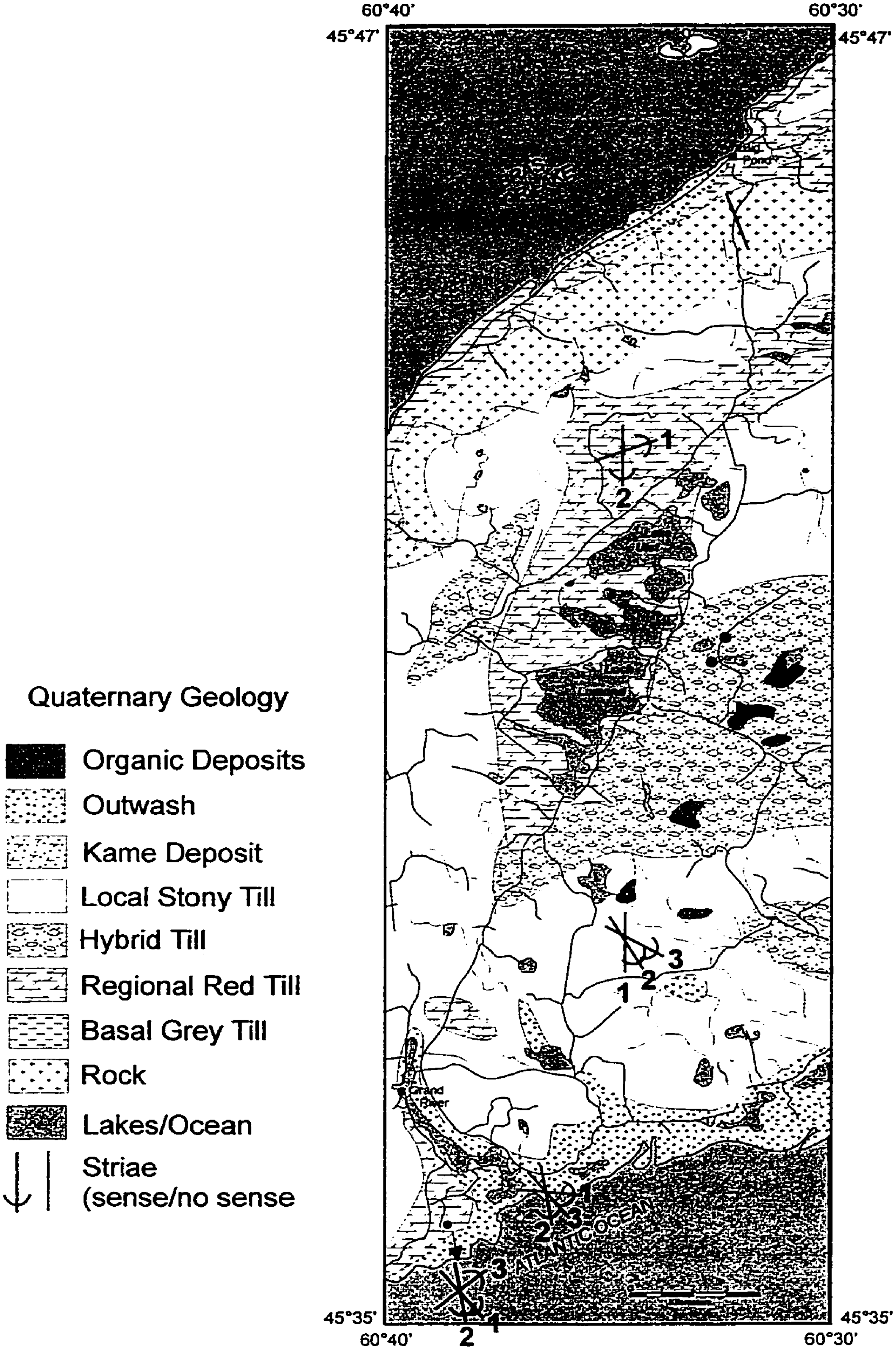


Figure 10: Map of Quaternary deposits within study area. Contacts between till units were determined from geochemcial sample pit data.

3.2 Stratigraphic Units

Grant (1988, 1994) described the regional surficial stratigraphy of Cape Breton Island simply by the thickness and extent of glacial deposits. Three units were recognized mainly through his interpretation of aerial photographs with field verification and included a till blanket (map unit 2a), a till veneer (map unit 2b) and a discontinuous till (map unit 2c) (Grant, 1988, 1994; Table 3). Grant (1994) generally did not attempt to correlate any of these till units in a genetic context, and did so sparingly with specific ice-flow events.

In an area to the east of this study area, McClenaghan *et al.* (1992), MacDonald and Boner (1993) and McClenaghan and DiLabio (1994, 1996) elaborated on local examples of Quaternary stratigraphy on southeastern Cape Breton Island. These investigators attempted to correlate specific drift units with known ice-flow events recorded by striations. McClenaghan and DiLabio (1994) concluded that drift thickness, glacial landforms and ice-flow patterns vary across their study area, and they recognized that a red silty till and a sandy grey till are both useful sample media for their work on Cape Breton Island. The ice-flow history and glacial stratigraphy from the work of Grant (1988, 1994), McClenaghan *et al.* (1992), McClenaghan and DiLabio (1996) and the results from the work of Stea *et al.* (1989) on mainland Nova Scotia are summarized in Table 2.

In developing an approach to the understanding of the glacial stratigraphy of the study area, traditional regional outcrop mapping of Quaternary exposures was carried out by examining local road-cuts, sea-cliffs and gravel pits. Previously described coastal exposures in the adjacent eastern study area (McClenaghan and DiLabio, 1994, 1996) were visited in order to gain insight into the regional stratigraphy of southeastern Cape Breton Island. This reconnaissance mapping resulted in the identification of distinct Quaternary sedimentary units in the study area. They include a well-indurated red diamicton, a series of mixed colour diamictons, a series of stony-sandy diamictons, and stratified glaciofluvial sediment. The discovery of a grey, matrix-dominated diamicton in a hand-dug geochemical sample pit (6652) justified its addition as a till unit. As there was limited exposure inland and the spatial distribution of these different units could not be ascertained from aerial photographs or the work of Grant (1988, 1994) and McClenaghan and DiLabio (1994, 1996), an interpretation of the sediment exposed in geochemical pits was attempted. This attempt to relate the limited exposure in geochemical sample pits to the regional stratigraphy was somewhat qualitative; therefore, a confidence factor was developed and assigned to each sample (Appendix 8). This approach will be reviewed in detail in the discussion of till types in Section 3.4 (Late Wisconsinan glacial history).

These diamictons, identified both in outcrops and in test-pits, are all believed to be tills deposited in the Late Wisconsinan (Grant 1994). Field evidence is presented to justify the stratigraphic relationships among these diamictons. Grain size analysis of the <2 mm matrix (Appendix 5) indicates notable variability between these diamictons. The clay content ranges from 2-30% of the matrix. The silt component ranges from 11- 58%, and sand ranges from 22-82 %. Seventy percent of the sample matrices are classified as "silty sand" using the ternary plot (Figure 9) of Shepard (1954). Five percent of the samples were classified as "sandy silt" and 12% were "sand." The remaining 13% fall into the "sand-silt-clay"category.

Basal grey diamicton

A grey diamicton was observed at only one location in the study area. It was sampled at site 6673 and is located stratigraphically below sample 6652. It was initially detected because of the sharp difference in colour with a stratigraphically overlying red diamicton and the contrasting pebble contents. The basal diamicton is grey to moderate brown, well indurated, texturally composed of 2:2:1 sand:silt:clay ratio, devoid of pebbles or cobbles, and contains black spotty inclusions. The sample did not react with dilute HCl. The elevation of the pit is approximately 1 m above the level of Lake Uist (150 ft : 46 m).

This diamicton unit is interpreted to be a lodgement till as it displays high induration, a relatively high clay content (20%) with approximately equal amounts of sand and silt (43% and 37%) and lack of pebbles. It will now be referred to as the "basal grey till" and associated with the ice-flow event LL-1 (Table 4). The basal grey till is not represented in many figures because it was found in only one location.

Red diamicton

The red diamicton occurs predominantly on the western side of the Salmon River Lowland (Loch Lomond Valley). Most exposures of it are below 250 ft (76 m). The red diamicton also occurs in a zone along the southeastern flank of the East Bay Hills from the 250-500 ft (76-152 m) elevations, along the Bras d'Or Lake side of the East Bay Hills between the 100-250 ft (30-76 m) elevations, and forms the core of many of the giant till ridges (Grant, 1988, 1994) which are one of the most prominent geomorphological features on Cape Breton Island. The Loch Lomond-Grand River road cuts through many

Table 4: A summary table of the striae (sense), fabric, orientation of geomorphologic features and pebble directions collected for this study. * Red Head ; **Kempt Head ; *** Pt. Michaud : n.s. = no sense determined, best fit azimuth LL = Loch Lomond, GR = Grand River, BG = Big Glen Formation

ICE FLOW EVENT	Stratigraphic Association	*Striae* East Bay Hills	*Striae* Mira Hills	*Striae* Collins Cove	*Striae* Atlantic Coast	Till Pebble Fabric	Land Form Orientation	Till Pebble Data
youngest **LL-6**	outwash						LL-GR s-sw drainage pattern	Salmon River rhyolite porphyry
LL-5	local stony till		120°		130° n.s.	130° * n.s.		Quartz arenite
LL-4	hybrid till	170°	150°	155°	155°	144° ** 178° ***		
LL-3	hybrid till		350° n.s.	035°				G.R. Granite B.G. Dolomite
LL-2	regional red till	060°		110°	090°		rock-cored till ridges 110° drumlins 065°	Limestone Quartz arenite
oldest **LL-1**	basal grey till						Loch Lomond Valley (low topo.)	

of these till ridges revealing exposures of a dusty brown to dark reddish brown diamicton. The geomorphological nature of these ridges will be discussed later in the text.

The red diamicton is highly indurated, massive and layered in form (Plate 6). The clay content ranges from 9-30%, with an average content of 22%. The average sand content is 38%, with a range from 22-59%. The average silt content is 40%, with a range from 32-58% . Overall, the combined silt-clay average is 62%. This red diamicton is matrix supported, with the rounded clasts making up 10-30% of the sediment. The majority of these clasts are red sandstone, red siltstone and red shale. Clasts of the harder lithologic types are commonly striated. This diamicton is interpreted to be a lodgement till because it is highly indurated, contains striated cobbles, has a high (up to 30%) clay content and contains far-travelled clasts. Sites where this till was found are represented on the site map as open circles (Figures 8 and 10). This till is related to the ice-flow event LL-2. It will be referred to as the "regional red till" in future discussions.

Stony-sandy diamicton

This stony-sandy diamicton is well exposed at the Grand River borrow pit (Figure 7). Aggregate has been removed from this site, resulting in the revelation of a bedrock core of alternating coloured volcanic rocks. Figure 12-A illustrates the coloured pattern of bedrock and coarse glacial sediment that forms the 4 m high south face of the pit. This diamicton is clast-supported. The lower western face of the pit contains a red clast and white sandy quartz matrix conglomerate of the Clam River Harbour Formation (White and Barr, 1998). Numerous other exposures of the stony-sandy diamictons are similar in texture and the angular nature of the clasts.

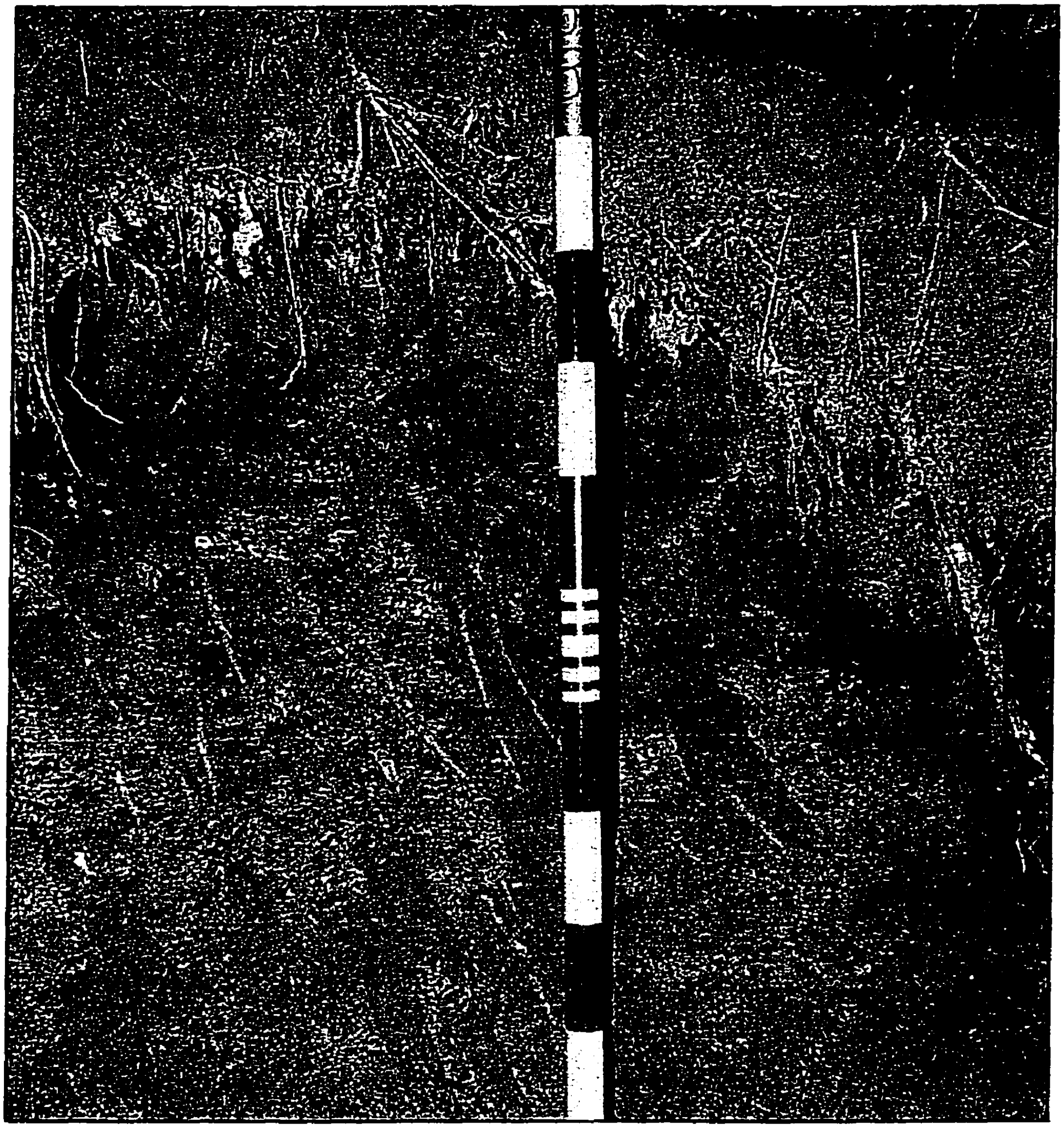


Plate 6: An example of the regional red till at sample site 96-MPB-6603, near Big Pond. This sample consisted of 28% clay, 43% silt and 29% sand which was one of the highest clay components from the study area samples. Note the matrix supported clasts making up between 10 and 15% of the till.

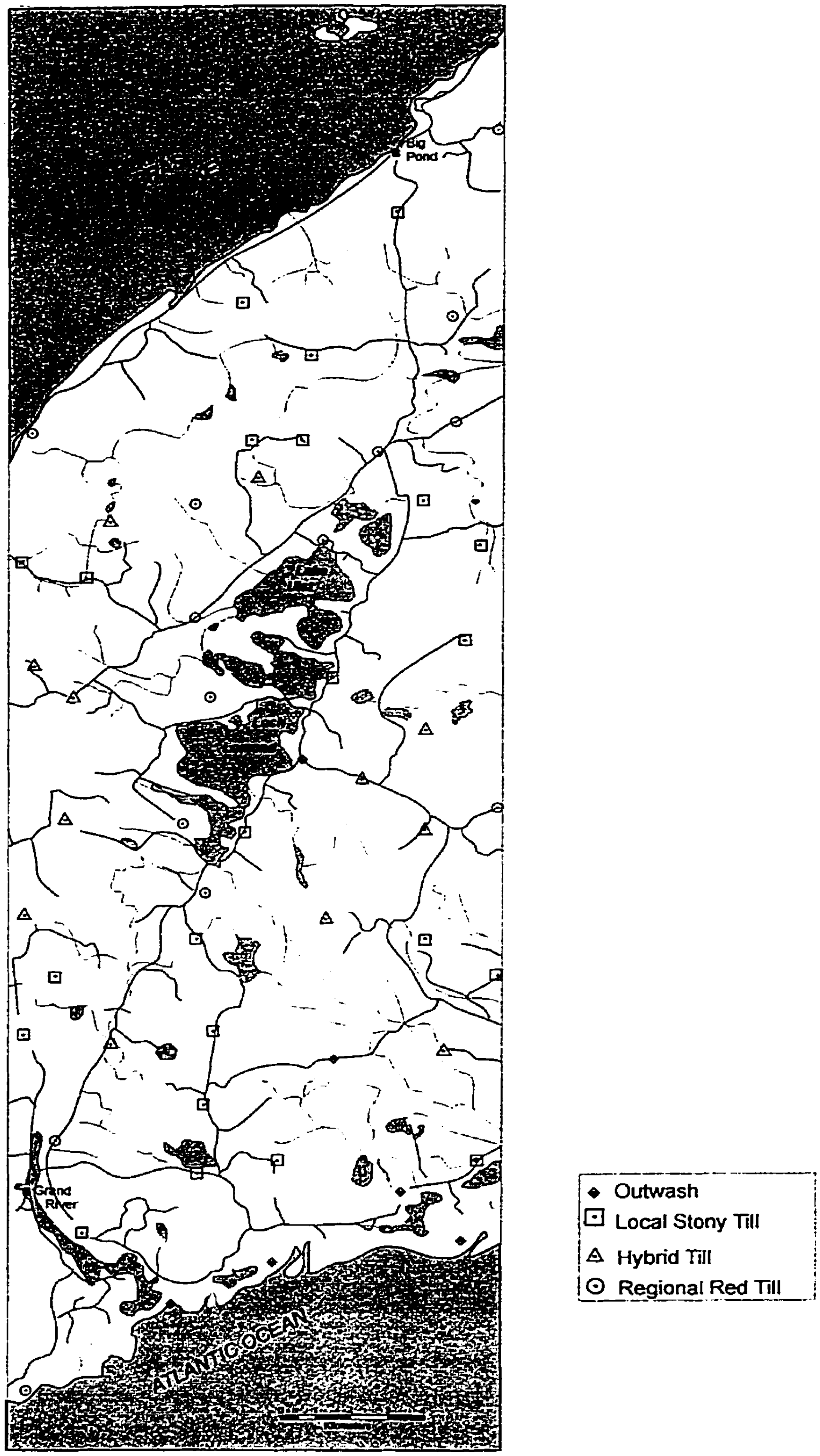


Figure 11: Map of the study area showing interpretation of stratigraphic unit at each sample location.

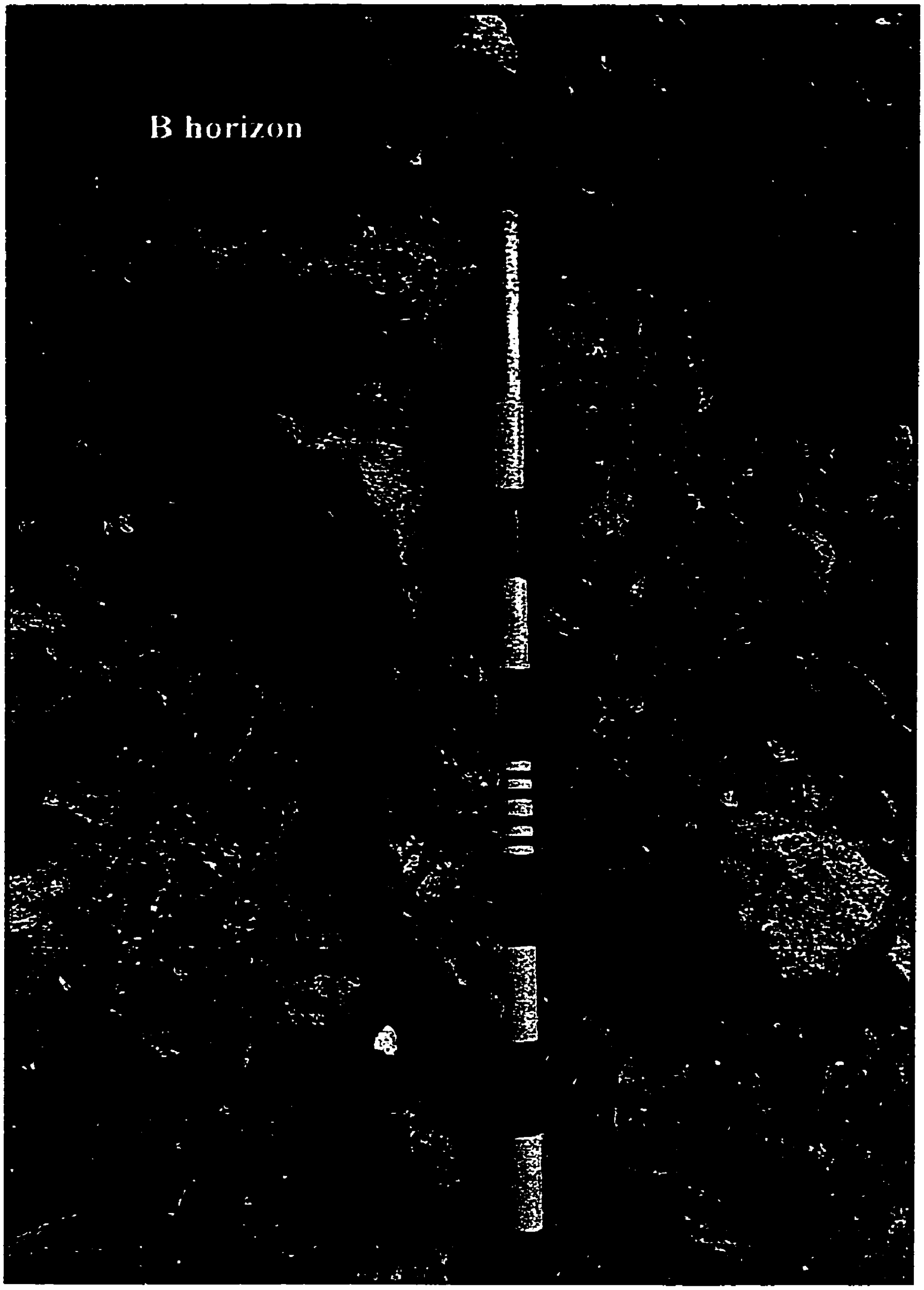
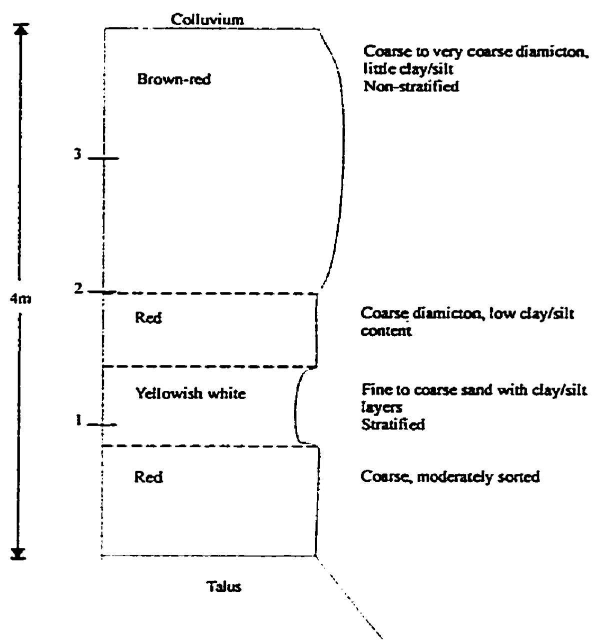


Plate 7: Exposure of local stony till and the development of a B-horizon soil profile. Scale divisions are 10 cm. Till is clast supported and composed of local granite and volcanic rocks.

A. East Grand River pit: local stony till stratigraphy



B. Rock-cored till ridge East Grand River gravel pit

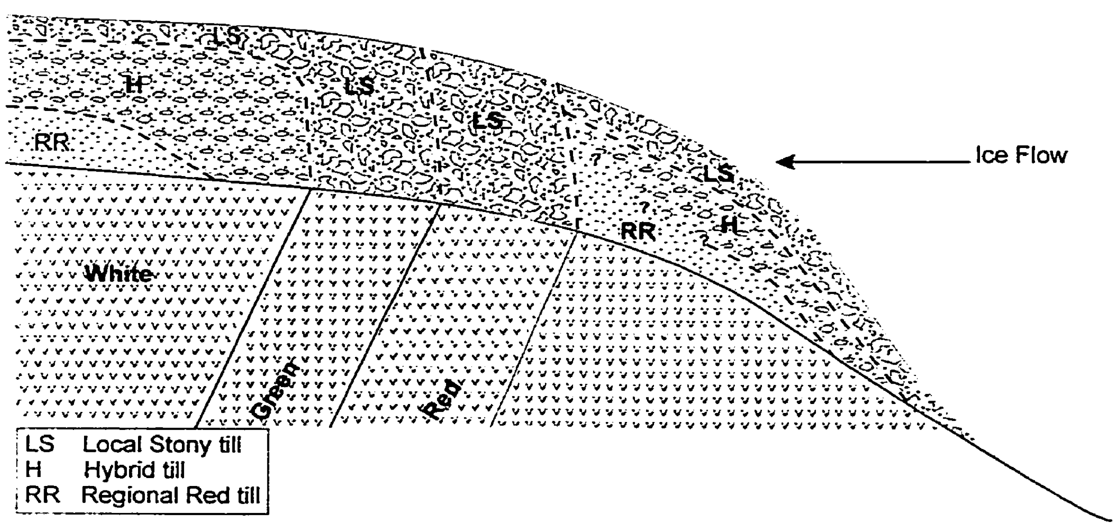


Figure 12: A)Sketch of cross-section of the center of a rock-cored till ridge showing varying stratigraphy created by the erosion banded volcanic rocks. B)Sketch showing relationship of bedrock to tills. A representative sequence of regional red till with hybrid tills and local stony tills are presented. Note ice-direction arrow.

The colour of these diamictons is variable and may be described as grayish brown to very dusky red, a reflection of the colour of the underlying outcrop source (Figure 11-B). The texture and the colour of such tills reflect inherent properties derived from the source bedrock. There is further variability in colour when this diamicton appears to be mixed with the stratigraphically lower regional red till. This will be discussed further in the next subsection. Field observations (e.g., 6610 and 6630) indicate that if the surface bedrock is granite, the colour of the diamicton will reflect the overall colour of the granite, and the texture of the matrix will be sandy (locally it contains granules of granite) along with angular cobbles and boulders of granite (e.g., 6610 and 6615). Plate 7 represents a typical local diamicton which contains angular fragments of grey to white quartz arenite from the Clam Harbour River Formation (White and Barr, 1998). In this case, down-ice transport is in the order of metres to tens of metres from actual outcrops. At most sites it was difficult to obtain clast fabric data from any of these diamictons due to the lack of suitable-shaped clasts (Plate 3) and the clast-supported nature of the till (Plate 7). This sandy-stony diamicton is typically composed of between 30-75% angular clasts.

The matrix is composed of an average of 63% sand, with a range from 36-82%. The silt component averages 30%, with a range from11-60%. The clay content averages 7%, with a range from 2-11%. The two finer components make up an average of 37% of the total matrix.

This diamicton is interpreted to be the product of several possible processes. It has most likely formed as a meltout till for the following reasons: the loose nature of the clasts and matrix, the angular nature of the clasts, the sandy nature of the matrix and apparent lack of finer-grained matrix (clay), and the apparent draping of these units over the underlying regional red till. This till is associated with ice-flow event LL-5. It will be referred to as the "local stony till" in future discussions.

Mixed diamicton

While trying to classify the diamictons, it became apparent that there were tills present that display some characteristics of either the regional red till or the local stony till or both tills. Generally, these diamictons are moderate brown in colour. The sand content averages 52%, with a range from 38-71%. Silt averages 38%, with a range from 23-52%. Clay has an average of 11%, with a range from 4-21%. The average silt and clay percentage is 48%. Three samples (6637, 6641 and 6649) reacted to dilute HCl. The confidence values used to rank these sediments is between 2 and 3 (Appendix 8).

Samples are usually found stratigraphically between the regional red till and the local stony till. Locally, they exhibit properties of either or both till types and hence are called the "hybrid till." Mechanisms of their formation are discussed in later subsections. The ice-flow events associated with these tills are referred to as LL-3 and LL-4, and the tills are represented by triangles on the sample location map (Figure 11).

Stratified sandy diamicton

A sixth stratigraphic unit is exposed on the southeastern side of Ferguson Lake as a roadside bank exposure (Plate 8). It consists of stratified sand, sub-rounded to angular gravel, with some silt and clay. This sediment is interpreted to be glaciofluvial in origin. A till sample was taken. Fortuitously, the exposure permitted closer observation, and the

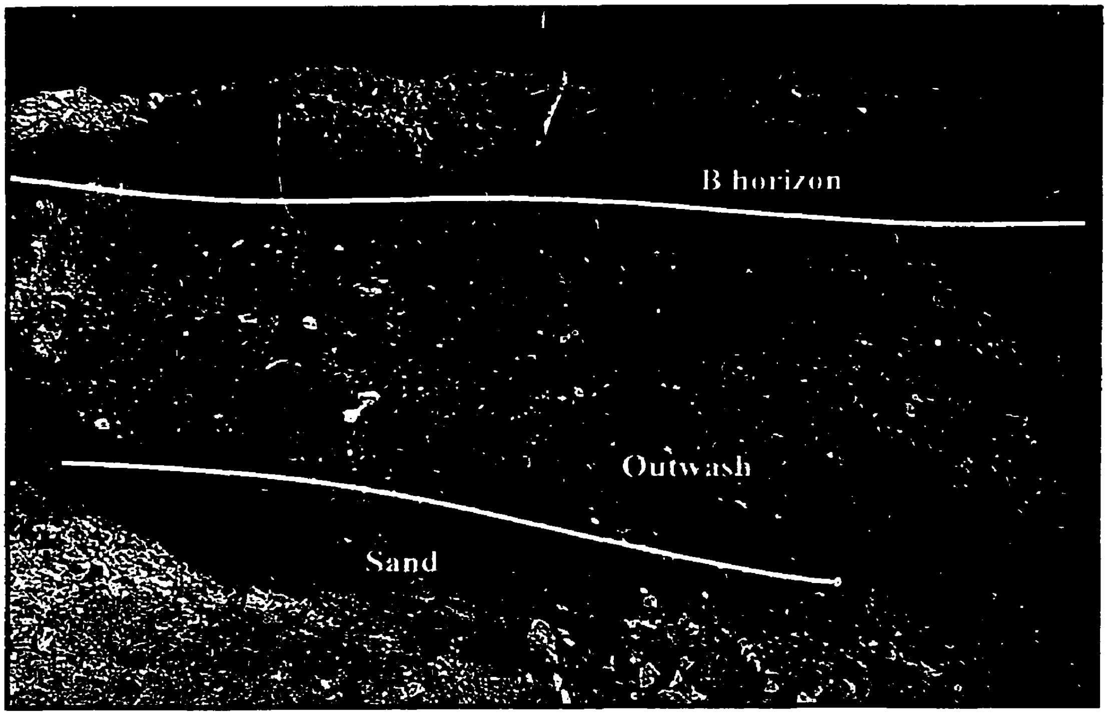


Plate 8: An example of post-glacial outwash sand and gravel east of sample 6654 at Ferguson Lake. Note child for scale. A unit of sand with distinct pebble layering is at the base of the unit. This site represents the ease of differentiating till from outwash when sampling from a surface pit as compared to a hand dug pit (Plate 1).

sample was rejected in the field and a new site selected. Glaciofluvial deposits were not intended to be sampled for geochemical analysis in this survey. There may be difficulty in distinguishing between glacial and glaciofluvial deposits in the field, especially when sampling from hand-dug pits which do not provide an adequate cross-sectional exposure of the sediments to interpret the sediment type. It is important for interpretative reasons to acknowledge and note the presence of the outwash. Six field samples have been determined to be glaciofluvial outwash. As a result, samples were assigned a confidence rating vetween 1 and 4 and a likely genetic type (till, outwash). The confidence rating for two samples (6631 and 6633) is 1 (Appendix 8), while the confidence rating for the majority of the others is 2 (Appendix 8). The average clay content of the six samples is 5% possibly indicating a sediment that was water washed. The average sand content is 68%, with a range from 49-80%. Silt values vary from 13-40%, with an average value of 26%. Many of the cobbles in these samples are sub-rounded and some clasts are striated. Four of these samples (6631, 6632, 6633 and 6653) were taken below the 50 ft (15m) topographic contour where they also flank the Atlantic coastline. The other two (6629 and 6657) are topographically higher (<250 ft - 76m) but exhibit features that suggest a glaciofluvial environment was responsible for the sorting process. The reasons for a glaciofluvial interpretation of this unit are the open work of the clasts and the sub-rounded nature of the clasts, along with their lower topographic elevation.

Other locations of stratified sediments (Plate 9) occur at Breacs Brook, near Big Pond. These layered units likely represent ice-contact kame deposits (Table 3) formed along the flanks of the East Bay Hills (Grant, 1988, 1994).

It should be noted that several potential sites were originally selected for

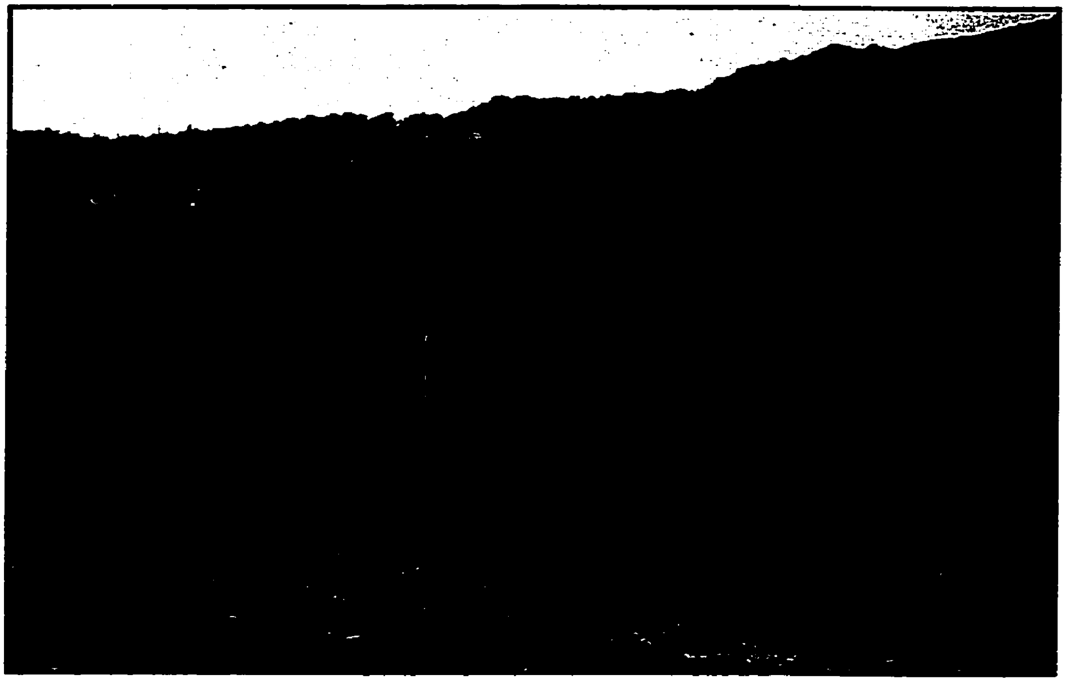


Plate 9: An example of a kame deposit, in a gravel pit, located on the flank of the East Bay Hills at Breac Brook, near Big Pond. Note the near horizontal stratification of gravel horizons in the picture. Sample 6603 (regional red till) was taken near this site.

sampling but were later rejected because of the sandy nature of the material. Other potential sites were avoided because the flat, low topography suggested the possibility of glaciofluvial outwash sediment being present. Highway No. 4, south of the village of Big Pond, is a good example of this type of topography, and samples were not taken in this area. However, site 6630 (Figure 8) was sampled below 1.4 m of outwash because a local stony till was recognized in a borrow pit at this location (Plate 10). Therefore, the opportunity always exists for till to exist below an outwash layer. The question is: How deep does one have to dig?

Glaciolacustrine deposits

Grant (1994) commented that glaciolacustrine deposits were present, although rare, on Cape Breton Island. There is some evidence that the shore, south of Big Pond, may contain a deposit similar to that described by Grant (1994) as being a subsurface glaciolacustrine deposit (Plate 11). The Big Pond deposit consists of an orange silty layer which is overlain by an organic material. The complete stratigraphy was not determined due to the slumped nature of the site. The organic material (wood) was subjected to Carbon 14 analysis and revealed an age of >36,280 years BP (Appendix 7). It is beyond the scope of this thesis to further investigate the site. This evidence is presented here as a point of information in order to formally record the data.

Fluvial deposits

Recent fluvial deposits are common in the area and consist of sand and gravel which were laid down in channels and flood plains. Examples of this alluvium are found

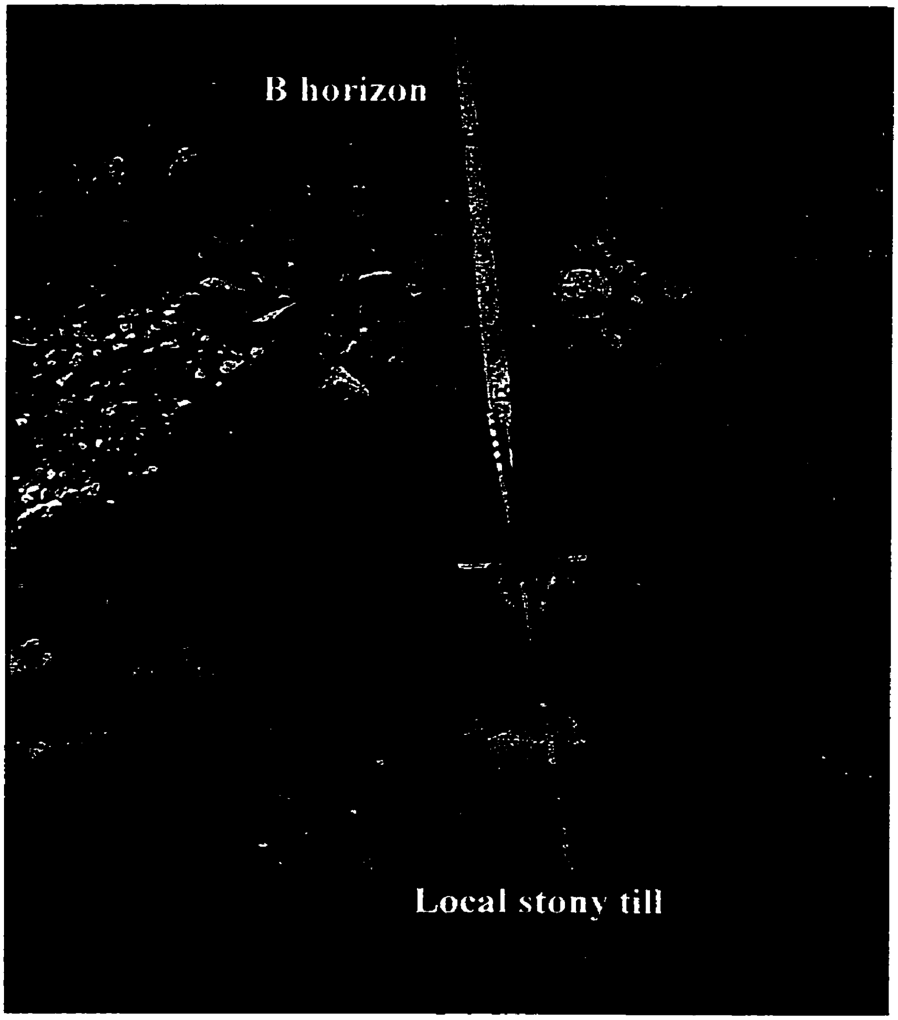


Plate 10: An example of 1.5 m of post-glacial outwash sand and gravel overlying a local stony till derived from the local pink granite. Note the increased roundness of clasts and sandy zones in the outwash, in contrast with clasts in the till which are angular. Sample 96-MPB-6630 was taken at a depth of 2 metres.

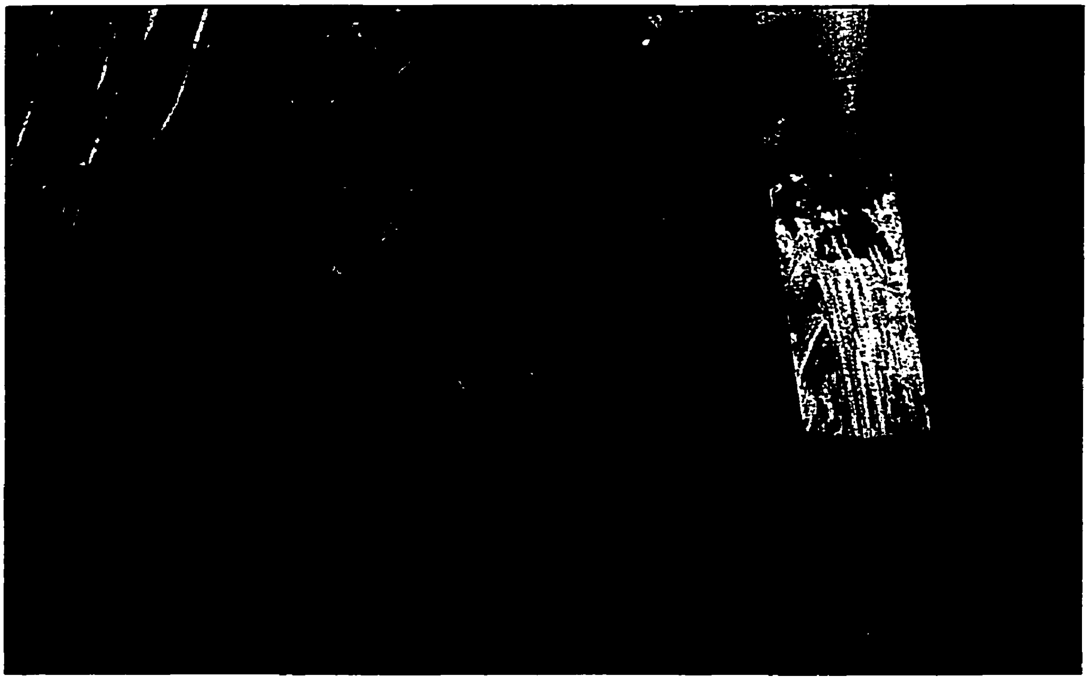


Plate 11: A mason's trowel exposes organic material which is underlain by orange silty sediment on the shore at Big Pond. The age of this organic material was determined to be >36,280 C^{14} yr BP. See text for details.

along Grand River, Breac Brook, MacIntyre Brook and also west of the northern Loch Lomond lake. Several exposures of postglacial alluvial terraces occur near the intersection of the road on the west side of the Loch Lomond Valley lakes and the Irish Cove road (Figure 2). This deposit is presently being used for construction aggregate. Grant (1988, 1994) refers to these deposits as 5a and 5b (Table 3).

Coastal beaches

Coastal beaches and associated bars and spits are found along the Atlantic coastline and the Bras d'Or Lake of the study area. These deposits have formed through the action of waves and currents on the material from glacial sediments to form the beaches we see today. Grant (1988, 1994) used Unit 6 to represent these deposits (Table 3).

Colluvial deposits

In the study area, colluvial deposits form from the processes of slumping and creep. The area most affected is the northwestern flank of the East Bay Hills. Sample 6644 was difficult to secure because of the layer of gravity-displaced rock which had formed a sheath over the till. Grant (1988, 1994) used Unit 7 to represent these deposits (Table 3).

Organic deposits

Organic deposits consist of vegetal matter which accumulated in bogs, fens, swamps and coastal salt marshes. Basin bogs are common along the East Bay Hills belt where they developed by the infilling of ponds and generally occupy small closed depressions in morainic and rocky terrains. These organic deposits have formed through excessive precipitation on surfaces which have become waterlogged due to low permeability of the substratum. In the central portion of the study area, north of the Stirling road and east of the Shaw Lakes pulp road, a large fen complex exists. It consists of meadows of sedge grasses that display the classic rib, and elongate ladder pools with an additional arrangement of circular-shaped pools. This area is the largest concentration of organic material in the study area (Plate 12). Other major bogs are located east of Barren Hill Lake (sample site 6614). Smaller deposits are found in the East Bay Hills. Plate 12 displays the ladder fens between samples 6610 and 6611. Grant (1988, 1994) designated these deposits as unit 8, but did not differentiate them (Table 3). Bogs and organic deposits also provide a record of changing climate and sea level. At Black Point, on the East Side Grand River Road, a shallow blanket bog displays typical sphagnum peat overlying a forest horizon rooted in till which is presently being transgressed by a cobble, pebble and sand beach (Plate 13). This represents a foreland bulge migration.

Contact relationships between stratigraphic units

A stratigraphic column is presented (Figure 13) to show the relationships among the glacial sediment units in the study area. Field evidence suggests the following relative relationships between till sheets. The contact between the basal grey till and the red till was observed to be sharp at the head of Lake Uist. As this exposure was the only one noted, this interpretation cannot be considered conclusive. The most likely scenario is that the grey till represents till left by an early ice advance. Its location has protected it

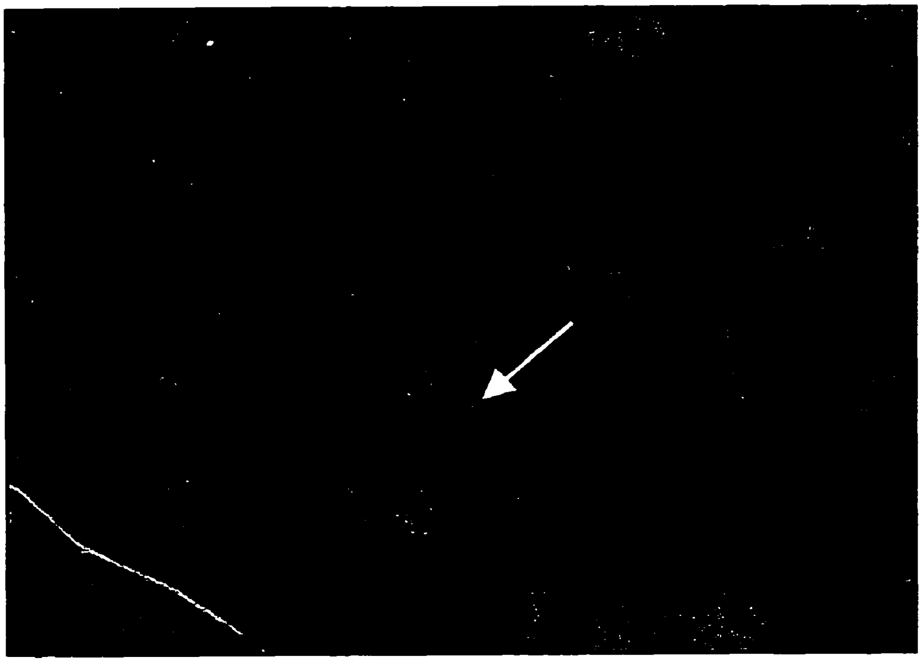


Plate 12: Ladder fen complex with associated bogs located between sample points 6610 and 6611. (from 1993 Province of Nova Scotia aerial photograph 93315-40)

Plate 13: A tree root on a beach at Grand River East and buried peat deposit indicating relatively recent sea-level rise.

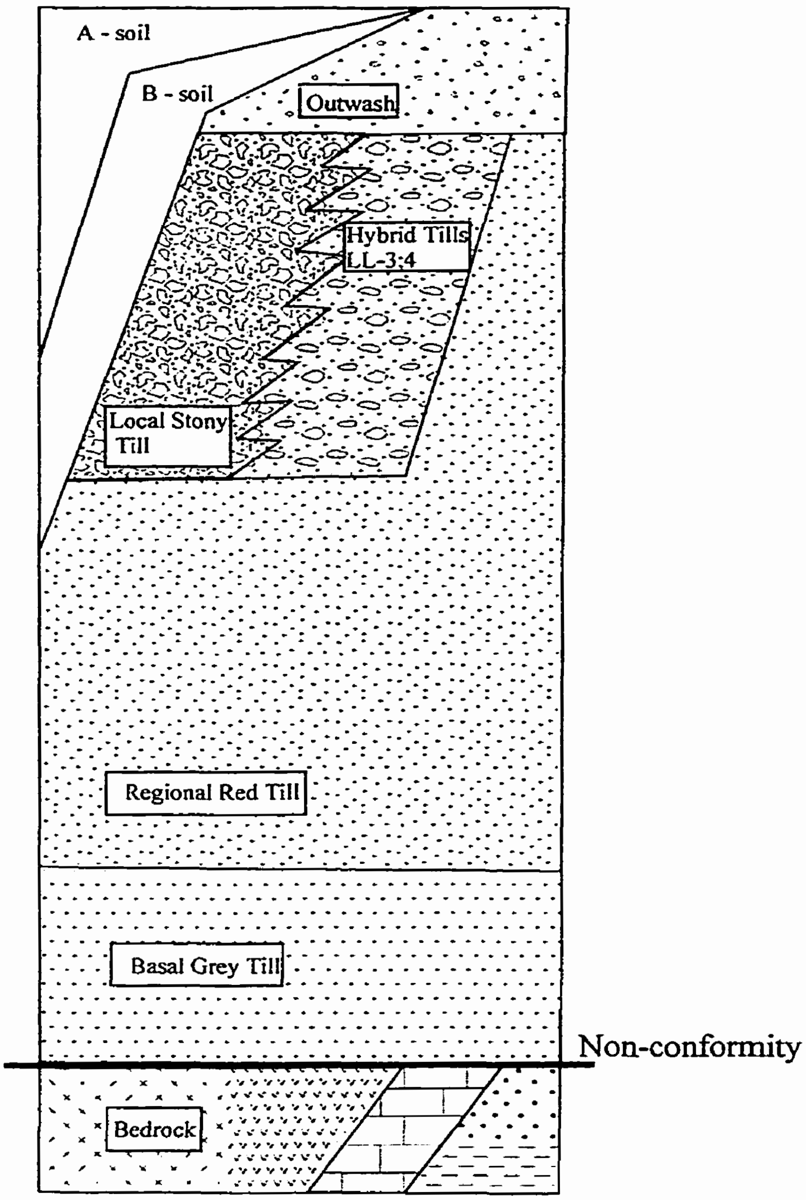


Figure 13: Stratigraphic section showing the relationships between the various glacial sediments.

from erosion by subsequent glaciation.

The best evidence of the erosive contact between two tills is present at the Narrow Lake quarry (between sample sites 6612 and 6613). The regional red till displays smearing and clings to the rock core cavities (Plate 14). The local stony till, with its loose angular clasts of quartz arenite, is draped over these pockets of the regional red till. The significance of these contacts will be further discussed in Section 3.4 (Late Wisconsinan glacial history).

At sample pit 6630 (Plate 10), 1.4 m of layered sandy gravel overlies a loose, salmon-coloured diamicton which consists of a silty-sand matrix but is clast-supported with angular clasts of salmon-coloured granite. This upper diamicton is composed of rounded cobbles and boulders with local southeasterly dipping sand lenses. This glacial sediment is interpreted to be glaciofluvial outwash sediment, deposited stratigraphically above a local stony till. Although the surface unit is classed as outwash, it was felt appropriate to sample the underlying till for geochemical and pebble analyses.

3.3 Ice-flow indicators

Streamlined and oriented landforms may indicate ice-flow direction and are the result of erosion or deposition at the base of the ice sheet by ice or water. The interpretation of an ice-flow record is typically complex due to: (1) partial deposition, (2) erosion by later glacial events, and (3) local variation in tills due to variable bedrock lithology.

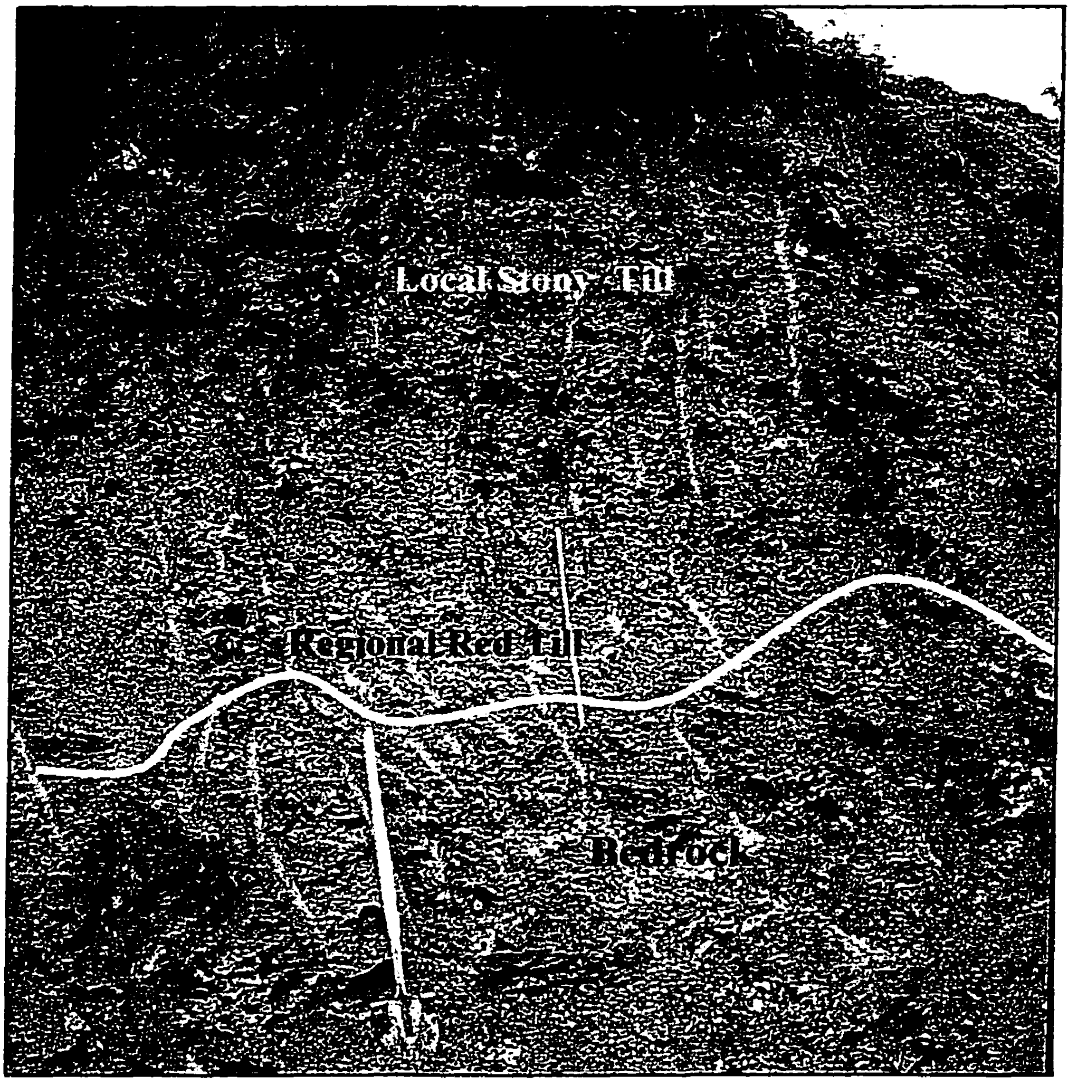


Plate 14: The contact relationships between bedrock, the early regional red till and the local stony till exposed in a rock quarry between samples 6612 and 6613 in the Loch Lomond Valley. The bedrock is locally overlain by regional red till which in turn is overlain by the local stony till. The vertical scratch marks were caused by the teeth of an excavator's bucket. The bedrock is quartz arenite from the Clam Harbour River Formation quartz arenite.

Surface landforms

Grant (1988, 1994) classified the surface distribution of sediment on the basis of distinctive patterns of relief, vegetation and drainage. He subdivided till-covered areas in Cape Breton Island on the basis of thickness and areal continuity, relative to the amount of bedrock outcrop. The thickness of the tills was used as a mapping tool because it conveyed information on texture as well as subsurface stratigraphy. It was noted that thicker accumulations of till tend to be finer grained and consist of several dissimilar superposed sheets. It should be noted that age or genesis was not implied in this classification scheme. These divisions appear to be comprehensive in a regional (Cape Breton Island) context. As this study is focussed on a much smaller area, an attempt is made to distinguish between individual till sheets.

Giant diamicton ridges

The largest and most extensive unconsolidated, positive-relief linear features on Cape Breton Island are a series of east-trending ridges described as giant till ridges (Grant, 1994). They range in height from 20-50 m, in width from 300-1000 m and in length from a few kilometres to 15 km. Their orientation is east-southeast in the southern half of this study area where they are prominent (Plate15). Plate 16, taken near L'Archeveque, shows the effect the ocean has on these bedrock-cored till ridges. They are composed predominantly of the regional red till which contains approximately 10-25% clasts, including red sandstone, siltstone, shale and some exotic clasts. The regional red till is in places overlain by the local stony till. Field evidence reveals that many, if not all, of these ridges are bedrock cored to some extent. The apex of the till ridges

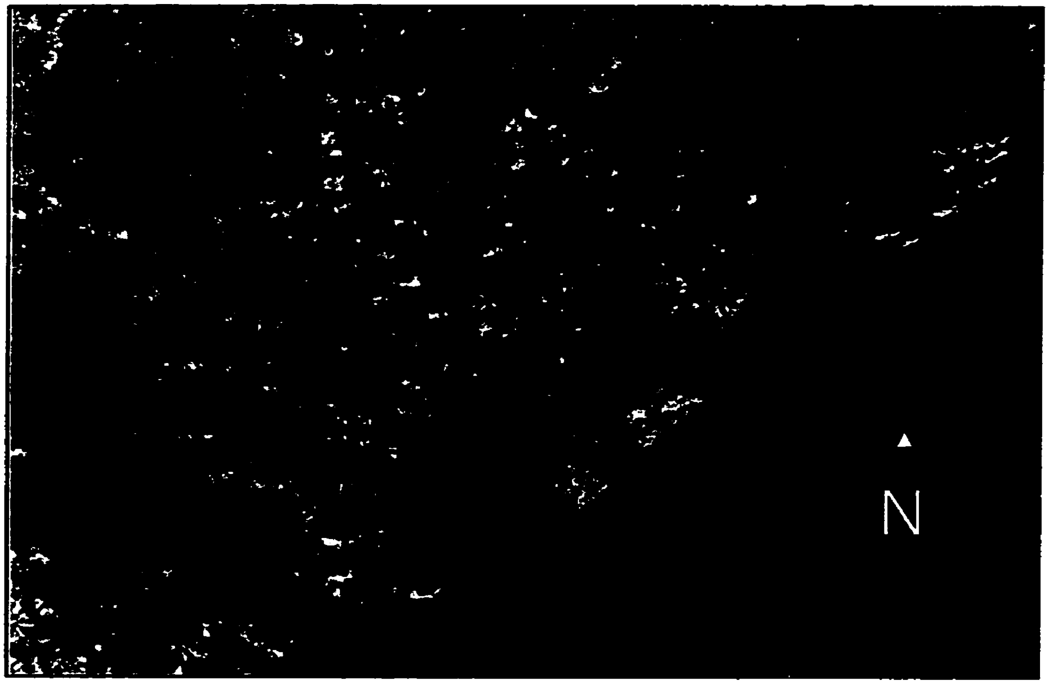


Plate 15: A landsat band 4, 5, 7 image of rock-cored till ridges. Image was acquirered just east of the study area. Note the northwest-southeast trend of the ridges and the tendency for the ridges to become less distinct, and the dominance of drumlinoid forms, towards the northeast.

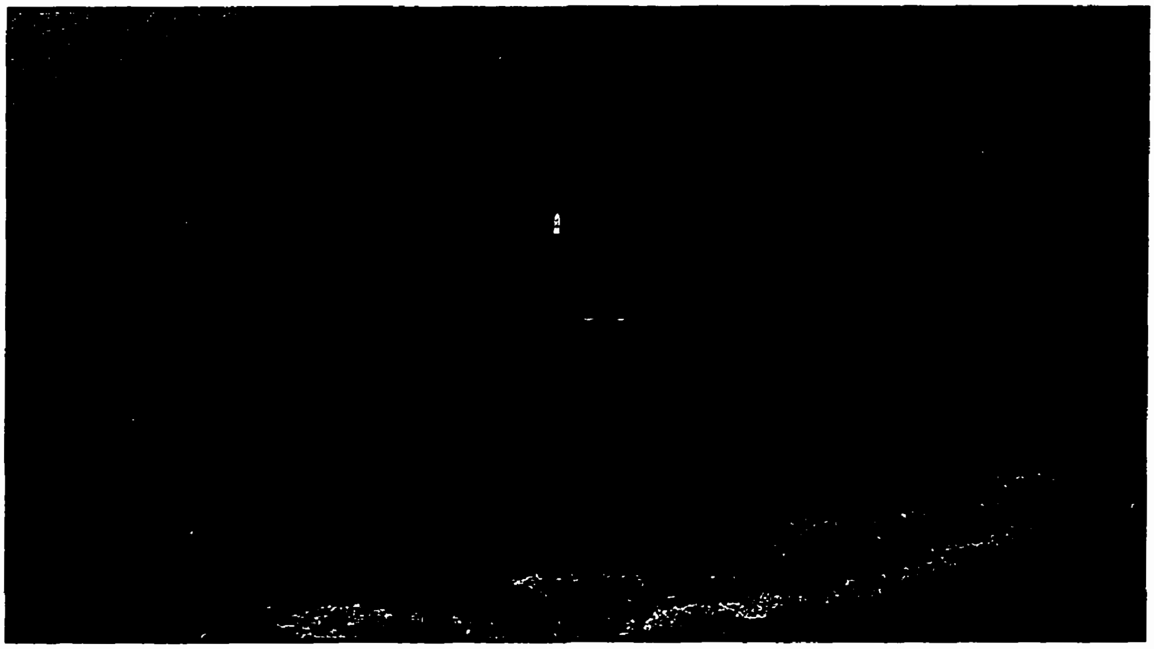


Plate 16: A portion of a rock cored-till ridge which is attached to the mainland by a sand and gravel tombolo at L'Archeveque. The bedrock is volcanic and part of the relatively competent Fourchu Group volcanic rocks.

appear to have formed around paleo-topographic highs. Grant (1994) suggested that the giant till ridges were formed by an early (eastward) flow, and were modified and shifted by subsequent ice movement. The crests of the giant till ridges generally parallel an early eastward ice flow. Grant (1994) suggested that the till on top of those ridges has been remoulded by subsequent flows. The crests locally contain boulder-sized slabs of soft red clastic sedimentary rocks which are believed to have been derived from the Loch Lomond Valley lakes.

It was noted that the sediment on these giant till ridges includes boulders of soft red clastic sedimentary rocks. The size and competence of this material suggests that the travel distance must have been relatively short for the preservation of these large clasts. The Loch Lomond Valley lakes area is considered to be the source of these blankets of coarse red sedimentary clasts because this region consists of similar rock types which are located within 5 km north and northwest of these till ridges. This is consistent with the last ice-flow event (LL-5) that occurred in this region.

Drumlins

Drumlins are confined to the Salmon River Lowland east of this study area. Here, these landforms extend from the head of Lake Uist in a northeasterly trend along the Salmon River Valley. These glacial features are from 1-3 km in length, range between 100-250 m in width and are approximately 10-15 m high. The lee slope points in the down-ice direction, in this case the flow being northeast. MacDonald *et al.* (1991) described the stratigraphy as consisting of reddish-brown silty and clayey, moderately compacted till that averages 10 m in thickness, overlain by a moderately compacted silty till. They suggested that the entire area, including the drumlins, is blanketed by a loosely compacted sandy till. Their data were obtained by coring drumlins. This stratigraphy is similar to the results of this study.

Ice erosional features

Ice erosional features, widespread over the study area, occur as multiple sets, and are more completely preserved than the depositional record. When two or more sets are present at one site, it is definitive evidence of multiple ice-flow events. Shaw (1996) and others have also suggested that these features may be the result of water erosion or deposition during a subglacial flood. Shaw (1996) suggested that drumlins may be formed by water erosion of subglacial till at the glacier base which is analogous to the formation of flute marks in turbidity deposits.

Striae

Striae have been measured in the study area. The most pronounced striae are in the East Bay Hills where trough-like features are cut into intermediate volcanic rock (Plate 17). This feature and accompanying striae trend 060° and were subsequently cut by striae which indicate glacial movement towards 170°. This outcrop also displays a rat-tail, indicating movement to the northeast.

On the Atlantic coast, just inland from Collins Cove, an outcrop of banded felsic volcanic rock displays two ice-flow directions. The first is a series of deeper but less abundant 155° striae which appear to be cut by 035-215° striae (no sense of movement discernible). A trough-like feature with accompanying 110° (stoss) striae fans out to the

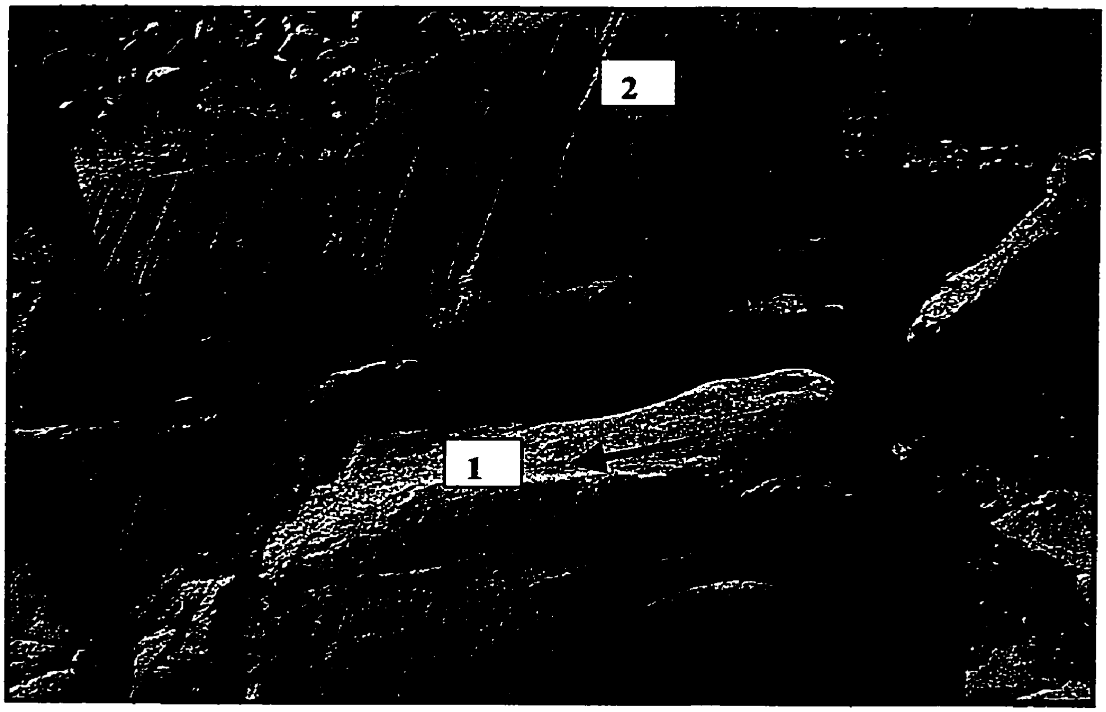


Plate 17: Early glacial grooves and striae at 055° (1) are exposed in outcrop in the East Bay Hills. A second set of striae at 170° (2) cuts the grooves. Top of picture is south.

east. However, it was not possible to determine the relationship to the other striae. A single set of 155° (stoss) striae occurs nearby at the intersection of the Grand River-Point Michaud Road and a logging road to Collins Cove.

In the Mira Hills area, the following striae have been recorded. A series of 170-350° striae (AGE 1) are cut by a set of 150° (stoss) striae and grooves (AGE 2). This set is subsequently cut by a 120-300° set of striae (AGE 3). A series of striae representing 160-340° and 030-210° were also recorded on outcrop near sample 6629.

On the Collins Cove shore near Red Head (Figures 2 and 10), a series of 090-270° and 170-350° striae are present. At Bottle Head near L'Archeveque, the following striae were recorded: 090°, 130° and 155°. Rat-tails are also present here, displaying a sense of 100°. No relationships were apparent.

Roche moutonnées

Roche moutonnées are prominent on almost all glaciated surfaces in the region. The up-dip slope of the stoss side indicates the direction of ice movement. In most cases, the sense of ice-flow direction is determined by the stoss and lee sides. The lee side is the surface which has been plucked, typically by a cold-based glacier. Plate 18 is an example of ice-flow sense being determined using stoss direction, in this case 150°.

Flutings

Flutings are of great importance for the determination of ice-flow direction as they give a good indication of the direction of the last ice-flow event (Lundqvist, 1990). They are most effectively seen on aerial photographs. Flutings are elongate, streamlined ridges

Plate 18: An outcrop of volcanic rock in the Mira Hills exhibiting stoss and lee surfaces indicating an ice-flow direction (arrow) of azimuth 150°. Striae with a sense of 150° cut a 170°-350° set of striae. A third younger set of 120°-300° striae cut across the 150° set.

of sediment aligned parallel to former glacier flow. They range from a few centimetres to a few metres high but are readily degraded by wind and water, which means that they become less apparent with time. The most generally accepted model for their origin regards flutings as the product of subglacial sediment deformation in the lee of obstructions (boulders) on the bed. Field and aerial photograph searches in this study area were not successful in locating the extent of flutings reported by Grant (1988, 1994). However, Grant (1988, 1994) reported that in the southern half of the study area, west of the Loch Lomond Lake, a strong pattern that ranges from 150-170° is evident. In the northern half of the study area, south of the East Bay Hills, Grant (1994) reported northeasterly-southwesterly fluting, parallel to the trend of the Salmon River Valley.

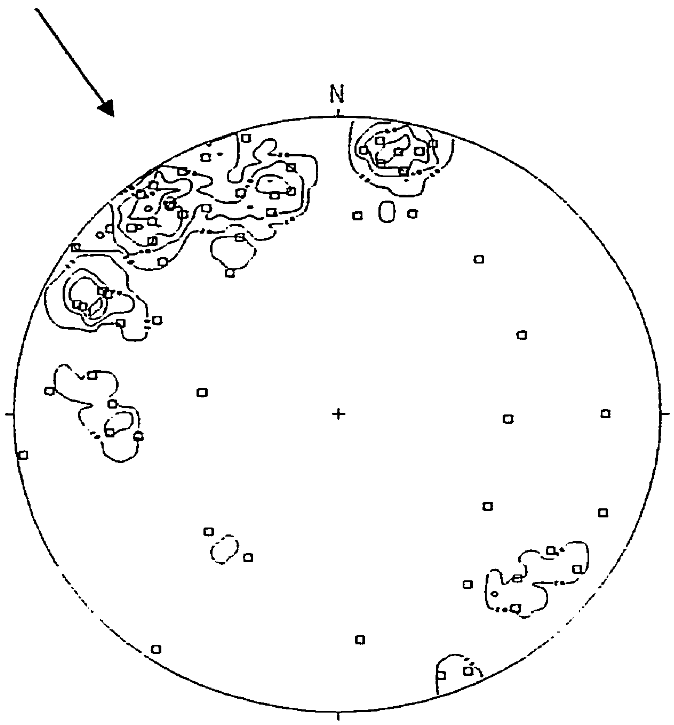
Till-pebble fabric

The best sites to collect till-pebble fabric information were along the Atlantic coastline where numerous vertical sections eroded into till and undeformed exposures of diamicton are present. A location is required where a statistically significant sample group of clasts (60 with a ratio >3:1, long axis:short axis) exists. It was also noted that sections which were not overlying rock exposures provided the best opportunities to collect meaningful data. Two sites, Kemps Point and east of Point Michaud (Figure 2), were found to be suitable because the pebbles were elongated as a result of reworking in the ice. The Kempt Head site is a 4 m high face of an orange-red, well-indurated diamicton. The clasts are angular to sub-angular and are mainly composed of granite; no outcrops were observed nearby. The till near Point Michaud Beach (Figure 2) is a moderately to well indurated, sandy, orange sediment composed of 30% angular to sub-rounded clasts, and is matrix supported. Till at both of these sites are hybrid till because of the reddish-brown colour, abundant local clasts (>30%) and sandy texture. The results of the fabric analysis were plotted on a Schmidt stereo diagram which indicated the following results for each site. The Kempt Head data indicated that the mean glacial flow was 144° (plunge = 12°) with the 1st eigenvalue equal to 0.625 (Figure 14). The Point Michaud data resulted in a mean flow direction of 178° (plunge = 6°) with the 1st eigenvalue equal to 0.596 (Figure 15).

A third fabric analysis was measured at Red Head (Figure 2). The data indicated a flow direction of 130° (plunge = 49°) with the 1st eigenvalue equal to 0.490 (Figure 16). These data are from a sandy, stony till located stratigraphically above the regional red till which is the major component of this rock-cored till ridge. This till is thought to represent the last southeasterly ice-flow movement for the area and is interpreted as a local stony till.

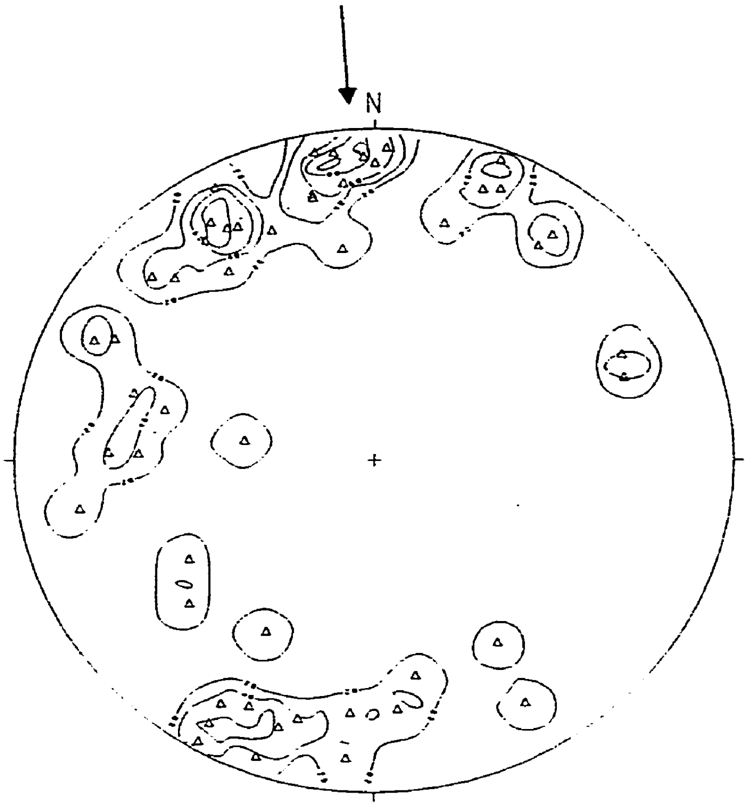
Till-pebble lithology

Till-pebble lithology is based on the collection of a statistically relevant number of pebbles and/or cobbles. It is not sufficient to be able only to identify rock types; one must know the exact location of outcrops from which the pebbles originated. The counted rock types are listed in Appendix 4 and in sub-section 2.5. Eight of the previous lithological types are presented as proportional dot maps: mafic volcanic (Figure 17), felsic volcanic (Figure 18), Salmon River rhyolite porphyry (Figure 19), granite (Figure 20), diorite (Figure 21), L'Ardoise quartz arenite (Figure 22), red-brown sedimentary rocks (Figure 23) and grey-black sedimentary rocks (Figure 24). The six remaining rock



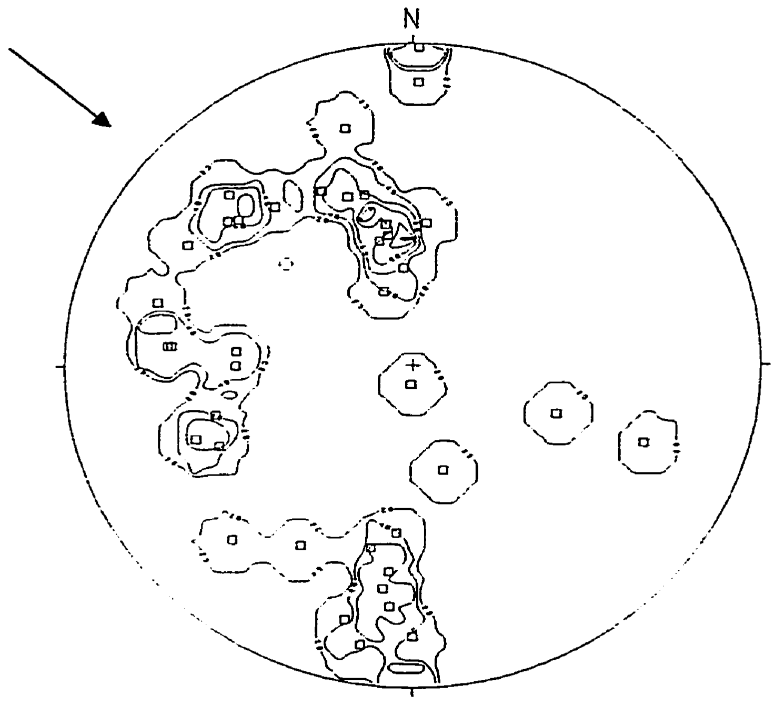
Projection .... Schmidt
Number of Sample Points 60
Mean Lineation Azimuth 324.4
Mean Lineation Plunge 12.3
Great Circle Azimuth 239.0
Great Circle Plunge 12.3
1st Eigenvalue 0.625
2nd Eigenvalue 0.247
3rd Eigenvalue 0.128
LN (E1 / E2) 0.928
LN (E2 / E3) 0.660
(LN(E1/E2)] / (LN(E2/E3)) .. 1.408
Spherical variance 0.4932
Rbar 0.5068

Figure 14: Schmidt stereonet projection of till fabric data from hybrid till LL-4 taken at Kempts Head. Arrow indicates direction of ice-flow



Projection .... Schmidt
Number of Sample Points 50
Mean Lineation Azimuth 357.6
Mean Lineation Plunge 5.5
Great Circle Azimuth 187.8
Great Circle Plunge 28.6
1st Eigenvalue 0.596
2nd Eigenvalue 0.309
3rd Eigenvalue 0.095
LN (E1 / E2) 0.658
LN (E2 / E3) 1.173
(LN(E1/E2)] / (LN(E2/E3)) .. 0.561
Spherical variance 0.5470
Rbar 0.4530

Figure 15: Schmidt stereonet projection of till fabric data from hybrid till LL-4 taken at Pt. Michaud. Arrow indicates direction of ice-flow.



Projection .... Schmidt
Number of Sample Points 40
Mean Lineation Azimuth 310.6
Mean Lineation Plunge 49.4
Great Circle Azimuth 175.9
Great Circle Plunge 58.7
1st Eigenvalue 0.490
2nd Eigenvalue 0.378
3rd Eigenvalue 0.132
LN (E1 / E2) 0.259
LN (E2 / E3) 1.056
(LN(E1/E2)] / (LN(E2/E3)) .. 0.245
Spherical variance 0.3644
Rbar 0.6356

Figure 16: Schmidt stereonet projection of till fabric data from local stony till LL-5 taken at Red Head. Arrow indicates direction of ice flow.

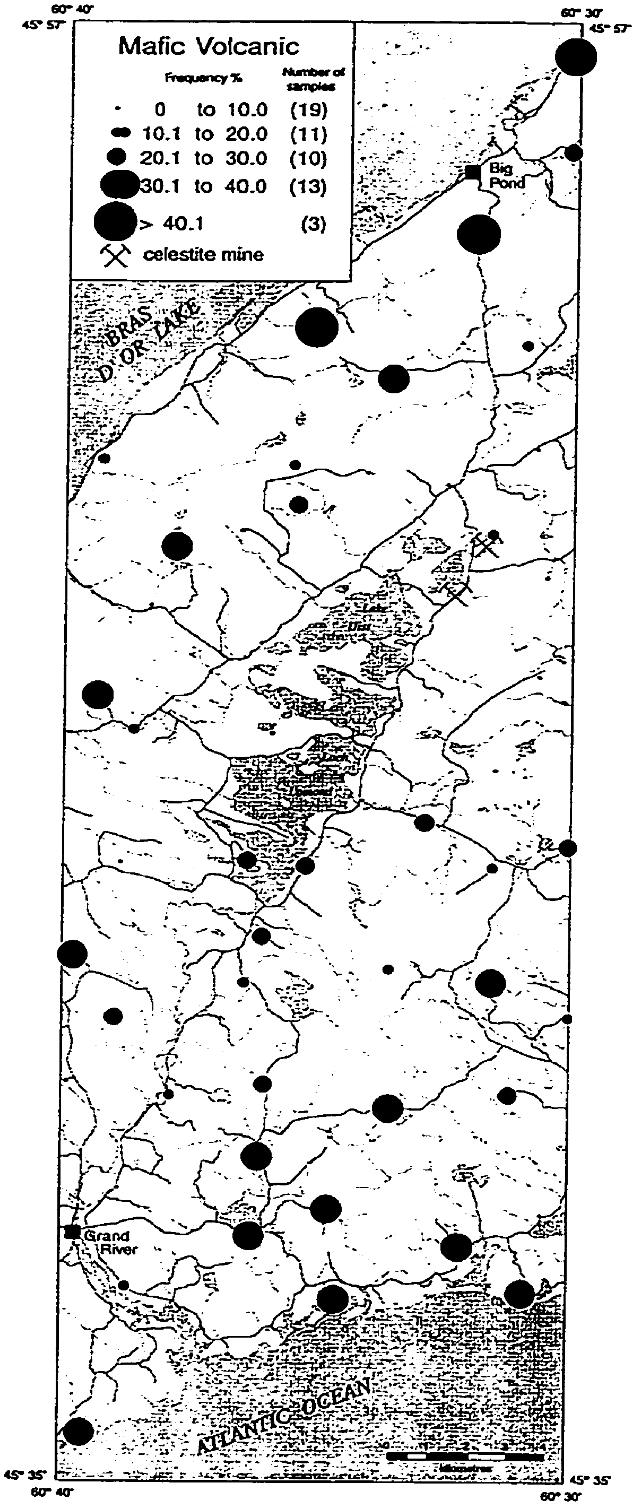


Figure 17: Distribution of mafic volcanic pebbles in till.

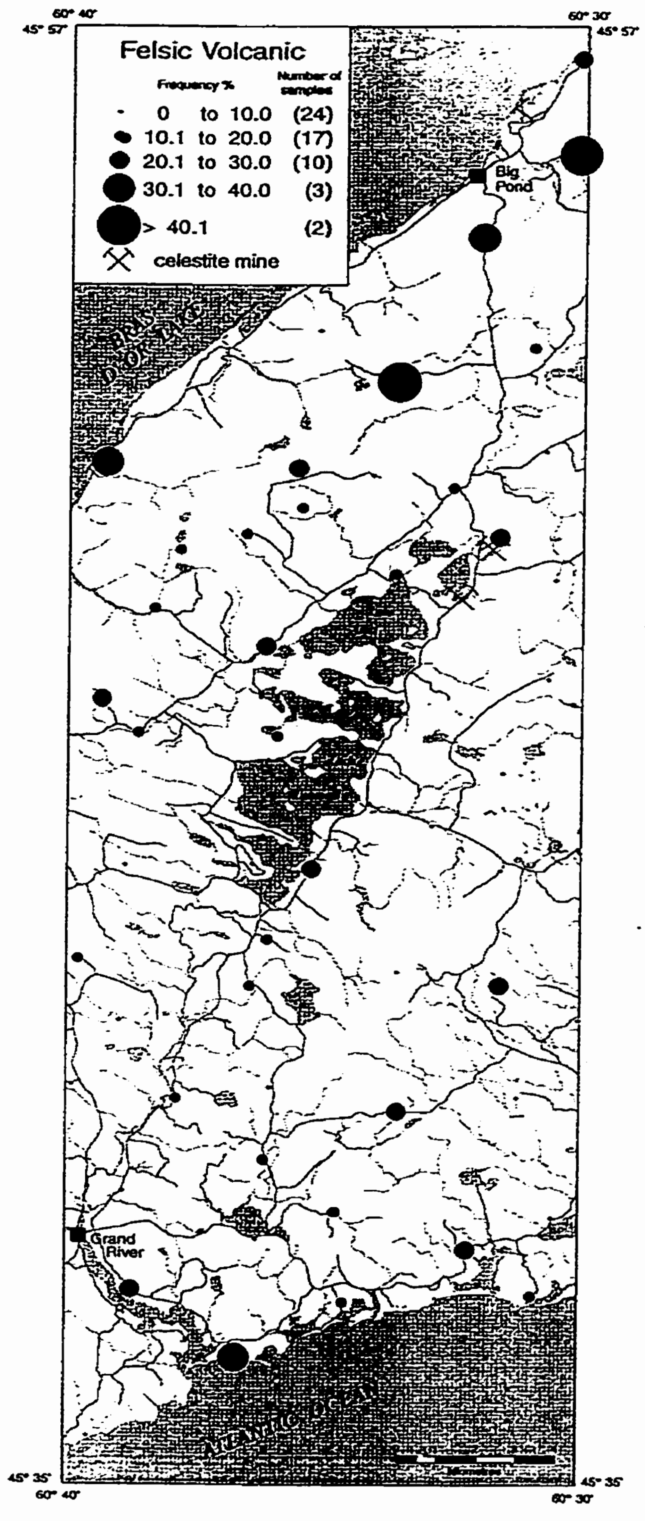


Figure 18: Distribution of felsic volcanic rock pebbles in till.

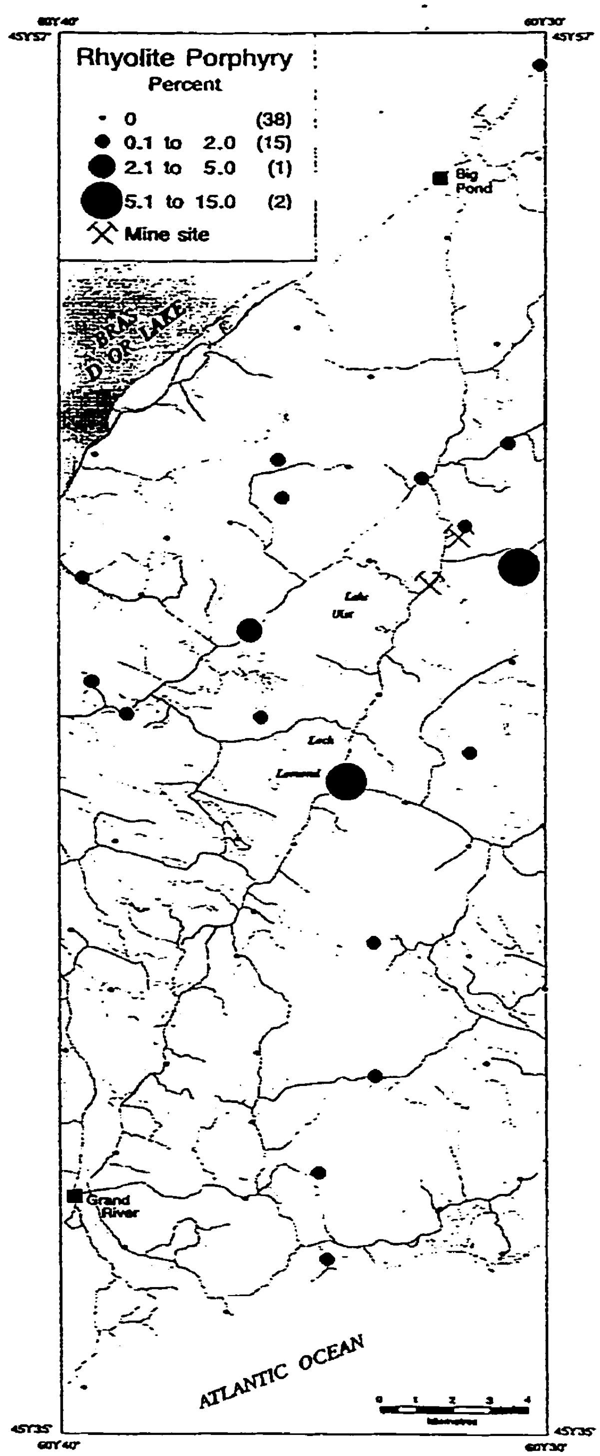


Figure 19: Distribution of Salmon River rhyolite porphyry pebbles in till.

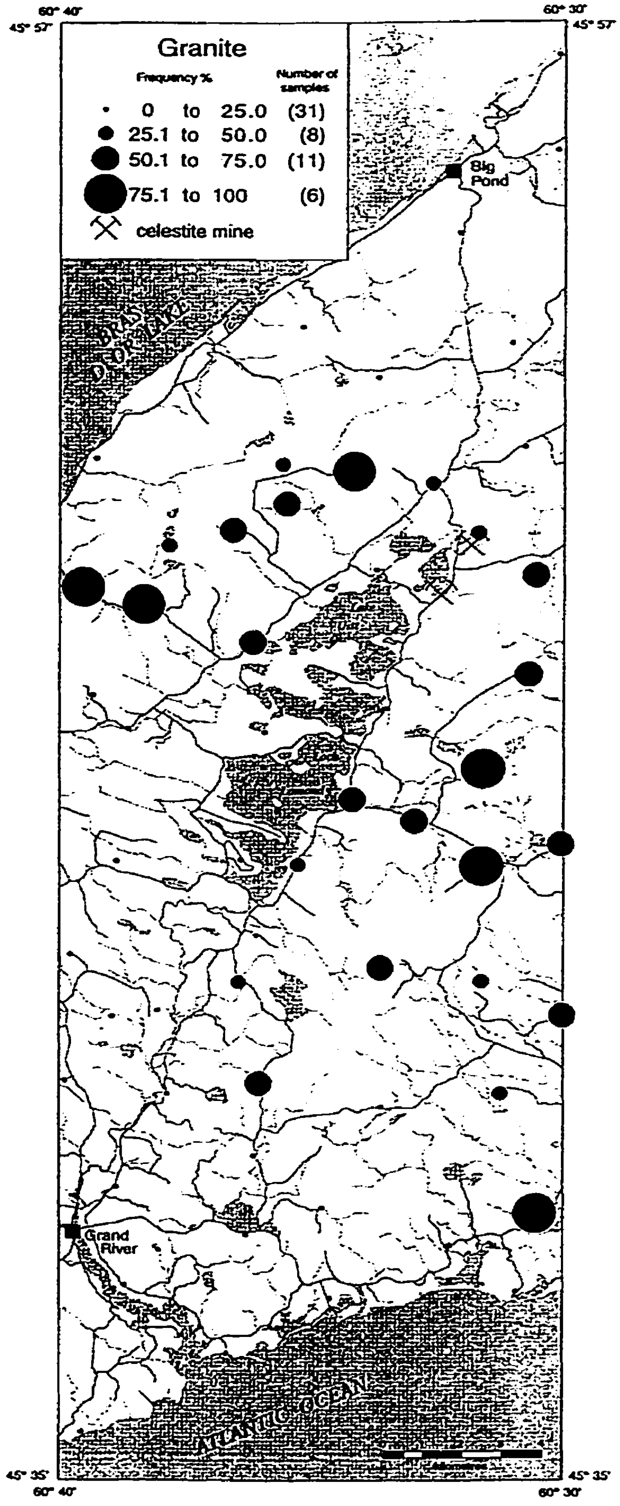


Figure 20: Distribution of granite pebbles in till.

Figure 21: Distribution of diorite pebbles in till.

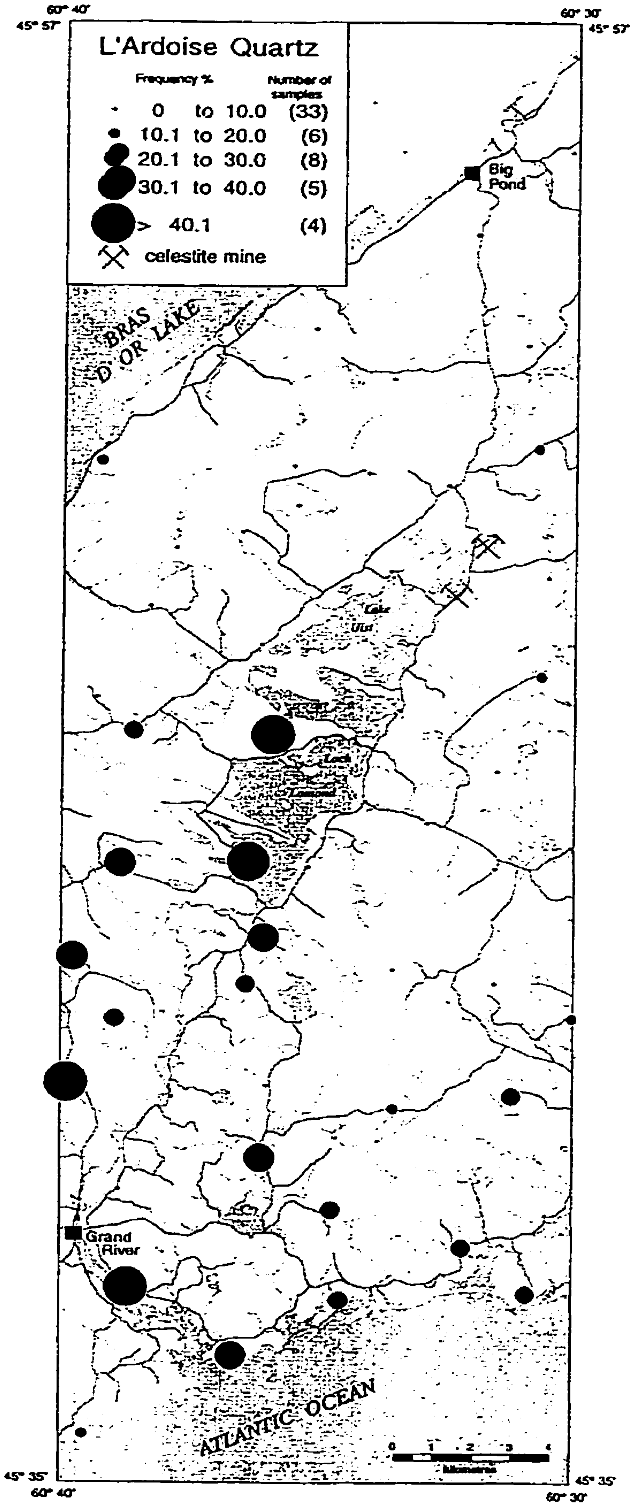


Figure 22: Distribution of undifferentiated Clam Harbour River Formation (also known as the L'Ardoise quartz arenite) pebbles in till.

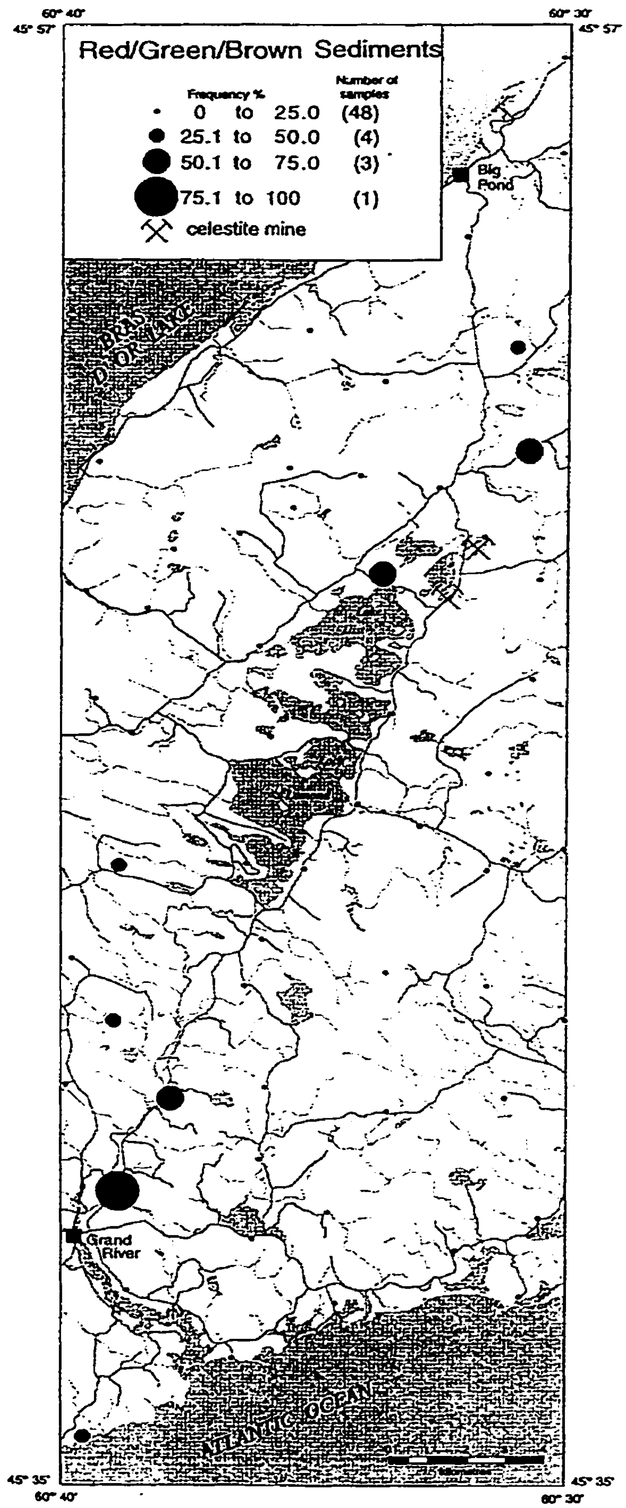


Figure 23: Distribution of undifferentiated red, green and brown sedimentary rock pebbles in till. Generally consists of Upper Mississippian rocks.

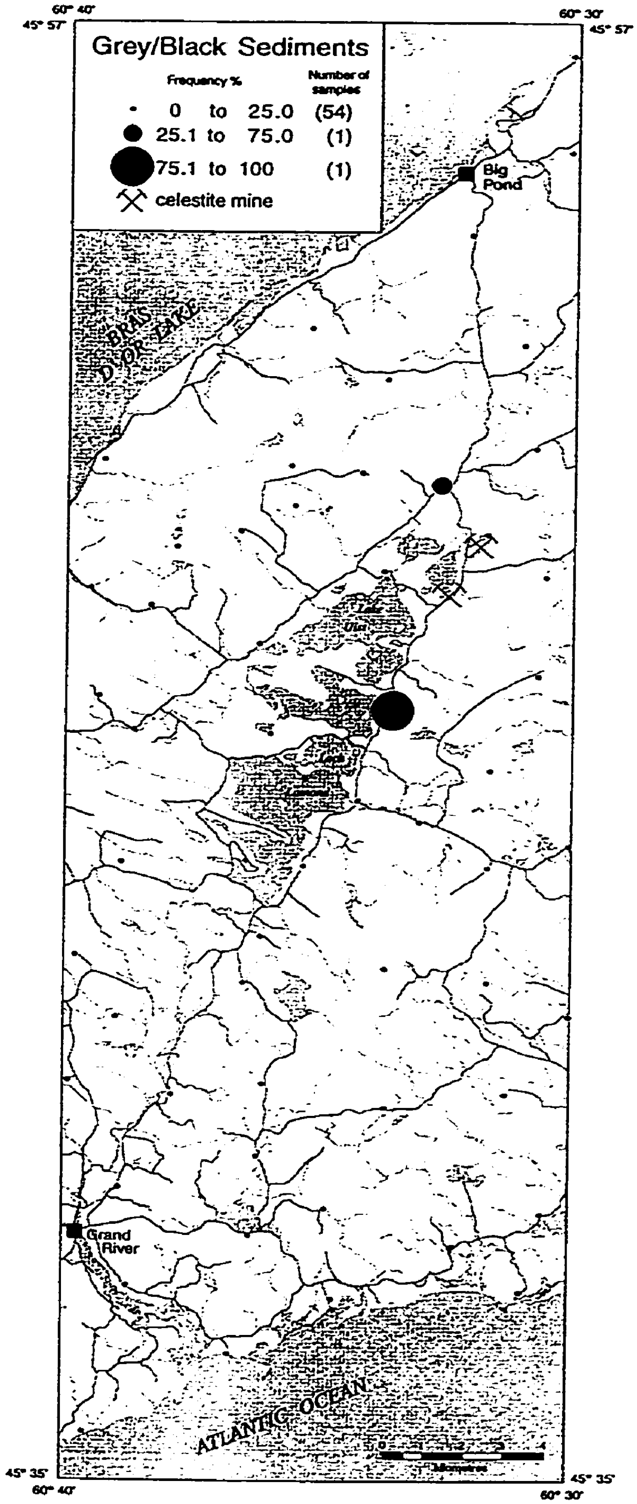


Figure 24: Distribution of undifferentiated grey, black sedimentary rock pebbles in till. Generally consists of Upper Mississippian rocks.

types were not plotted because of their relatively low abundance. The L'Ardoise quartz arenite samples were added because of the significant amount of outcrop to the west of the study area. This rock (with its dominant quartz content) can easily be mistaken for exotic quartzite pebbles. Gossan or oxidized portions are commonly associated and make up approximately 30% of these clasts. These portions may be classified as a subset. Pebble lithology abundance data are listed in Appendix 4 as total counts and frequency percent. The pebble percentages were plotted as proportional dots on maps, similar to the till geochemical data, for selected rock categories. The following comments describe the distribution of the proportional plots for these rock categories.

Mafic volcanic rocks

Pebbles of mafic volcanic rocks (Figure 17) are prevalent in the local meltout till in the East Bay Hills and the Mira Hills of the study area (Figure 17). It is worth noting that these areas are underlain by volcanic rocks of the East Bay Hills Group and the Stirling Group, respectively (Figure 3). Volcanic rocks are also concentrated in the unit designated as outwash (LL-6). Clasts derived from volcanic rocks are not prominent in the Loch Lomond lowlands, an area comprised mainly of the regional red till. The exception to this is sample 6659, located in the extreme northeastern corner of the study area, with over 41% of the pebbles being classed as mafic volcanic rock. The mixed till locations have approximately 30-40% pebbles from mafic volcanic rock units, especially in the central western part of the study area. Overall, mafic volcanic rocks make up 21% of all pebbles counted and constitute the second largest lithological population.

Felsic volcanic rocks

Pebbles derived from felsic volcanic rocks are concentrated in the East Bay Hills (Figure 18) where they make up >40% of the clasts in samples 6603 and 6644 and have been assigned to the regional red till. They make up about 30-40% of the pebbles in the two most northerly samples of the local stony till (6650 and 6658). Lesser amounts were found in samples assigned to the outwash category on the southern edge of the study area. Felsic volcanic rocks comprise 13% of the total pebbles counted in the study. In summary, felsic volcanic rocks occur predominately in till deposited near felsic volcanic rocks, especially in the East Bay Hills, and to a lesser degree in the Stirling belt in the Mira Hills.

Mafic porphyry rocks

Mafic porphyritic rocks are distinctive because they are composed of white feldspar phenocrysts set in a dark mafic matrix. They are minor in abundance in the study area. These pebbles are representative of dykes which occur in both the East Bay Hills belt and the Stirling belt (S. M. Barr, per. comm., 1998) and, therefore, their presence is not helpful in determining ice-flow directions because of the two possible source areas. The highest concentrations of these pebbles are in samples 6647, 6629, 6618 and 6628 where they represent 2-4% of the total pebbles present in each sample. These pebbles appear to be derived from the nearby source rocks in each belt. These rocks are found in the local stony till, outwash and regional red till. Overall, dyke rocks make up <1% of the total pebbles counted in this study area because of the limited extent of outcrop.

Salmon River rhyolite porphyry

The Salmon River rhyolite porphyry is one of the most recognizable rocks in southeastern Cape Breton Island, characterized by quartz phenocrysts set in an aphanitic pink matrix. This lithology was used successfully by McClenaghan *et al.* (1992) to define the major eastward ice-flow event because of its distinctive colour and its limited area of occurrence in southeastern Cape Breton Island. The Salmon River porphyry comprises only 1 km^2, approximately 3 km east of Enon (Figure 2) on the eastern edge of this study area. Clasts of the Salmon River rhyolite porphyry were found in minor quantities in 18 of the till samples (Figure 19). Sample 6657 contains 15% rhyolite porphyry pebbles. Samples 6647 and 6643 contain 4% and 5% rhyolite porphyry clasts, respectively. The pebbles are generally <2 cm in diameter and are well-rounded. There is little doubt that these pebbles were derived from a bedrock source to the east. The significance of these pebbles in the study area is discussed in section 3.4.

Granite

Granite is common in the East Bay Hills belt, the Stirling belt and the Coastal belt. In this study, no attempt was made to differentiate between the various types of granite clasts, except to note the presence of clasts from the Grand River Pluton (see next section). Because granite is more resistant to weathering than many other rocks, it may remain in the till over longer distances of transport. For this study area, granite is almost ubiquitous in all the sample sites (Figure 20; Appendix 4). Six samples contain over 75% of clasts derived from granitic rocks. They include 6601, 6602 and 6624 in the East Bay Hills, and 6630 on the southern coast, which occurs on the St. Esprit Pluton (Barr *et al.*,

1996) in the local stony till. The two remaining samples (6610 and 6611) are assigned to the hybrid till located on the Chisholm Brook Pluton (McMullin, 1984). The regional red till contained <25% granite in all but one of its samples. Sample locations 6612 (regional red till) and 6642 (local stony till) in the Loch Lomond valley were the only sites which did not contain any granite pebbles. Granitic pebbles form the largest population (31%) of all lithologies.

Grand River Granite

The Grand River Pluton (Barr *et al.*, 1996) is composed of a grey to pink, medium-grained leucogranite which makes it distinct from the other granites in the study area because of its abundant quartz and sericitized feldspar. Barr *et al.* (1996) reported three outcrops of this granite type west of Grand River. These outcrops occur in the southwestern corner of this study area. Thin-section examination (S. M. Barr, per. comm., 1998) identified this granite type as making up 63% of the clast population from sample site 6654 (Figure 5). These pebbles are angular and show no signs of rounding. The sample was collected at the top of a rock-cored till ridge at the southern end of Ferguson Lake, which is 4 km northeast of outcrops of the Grand River Granite. Overall, this granite represents <2 % of the total pebbles counted in the study area (Appendix 4).

Diorite and gabbro

Intermediate to mafic intrusive rocks do not represent a major component of the pebbles determined in this study (Figure 21). In fact, diorite makes up <3% of all samples in the area. Gabbro was counted only in sample 6638, which is on the central eastern edge of the area and makes up <0.1% of the total count. Diorite has its largest concentration in the hybrid till, especially in sample 6604 where it makes up >10% of the clasts in that sample. The next highest concentration is in local stony till and hybrid till on the east side of the Loch Lomond Valley lakes. It is also makes up 5-10% of the clasts in samples from sites in the southern East Bay Hills (Figure 21; Appendix 4). Diorite from the Chisholm Brook Pluton is the most likely source of these clasts. The St. Peters Gabbro is the most likely source of mafic intrusive clasts in the study area.

L'Ardoise quartz arenite

The L'Ardoise quartz arenite because of its visual similarity to quartzite was the most difficult clast to classify during the pebble counts. These rocks occur on the southwestern edge of the study area.and represent the Clam Harbour River Formation of the Horton Group (White and Barr, 1998). The name L'Ardoise has been retained in this study for two reasons. First, these rocks occur in what was known for many years as the L'Ardoise thrust block. Second, the fieldwork for this study was completed before the revised formal map units of White and Barr (1998) was published. Overall, these pebbles make up 14% of the total number of pebbles counted in this study (Figure 22). A subgroup of 30% of the L'Ardoise quartz arenite pebbles appear rusty as a result of oxidized sulfides. These rusty components are similar to oxidized zones exposed at a small gravel-crushing quarry at Narrow Lake on the McNabb Road (between samples 6612 and 6613) where channel-lag deposits occur with abundant oxidized (pyrite) zones. Within a few metres of this site, the clast-supported till is composed of local angular boulders and fragments. These pebbles predominate in the southwestern part of the study area. They occur in the regional red till, the hybrid tills and the local stony till. These clasts are sparse in the northern half of the study area.

Vein quartz

Vein quartz makes up <1% of the total pebbles counted in the study area. The source may be directly from veins, but some of the vein quartz pebbles may have been derived from Carboniferous conglomerate. Their use as an indicator of glacial transport is minimal (Appendix 4).

Red, green and brown sedimentary rocks

Red, green and brown pebbles are Early Carboniferous clastic sedimentary rocks which occur mainly in the Loch Lomond Basin and along the Salmon River Lowlands, although they also underlie part of the Bras d'Or Lake and Northumberland Strait. They represent 10% of the total pebbles in the study area (Figure 23). They are the predominant constituent in sample 6636 where they make up over 90% of the clasts. In samples 6637, 6652 and 6608 they make up >50% of the clasts. These samples are assigned to either the regional red till or the hybrid till. Four samples contain >25% of these clasts: 6607, 6613 and 6635 (red and hybrid till) and 6626 (outwash).

Grey and black sedimentary rocks

Grey and black clasts are Late Carboniferous sedimentary rocks which occur in the northeastern portion of the study area. They make up <4 % of the total pebbles sampled in the area (Figure 24). Sample 6642 (Figure 8) contains >75% of these clasts and sample 6648 contains approximately 50% of the clasts. The other 54 sites contain <25% of these clasts. These samples pits are found in the northeastern portion of the study area.

Limestone

Limestone pebbles represent <1% of the total pebbles collected in the study area. Rounded to well-rounded limestone pebbles accounted for 52% of the pebbles collected from sample pit 97–DS-002 (Figure 8). Some of the limestone pebbles are striated, while others exhibit sparite and dogtooth spar in cavities. A few of the limestone pebbles emitted a petroliferous odour when struck with a hammer. It is estimated by field observation that the clay content of matrix of the till sample would be >25% (sieve analysis was not carried out). The matrix of the sample 97-DS-002 readily reacted when tested with dilute HCl indicating the presence of carbonate in the matrix. The matrix is believed to be also derived from the same source as the limestone pebbles found in the sample 97-DS-002.

Three pebbles of brown dolomite occur in sample 6603 (2% of total pebbles in the sample) and have been reported as limestone rather than as "other category "in Appendix 4 because of the carbonate relationship. These pebbles, when scratched or struck with a hammer, release a petroliferous odour, a characteristic feature (Boehner and Prime, 1993) of the Big Glen Member (dolomite) of the Uist Formation (Figure 6). This unit outcrops on the Salmon River road approximately 5 km east of Enon (Figure 3). The significance of these clasts in till in the study area will be examined in the discussion (Chapter 5).

Other rocks

This category represents <2% of the total counted pebbles for the study area. They include many unidentified samples, at least some of which represent weathered and unrecognizable samples of the previous 13 described lithologies.

3. 4 Late Wisconsinan glacial history

Introduction

The Laurentide ice sheet did not have the same effect on Maritime Canada, in particular southeastern Cape Breton Island, as it did on the Canadian Shield region of Canada. Stea *et al.* (1989) suggested that the interplay of the regional ice sheets and local ice caps, and the physiographical variation of mainland Nova Scotia produced distinct zones of erosion and deposition, each of which is characterized by discrete transport histories. The study area was characterized by a thin dynamic ice sheet that was probably significantly influenced by topography (Grant, 1994). The local highland regions in the study area (the East Bay Hills and the Mira Hills) (Figure 1) played an important role in the development of erosional and depositional patterns. Grant (1989) and Stea (1989, 1999) suggested that many small ice concentrations existed during the Wisconsinan which produced several ice-accumulation centers. Grant (1989) stated that Cape Breton Island was subject to glaciations of decreasing vigor or intensity during the Wisconsinan glacial stage. This section will discuss the significance of stratigraphic units with respect to ice-flow indicators.

Summary of ice-flow indicators

Table 4 provides a summary of field data for the ice-flow directions that deposited the tills in the study area. Four tills are described, based on the striae record, fabric, landforms and till pebble lithologies. The till order has been determined by the cross-cutting striation record and the determination of sense direction for these striae. Till pebble fabric data are correlated with the striae record. The development and orientation of landforms is discussed as an indicator of ice-flow movement. Finally, the significance of till pebble lithologies is discussed and correlated with the previous data.

Striae record

The striae record (Table 5) documents field observations, including the determination of the sense of movement through the use of roche moutonnée features and rat-tails. Cross-cutting relationships determine the relative age of the ice-flow events assigned to the various tills in the study area. A question mark indicates there is some doubt as to the actual flow direction azimuth. Striae are reported in four locations in the study area, including the East Bay Hills, Mira Hills, Collins Cove and the Atlantic coastline.

Till-pebble fabric record

Three fabric determinations were conducted on tills in the study area. The tills at Kemp Head (sample 6632) and east of Point Michaud (sample 6635) are assigned to the hybrid till (144° and 178°), associated with ice-flow event LL- 4 (Table 4). The till at Red Head (Figure 2) is a local stony till (130°), associated with the LL-5 ice-flow event.

Table 5: A table comparing published striae with striae from this study, fabric from this study, orientation of geomorphic features. CODE: G = Grant, (1994); MD = McClenaghan and DiLabio, (1994, 1996); EBH = East Bay Hills. Capital letters and Roman numerals are after original authors.

Grant	**M D**	**E B H**	**Mira Hills**	**Collins Cove**	**Coast**	**Fabric**	**Land Forms**
			local stony 120°		130°	Red Head 130°	
			hybrid 150°	155°	155°	144°	
G	**V** 165°-180°	170°	hybrid 350°	035° ?		178°	
E_1							
D	**IV**						
C_2 140°	?						
B 070°-115°	**III** 080°-110°	060°		red regional 110°	090°		rock-cored till ridges 110°
	II 095°-110°						
	I 120°-150°						

It was observed that if a rock outcrop was located near a potential fabric site, the clasts are generally not suitable for fabric determinations. The collection of fabric data was also attempted at many exposures of the regional red till that occurred in the giant till ridges, but because the majority of the clasts are small and rounded (a function of the soft nature of the Carboniferous lithologies), no useful data were obtained.

Landforms

The most significant geomorphological features in the study area are the "giant till ridges" (Grant, 1988, 1994; McClenaghan and DiLabio, 1994, 1996). Field observations indicate that these features commonly contain an internal bedrock core. The orientation of the long axis of these landforms may be influenced by the orientation of the paleo-topographic highs developed prior to glaciation and overprinting by an early west-to-east ice advance (LL-1). The orientation of these landforms in the study area is approximately 110° which correlates with the fabric data (Table 2) collected from the red silty till (unit III) of McClenaghan and DiLabio (1996).

This study suggests that these features are giant "bedrock-cored" till ridges. This observation has not been previously noted by Grant (1994) or McClenaghan and DiLabio (1994, 1996) who referred to these features only as giant till ridges.

In the northeastern part of the area, drumlins have a northeastern orientation. These drumlins were reported by MacDonald and Boner (1992) to have a core of red, compact material which is draped by two additional diamictons with decreasing degree of induration. It is suggested that the paleotopographic depression (Loch Lomond Valley) funneled ice (from the west, LL-2) to the northeast along the Loch Lomond-Salmon River valleys, producing the basal layer for the drumlins. Subsequent ice movements deposited the overlying tills on the original drumlinoid form. This process may be likened to that involved in valley glaciation (Benn and Evans, 1998).

Pebble record

Till pebbles collected from regional sample sites can be good indicators of the direction of ice-flow movements. The important criterion is that there must be unique geological units present in or adjacent to the sample sites. In the study area, most lithologies cannot be used because the units are ubiquitous and are repeated which makes the interpretation of clast provenance difficult. When an area has multiple flow-movements, as the study area does, then the interpretations are further complicated. However, the study area has several distinctive lithologies that are useful for the purpose of ice-flow history interpretation. They include the Salmon River rhyolite porphyry (McMullin, 1984; Barr *et al.*, 1996), the Grand River granite (Barr *et al.*, 1996), the L'Ardoise quartz arenite (Clam Harbour River Formation, White and Barr, 1998), the Big Glenn Formation dolomite (Boehner and Prime, 1993) and Windsor Group limestone (Boehner and Prime, 1993). The dispersal of these distinctive lithologies has been summarized in Table 6. This table correlates the various pebbles with an ice-movement event and till type, along with the location of the sample pit and the approximate suggested transport distance.

The presence of limestone pebbles is described in the till-pebble lithology section. Two distinct limestone units exist in the region. Limestone was noted in only one sample (97-DS-002). Glacial transport distance for this limestone was relatively short (possibly a

Table 6: Table showing details of till pebble lithology data which are summarized in Table 4.

TILL	FLOW	PEBBLE TYPE	SAMPLE (S)	DISTANCE
LL-6 outwash	(S)	Salmon River rhyolite porphyry	6657	? Movement from east to west
LL-5 local stony till	120° 130°	L'Ardoise quartz arenite	6634 (?)	<3 km
LL-4 hybrid till	155° 180°	no pattern observed		
LL-3 hybrid till	350° 035°	Grand River granite Big Glen Formation dolomite	6654 6603	4 km 8 km
LL-2 regional red till	060° 110°	Windsor Group limestone L'Ardoise quartz arenite	97-DS-002 6640, 6612 6655, 6614	<2 km
LL-1 basal grey till	?	no pebbles observed	6673	

few 10s of m) because several of the limestone clasts still exhibited cavities lined with dogtooth spar and sparite. The pebbles are not fossiliferous, which would suggest that the source of the limestone was local: i.e., from the Loch Lomond area and not from the Irish Cove fossiliferous limestone deposit located in the northwestern part of the study area (Figure 3). Boehner and Prime (1993) indicated from drill-hole sections that the Loch Lomond Valley is underlain by limestone. The presence of these limestone clasts at site 97-05-002 is a good example of the regional red till incorporating local bedrock while still maintaining its more exotic clast content and matrix composition because of the distinctive original colour and texture of the matrix. The strong effervescent of this sample to HCl indicates that comminution had taken place and a carbonate signature had been imparted to the till matrix.

The ice-flow event responsible for the deposition of regional red till was flowing eastward as it crossed the East Bay Hills, quarried the limestone in the Loch Lomond Valley, incorporating these carbonate components into the matrix and clast populations, and deposited them a short distance (<1-2 km) to the east up against the Precambrian rocks in the Mira Hills.

Sample 6654 (Ferguson Lake) contained a population of 60% Grand River Granite pebbles and 40% clasts from mafic volcanic rocks. Although this till sample has been assigned to a hybrid classification, it is most likely an end member till (Stea, 1999), properties of which were controlled by bedrock source areas and the dynamics of the glacier depositing the till. The only known source of this granite is 4 km to the southwest (Barr *et al.*, 1996). Therefore, this till must have been deposited by the northerly (LL-3) ice flow. A till containing more than 60% of one clast type typically suggests that the till is close to source. Therefore, the possibility exists that the Grand River Granite contact extends further to the northeast. The extent of the Grand River Granite (Barr *et al.*, 1996) was based on a small number of outcrops, a result of the extensive till cover (S. M. Barr, per. comm., 1997).

The recognition of three rounded pebbles of petroliferous dolomite from the Big Glenn Formation (Boehner and Prime, 1993) in sample 6603 in the northern part of the study area suggests a northerly ice-flow event. The sample has been classified as the regional red till mainly because of its high induration, red colour and clay content (28%). However, it is suggested that it may represent a good example of overprinting; that is, the injection of clasts (matrix or fabric) into older tills by overriding ice (Stea, 1999). In this case, the scenario suggested is that the regional red till was deposited in the area by the eastward (060°-110°) flow. A subsequent flow quarried the dolomite from the Big Glenn Formation and moved northward (350°-035°) a distance of 8 km and overprinted these pebbles on the older regional red till.

The L'Ardoise quartz arenite distribution (Figure 22) displays two different dispersal patterns when the till types are considered. Samples of regional red till (e.g., 6640, 6612, 6655 and 6614) contain 25-40% quartz arenite to the east of the actual eastern contact. Samples of the local stony till (e.g., 6625, 6626, 6614, 6617, 6634, 6628 and 6621) contain 20-40% quartz arenite pebbles and are southeast of the eastern contact of the Clam Harbour River Formation. These two patterns correlate well with the observed striae patterns for each till.

The L'Ardoise quartz arenite bubble plot (Figure 22) displays two dispersal patterns, if one isolates samples assigned to specific till types. The red regional till (samples 6640, 6612, 6655 and 6614) contain 25-40% quartz arenite pebbles. These sample sites are located due east of the eastern contact of the Clam Harbour River Formation. This would indicate that a west to east flow movement was responsible for the dispersal pattern of quartz arenite. Samples 6625, 6626, 6614, 6617, 6634, 6628 and 6621 are assigned to the local stony till. These sample pits yielded 20-40% quartz arenite pebbles. The pits are located southeast of the Clam Harbour River Formation. An ice movement from the northwest coincides with other physical evidence to indicate that this event took place.

Discussion of till types

The key question is: How does one identify a specific till type when examining sections or collecting till samples from shallow pits? Obviously, it is difficult to do so in the field when one considers the size of the limited exposure in pits from which the sample is taken. As suggested in section 3.2, samples were assigned to the various stratigraphic units by considering a host of factors, and then rated with a confidence factor. The factor was designated by a number from 1 to 4, with 4 having the highest level of certainty (Appendix 8). It became apparent that field observations of the textures and the petrology of the diamictons could be used to differentiate them. The identification of distinct till types (not necessarily in hierarchical order) is based on the compactness of the sediment, the relative abundance of pebbles and cobbles, the angularity or roundness of the clasts, the proximity of the clasts to their source outcrops, the presence of exotic pebble lithologies, the presence of striated clasts, the relative amount of sand and clay, the approximate elevation of the sample site, the colour of the sample, the presence/absence of sand layers or lenses in till and compactness. An early endeavour was made to group the diamictons using a colour criterion based on the Munsell Rock-Colour chart. Colour is useful in discriminating between these diamictons; however, the use of colour alone is hampered by the intermixing of the diamictons, making a definitive determination difficult. The till types identified in this study are summarized and discussed in the following section (Figure 11) and include: the basal grey till, the regional red till, hybrid till(s) and the local stony till.

Basal grey till

The recognition of basal grey till is based on one exposure at sample sites 6652 and 6673 where a grey till is overlain by a red diamicton. The grey till is compact, contains more sand and less clay than the overlying red till, and is stone-poor. A similar stratigraphy was reported by McClenghan and DiLabio (1996) at the Fox Cove section, where a 1 m thick, stone-poor, compact grey silty till with a well-developed east-trending fabric overlies a stone-poor, orange red silty till. The Fox Cove site is overlain by a stone-poor, compact, dark red silty till. In the study area, traverses along the Atlantic coastline did not reveal any other exposures of this basal grey till at the base of thick sections eroded by waves. Drilling or backhoe trenching may be the only ways to delineate the full extent and thickness of this grey till (Table 7) which is a result ice-flow LL-1.

Regional red till

The regional red (lodgement) till (Plate 6) is the most prominent and uniformly coloured till in the study area. It is dark red-brown and is the main component of the giant

Table 7: Comparison of till characteristics, distribution and flow orientation in southeastern Cape Breton Island by previous authors and in the present study area. The azimuths refer to the direction the glacier was moving. Letters and Roman numerals are the designations used by the authors. (SE CBI = southeastern Cape Breton Island.)

Grant (1988, 1994)		**McClenaghan and DiLabio (1994, 1996)**		**This study (2000)**	
				LL-6	outwash
H	Highlands: radial flow ? in SE CBI			**LL-5**	local stony till 120° - 130°
G	Bras d'Or: radial flow 160°	**V**	sandy till 165° - 180°	**LL-4**	hybrid till 155° - 180°
E_1	Bras d'Or: radial flow 050°				
D	locally derived grey till 340° - 030°	**IV**	sandy till 000° - 030°	**LL-3**	hybrid till 350° - 035°
C_2	not contiguous 140°	**?**	not observed		not observed
B	red silty till 070° - 115° formed giant till ridges	**III**	red silty till 080° - 110°	**LL-2**	regional red till 060° - 110°
		II	grey till 095° - 110°	**LL-1**	basal grey till
A	Highlands: ? in SE CBI	**I**	orange -red till 120° -150°	**?**	

till ridges. The source of the red silty matrix of the till is to the west, possibly as far away as the Northumberland Strait region (Stea, 1999; Grant, 1994; McClenaghan and DiLabio, 1994, 1996). Stea (1999) referred to the ice-flow event that deposited this till as the Escuminac Phase (2) ice advance. Grant (1994) called this ice advance B, whereas McClenaghan and DiLabio (1996) designated a similar till as Unit III (Table 2). All three authors agree that an east-trending ice-flow event deposited this till.

The regional red till in this study area is best preserved in the Loch Lomond Valley, predominantly below the 250 ft (76 m) contour interval, although a few samples were collected between 250-500 ft (76-152 m). This till is present along the Grand River-Loch Lomond road where the bedrock-cored till ridges are well exposed. In many cases the regional red till is not reported because it is typically covered by younger glacial sediments (which is the sampled medium because it meets the criteria of sampling "a till" at a minimum depth of 0.6 m). A sampler could attempt to dig until he/she reached the regional red till (if it existed at that location at all) but this would not be a productive sampling technique. A similar scenario is exhibited in Plate 10 where outwash overlies till. It may be more appropriate to sample with backhoes or by drilling but costs would escalate. The thickness of the younger till can be quite variable, making obtaining a regional red till sample difficult to impossible with the sampling methods used in this study. The sample location map displays only the till type sampled and does not indicate whether other till types are also present at these sites.

Hybrid tills

A hybrid till (Stea, 1999) is a till whose properties are controlled by the reworking of older tills by younger ice sheets. The two independent processes which make this possible are inheritance and overprinting (Figure 25). The latter is suggested here as the mechanism responsible for the injection of local clasts (and matrix) into older red lodgement till by overriding ice. In this study, identification of the hybrid till based on colour alone is impractical due to the presence of red Carboniferous beds in the Loch Lomond Valley which are similar in colour and composition to the Carboniferous beds of the Bras d'Or Lake and the Gulf of St. Lawrence areas. The latter two source areas are considered the provenance for the red silty till matrix of the bedrock-cored till ridges described by Grant (1994).

Examination of a bedrock-cored ridge (sample site 6637), reveals an upper surface that is covered with boulders and cobbles of soft red shale, siltstone and sandstone. It is unlikely that the source of these large angular clasts was the Bras d'Or Lake basin (tens of kilometers) or the Gulf of St. Lawrence (hundreds of kilometers). Instead, it is suggested that the source of these clasts was the much closer Loch Lomond basin (kilometers away), and that the clasts were overprinted (draped) on the surface of the giant till ridges by a later southward ice-flow event. Because subsequent ice-flow events likely decreased in intensity and influence as they extend from local ice centers, the Loch Lomond Valley seems to be the most likely source area. The diminishing intensity and extent of each subsequent ice-flow event is put in perspective in Figure 26 (Stea, 1999). The hybrid tills are associated with ice-flow events LL-3 and LL-4 (Table 7).

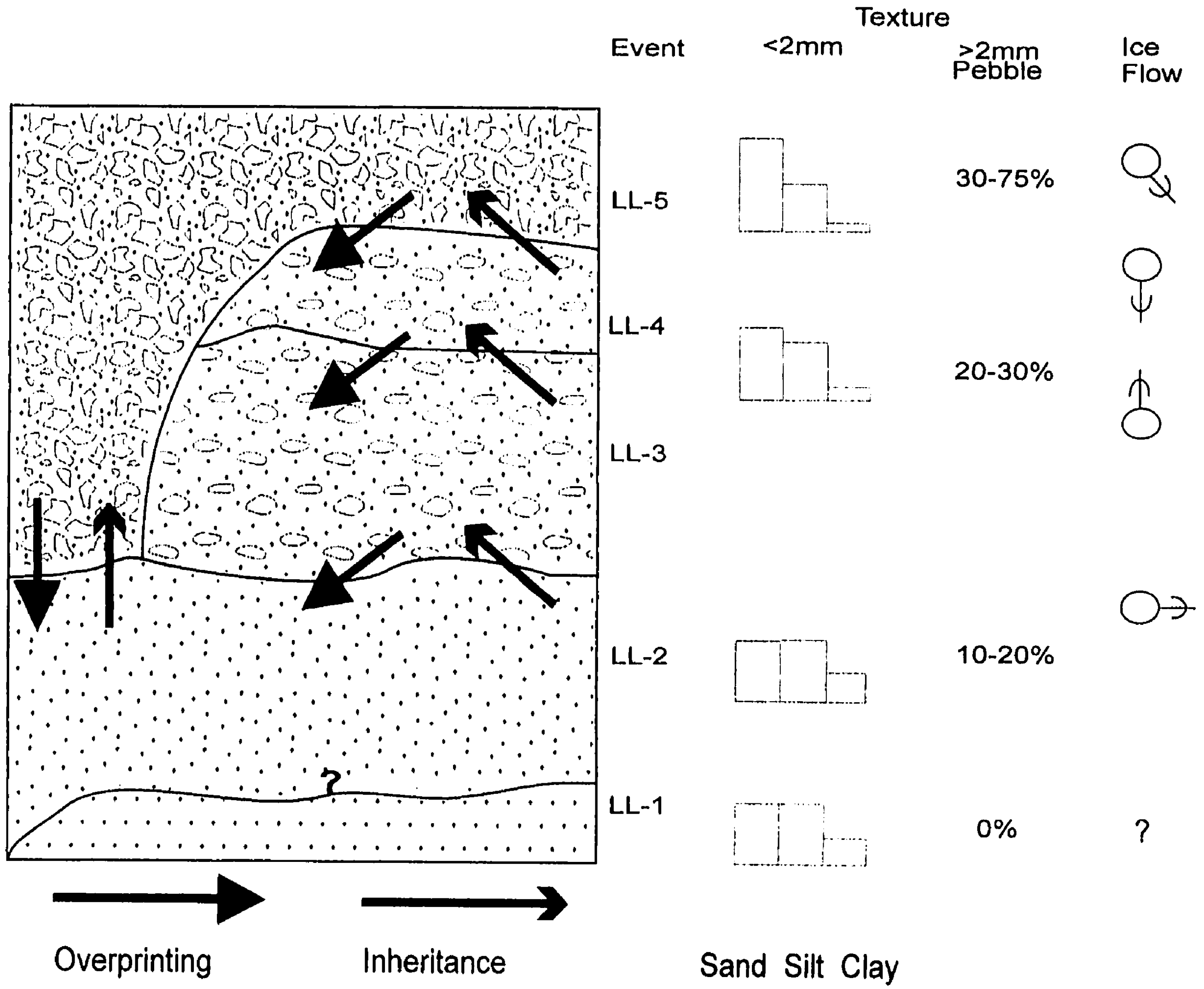


Figure 25: Schematic diagram relating the till with overprinting and inheritance features. Each till unit is shown with the texture of the < 2 mm matrix fraction of each till, the relative percent clasts in each till and the direction of ice flow. (Modified from Stea, 1999)

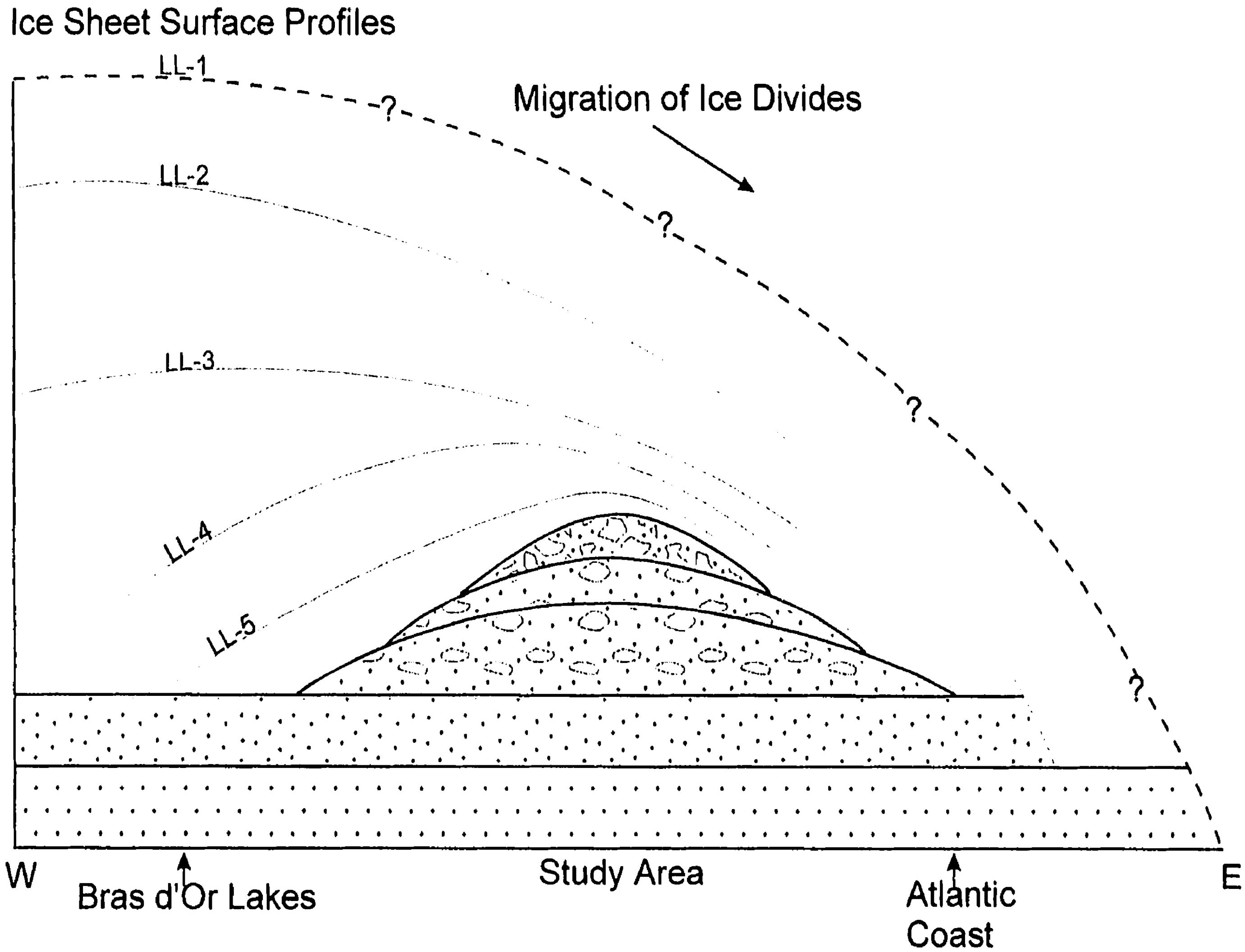


Figure 26: Conceptual model of the relationship of the tills to the migration and size of ice-divides and ice-sheet surface profiles for the study area. No horizontal or vertical scale implied: (Modified from Stea, 1999)

Local stony till

Twenty-five of the till samples were classified as local stony till. Generally, they are located in areas >250 ft (76 m) in the East Bay Hills and the Mira Highlands. However, a suite of samples are concentrated on the eastern side of the Loch Lomond Valley at elevations <250 ft (76 m).

The local stony till is generally composed of angular to sub-angular clasts which typically indicate a short comminution period or transport distance. Granite commonly underlies the southern half of the study area, and the granitic clasts and matrix influence the overall colour of the till. The matrix is generally composed of granules and sand-sized particles that may be traced back to the outcrop where it had been quarried. At sample site 6630, the till is salmon-pink and contains cobbles and pebbles from the Lower St. Esprit Pluton (Barr *et al.* 1996) which exists within tens of meters from this till location. Each sample of local stony till reflects the near-source bedrock whose broken constituents are a large component of the local till (e.g., sample sites 6610 and 6651).

Grant (1988, 1994) suggested that his ice-flow D (Table 2) deposited a locally derived grey till when the predominant ice-flow was from the south to the north. McClenaghan and DiLabio (1996) found a similar trend from 000°-030° and concluded that their ice flow IV was responsible for the deposition of a sandy till. Stea (1994) ascribed a similar till to his Scotian Ice Flow Phase 3. This study suggests (Table 7) that an LL-5 ice-flow (orientation 120°-130°) was responsible for the deposition of this local stony till. This conclusion is based on striae evidence on outcrops in the Mira Hills and along the Atlantic coast. A till fabric was also determined on the uppermost local stony till at Red Head which suggested that it was deposited by a 130° flow movement.

Outwash

Sample 6630 was obtained from a test pit abandoned by a highway contracting company in the search of aggregate for new highway construction (Figure 7). In cross-section, the upper strata consists of layered, sorted and rounded material as well as beds of sand. At a depth of 1.5 m, a contact with a local stony till (described previously) was observed. This exposure, together with the section exposed at Ferguson Lake, emphasizes the difficulty with the recognition of till vs.outwash from a hand dug pit as compared to a site exhibiting a larger exposure. The sampler is at risk of misidentifying outwash as till because the profile is not well exposed in a small diameter pit. The roundness of the pebbles and cobbles will also help distinguish between till and outwash. However, the presence of striated pebbles in sediment similar to outwash may occur, making a field determination difficult. A sandy zone in the outwash can also be interpreted as a sandy component in a meltout till. To avoid misidentification, one should inspect the relative amount of clay present. In this study area, if the clay is >15% of the matrix, then one is relatively certain that it is a till. If the clay content is <10% then one should suspect the sample to be outwash. Outwash is also most likely to occur in low topographic zones. However, as just observed, outwash may rest stratigraphically on a previous till or bedrock. This does not prevent sampling till(s) under the outwash as performed at sample site 6630.

Sample 6657 is assigned to the outwash category because of its open work fabric and rounded clasts. The original field notes indicate that when sampling took place, it was debatable, in the field, as to whether it was till or outwash ("loose; mixed angular and rounded cobbles and pebbles; small pockets of sandy silt; possible outwash, but there is too much fine-grained material (clay); full range of particle sizes"). The grain-size analysis subsequently confirmed that the <2 mm fraction was composed of 80% sand and 6% clay which indicates that this is a water-washed glacial sediment.

The presence of 34 (15% of total) small, well-rounded pebbles and several cobbles of the Salmon River rhyolite porphyry in sample 6657 raised one predominant question: If the closest outcrop of the Salmon River rhyolite porphyry is 7 km north-northeast of sample site 6657 and the recorded ice-flow directions are east, north and south, why do these distinctive lithology pebbles appear in such abundance west of the outcrop of the Salmon River rhyolite porphyry? Because sample pit 6657 (Figures 5 and 20) has been classed as outwash, it is now possible to suggest that former glacio-fluvial channels flowing westward from the Mira Hills and southward parallel to the Loch Lomond Valley were responsible for the dispersal of these pebbles. The well-rounded nature of these small (<2 cm) rhyolite porphyry pebbles also indicates substantial fluvial action. Recent fluvial action by Kates Brook (parallel to the Stirling road) may have also reworked this sediment to some degree.

Topographic contour lines are superposed on the map of the study area, along with additional heavy arrows indicating the inferred direction of the glaciofluvial drainage (Figure 24). The Loch Lomond Valley and Grand River are considered to be the main conduits for these glaciofluvial waters towards the south. From aerial photography interpretation, a subsidiary channel which flowed southeast from Ferguson Lake to St. Esprit Lake is also suggested.

Figure 27: Study area with arrows indicating the glacio-fluvial channels that distributed sediment in the area. These channels parallel present-day drainage patterns.

Summary of till types

In Figure 28, three till types and outwash, determined by the post-sampling interpretation of date (Appendix 8), are plotted on a ternary diagram with 100% sand, silt and clay as the end-members. A definite cluster is present for all the samples delegated to the regional red till category. The other till units and outwash plot in a broad mixed undifferentiated group which does not display any affinity for a separate grouping. This study suggests that this is a reasonable phenomenon. The regional red till is likely to have unique character because it represents a homogenous mixture that has been forming from a more consistent widespread source of soft red Carboniferous units and has had more time to develop its own characteristics compared to the local stony and hybrid tills. The hybrid tills and the local stony till of this area owe their existence to a host of specific local outcrops that, when eroded, have not had time to undergo extensive comminution to develop and become a distinct till unit. Therefore, they form a broad intermixed field as shown in Figure 28.

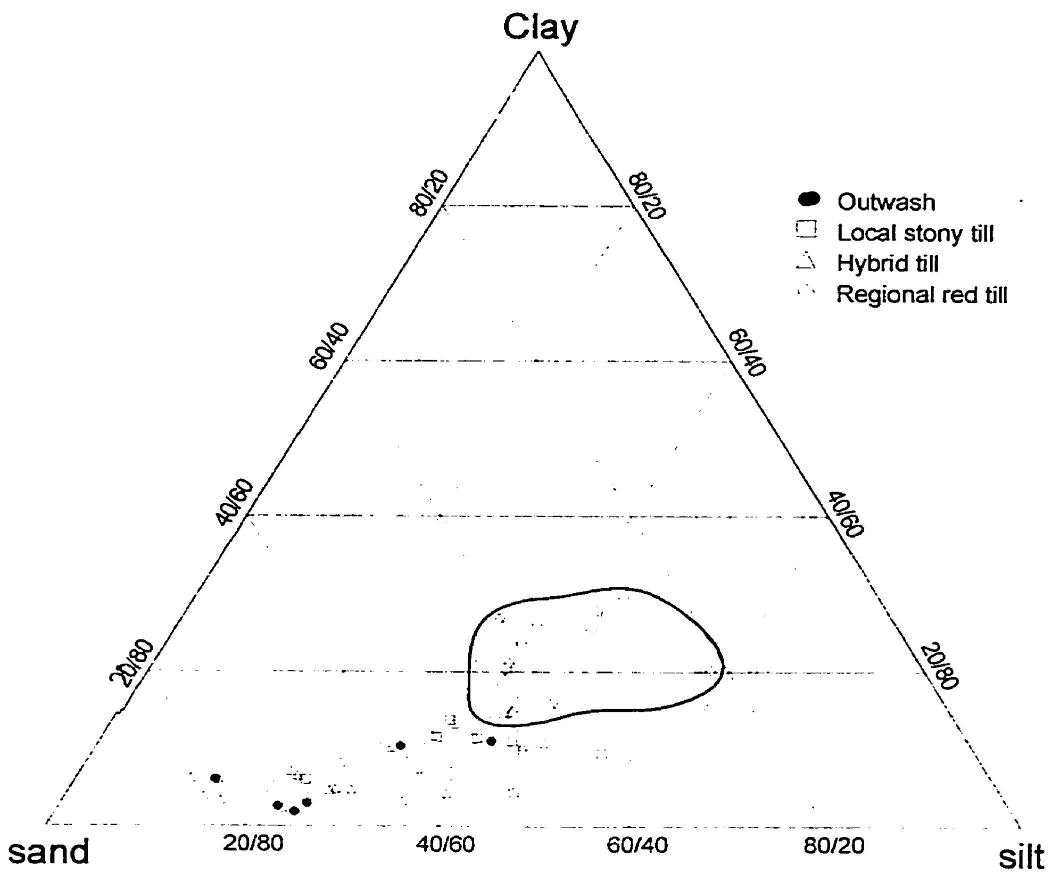


Figure 28: Ternary plot showing sand-silt-clay ratio in till units and outwash of differentiated tills. The regional red till samples plot in the circled field.

3.5 Conclusions

The Late Wisconsinan glacial history is complex in southeastern Cape Breton Island. This study generally agrees with the findings of Grant (1988, 1994) and McClenaghan and DiLabio (1994, 1996) (Table 7). Variations and comments are suggested here which add to the database and the understanding of the Late Wisconsinan glacial history of southeastern Cape Breton Island.

❑ Fabric and striae data indicate that an ice-flow event (LL-5) with a direction of 120°-130° may have deposited the local stony till in the area. This ice advance may

❑ be a variation of event LL-4 which has a flow-direction of 144°-178° and produced the upper hybrid till.

❑ The term giant till ridge should be changed to (giant) bedrock-cored till ridge. Field evidence suggests that these geomorphological features are formed by draping till over paleo-topographic highs by the easterly trending ice-flow event, LL-2.

❑ The five till and outwash units can be distinguished using textural information as well as ice-flow determinations (Figure 23). Figure 23 attempts to explain the relationships between tills through the processes of overprinting and inheritance between tills. The texture of the tills indicates that the younger tills are somewhat immature compared to the older and more extensive ice-flow events.

CHAPTER 4

APPLIED GEOCHEMISTRY

4.1 Introduction

Mineral exploration by drift prospecting has long relied on glacial dispersal models to trace indicator erratics in glacial deposits and locate their bedrock sources. These erratics may be lithological, mineralogical, or geochemical indicators. This chapter examines the results from the till geochemical sampling program in the study area. Although regional till geochemical surveys are usually implemented for mineral exploration, they also provide baseline data for environmental, agricultural and land use planning.

4.2 Data Quality

Refer to the analytical quality control section in Chapter 2 for details. Since two separate analytical methods (ICP-ES and INAA) were performed on the <0.063 mm fraction, the data are presented for each method.

Analytical precision

In this study, scatter plots were generated to check the precision of the duplicate analytical pairs, and the *Pearson product moment* correlation coefficient (Noether, 1971) was calculated and graphed (Quattro Pro 6). It is denoted by the symbol **r**. The correlation coefficient **r** may lie between -1.000 and +1.000 with +1.000 representing a perfect precision correlation and a value of 0 indicating that there is no similarity between the duplicate samples. A negative value approaching -1.000 would indicate that duplicate samples have an inverse relationship.

Analytical precision: ICP-ES

The precision for aqua regia ICP-ES data is variable. Two elements, Sr and Pb, have perfect correlation values of 1.000. The **r**-values of nine elements (Ca, Cu, K, Li, Mn, Ni, Y, Zn, and Zr) are > 0.990. Another 4 elements (Al, Mg, Nb, and V) have values >0.900. Thus, 83% of the elements have an r-value >0.900. The remaining 3 elements and their corresponding **r**-values are Hg (0.857), Mo (0.486) and Bi (0.023). Hence, one should be careful placing much confidence in the Mo and especially the Bi values. Four elements (Sr, Pb, Cu, Ni) were selected to illustrate the precision of the ICP-ES method (Appendix 2-B).

Analytical precision: INNA

The precision for the INAA data does not appear to be as good as the ICP-ES precision for most of the 25 samples. The **r**-values for 11 elements (As, Br, Ce, Co, Cr, Cs, Fe, Hf, Na, Sc, Sm) are >0.900 (44%). Another 3 elements (Eu, La, Nd) have **r**-values > 0.800. Five elements and their corresponding **r**-values are as follows: Zn (0.723), Sb (0.690), Th (0.577), Ba (0.548) and Rb (0.286). The remaining six elements (Au, Tb, Ta, U, Yb, Lu) all have negative **r**-values which indicates an inverse linear trend. Four elements (Na, Zn, Cr, Ba) were selected to indicate the precision of the INAA method (Appendix 3-B).

Analytical accuracy

Accuracy is estimated by repetitive analysis (seven samples) of a control standard (TCA 8010) supplied by the Sedimentology Laboratory of the Geological Survey of Canada.

Analytical accuracy: ICP -ES

Analytical accuracy graphs are presented in Appendix 2-C for 13 elements determined by ICP-ES. The average value for the GSC standard reported from previous repetitive analysis (McClenaghan et al., 1992) are plotted on the graphs as a dashed line and the ± 20% as solid lines. Eleven of the elements exhibit a strong near-linear trend for the reference standard. The remaining two elements, Bi and Mo, are erratic with several analyses equal to the average but with the remainder being either >+20% or >-20% of the previous average value. The first 11 elements, although linear, display values consistently below the average. Some elements (Al, Ca, Sr, V, and Y) are within -20% of the average concentration determined for the batch. Sr displays the most consistent value which is within -5% of the average value. The remaining elements are within the following range from the average used:
Cu (<-30%), K (<-30%), Mg (<-50%), Ni (<- 40%), Mn (<-30%) and Pb (<-60%).

For the latter elements, the accuracy would not be considered acceptable. However, these results do not mean that the analyses for this study are incorrect or inaccurate, but rather that they were different from the average of the repetitive analyses from those from McClenaghan et al (1992). This method of comparing to a previous analysis batch is not ideal. It is based on the premise that the previous analyses were accurate. Cumulative error is a possible result of such a procedure. One should actually be comparing their analyses of standards to a running average from all the analyses that determined the concentration of the said standard, in this case TCA-8010. In order to be a true reference standard, a database of all analyses should be compiled so that future batch analyses may be compared with these values. This is presently being done at the GSC and should be completed by January 2001 for retrieval by users of the standard. Factors such as different laboratory procedures, new instrumentation, chemical matrices and sample matrix differences may all well contribute to these variations. These values are still useful in this study because we are actually comparing the relative geochemical concentrations within the study area. An anomalous value will be anomalous if the precision of the analyses is acceptable as it is in this case for most elements.

Analytical accuracy: INAA

Analytical accuracy plots for 25 elements determined by INAA are presented in Appendix 3 -C. The average value for the GSC standard reported from previous repetitive analysis (Klassen, 1992) are plotted on the graphs as a dashed line and the ± 20% as solid lines. Mean values for Co, Fe, Hf, Na, Sc, Sm, Th, Eu and Yb are within ±10% of the mean estimated by a previous analysis (GSC Open File 3675). Mean estimated values for Sb, La, Nd, Lu and Yb are within ± 20% of the above previous analysis. The remaining elements have one or two analyses outside the ± 20% range. Values are not consistently higher or lower than the average from a previous sample. Uranium is between 25% and 40% lower than the average while gold is approximately 15% to 40% higher than the average. Most of the elements occur at low concentrations, near detection limits, and estimates of analytical accuracy applied to these elements are more difficult to assess. However, no obvious "instrumental drift" (Thompson,1983) is apparent with these analyses. This indicates good management of analytical procedures by the laboratory.

4.3 Geochemical patterns

A total of 43 elements are reported as six distinct dispersal patterns in this study. These elements that are reported in various patterns are summarized in Table 8 and the patterns (A to F) are visually depicted in Figure 29. These patterns include:

- **Pattern A** , a single anomaly mainly located in the Loch Lomond Valley.
- **Pattern B,** a pattern with multiple concentrations in the Loch Lomond Valley which is underlain by Carboniferous marine and terrestrial sedimentary rocks (Boehner and Prime, 1993).
- **Pattern C,** high concentrations in the Loch Lomond Valley and the East Bay Hills in the northern quadrant of the study area. Granite and volcanic rocks form the East Bay Hills (Barr et al, 1996).
- **Pattern D** depicts high concentrations in the Loch Lomond Valley and the L'Ardoise Block in the southwestern quadrant of the study area. This region is underlain by Horton Group clastic sediments (White and Barr, 1998).

- **Pattern E,** high concentrations that occur in the Loch Lomond Valley and the Mira Hills in the southeastern quadrant of the study area. This area is underlain by the Stirling Group which consists primarily of volcanic rocks (Barr et al, 1996).
- **Pattern F** is best described as random dispersion; however, in all instances the Loch Lomond Valley does not exhibit anomalous concentrations. Concentrations are dispersed in the East Bay Hills (north), L'Ardoise Block (southwest) or Mira Hills (southeast) parts of the study area.

To put these patterns in perspective the reader is referred to the detailed bedrock geology map (Figure 3) and Quaternary geology map (Figure 10).

Table 8: Summary table for till geochemistry patterns for the <0.063 mm size fraction of till samples. The six distribution patterns are designated A to F. The area codes are: LLV = Loch Lomond Valley; EBH = East Bay Hills; LB = L'Ardoise Block; MH = Mira Hills. The bold element indicates that bubble plot maps for these elements are included in Appendix 6.

PATTERN	AREA	ICP-ES	INNA
A	Single Anomaly	**Pb**, Zr	**Ba**
B	LLV	Mo, Nb, Y	**La**, Ce, Cs, Eu, Lu, Nd, Sm, Sc, Te,Y
C	LLV + EBH	Al, Hg	**Zn**, Fe, Th, U
D	LLV + LB	**Ni**, Li, K	**Cr**, As, Co, Rb, Sb
E	LLV + MH	**Cu**, Mg, Mn	---------
F	No Pattern	**Sr**, Bi, Ca, V	**Au**, Na, Br, Hf, Ta

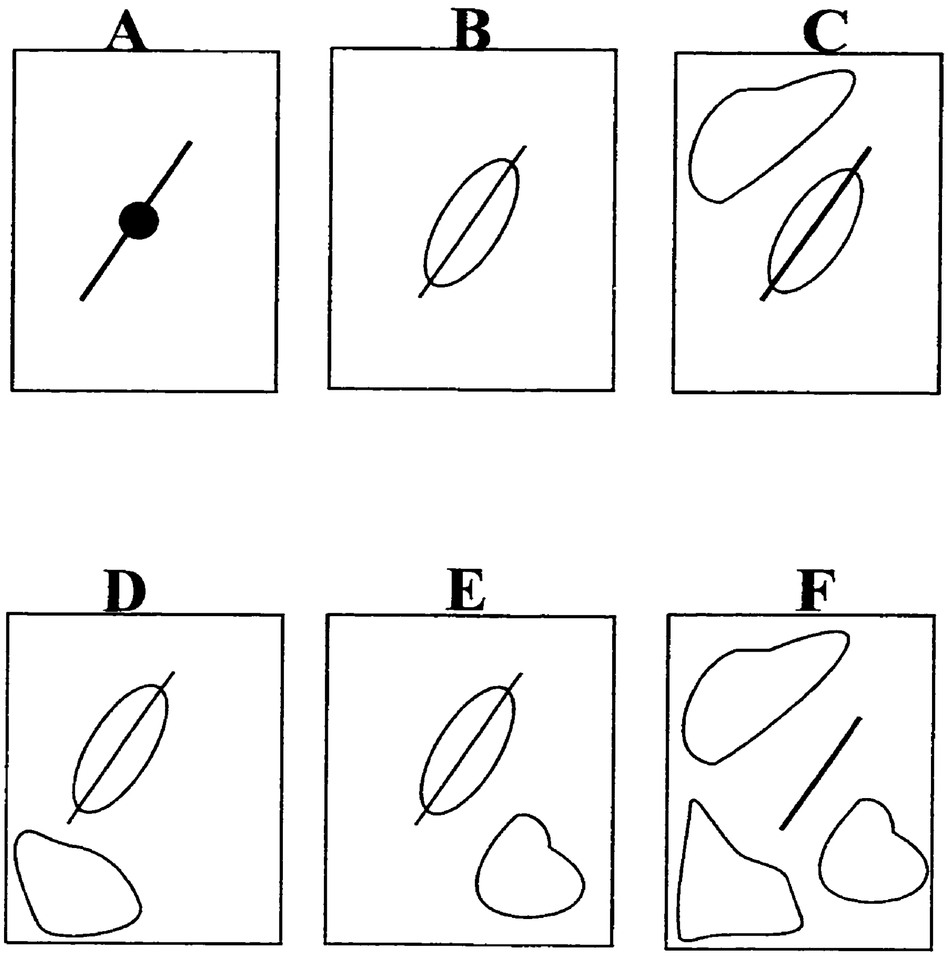


Figure 29: Patterns of anomalous geochemical values in the study area. Polygons refer to clusters of anomalous values, line indicates axis of Loch Lomond Valley.
A =Loch Lomond Valley (LLV) single anomalies
B= LLV trends
C=LLV + East Bay Hills (EBH)
D=LLV +L'Ardoise Block (LB)
E=LLV + Mira Hills (MH)
F=No pattern (no LLV)

Geochemical patterns

Pattern A : Single anomaly

Lead, barium and zirconium exhibit a single isolated anomalous pattern. The map and statistics for Pb and Ba appear in Appendix 6.

Pb

Lead values range from 6 ppm to 500 ppm with a mean of 28 ppm. The detection limit is 2 ppm. Lead occurs as an isolated maximum value of 500 ppm at the MacRae celestite quarry, sample site 6609. This is not surprising since the main accessory mineral associated with the celestite is galena. Sample 6701, taken 2.4 m below sample 6609, has a value of 403 ppm. The next highest value of 132 ppm occurs at site 6657 at the intersection of the Loch Lomond and Stirling roads (Figure 8). There are 11 concentrations in the 23 ppm to 48 ppm range of which five form a northerly halo around the MacRae open pit. The remaining six values of this range occur in the northwest corner of the study area and also flank sample 6657 to the northeast and southwest along the Loch Lomond road.

Ba

Barium has a range from 260 ppm to 5300 ppm with a mean of 590 ppm. The detection limit is 50 ppm. Seven additional concentrations from 670 ppm to 920 ppm are noted. They occur at the following sample sites: 6657 (720 ppm), 6656 (850 ppm), 6641 (690 ppm), 6610 (680 ppm), 6638 (810 ppm), 6609 (860 ppm) and 6626 (670 ppm). A concentration of 920 ppm is also reported in sample 6603. Sixteen concentrations between 530 ppm and 670 ppm are generally clustered in the East Bay

Hills and are all west of the higher concentration samples. Dispersal appears to be from west to east; however, a fan-shaped pattern appears southward of sample 6642 (APPENDIX 6). Sample 6701, taken below sample 6609, has a concentration of 1100 ppm.

Zr

Zirconium values range from 2 ppm to 13 ppm with a detection limit of 1 ppm. Three samples (6642, 6638 and 6630) have values from 10 ppm to 13 ppm. These occur along the eastern edge of the Loch Lomond Valley and also along the extreme eastern edge of the study area. Both of these areas are underlain by the Chisholm Brook granite and Stirling Group volcanic rocks. Eight samples (6 ppm to 10 ppm) are scattered through the area, although two are located between sample sites 6642 and 6638.

Pattern B: Loch Lomond Valley

A total of thirteen elements exhibit an affinity with the Loch Lomond Valley with lesser concentrations in the remaining areas. These elements are molybdenum, niobium, yttrium, cerium, cesium, europium, lanthanum, lutetium, neodymium, samarium, scandium, terbium and ytterbium. The common feature is the predominance in samples 6656 and 6657 of anomalous values for each of the previous elements. The La map represents this pattern.

Mo

Molybdenum concentrations range from 1 ppm to 6 ppm (with a detection limit of 1 ppm). Concentrations of 6 ppm occur at samples sites 6656 and 6657 and at an additional site on the Atlantic Coast at L'Archeveque (6632). Three other samples sites in the East Bay Hills (6601, 6604 and 6650) have concentrations of 5 ppm. The precision and accuracy are low for Mo.

Nb and Y

These two elements are similar in distribution. Both have a detection limit of 1 ppm. The upper concentrations are from 15 ppm to 36 ppm and 20 ppm to 42 ppm respectively. The next interval includes 10 and 13 samples. These values form a halo around the anomalous samples with a stronger distribution of Nb in the East Bay Hills. There does not appear to be any concentration in the Loch Lomond Valley samples.

Ce

Cerium has a range from 40 ppm to 320 ppm and a mean of 81 ppm. The detection limit is 3 ppm. The two anomalous concentrations occur at sample sites 6656 (310 ppm) and 6657 (320 ppm). A similar secondary pattern is present with the southern scattering of values but there is a trend for values to increase in this population in the northern half of the study area.

Cs

Cesium values range from less than the detection limit of 1 ppm to 20 ppm. The mean value is 5.5 ppm. Five samples with concentrations between 11 ppm and 20 ppm are considered to be anomalous: 6642, 6652, 6637, 6656 and 6657. The second largest concentrations of 7 ppm to 11 ppm (9 samples) are located predominantly in the East Bay Hills. It is noteworthy that a single sample, 6673 (below sample 6652), has the highest reported Cs value (35 ppm) which is nearly double the highest reported value (20 ppm) in the study area.

Eu

Europium has a range from 0.9 ppm to 4.3 ppm with a mean of 1.4 ppm. The detection limit is 0.2 ppm. Two concentrations >2.9 ppm are found at sites 6656 and 6657. The next population of 15 samples is scattered throughout the area but is more pronounced in the southern half of the study area.

La

Lanthanum has a range from 23 ppm to 91 ppm and a mean of 40 ppm. The detection limit is 0.5 ppm. The two highest concentrations of La are found at sample sites 6656 (89 ppm) and 6657 (91 ppm). This is the typical pattern for the other eight REE. A secondary concentration stretches along the Loch Lomond Valley. The following sample sites are almost always included in this group: 6603, 6609, 6652 and 6638.

Lu

Lutetium concentrations have a range from 0.3 ppm to 1.3 ppm and a mean of 0.6 ppm. The detection limit is 0.05 ppm. Three samples with concentrations between 0.9 ppm and 1.3 ppm occur at sites 6656, 6657 and 6654. This is similar to Ytterbium.

Nd

Neodymium has a range from 13 ppm to 63 ppm with a mean value of 23.6 ppm. The detection limit is 5 ppm. Again, the 2 highest concentrations are at sample sites 6656 and 6657. A secondary set of 9 values of 28 ppm to 45 ppm are similar in distribution to Europium and are concentrated in the southern half of the study area.

Sc

Scandium has a range from 7 ppm to 38 ppm with a mean of 13 ppm. The detection limit is 0.1 ppm. The high concentration of 38 ppm occurs at sample site 6656. Four additional concentrations are found at sites 6604 (17 ppm), 6615 (18 ppm), 6654 (17 ppm) and 6652 (17 ppm). Note that sample 6673, taken below sample 6652, had a concentration of 24 ppm. Sixteen additional concentrations between 13 ppm and 17 ppm are scattered throughout the study area.

Sm

Samarium has a range from 3.1 ppm to 17 ppm and a mean of 5.5 ppm. The detection limit is 0.1 ppm. The two highest concentrations are found in samples 6656 (13 ppm) and 6657 (17 ppm). It has a similar pattern as Nd.

Tb

Terbium ranges from below the detection limit of 0.55 ppm (20 samples) to 3.1 ppm. The high concentrations are at sample sites 6656 (2.2 ppm) and 6657 (3.1 ppm). The next population of 15 samples is spread over a range of 1 ppm to 2 ppm, occurring generally in the southern half but with a few samples scattered in the northern half of the study area.

Yb

Ytterbium has a range from 1.9 ppm to 8 ppm with a mean of 3.8 ppm. The detection limit is 0.2 ppm. Three samples (6656, 6657 and 6654) at Ferguson's Lake (Figure x) show concentrations between 5.7 ppm and 8 ppm. The secondary indicator bubble plots occur in the southern half of the study area. A common secondary site is 6659 located at the northeastern corner of the study area.

Pattern C: Loch Lomond Valley and East Bay Hills

Aluminum, iron, mercury, thorium, uranium and zinc display a northerly cluster of concentration in the East Bay Hills and are also associated with the Loch Lomond Valley pattern. Concentrations of these elements are always elevated at sample sites 6656 and 6657, east of the lakes of the Loch Lomond valley. A consistent sample site of interest is 6659 in the northeast corner of the study area. The Zn map represents this pattern in Appendix 6.

Al

Aluminum values range from 1.16% to 5.43% with a mean value of 2.34%. The detection limit is 0.01%. Only two samples (6642 with 4.56% and 6650 with 5.43%) appear to be anomalous in the study area.. Samples 6604, 6615, 6645, 6656 and 6657 all have values over 3.0%. They may reflect the weathering of feldspars from the granitic rocks.

Fe

Iron values range from 1.8% to 10.3% and a mean of 3.8%. The detection limit is 0.01%. Five samples are much higher than the rest (5.32% to 10.3%) and include samples 6656 and 6657 in the Loch Lomond Valley, and samples 6604, 6650 and 6658 which extend along the top of the East Bay Hills. The next set of 14 concentrations (4.01% to 5.32%) are scattered over the study area with no definite trend present.

Hg

Mercury concentrations are highest at sample sites 6657 (197 ppb) and 6642 (234 ppb). Nine of 10 additional samples are found in the East Bay Hills with values between 66 ppb and 197 ppb. Site 6656 has a concentration of 92 ppb. There are lower values in the southwest of the study area of between 41 ppb and 66 ppb.

Th

Thorium values range from 8 ppm to 22 ppm with a mean of 12.5 ppm. The detection limit is 0.2 ppm. The three highest concentrations are located at sites 6656 (21 ppm), 6657 (22 ppm) and 6602 (18 ppm). Twelve samples (14 ppm to 18 ppm) are scattered around the Loch Lomond Valley and also in the East Bay Hills.

U

Uranium values range from of 1.7 ppm to 10 ppm with a mean of 3.6 ppm. The detection limit is 0.5 ppm. The maximum value of 10 ppm is at sample site 6657. Fourteen concentrations between 4 ppm and 6 ppm are located in a cluster immediately north of sample 6657. This element has a pattern that is similar to Thorium.

Zn

Zinc values range from <50 ppm to1030 ppm with a mean of 121 ppm. The detection limit is <50 ppm. Five zinc concentrations occur at the following sample sites: 6609 (364 ppm), 6642 (326 ppm), 6657 (1030 ppm), 656 (276 ppm) and 6644 (252 ppm). Sample 6701, taken stratigraphically below 6609, has 4992 ppm. The next 19 concentrations (100 ppm to 252 ppm) are scattered throughout the study area.

Pattern D: Loch Lomond Valley and L'Ardoise Block

Eight elements (As, Co, Cr, Ni, Li, K, Rb, and Sb)display this pattern. This pattern is represented by As, Co, Cr and Ni. They include arsenic, cobalt, chromium, nickel, lithium, potassium, rubidium and antimony. There is a trend along the Loch Lomond Valley and a southwestern cluster associated with the L'Ardoise Block is prominent (Figure 29). A localized concentration of potassium values occur on the southwestern portion of the East Bay Hills. This pattern is represented by the nickel, arsenic, cobalt and chromium maps in Appendix 6 .

As

Arsenic values range from 1.4 ppm to 22 ppm with a mean of 7 ppm. The detection limit is 0.5 ppm. The five samples with the highest values are 6657 (16 ppm), 6612 (14 ppm), 6625 (22 ppm), 6634 (18 ppm) and 6652 (15 ppm). Fifteen samples form the next statistical group and they are scattered but somewhat concentrated in the southwestern quadrant of the study area. Sample 6673 (located below 6652) has a lower concentration of As than sample 6652.

Co

Cobalt values range from 2 ppm to 21 ppm, with a mean of 12 ppm. The detection limit is 1 ppm. Fourteen samples are plotted as the 15 ppm to 21 ppm bubble. They occur in samples 6642 and 6656, and form a distinct cluster in the southwestern quadrant of the study area. In the northern sector of the study area , only sample 6603 (14 ppm) and sample 6658 (12 ppm) have high values.

Cr

Chromium values range from 25 ppm to110 ppm and a mean of 60 ppm. The detection limit is 5 ppm. Ten samples lie in the 76 ppm to 110 ppm range: 6656 (110 ppm), 6652 (99 ppm), 6655 (88 ppm), 6626 (87 ppm), 6635 (86 ppm), 6612 (86 ppm), 6657 (83 ppm), 6640 (81 ppm), 6659 (81 ppm) and 6627 (76 ppm). The highest concentration of Cr is found at sample site 6671 (140 ppm) which is stratigraphically below sample 6652. Fifteen samples range from 61 ppm to 76 ppm and are scattered throughout the study area.

K

The distribution pattern for potassium is very similar to that of nickel. Values range from 0.04% to 0.28% with a mean of 0.12%. The distribution is skewed towards the higher values. The maximum concentrations are from 0.12% to 0.29% and occur in 8 samples: 6635, 6636, 6637, 6656, 6640, 6642, 6609 and 6638 (listed from the south to the northeast). Several threshold values ranging from 0.12% to 0.21% occur in samples from the area flanking the East Bay Hills.

Li

Lithium values range from 2 ppm to 53 ppm with a mean of 25 ppm. The detection limit is 1 ppm. Seven high concentrations of lithium cover in an area similar to those of nickel. It should be noted that sample 6673 (below 6609) again has the highest value in the analysis group with a concentration of 59 ppm. Sample 6633, taken on the southern coastline, has a concentration of 53 ppm. The remaining notable concentrations (36 ppm to 53 ppm) occur at sites 6656, 6642 and 6640 in the Loch Lomond valley and 6626, 6627 and 6637 in the L'Ardoise Block.

Ni

Nickel values range from <1 ppm to 35 ppm with a detection limit of <1 ppm. The mean concentration is 21 ppm. Nickel displays a near-perfect normal distribution (Appendix 2-A). Nine samples with values from 28 ppm to 35 ppm are distributed along the Loch Lomond Valley and extend along the area underlain by the Clam Harbour River Group (White and Barr, 1998) in the southwestern part of the study area. Specifically, these concentrations are clustered on the western side of the Loch

Lomond Valley. The highest Ni value (35 ppm) is at sample site 6635 in the extreme southwest corner of the study area. Additional values surround these anomalous samples. It is interesting to note that the two deeper samples 6673 (6652) and 6701 (6609) have concentrations of 36 ppm and 37 ppm respectively.

Rb

Rubidium has a range from 33 ppm to 170 ppm with a mean of 87 ppm. The detection limit is 15 ppm. Eight concentrations are between 120 ppm and 170 ppm. These sites, in order of decreasing concentration, include: 6652 (170 ppm), 6656 (150 ppm), 6655 (140 ppm), 6635 (130 ppm), 6612 (130 ppm), 6601 (120 ppm), 6626 (120 ppm) and 6637 (120 ppm). These sample sites are concentrated in the southwestern quadrant of the study area. Eighteen values from 89 ppm to 110 ppm are mainly concentrated in the central region but are absent from the southeast and East Bay Hills.

Sb

Antimony has a range from 0.5 ppm to 2.1 ppm with a mean of 0.8 ppm. The detection limit is 0.1 ppm. Four sample values have values in the 1.4 ppm to 2.1 ppm range. They are: 6602 (2.1 ppm), 6652 (1.6 ppm), 6657 (1.6 ppm) and 6612 (1.4 ppm). A cluster of 18 samples is spread throughout the study area but there appears to be a concentration of values near the village of Grand River.

Pattern E: Loch Lomond Valley and Mira Hills

Pattern E is shown in concentration maps for the elements copper, manganese and magnesium (Figures 32, 33). The Loch Lomond Valley is still the most prominent feature when viewing the bubble geochemical maps but concentrations of these elements are common in the Mira Hills. The copper map (Appendix 6) represents this pattern.

Cu

Copper concentrations range from 2 ppm to 571 ppm with a mean of 36 ppm. The maximum value of 571 ppm is located at sample site 6642. The next highest concentration (122 ppm) is found in sample 6634. The next five highest values are found in the following samples: 6632 (49 ppm), 6654 (53 ppm), 6615 (63 ppm), 6618 (52 ppm) and 6657 (50 ppm). Less significant values are scattered over the study area but a halo of this population sample (25 ppm to 49 ppm) exists around the 49 ppm to 122 ppm population in the southern and southeastern quadrant of the study area.

Mn

Manganese values range from 88 ppm to 6285 ppm (0.6%) with a mean value of 862 ppm. The four most significant values are in the following samples: 6609 (2697 ppm), 6657 (4542 ppm), 6656 (6285 ppm) and 6701 (4204 ppm). The bubble plots identify 10 additional sites >961 ppm. They are all taken on Barren Hill Lake Road and all samples along the Atlantic coastline. Several other sites occur on the Stirling Road and in the Shaw Lakes area, east of the Loch Lomond Lakes.

Mg

Magnesium has a minimum value of 0.10% and a maximum value of 2.14% with a mean of 0.85%. Eight samples have values between 1-2% Mg. These include 6642, 6656, 6637, 6615, 6654, 66340, 6618 and 6638. They are all located in the southeastern quadrant of the study area. Lower concentrations are found in the East Bay Hills area in samples 6649, 6606, 6604 and 6603, but most of these values surround the larger concentration samples.

Pattern F: Random Dispersion

This pattern is different from the other five because no anomalous concentrations occur in the Loch Lomond Valley. The high values are distributed between two zones, the East Bay Hills and the Mira Hills. These elements are strontium, bismuth, bromine, calcium, gold, hafnium, sodium, tantalum, and vanadium. Gold has been assigned to this pattern because of anomalous values in the southwestern quadrant of the study area. Maps of sodium, gold and strontium are included to represent this pattern in Appendix 6.

Au

Gold values range from less than the detection limit of 2 ppb to 35 ppb. The mean is 11 ppb. Two anomalous samples occur at sites at 6615 (35 ppb) and 6634 (32 ppb). The repeatability of the value from duplicate (6615) field sample 6616 (20 ppb) probably reflects the nugget effect that is associated with gold analyses. Sample 6615 was also sampled for a heavy mineral analysis and one gold grain was reported (Appendix 9). Five samples with gold values ranging from 15 ppb to 21 ppb are scattered in the area: 6654 (21 ppb), 6621 (18 ppb), 6655 (18 ppb), 6602 (16 ppb) and 6643 (17 ppb). Twenty-five samples with values from 10 ppb to 15 ppb are generally scattered in the northern half of the study area.

Bi

Bismuth values range from <5 ppm to 13 ppm with a detection limit of <5 ppm. The mean value is 7 ppm. Bismuth did not exhibit good precision with the duplicate samples that were analyzed and thus no confidence in the accuracy and precision of Bi.

Br

Bromine has values which range from less than the detection limit of 0.5 ppm to a maximum of 260 ppm. The mean is 40 ppm. Four samples contain concentrations from 100 ppm to 260 ppm. These are all located in the East Bay Hills: 6604 (130 ppm), 6645 (130 ppm), 6650 (260 ppm) and 6658 (110 ppm). Twelve samples with concentrations between 50 ppm and 100 ppm are scattered throughout the study area.

Ca

Calcium has a range from 0.02 % to 0.56 % with a mean of 0.2 %. The detection limit is 0.01 % and samples with values above the detection limit are prevalent in the East Bay Hills and the Mira Hills. There are no elevated values in the Loch Lomond Valley.

Hf

Hafnium values range from 4 ppm to 19 ppm, with a mean of 11 ppm. The detection limit is 1 ppm. Seven sample sites have concentrations between 15 ppm and 19 ppm, and are mainly located west of the Loch Lomond Valley: 6644 (15 ppm), 6651 (16 ppm), 6601 (15 ppm), 6647 (17 ppm), 6627 (18 ppm), 6625 (19 ppm) and 6620 (15 ppm). Eighteen samples with concentrations between 12 ppm and 15 ppm are scattered throughout the study area.

Na

Sodium has a range from 0.39% to 2.32 % with a mean of 1.16%. The detection limit is 0.01%. Nine samples have values between 1.61% and 2.32%. They include samples 6604 (1.80%), 6651 (1.74%) and 6623 (1.61%) in the East Bay Hills and samples 6643 (1.82%), 6639 (1.85%), 6610 (1.96%), 6641 (1.70%), 6611 (2.32%) and 6618 (1.67%) in the Mira Hills (Appendix 6).

Sr

Strontium values range from 6 ppm to 804 ppm with a mean of 37 ppm. The detection limit is 1 ppm. It is highest in sample 6609, the former MacRae celestite open pit, with a concentration of 804 ppm. Sample 6701 (2.4 m stratigraphically lower than 6609) has a concentration of 1088 ppm. The next highest concentration range includes values from 30 ppm to 57 ppm with a population of 17 samples. These samples are in 2 separate clusters. Nine sample sites are located north and northwest of site 6609 and high values are ubiquitous for sample locations along the top of the East Bay Hills. The second cluster of 8 samples is located in a fan-shaped pattern south of sample site 6609 (Appendix 6 and Figure 35).

Ta

Tantalum values range from below the detection limit of 0.5 ppm to a high of 1.9 ppm. Seventeen samples have concentrations below the detection limit. Eleven samples with values from 1.5 ppm to 1.9 ppm are scattered over the entire study area with the exception of the Loch Lomond Valley.

V

Vanadium concentrations range from 18 ppm to 100 ppm with a mean of 40 ppm. The detection limit is 1 ppm. Six samples range from 55 ppm to 100 ppm. They include 6650 (55 ppm), 6601 (59 ppm) and 6604 (60 ppm) in the East Bay Hills. Three samples occur in the central southern map area: 6656 (100 ppm), 6615 (90 ppm) and 6618 (62 ppm). No recognizable pattern exists for V.

4.4 Discussion

Distribution patterns for the lithophile elements, which include five of the major elements (Al, Na, K, Ca, and Mg) along with Sr and Ba, may be difficult to interpret because of their ubiquitous occurrence in rock-forming minerals and their relatively high concentrations especially, in igneous rocks. The siderophile elements, which include Fe, Co, Ni and Mo, are of interest in this study because they are of economic importance. The chalcophile elements, including Cu, Pb, Zn, Ag and Au, are interest in this study because the area has the potential to host base metal deposits.

In the study area, high concentrations of elements are assumed to be mechanically dispersed by glacial processes. It is suggested that the local stony till is more porous and permeable (k-value = 10^{-3} m/da) and therefore more susceptible to oxidation and weathering by meteoric and groundwater percolating through. The regional red till will not show virtually any changes in chemistry because the influence of water is minor given the low coefficient of permeability (k- value = 10^{-5} m/da) (Heath, 1995) of the silty to clay-rich tills of the regional red till and the crystalline nature of the underlying rocks. Thus areas underlain by local stony tills and on steep slopes may be affected by hydromorphic dispersion which will be readily visible and identifiable.

Sources of elevated concentrations

The presence of elevated values may be derived from three possible sources: 1) Patterns may be a result of differences in the composition of different bedrock types. First concentrations may be a result of primary lithologies. The major elements Al, Na, K, Ca, Mg, Fe, as well as Ba and Sr, are generally associated with different bedrock compositions; 2) the high concentrations can be from known mineral and bedrock located in the immediate area which include the Kaiser celestite, the Pine Brook barite, the Yava sandstone-hosted galena (sphalerite) or the Stirling volcanogenetic massive sulfide deposits (Figure 3). Economic elements of interest associated with these deposits include Ba, Cu, Sr, Pb, Mn, Zn, and Au. There are numerous smaller mineral showings in this region and each have their own individual element associations (Figure 7 and Appendix 10); 3) some elevated concentrations may be from elements may be from unknown bedrock types or undiscovered mineral deposits.

Selected bubble plot maps are presented to represent the geochemistry of the study area. Six different patterns of dispersal for the 42 elements have been identified (Figure 29 and Table 8). To understand the distribution and potential source of a particular element solely on the basis of the geochemical dispersal plot is a difficult task. Representative maps have been selected to portray the typical dispersal pattern of these elements and to aid in the interpretation of their provenance. Multiple showings of similar types of bedrock mineralization will hamper the identification of the bedrock source location of the anomalous geochemical values.

No evidence of ice-flow from east to west was found in the study area demonstrated (Chapter 3). Therefore, there should not be any dispersalof elements in the study area if a mineral deposit is east of this study area. In contrast, mineralization west of the study area should be detectable in glacial till in the study area because ice flows did transport debris from west to east.

Ba dispersal (Figure 29, Pattern A) is a good example of how the concentration of some elements (Ba, Pb and Zr) are associated with the Loch Lomond Valley. The largest barite occurrence in the study area is at Pine Brook (Figure 7). Samples collected in this study failed to detect any anomalous concentrations of Ba near the deposit. Ba is dispersed mainly in the Loch Lomond Valley and to the east (Appendix 6) but a consistent number of samples with concentrations also occur in the East Bay Hills (Appendix 6). It is difficult to recognize any one source for the dispersal pattern. From the Ba distribution patterns (Appendix 6), these questions arise. Are the anomalous concentrations of Ba associated with the Pine Brook deposit to the west? ; Are they associated with barite mineralization on the Enon-Salmon River Road? Or are they indicative of an unknown deposit(s) in the area? If the answers to the first two questions is yes, that would imply glacial transport from west to east and north to south; both of which are consistent with the interpretation of the glacial history of the study area (Chapter 3). The third question remains unanswerable at present.

Pattern B (Figure 29) is best demonstrated by the element La and as such is useful to represent the other rare earth elements and transitional elements listed in

Table 8. These elements generally occur in the internal lattices of minerals in some late-forming igneous rocks such as pegmatites. Few if any pegmatitic rocks occur in the study area and therefore are not likely the source. An alternative source for these elements might be heavy minerals deposited originally in Carboniferous sedimentary rocks of the Northumberland Strait. During Wisconsinan glaciation, these sedimentary rocks were incorporated into the till which was deposited in the study area. Elements such as Cr, Zr and Nb are extremely useful because they exist as immobile trace elements in the form of heavy minerals such as zircon, rutile and chrome spinel (Preston et al., 1998) and may provide insights to the source of REE. However, Nb was analyzed by aqua regia ICP-ES which would not determine the total Nb in the heavy minerals. Therefore, it is difficult to integrate partial trace element geochemistry with the heavy mineral chemistry. The case of Cr is quite different and will be examined in the Pattern D discussion. Elements such as Mo are not presented in this section of this report because the accuracy and precision displayed was poor.

Pattern C includes the elements Al, Hg, Fe, Th, U and Zn. The map for Zn is representative of this dispersal pattern (Appendix 6). The concentrations are scattered and difficult to interpret. A pattern exists within the Loch Lomond Valley and the western side of the East Bay Hills. The anomalous values may be derived from the west, based on an eastward ice-flow event. The Jubilee carbonate-hosted Pb and Zn deposit in central Cape Breton Island (Figures 2 and 3) and could be a possible source. Locally, numerous showings of Zn and related mineralization occur in the study area (Figure 7). If these occurrences are the source, one assumes that dispersal was governed by been governed by a northward and even a westward (?) ice-flow event to produce the observed geochemical patterns.

Pattern D (Figure 29) includes the following elements Ni, Li, K, Cr, As, Co, Rb and Sb. Pattern D is represented by the Ni and Cr maps (Appendix 6). The economic elements most commonly associated with ultramafic and mafic igneous rocks are Ni, Cr, and Co. Normally Cr values are notably greater than Ni values in crustal mafic and basaltic rocks because of primary dispersal (Krauskopf, 1967). The relative dispersal patterns of Ni (1-35 ppm - partial extraction) and Cr (25-110 ppm - total extraction) are quite similar. The St. Peters gabbro (10 km west of the study area, Figure 3) may have been the source of these Ni values but local basaltic rocks in the East Bay Hills and the Mira Hills are also a possible source. Gabbro plutons in the Stirling Belt (Figure 3) are east of the Ni and Cr till concentrations and are not considered a likely source because there is no east to west flow event to facilitate that dispersal pattern. Lithogeochemical data (Barr et al., 1994) reports Ni concentrations in the range of 27-861 ppm with a mean of 118 ppm from mafic rocks in the Mira Hills.

The topic of heavy minerals led to the discussion of the stability of the mineral, chrome spinel. The source of the Cr may have been from heavy minerals (i.e. chrome spinel), that were deposited in the Northumberland Strait as Carboniferous sedimentary rocks, whose provenance is possibly the Eastern Townships of Quebec. In the case of Cr, the analysis represents the total chromium concentration present in the till because Cr was determined by INAA analysis (total extraction). This time the comparison can be made between the till geochemical data and to the heavy mineral chemistry data because they are both based on total extractions. One can assume that the dispersal of chromium is solely by mechanical means and secondary hydromorphic dispersal is impossible. This allows one to concentrate on the dispersal pattern itself without having to consider secondary hydromorphic dispersal.

The following approach was developed to help interpret the dispersal patterns of the elements. Four copies of the Cr map were placed side by side on a 11"X 17" sheet of paper. The first map was prepared so that only the samples representing the regional red till values were on the map. Similarly, the second map displayed the hybrid till samples and the third map represented the local stony till concentrations. The fourth map is an map with all the concentrations retained for comparative purposes. Samples attributed to the outwash are included on this fourth map but are not singled out. This sheet was then reduced to an 8 ½" x 11" sheet and is included as Figure 30.

In Figure 30, Map A, the regional red till displays an elevated concentration of Cr in the regional red till along the western edge of the Loch Lomond valley suggesting that the Cr had a source to the west of the study area. On map B representing the hybrid tills, a concentration of high values also is present on the western edge of the study area. This appears to be an example of the hybrid tills inheriting matrix from the regional red till. Map C represents the local stony till and appears to have been also influenced by the previous tills through the inheritance mechanism. However, because this flow event (LL-5) produced the local stony till and was somewhat weaker than previous events (Figure 26), the Cr was not dispersed far from the original location of the regional red till and not far from the hybrid till at the extreme western edge of the study area. Note that the outwash samples also tend to

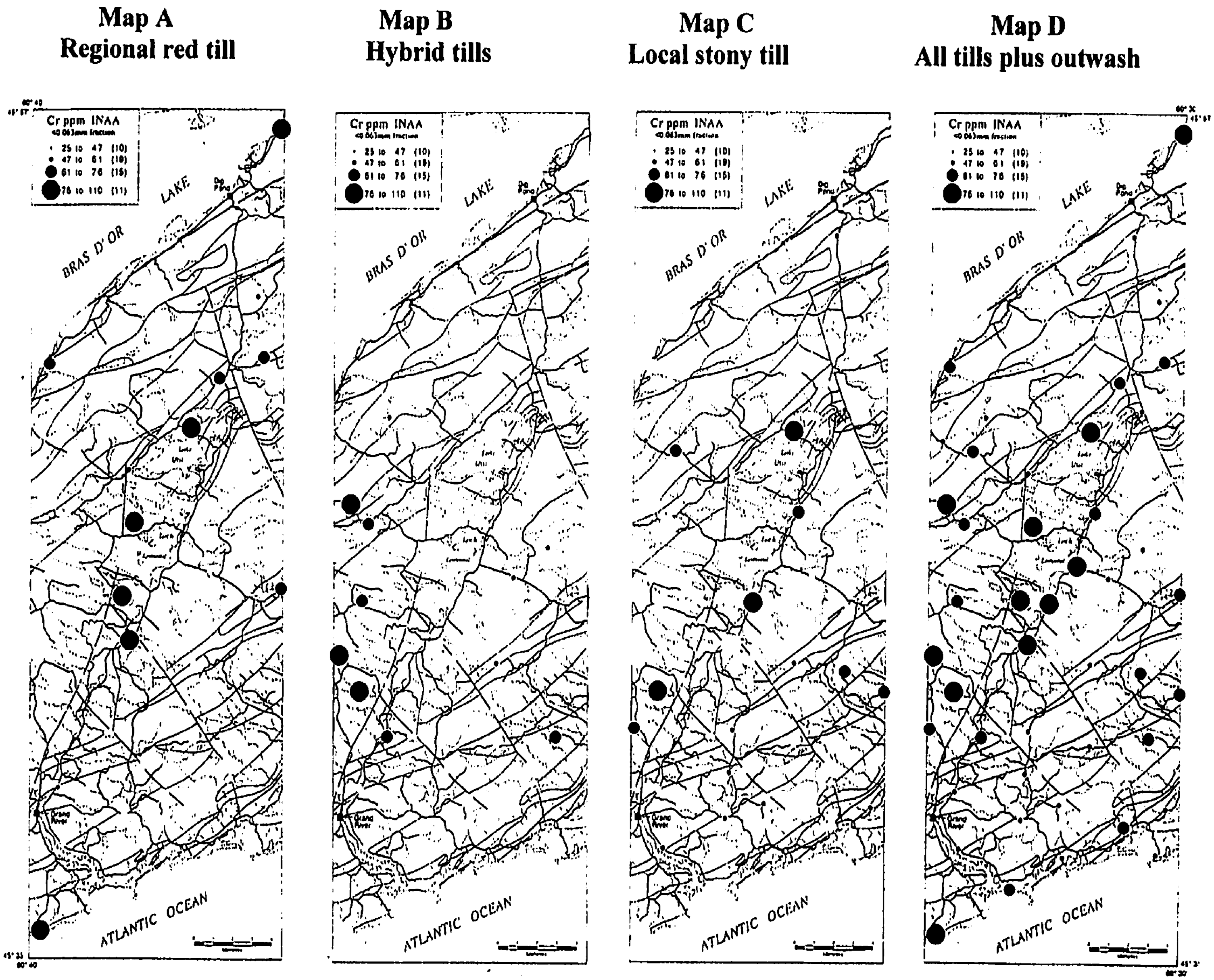


Figure 30: Cr geochemical patterns in differentiated till.

have anomalous values of Cr associated with them. This affiliation is expected because the Cr is believed to be in the form of chrome spinel, a heavy mineral and a glaciofluvial (fluvial) mechanism would be the best concentrator of heavy minerals. This may be why how Cr was concentrated at sample site 6657.

A biogeochemical survey (Dunn et al., 1992, 1994) similarly indicated anomalous concentrations of Ni in the southwestern part of the study area. It is reasonable to expect that the biological samples (twigs and bark from spruce and fir) would also be anomalous as a result of the trees growing in till that contained anomalous concentrations of Ni. Dunn et al. (1992, 1994) did not offer any suggestions for the source of the nickel concentrations. A possible source in the region is St. Peters Gabbro (Barr et al., 1994) located to the west of the study area (Figure 3). In the regional red till one observes that the majority of the anomalous values are associated with Pattern A (Loch Lomond Valley; Figure 29) which would be expected if the gabbros were the source. The hybrid till, which is in part composed of components of the regional red till, also displays increased Cr values along the western edge of the study area. Either the north (LL-3) or the south (LL-4) ice-flow event may be responsible for the dispersion of Cr as a result of inheritance from the red regional till. The local stony till appears to have also inherited some Cr from the regional red till and displays a southerly pattern of concentration which would correspond to the southeasterly ice-flow event (LL-5).

Pattern E (Figure 29) which includes the Loch Lomond Valley and the Mira Hills area is characterized by anomalous Cu, Mg and Mn values and is represented by the Cu map.

Concentrations of Cu are prevalent in the southern half of the study area and show some affinity for the Loch Lomond Valley. Most Cu showings are also in the southern zone (Figure 7) and as such dispersal may not be far from source. The difficulty is to determine which high value was derived from which showing in Figure 7.

In Pattern F, Sr, Na and Au are included in Appendix 6 as the representative maps. Other elements with this pattern include Bi, Ca, V, Br, Hf and Ta. The highest value of Sr (804 ppm) is reported from sample pit 6609 which is beside the former MacRae celestite open pit. Sample 6701, taken at 2 m depth at the same site contained 1088 ppm Sr. Given these high values, the source of these Sr concentrations is possibly within meters of the sample site.

The next highest concentrations of Sr (37-57 ppm) occur in the tills of the Mira Hills and the East Bay Hills (Figure 31). Besides actual sedimentary deposits of Sr-minerals, the average crustal abundance of Sr in the following rock types is indicated: basalt (465 ppm), granite (270 ppm) and shale (450 ppm) (Krauskopf, 1967). Rocks of these compositions either underlie the secondary high till values or are potential source rocks to the glacial advance. Barr et al. (1996) reported an average Sr concentration of 374 ppm (40 samples) from igneous rocks in the East Bay Hills and 352 ppm (47 samples) from similar rocks in the Mira Hills.

The similarity of the bedrock in both areas and the similar range of concentration of Sr would seem to favour these rocks as being a source for the geochemical values. However, the Mira Hills pattern may also be explained by a dispersal fan whose origin is the MacRae celestite pit (6609). A fan-shaped pattern occurs in the southeastern quadrant but there is a skip zone between the MacRae pit and the fan. A skip zone develops when the glacier erodes bedrock and debris is carried englacially transported a distance before being released as till This movement requires a north to south ice-flow pattern which could have been the LL-4 event which produced the upper hybrid till.

Evidence from McClenaghan et al. (1992) indicates several high values of Sr in the southwestern part of their study area. These values appeared to be isolated in their report but when put in context with the results of this study the adjacent samples now appear to be part of a dispersal fan. However, their presence does not resolve the question as to whether this is a dispersal fan from the celestite deposit from the north or whether the high values reflect the igneous rocks of the area. It is concluded that the best scenario is the igneous source because it explains the Sr values in both the East Bay Hills and the Mira Hills areas with the same reasoning. This reasoning also explains the anomalous values in the East Bay Hills without the difficulty of explaining how these anomalies could be dispersed there when there has not been a reported ice-flow event to the northwest. A further suggestion is that an alternative source exists in the form of undiscovered celestite deposits in the immediate area.

The same multi-map method used for Cr (Figure 30) is applied to Sr (Figure 31). On map A (Figure 31), the regional red till does not appear to contain any amount of Sr in the study area because there were no known celestite deposits in the west. Therefore, the regional red till is not a useful medium to use for Sr exploration in this area. Map B (Figure 31) displays concentrations in the East Bay Hills which are not likely to have come from the known celestite deposits because an east to west flow-event would be required. Map C (Figure 31) shows samples assigned from samples

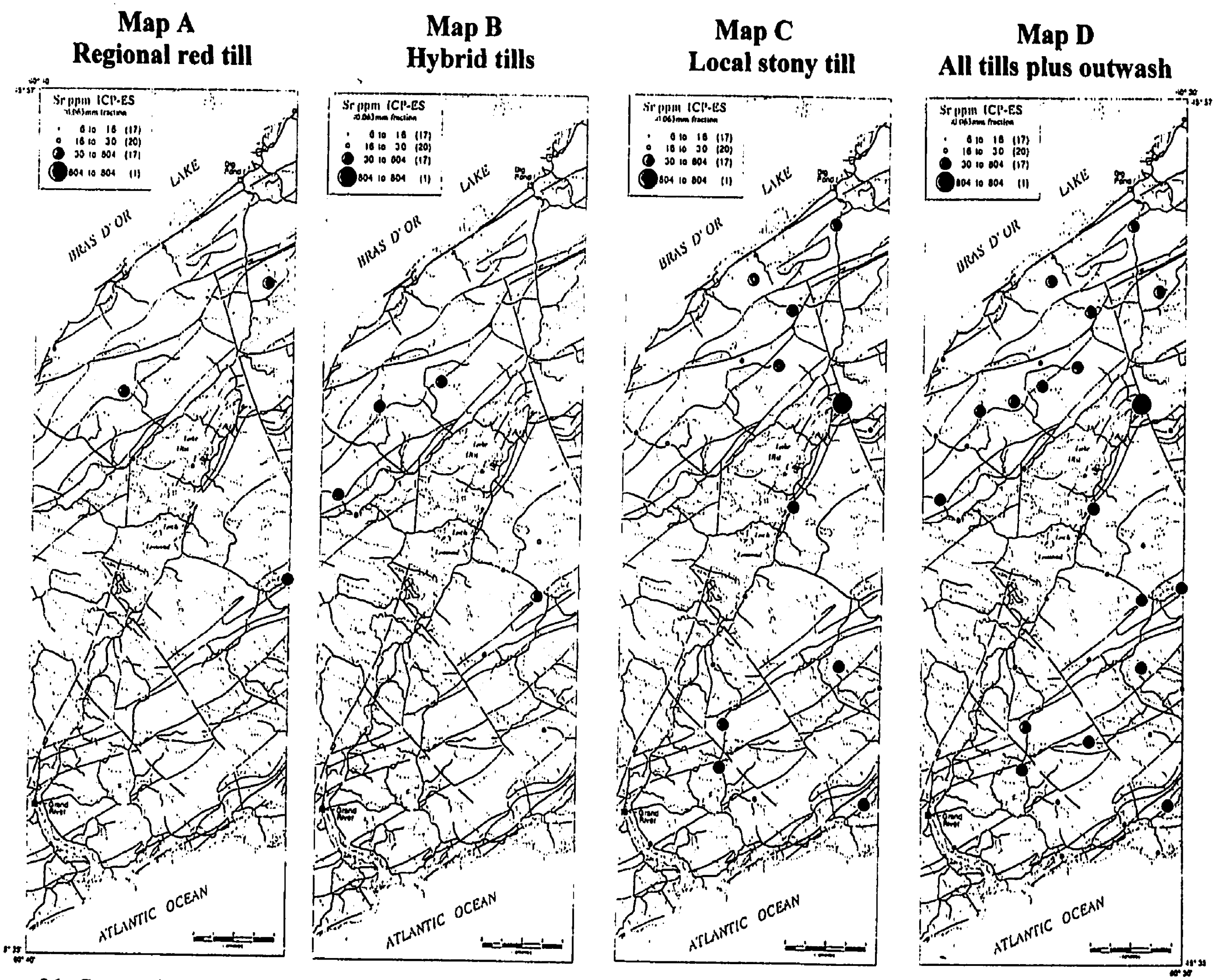


Figure 31: Sr geochemical patterns in differentiated till.

assigned to the local stony till and it appears that a dispersal fan exists from sample pit 6609 towards the south as described previously. The interpretation of Map D (Figure 31) is complicated because at least 4 glacial sediments have been sampled and the plotted results do not offer a simple interpretation. In contrast to Cr, the outwash sample sites do not contain anomalous values of Sr (Figure 31) because Sr would react as a hydromorphic element and therefore would be more mobile than chromite (solid) in a glaciofluvial environment. The native element Au, reported in ppb, is of interest for economic reasons. It is also of interest because it is inert and does not weather, thereby any dispersion pattern is be strictly mechanical. However, Au values are scattered over the study area and an interpretation of the dispersal mechanism difficult. The highest values (32-35 ppb) are found at sites 6615 and 6634. Heavy mineral analysis (Appendix 9) was carried out on a sample from site 6617, which is located approximately 2 km south of 6615. One grain of Au was reported and classified as reshaped (DiLabio, 1991). This observation suggests the gold grain may have been subjected to extensive working in the glacier and would not be considered to have a local source. However, the sample was from a local stony till with granite as the predominate clast which may suggest a more local source unless the Au was inherited from another till. A sample for heavy mineral analysis was selected from this site 6617 because the till contained fragments of gossan, a potential indicator of oxidized sulfides and sometimes precious metals. Budget constraints did not permit further heavy mineral sampling and subsequent analysis.

The elemental concentrations from sample pit 6657 consistently display anomalous values for approximately two thirds of the 43 reported elements. The sample site has been assigned to the outwash category for previously described reasons. The anomalous values (6657) include Fe and Mn (INAA: total extraction). These elements are known for their scavenging properties in which other metallic ions are commonly precipitated on surfaces where Fe and Mn are already present. These two elements were analyzed by the INAA method which effectively determines the total amount of the element in the sample. A partial extraction method (e.g. agua regia used for the ICP-ES method) would be better for this purpose as it is not essential to know the internal chemistry of the mineral species but rather the actual amount of Fe and Mn exposed on the mineral surfaces because that is where Fe and Mn actually chemically complex the elements they scavenge. Other anomalous elements include Zn, Mo, Hg, Cd, Sb, U, Th, and As. With this interpretation, the values associated with this sample should be treated with care as suggested by Gleeson et al. (1989) because the down-ice distance from source is much greater than most till anomalies. Before one tries to interpret glaciofluvial anomalies, one must first understand the till stratigraphy.

Conclusions

The geochemical patterns in this area are complex and a function of the repeating bedrock type, the geomorphology of the area, the numerous ice-flow events resulting in the deposition of multiple related tills and numerous small zones of mineralization. An integrated understanding of the glacial process is necessary for an interpretation of the geochemical dispersal of elements and the subsequent resultant patterns. This process begins at the planning and sampling stage.

The highest Sr and Pb values are directly over the MacRae celestite open pit, to indicating that the highest concentrations of these two elements occur directly over a known deposit. However, Pb dispersal is weak and the next highest concentration is at sample site interpreted to be attributed to glaciofluvial sediment. No other concentrations of interest are present. It is encouraging to see that the celestite deposit might have been a drill target if these geochemical results were present in a till geochemical exploration program before the discovery of the celestite deposit.

The local stony till is the most useful medium to use for Sr mineral exploration in the study area. The regional red till is not as useful because it reflects a more distant provenance. The regional red till was not totally preserved as a till on the eastern edge of the study area because it was likely eroded and incorporated in the subsequent hybrid and local stony tills. However, it is suggested the regional red till be used as a sampling medium for elements such as Cr because their source is considered to be to the west.

The dispersal pattern for Ba is complex and deserves detailed study and additional sampling. It probably offers the most promise for finding additional deposits in the study area.

CHAPTER 5

DISCUSSION AND RECOMMENDATIONS

5.1 Introduction: The Problem

The purpose of this chapter is to integrate the results of the geological and geochemical investigations and to compare this study with others done regionally or ones that are relevant within the context of this study. The association with mineral occurrences will also be addressed.

Thompson (1986) stated "the ideal geochemical survey is based on regular systematic sampling of the same material across a survey area." However, as this study have demonstrated, mineral exploration geologists and prospectors need to understand the complexity of sampling in complex glaciated terrains. It is crucial to consistently sample the same material so that valid conclusions can be formulated from geochemical results. In this study, the results were difficult to interpret given the complexity of the bedrock geology of the study area. The glacial sediments that are superimposed on repeating bedrock geology are the product of at least four distinct ice-flow episodes, each of which had its own distinct method of formation, flow direction and erosive intensity. Local topography has also influenced the direction of ice and water flow in the area. And yet this complexity was seen to offer the opportunity to increase the knowledge of how mineral occurrences would be detected in glaciogenic sediment. However, it became obvious as the study progressed that the standard methodology employed at the outset of this study was not compatible with this complex stratigraphy. In an attempt to understand and interpret the results, several new techniques were developed that should be applied in future studies in similar terrain.

5.2 Geochemistry and the tills

Orientation surveys are often performed in geochemical studies to determine the best unit (till) or horizon to sample (Levinson, 1980). McClenaghan *et al.* (1992) carried out such a study in the Mira River area (Figure 1). It was deemed appropriate to follow their recommendations for sampling methodology in this study because of the adjacent setting, similar glacial stratigraphy, similar bedrock geology, and comparable glacial history.

McClenaghan and DiLabio (1994) suggested that the red silty till and the local sandy grey till were suitable media to use for till geochemical surveys. In their study, McClenaghan *et al.* (1992) were able to evaluate till geochemical concentrations without differentiating between the tills. Certainly, Quaternary maps (Grant, 1994) of the region do not show appreciable differences in till distribution patterns. However, geochemical dispersal patterns in the Mira River study area appear to lack the complexity of those in the present study area, perhaps the result of more consistent, extensive till sheets. This apparent increase in continuity of till sheets may be related to subdued bedrock topography. Subdued bedrock topography would impart consistency on the local dynamics of each ice-flow event resulting in more consistent till distribution. Bedrock-cored ridges (evident as till ridges on previous Quaternary maps; Grant, 1994) are exclusive to this study area, and impart significant relief and topographic variability on a local scale. Distribution of tills on the bedrock ridges is complex; the regional red till is common on the flanks, whereas the hybrid tills and local tills dominate at the tops of the ridges. The bedrock ridges, together with other major bedrock topographic features in the study area (East Bay Hills, Mira Hills), most likely predated Wisconsinan glaciation and may have been the primary influence on the variability of local stratigraphic units.

When conducting geochemical exploration surveys in the area, one must realize that it is essential to consistently sample the same medium (till) or horizon at all times so that the results may be meaningfully evaluated (Batterson and Liverman, 1999; Martin and McClenaghan, 1999). Designers of sampling programs are generally aware of this procedure which requires an understanding of the local glacial stratigraphy and ice-flow history in order to successfully interpret geochemical results. An important component of the sampling program is the collection of field notes. In this study, it was this field database that was critical in the overall evaluation of the results.

One of the difficulties encountered during the sampling phase of this study was the identification of the till unit being sampled. Klassen (1997, 1999) pointed out that when sampling till in hand-dug pits, sedimentary structures and stratigraphic relationships required for classification and genetic distinctions cannot be established reliably. The primary reason for this situation is the limited exposure offered by a hand-dug pit. This uncertainty was a similar concern and difficulty in this study. However, field notes could be used to subjectively assign a stratigraphic designation to individual samples. This was possible using a variety of field criteria including texture, colour and compactness. The effectiveness of this method is illustrated by the exclusivity of the regional red till as shown in Figure 28. In this ternary plot, the samples identified as being red regional till form a cluster which was separate from the remaining glacial sediments. On the basis of this plot aand till colour, all samples from the study area with >20% clay might be classified as a regional (red) till. It is suggested that detailed field observations, including clast shape, colour, degree of compaction, and striae on cobbles and pebbles, should either be compiled and evaluated or included in reports so others can re-evaluate subjective conclusions. The interpretive value of these descriptive methods does not become evident until they need to be applied.

This method of classification of till samples resulted in the production of three maps for each element, with each map representing elemental concentrations in a particular stratigraphic unit (regional red till, hybrid tills, local stony till). The unique sedimentary characteristics of the regional red till, which became evident only on qualitative analysis of field notes, demonstrate that original assumptions of the spatial continuity of stratigraphic units on a local scale are invalid. It is evident that the subtle geomorphic differences between the Mira River (McClenaghan *et al.*, 1992) and Loch Lomond (this study) may result in significant stratigraphic differences. However, the *after-the-fact* assignment of a particular stratigraphic unit to each sample that was applied in this study resulted in an uneven distribution of sample sites for each of the three stratigraphic units. Thus it became evident that a sample pit survey designed to delineate the spatial distribution (and geomorphological associations) of specific stratigraphic units may be an important component of a geochemical survey and should be used to plan the optimum geochemical sampling grid.

Chromium was selected to demonstrate the usefulness of this method (Chapter 4). Distinct patterns associated with discreet ice-flow events were evident for each specific stratigraphic unit; however, the map that displays geochemical data for all sites (Map D, Figure 30), and therefore for all stratigraphic units, displays a complex dispersal pattern not easily associated with any discrete event or source. Consideration of the Cr map suite

(Figure 30) helps one understand the complexity of the patterns and, at the same time, the necessity to separate stratigraphic units at the Loch Lomond site for plotting and interpretation purposes. This result validates the need to integrate glacial history and sample site stratigraphy with geochemical results.

5.3 Implications for mineral exploration

The complexity of the glacial stratigraphy gives rise to the question as to which stratigraphic unit is best suited to the identification of anomalous concentrations of a particular element (or all elements). Three distinct till types were recognized in this study. The regional red till (Table 7) is equivalent to the red silty till of McClenaghan and DiLabio (1994, 1996). It would be fortuitous to equate one of the hybrid tills or the local stony till to the local sandy grey till recognized by McClenaghan and DiLabio (1994), although the local stony till may be the correlative because it is closer to being an end-member till. It should be pointed out that no field determination was possible to distinguish between the two hybrid tills (produced by ice-flow events LL-3 and LL-4) in this study. Rather, their uniqueness is based on the ice-flow evidence presented. The local stony till has been assigned to the last ice-flow event (LL-5) because of agreement between fabric data.

Gleeson *et al.* (1989) suggested that ablation till is generally much farther traveled than lodgement till and thus a more difficult medium to utilize in the search for mineral deposits. Although this is probably true for terrain covered by continental glaciers, it may be the opposite in this study area. Because this area was influenced by waning glaciers (LL-3,4 and LL-5; Figure 21), the strength of these glaciers to move the material far from source is reduced. Therefore, one may conclude that the local stony (ablation) till is a good medium to sample for anomalous concentrations representing local mineralization. The two hybrid tills contain physical properties somewhere between the properties of the end-member tills because of their inherited (mainly matrix) and overprinted (mainly clasts) constituents, and may display element concentrations which are indicative of both regionally derived mineralization and locally derived mineralization.

Figure 25 indicates the upward coarsening of the matrix and clast components of the tills in this area. The same feature was repeated by Stea *et al.* (1989); the later phase tills are characterized by dominance of clasts over matrix mode and represented more local dispersal. Early phases are dominated by the matrix component and have a greater percentage of far-traveled components (clasts and matrix). The relationship of clast size and relative matrix textures was similarly reported by Dreimanis and Vagners (1971). These trends in grain size are consistent with the observations of this study, and can be utilized to help recognize the stratigraphic units being sampled.

In this study, the regional red till (LL-2) has an average clay content of 22%. Campbell and Schriner (1989) reported that the average clay content of tills in northern Saskatchewan (Canadian Shield) is 5%. A common clay content of 3-15% is reported by McClenaghan (per. comm., 1999) for tills in the Canadian Shield (Ontario). The abundance of clay in the red regional till is most likely a function of the source of the sediment. Canadian Shield rocks are generally crystalline in nature and would not be expected to produce as much clay as compared to the red Carboniferous clastic sedimentary source rocks in this study area. The amount of clay reported is based on particle size determination (<0.002 mm) which may consist of actual clay minerals (chlorite, illite, smectite, etc.) and will include mineral material that has been comminuted or crushed (quartz, feldspar, calcite amphiboles, etc.) during glacial transport. If actual clay minerals exist, they have an affinity to attract and concentrate metallic ions. The major influence on the till geochemistry in this study area is from the clay sized fraction which is due to the till texture (clay fraction). The abundance of clay in tills in this study area has the potential to reinforce geochemical patterns. Even the hybrid tills (LL-3 and LL-4) have greater clay abundances than tills in Canadian Shield areas. The difference is attributed to inheritance from the red regional till (LL-2) and also the addition of product from local clay-rich rocks (Stea and Finck, 1999; Klassen and Thompson, 1989). Thus, interpretive and comparative analyses of geochemical patterns or anomalies in the Loch Lomond study area must consider the clay content of the stratigraphic units from which the samples were obtained. This again reinforces the need to stratigraphically identify each sample analyzed, as the clay content is quite variable within the four stratigraphic units.

In the discussion of geochemistry in Chapter 4, the conclusion was drawn that sample 6657 (elevated values for several elements) was sampled in outwash. Further evidence to support this conclusion is found in the till pebble counts. The presence of abundant pebbles of Salmon River rhyolite porphyry in pebble counts for sample 6657 was an enigma until the genesis of the sample was established. McClenaghan and DiLabio (1994) reported the usefulness of this lithology as an indicator of an eastward flow-event. Glaciofluvial sediment was not considered to be an optimum sampling medium because it contains material derived over a much larger source area and more than one direction of transport that may be unrelated to ice-flow directions. That the sample was collected at all illustrates the difficulty in differentiating till from other stratigraphic units. However, on the basis of pebble counts, this sample did not conclusively support ice movement from east to west which was not evident in other ice-flow indicators. Rather, it demonstrated a glaciofluvial channel direction.

One of the difficulties in interpreting the geochemical concentrations in this study area was the repetitive nature of the bedrock geology. This observation is based on a superficial look at the till pebble clasts rather than a detailed mapping of rock outcrops. McMullin (per. comm., 2000) indicated that the Irish Cove Pluton samples and the Chisholm Brook Suite samples would be difficult to distinguish in hand sample. Batterson and Liverman (1999) recognized that dispersal trains on the Island of Newfoundland are commonly less well defined due to chemical similarities in adjacent rock units. This circumstance, which can occur anywhere, is not a direct result of a complex glacial history or its location at the margin of an ice-field. However, when all three of these circumstances coincide, as in southeastern Cape Breton Island, the difficulty in interpreting the geochemical patterns is exacerbated. Batterson and Liverman (1999) recommended the adoption of a multifaceted approach (similar to that employed in this study) which includes clast fabric analysis and lithological classification, striae and surficial mapping, in addition to geochemical annalysis in order to simplify the task of anomaly interpretation.

Sample 6701, which was taken stratigraphically below 6609 at the same site, contained the highest values of Sr and Pb for the entire study area. This is to be expected as these samples were taken at the edge of a former celestite quarry. It could be suggested that these concentrations would have demanded further exploration if one was not aware of the nearby Sr mineralization which in all likelihood would have resulted in the discovery of the celestite deposit with the associated galena. The upper till (sample 6609) is local stony till (the youngest till). Batterson and Liverman (1999) suggested that a given mineralized zone will be easier to recognize in areas dominated by local ice-flow as opposed to regional ice-flow, as the till contains a greater proportion of local material. However, Shilts and Smith (1989) emphasized that till deposited during a single glaciation may be represented at or near the surface by several distinctive facies. These facies represent how the till was released from the ice, not how debris of which they are composed was eroded and transported. It would seem that the comments of Batterson and Liverman (1999) and Shilts and Smith (1989) apply to the interpretation of the glacial history of this area. Earlier in the geochemical discussion (Chapter 4), two points were suggested: (1) The local stony till is the best to utilize for drift prospecting of Sr in the study area; (2) A possible Sr dispersal fan in the local till includes a skip-zone which formed because the debris had been carried englacially before release (possibly due to ablation) to the present location. Thus, an understanding of the glacial processes that were locally dominant is important in the interpretation of the dispersal patterns.

5.4 Recommendations

The following recommendations are an attempt to relate the significant alterations to the methodology for future surveys that should be employed when attempting a study of this nature.

- ❑ Pre-sampling preparation which would include an initial visit to the field area along with air photo interpretation would be prudent in regions of complex glacial stratigraphy and limited exposure. The following steps are suggested:
  - i Identify the different terrains in the area of interest such as:
    - a. Peatland areas
    - b. Slopes in subdues terrain
    - c. Large features, cliffs and extended slopes
    - d. River valleys
  - ii Plan a grid that includes all of these components and attempt to incorporate a geometric structure to the area.
    - a. Choose sites on a regular grid system with some allowance to obtain better sample media
    - b. Interpret the till type present in each pit while at the site
  - iii Analyze which morphology supports which till
  - iv Re-establish a grid to locate sites with a specific stratigraphy

While the forgoing suggestions are valid, the following protocol may prove to be more useful for a successful evaluation of till geochemical dispersal patterns.

I Sample as per the original protocol but increase the sample density

II Perform sample preparation on all samples

III Complete grain-size analysis on the <2 mm size fraction

IV Categorize the samples into till types using field data, grain-size analysis, clast percentages, till induration and colour

V Send all samples to the laboratory in the numerical order in which they were sampled

VI When the geochemical results have been completed and returned, sort the data into the pre-determined till types (IV) and plot the information accordingly on separate maps

VII Analyze the pattern which now represents the same material across a survey area.

The latter methodology is preferred, as logistics and filed costs are greater than analytical costs. Attention to detail in field notes is another essential requirement.

- ❑ Additional sampling of the regional red till in the Loch Lomond Valley has the potential to delineate possible sources of Ba mineralization.

- ❑ Till pebble counts can be utilized to delineate the bedrock contacts in the region. Bedrock mapping has been hampered by lack of outcrops. A better understanding of bedrock distribution will aid in geochemical anomaly interpretation.

- More detailed stratigraphic analyses (possibly using additional sample pits) is required to better delineate the 120°-130° (LL-5) ice-flow event.

- A better understanding of the controls on bedrock topographic variability is required to understand the local variability of the distribution of stratigraphic units.

- Textural analysis can be carried out on the <2.00 mm till fraction to assist in the determination of distinct stratigraphic units in similar terrains.

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APPENDIX 1 FIELD OBSERVATIONS

A	A	B	C	D	E	F	G	H	I
1	SAMPLE	UTM	EASTING	NORTHING	TILL COLOUR	< 2.00 mm	PEBBLE	SAMPLE	COMMENTS
2		ZONE			MUNSELL : MOIST	TEXTURE	4-64 mm	DEPTH (m)	
3	96MPB6601	20	683500	5074600	moderate brown	sand	20%	0.6	granite outcrop less than 2 m depth
4	96MPB6602	20	681850	5075000	moderate brown	silty sand	25%	0.7	compact till
5	96MPB6603	20	693700	5087650	moderate brown	silt, sand, clay	15%	1.0	Mn nodules? Dolomite pebbles
6	96MPB6604	20	682250	5072250	moderate brown	silty sand	50%	0.7	Groundwater Table at 0.6 m
7	96MPB6605	20	683200	5071200	moderate brown	silty sand	35%	0.6	Groundwater Table at 0.5 m
8	96MPB6606	20	685750	5076600	moderate brown	silty sand	25%	0.5	Groundwater Table at 0.4 m
9	96MPB6607	20	692750	5082300	moderate brown	silty sand	35%	0.6	GroundwaterTable at 0.5 m
10	96MPB6608	20	693150	5079450	dark reddish brown	sand, silt, clay	30%	0.6	semi-compact; rounded pebbles
11	96MPB6609	20	692050	5076850	moderate brown	silty sand	20%	0.6 - 0.8	Mn frags; 96MPB6701; heavy mineral sam.
12	96MPB6610	20	692400	5070500	dark yellowish brown	silty sand	75%	0.7	compact; clast supported
13	96MPB6611	20	692450	5067800	dark yellowish brown	silty sand	<10%	0.6	striated pebbles
14	96MPB6612	20	686100	5067700	moderate brown	silty sand	20%	0.6	compact till
15	96MPB6613	20	683000	5067650	moderate brown	sandy silt	25%	0.5	angular pebbles
16	96MPB6614	20	686300	5064200	dark yellowish brown	silty sand	50%	0.7	mix of rocks present
17	96MPB6615	20	686900	5061600	moderate brown	sand	75%	0.6	granite; compact, lodgement
18	96MPB6616	20	686900	5061600	moderate brown	sand	75%	0.6	field duplicate of 96MPB6615
19	96MPB6617	20	686750	5059600	grayish brown	silty sand	35%	0.6	heavy mineral analysis
20	96MPB6618	20	692550	5064600	dark yellowish brown	silty sand	25%	0.6	3 m thick
21	96MPB6619	20	689950	5064900	dark yellowish brown	silty sand	25%	0.6	compact till
22	96MPB6620	20	693100	5061500	moderate brown	silty sand	25%	0.45	compact till
23	96MPB6621	20	694600	5063700	grayish brown	sand	25%	0.6	compact till
24	96MPB6623	20	689400	5081250	dark yellowish brown	sandy silt	20%	0.6-0.75	striated cobbles; 40% cobbles
25	96MPB6624	20	688850	5078650	grayish brown	silty sand	50%	0.55	angular cobbles
26	96MPB6625	20	681850	5061500	moderate brown	silty sand	25%	0.6	striated cobbles, loose
27	96MPB6626	20	683000	5063300	moderate brown	silty sand	10%	0.55	soft, slaty with trace quartzite
28	96MPB6627	20	681900	5065050	moderate brown	silty sand	25%	0.5	striated metasedimentary rocks
29	96MPB6628	20	688650	5058200	grayish brown	silty sand	25%	0.5	weakly compact
30	96MPB6629	20	690150	5060850	moderate brown	silty sand	35%	0.7	striated quartzite cobble
31	96MPB6630	20	694100	5058000	grayish brown	silty sand	30%	2.0	granite:sub-angular; sample below outwash
32	96MPB6631	20	693650	5055900	dark yellowish brown	silty sand	30%	0.6	sub-angular granite pebbles with boulders
33	96MPB6632	20	688800	5055450	dusky brown	sand	30%	0.7	loose till
34	96MPB6633	20	686300	5054100	dusky brown	silty sand	10%	0.65	0.35 m organic cover near ocean shore

APPENDIX 1 FIELD OBSERVATIONS

A	A	B	C	D	E	F	G	H	I
35	96MPB6634	20	683550	5055700	dusky brown	silty sand	20%	0.8	angular fragments
36	SAMPLE	UTM	EASTING	NORTHING	TILL COLOUR	TILL	PEBBLE	SAMPLE	COMMENTS
37		ZONE			MUNSELL : MOIST	TEXTURE	4-64 mm	DEPTH (m)	
38	96MPB6635	20	682600	5051800	dark reddish brown	clayey silt	20%	0.7	compact till
39	96MPB6636	20	683250	5058650	dark reddish brown	sandy silt	10%	0.6	top of giant till ridge
40	96MPB6637	20	684450	5061300	dark reddish brown	silty sand	20%	0.5	edge of giant till ridge
41	96MPB6638	20	694450	5068150	moderate brown	sand, silt, clay	15%	0.7	compact till
42	96MPB6639	20	693450	5073150	grayish brown	silty sand	10%	0.65	rounded pebbles
43	96MPB6640	20	686750	5071350	moderate brown	silt, sand, clay	35%	0.5	compact
44	96MPB6641	20	690600	5068800	moderate brown	silty sand	30%	0.6	
45	96MPB6642	20	689900	5072100	grayish brown	silty sand	40%	0.45	outcrop arkosic sandstone less than 2 m
46	96MPB6643	20	693550	5075900	moderate brown	silty sand	30%	0.65	striated cobble; < 2% cobbles
47	96MPB6644	20	682150	5078800	moderate brown	silty sand	15%	0.6	steep hill side, in part colluvium?
48	96MPB6645	20	687150	5077700	moderate brown	siltty sand	30%	0.65	compact, stony till
49	96MPB6646	20	687150	5077700	moderate brown	silty sand	30%	0.65	field duplicate for 96MPB6645
50	96MPB6647	20	686400	5073750	moderate brown	silty sand	30%	0.55	Groundwater Table at 0.4 m
51	96MPB6648	20	690850	5078100	moderate brown	sandy silt	25%	0.6	compact sandy till
52	96MPB6649	20	684100	5076450	moderate brown	sand, silt, clay	35%	0.55	compact, Groundwater Table at 0.4 m
53	96MPB6650	20	687400	5082600	grayish brown	silty sand	60%	0.5	till <1 m with angular volcanics
54	96MPB6651	20	687000	5078800	dark yellowish brown	sandy silt	35%	0.15-0.25	granite, local oxidation,GW Table at 0.2 m
55	96MPB6652	20	689550	5075750	moderate brown	silt, sand, clay	30%	0.4	reddish (lower till sampled 96MPB6673)
56	96MPB6653	20	692050	5057150	grayish brown	silty sand	20%	0.7	some striated cobbles; 30% cobbles
57	96MPB6654	20	686700	5057200	grayish brown	silty sand	65%	0.6 - 1.0	compact but local(?)
58	96MPB6655	20	686700	5065700	moderate brown	silt, sand, clay	30%	0.55	hole making water
59	96MPB6656	20	687750	5067700	very dusky red	sand	75%	0.6	mix of rounded and angular cobbles:
60	96MPB6657	20	689050	5069350	dusky brown	sand	25%	0.4	mix of rounded and angular cobbles : OW?
61	96MPB6658	20	691350	5085300	moderate brown	silty sand	0	0.3 - 0.5	friable, soft, shaly metavolcanic rocks
62	96MPB6659	20	693800	5090200	moderate brown	silty sand	20%	0.6 - 0.8	3 m + thick till
63	96MPB6673	20	689550	5075750	moderate brown	sand, silt, clay	0	0.6	grey till below 96MPB6652
64	96MPB6701	20	692050	5076850	moderate brown	silty sand	20%	2.4	sample below 96MPB6609
65	97-DS-002	20	690300	5073200	moderate brown	not determined	35%	0.6	additional sample taken for pebble count

APPENDIX 1 FIELD OBSERVATIONS

A	J	K	L	M	N	O	P	Q
1	SAM	SLOPE	SLOPE	VEG.	SITE	GEOLOGY	MAP	BEDROCK
2		AZIMUTH	ANGLE	TYPE	TYPE	MAP	SYMBOL	TYPE
3	6601	180	05	1	1	Barr	Hlm	monzogranite
4	6602	250	15	1	2	Barr	Hlm	monzogranite
5	6603	200	20	2	5	Barr	Ch	clastics at basalt contact
6	6604	080	05	1	1	Bar	Hlm (HEt)	monzogranite (felsic tuffs)
7	6605	060	< 10	1	1	Boehner	DCs	sandstone
8	6606	190	12	6	1	Barr	Hlm & HEt	monzogranite and volcanics
9	6607	130	12	1	3 (in 6)	Boehner	ICgv	sandstone
10	6608	170	<10	1	1	Boehner	ICbb	red clastics
11	6609	180	35	2	6	Boehner	eCll	gypsum,red clastics
12	6610	180	20 +	1	2	Barr	HCBg	granodiorite
13	6611	0	0	6	3	Barr	HCBg (HCBd)	granodiorite, (diorite)
14	6612	0	0	1	1	Barr	CW	gypsum, limestone
15	6613	250	15	6	1 or 3	Barr	DCs	sedimentary (quartzite)
16	6614	110	,10	1	2	Barr	HCBg	granodiorite
17	6615	240	10	1	2	Barr	HCBg	granodiorite
18	6616	240	10	1	2	Barr	HCBg	granodiorite
19	6617	270	<5	1	2	Barr	HCk	arkose
20	6618	305	10	1	2	Barr	HCBg	granodiorite
21	6619	230	10	2	2	Barr	HSrf	felsic volcanics
22	6620	011	05	1	1 & 3	Barr	HSa	intermediate volcanics
23	6621	110	12	2	2	Barr	HCBd	diorite
24	6623	0	0	2	1	Barr	HEt & HEab	mafic volcanics and m. porphyry
25	6624	110	15	2	1	Barr	Hlm	monzogranite
26	6625	070	<10	1	1	Barr	DCs	sedimentary (quartzite)
27	6626	0	0	1	1 (3)	Barr	DCs	sedimentary (quartzite)
28	6627	135	<10	1	1 (3)	Barr	DCs	sedimentary (quartzite)
29	6628	200	20	1	2	Barr	HSa	intermediate volcanics
30	6629	220	20	1	1	Barr	HCBq	diorite
31	6630	000	00	1	6	Barr	DI	hornblende-biotite monzodiorite
32	6631	160	05	1	6	Barr	HFc	felsic tuffs
33	6632	180	15	1	2	Barr	HSa	felsic tuffs
34	6633	180	05	1	1	Barr	HSa	mafic volcanics

APPENDIX 1 FIELD OBSERVATIONS

A	J	K	L	M	N	O	P	Q
35	6634	120	05	1	2	Barr	HSa	mafic volcanics
36	SAM	SLOPE	SLOPE	VEG.	SITE	GEOLOGY	MAP	BEDROCK
37		AZIMUTH	ANGLE	TYPE	TYPE	MAP	SYMBOL	TYPE
38	6635	230	< 05	1	2	Barr	HSa	intermediate volcanics
39	6636	270	40	1	6	Barr	CW ?	gypsum
40	6637	320	30	2	2	Barr	CW ?	gypsum
41	6638	300	10	1	2	Barr	HCBq	granodiorite
42	6639	350	10	6	3	Barr	HCBq	granodiorite
43	6640	270	10	4	3	Boehner	Cml	grey shale with gypsum
44	6641	005	< 05	1	1	Barr	HCBq	granodiorite
45	6642	285	30	4	3	Boehner	eCc	red clastics, nodular limestone
46	6643	300	15	1	1	Boehner	eCu	red clastics, marine limestone
47	6644	270	40	1	1	Barr	HEad	volcanics
48	6645	070	15	2	1	Barr	Hlm	monzogranite
49	6646	070	15	2	1	Barr	Hlm	monzogranite
50	6647	110	20	1	1	Barr	CC	Shale, siltstone
51	6648	140	35	8	2	Boehner	ISsm	grey sandstone, coal
52	6649	0	0	1	1	Barr	Hlm	monzogranite
53	6650	040	< 10	2	1	Barr	HEad	andesite
54	6651	000	00	1	1	Barr	HEad & HEt	felsic and mafic volcanics
55	6652	090	05	1	2	Boenher	ICms	grey sandstone, coal
56	6653	180	05	1	2	Barr	HCb	maroon to red conglomerate,ss
57	6654	090-270	25	2	road section	Barr	HSa	andesite tuff
58	6655	000	25	6	1	Barr	HCBq	quartz monzodiorite
59	6656	0	0	1	2	Barr	CW (HCBg)	gypsum, lmst, (granodiorite)
60	6657	0	0	1	1	Barr	HCBg	granodiorite
61	6658	180	05	2	1	Barr	HEad	mixed tuffs
62	6659	320	10	2	2	Barr	Ch	clastics
63	6673	090	05	1	2	Boenher	ICms	grey sandstone, coal
64	6701	180	35	2	6	Boehner	eCll	gypsum,red clastics
65	002	270	18	4	3	Boehner	eCe	gypsum,limestone

APPENDIX 1 FIELD OBSERVATIONS

A	R	S	T	U	V	W	X	Y
1	FORMATION	REACTION	COBBLES In TILL	DRIFT		THICKNESS		SAM
2	NAME	10% HCl	> 64 mm	THICKNESS	Ao	Ae	B	
3	Irish Cove Pluton	no	granite	< 2 m	1 cm	1 cm	6 cm	6601
4	Irish Cove Pluton	no	volcanics, granite	2+ m	4 cm	0 cm	50 cm	6602
5	Horton Group	no	volcanics, granite	3+ m	5 cm	0 cm	30 cm	6603
6	Irish Cove Pluton (East Bay Hills Group)	no	no cobbles	< 2 m	2 cm	4 cm	24 cm	6604
7	L'Ardoise Block : Devono-Carboniferous	no	red SS, granite, quartzite	2 m (?)	6 cm	1 cm	1 cm	6605
8	Irish Cove pluton & East Bay Hills	no	granite, basalt	2 m (?)	1 cm	5 cm	15 cm	6606
9	Glengarry Valley F. - Morien Group	no	sandstone	2 m	4 cm	10 cm	14 cm	6607
10	Big Barren F. - Morien Group	no	sedimentary	2+ m	1 cm	0 cm	60 cm	6608
11	Loch Lomond F. - Windsor Group	no	granite, red sandstone	6.0 m	1 cm	0 cm	30 cm	6609
12	Chisholm Brook Suite	no	granite, volcanics	3 m	1 cm	5 cm	12 cm	6610
13	Chisholm Brook Suite	no	granite, porphyry	3 m	10 cm	10 cm	10 cm	6611
14	Windsor Group	no	quartzite, red sedimentary	2 m	1 cm	0 cm	40 cm	6612
15	L'Ardoise Block : Devono-Carboniferous	no	red sedimentary, quartzite	2 m	4 cm	4 cm	15 cm	6613
16	Chisholm Brook Suite	no	quartzite, volcanic, granite	3 m	6 cm	<1 cm	50 cm	6614
17	Chisholm Brook Suite	no	granite	2+ m	10 cm	6 cm	28 cm	6615
18	Chisholm Brook Suite	no	granite	2+ m	10 cm	6 cm	28 cm	6616
19	Kelvin Glenn Group	no	rhyolite w sulfides, quartzite	2+ m	2 cm	2 cm	40 cm	6617
20	Chisholm Brook Suite	no	rhyolite w sulfides, igneous	3 m	5 cm	4 cm	12 cm	6618
21	Stirling Group	no	granite, mafic volcanic	2 m	3 cm	2 cm	35 cm	6619
22	Stirling Group	no	granite, quartzite, volcanic	2 m	1 cm	10 cm	30 cm	6620
23	Chisholm Brook Suite	no	red quartzite, granite, volcanic	3 m	1 cm	1 cm	40 cm	6621
24	East Bay Hills Group	no	volcanics, porphyry, pyroclastics	< 2 m	3 cm	12 cm	35 cm	6623
25	Irish Cove Pluton	no	granite, mafic volcanic	2 m	10 cm	0 cm	30 cm	6624
26	L'Ardoise Block : Devono-Carboniferous	no	quartzite, slate, volcanic	3+ m	2 cm	2 cm	34 cm	6625
27	L'Ardoise Block : Devono-Carboniferous	no	No cobbles	2 m	1 cm	0 cm	45 cm	6626
28	L'Ardoise Block : Devono-Carboniferous	no	volcanic, quartzite with gossan	3 m	4 cm	3 cm	18 cm	6627
29	Stirling Group	no	mafic pyroclastic	2 m	1 cm	0 cm	25 cm	6628
30	Chisholm Brook Suite	no	granite, mafic volcanic	< 2 m	2 cm	5 cm	34 cm	6629
31	Lower St Espirt Pluton	no	granite	3+ m	2 cm	4 cm	40 cm	6630
32	Fourchu Group	no	granite	2 m	2 cm	10 cm	20 cm	6631
33	Stirling Group	no	no cobbles	2 m	2 cm	5 cm	30 cm	6632
34	Stirling Group	no	no cobbles	2 m	35 cm	5 cm	0 cm	6633

APPENDIX 1 FIELD OBSERVATIONS

A	R	S	T	U	V	W	X	Y
35	Stirling Group	no	no cobbles	2 m	0 cm	0 cm	30 cm	6634
36	FORMATION	REACTION	COBBLES in TILL	DRIFT		THICKNESS		SAM
37	NAME	10% HCl	> 64 mm	THICKNESS	Ao	Ae	B	
38	Stirling Group	no	no cobbles	2 m	0 cm	0 cm	40 cm	6635
39	Windsor Group	no	red sediments	10 m	0 cm	6 cm	30 cm	6636
40	Windsor Group	weak	red sediments	5+ m	10 cm	0 cm	10 cm	6637
41	Chisholm Brook Suite	no	granite, volcanics w sulfides, quartzite	3 m	?	?	20 cm	6638
42	Chisholm Brook Suite	no	granite, volcanics	2 m	0 cm	4 cm	25 cm	6639
43	MacKeighan Lake F. - Canso Group	no	no cobbles	2+ m	0 cm	0 cm	25 cm	6640
44	Chisholm Brook Suite	weak	mafic volcanic	2 m	8 cm	20 cm	0 cm	6641
45	Windsor Group	no	sandstone	< 2 m	2 cm	0 cm	30 cm	6642
46	Uist F. - Windsor Group	no	granite	2 m	5 cm	3 cm	45 cm	6643
47	East Bay Hills Group	no	volcanics,	< 2 m	4 cm	6 cm	40 cm	6644
48	Irish Cove Pluton	no	granite	2 m	3 cm	4 cm	30 cm	6645
49	Irish Cove Pluton	no	granite	2 m	3 cm	4 cm	30 cm	6646
50	Canso Group	no	no cobbles	2 m	6 cm	0 cm	24 cm	6647
51	Silver Mine F. - Riversdale Group	no	sandstone, granite	2 m	0 cm	0 cm	40 cm ?	6648
52	Irish Cove Pluton	weak	granite, volcanics	2 m	1 cm	0 cm	30 cm	6649
53	East Bay Hills Group	no	volcanics	< 1 m	3 cm	5 cm	0 cm	6650
54	East Bay Hills Group	no	granite, volcanics (bleached)	< 1 m	5 cm	0 cm	0 cm	6651
55	Silver Mine F. - Riversdale Group	no	sandstone, mafic volcanic	0.2m	2 cm	4 cm	22 cm	6652
56	Bengal Road Formation	no	red sedimentary,volcanic, quartzite	3 m	4 cm	3 cm	4 cm	6653
57	Stirling Group	no	quartz- rich rock, mafic volcanics	10+ m	3 cm	0 cm	30 cm	6654
58	Chisholm Brook Suite	no	felsic and mafic volcanics	3 m	3 cm	0 cm	30 cm	6655
59	Windsor Group (Chisholm Brook Suite)	no	granite	2 m	1 cm	0 cm	10 cm	6656
60	Chisholm Brook Suite	no	Salmon R. porphyry, quartzite, granite	2 m	2 cm	0 cm	5 cm	6657
61	East Bay Hills Group	no	green volcanics	< 1 m	10 cm	0 cm	20 cm	6658
62	Horton	no	volcanic	3+ m	5 cm	0 cm	30 cm	6659
63	Silver Mine F. - Riversdale Group	no	no cobbles or pebbles	1+ m	na	na	na	6673
64	Loch Lomond F. - Windsor Group	no	granite, red sandstone, Mn clumps	6.0 m	1 cm	0 cm	30 cm	6701
65	Enon F. - Windsor Group	strong	granite, smaller limestone	2.0 m	0 cm	0 cm	20 cm	002

APPENDIX 2-A: ICP-ES DATA

SAMPLE	Al %	Bi ppm	Ca %	Cu ppm	Hg ppb	K %	Li ppm	Mg %	Mo ppm	Nb ppm	Ni ppm	Mn ppm	Pb ppm	Sr ppm	V ppm	Y ppm	Zn ppm	Zr ppm
96 MPB 6601	2.50	7	0.20	11	71	0.14	31	0.64	5	5	17	526	28	23	59	6	87	6
96 MPB 6602	2.98	12	0.25	18	92	0.10	25	0.83	4	8	16	518	17	24	45	10	66	4
96 MPB 6603	2.47	8	0.53	26	-5	0.29	37	1.24	4	12	30	994	22	32	43	16	123	13
96 MPB 6604	3.56	13	0.36	17	84	0.06	24	1.02	5	9	18	688	14	35	60	10	100	8
96 MPB 6605	2.15	-5	0.14	28	66	0.11	21	0.64	3	6	21	537	17	21	35	7	56	3
96 MPB 6606	2.75	10	0.40	20	47	0.12	22	0.97	4	8	16	489	19	40	46	8	82	5
96 MPB 6607	1.70	7	0.25	18	9	0.10	19	0.64	3	5	21	497	32	31	35	6	91	5
96 MPB 6608	2.15	8	0.03	12	78	0.11	29	0.48	4	4	28	336	33	12	40	5	72	3
96 MPB 6609	2.02	9	0.17	37	12	0.28	27	0.87	4	11	26	2697	500	804	40	15	331	5
96 MPB 6610	2.09	7	0.18	19	28	0.12	19	0.76	3	6	18	1089	19	23	29	8	90	4
96 MPB 6611	1.22	-5	0.31	12	-5	0.05	9	0.58	2	9	8	536	7	31	32	10	42	6
96 MPB 6612	2.30	-5	0.04	42	24	0.15	34	0.83	4	3	33	666	17	9	25	5	55	4
96 MPB 6613	1.40	6	0.13	14	14	0.13	32	0.62	2	5	27	670	10	12	20	6	49	5
96 MPB 6614	2.11	9	0.14	39	24	0.10	20	0.85	3	5	16	1298	11	19	31	8	59	3
96 MPB 6615	3.22	9	0.50	63	47	0.05	24	2.14	4	9	21	1787	11	44	90	12	73	5
96 MPB 6616	3.14	11	0.56	66	39	0.05	22	2.00	4	9	17	1726	11	48	84	12	74	5
96 MPB 6617	1.96	8	0.24	16	16	0.08	22	1.01	3	5	22	563	11	33	47	6	44	3
96 MPB 6618	2.34	7	0.35	52	26	0.06	15	1.37	3	5	19	826	11	32	62	7	113	4
96 MPB 6619	2.12	8	0.16	27	15	0.09	17	0.95	3	6	20	820	12	23	37	8	63	3
96 MPB 6620	1.76	-5	0.21	27	13	0.06	15	0.84	2	6	18	467	8	23	36	7	40	4
96 MPB 6621	2.65	6	0.22	16	31	0.04	13	0.70	4	6	18	498	8	20	40	7	45	3
96 MPB 6623	1.99	8	0.56	17	21	0.10	16	0.71	2	6	13	544	16	57	40	7	71	5
96 MPB 6624	2.42	9	0.40	15	47	0.13	18	0.72	3	10	14	756	16	32	42	11	69	5
96 MPB 6625	1.71	6	0.03	37	48	0.08	28	0.51	4	5	25	776	16	6	20	7	55	2
96 MPB 6626	1.89	-5	0.02	18	31	0.09	36	0.71	3	3	34	564	9	6	23	5	54	3
96 MPB 6627	2.06	-5	0.06	17	47	0.12	39	0.56	2	4	29	328	10	8	22	5	53	2
96 MPB 6628	1.94	7	0.18	23	30	0.05	19	0.87	2	5	20	509	8	19	37	6	44	2
96 MPB 6629	1.93	6	0.30	31	33	0.04	12	0.71	3	5	14	470	6	30	39	6	32	3
96 MPB 6630	2.17	8	0.47	33	14	0.10	25	1.50	4	7	29	1008	13	35	50	8	82	10
96 MPB 6631	2.43	8	0.10	27	11	0.08	28	1.03	3	4	29	617	15	18	39	5	65	3
96 MPB 6632	1.75	9	0.24	49	7	0.06	17	0.99	6	5	23	1067	13	18	38	8	69	4
96 MPB 6633	2.31	7	0.11	15	41	0.10	53	0.81	3	5	27	331	17	12	32	7	103	2
96 MPB 6634	1.99	7	0.17	122	27	0.07	23	1.01	4	6	24	1186	20	16	35	8	79	4
96 MPB 6635	2.15	9	0.03	27	12	0.22	35	0.85	4	4	35	961	26	10	29	6	88	6
96 MPB 6636	1.72	-5	0.02	7	8	0.23	23	0.81	2	4	23	276	8	6	45	5	36	6

APPENDIX 2-A: ICP-ES DATA

SAMPLE	Al %	Bi ppm	Ca %	Cu ppm	Hg ppb	K %	Li ppm	Mg %	Mo ppm	Nb ppm	Ni ppm	Mn ppm	Pb ppm	Sr ppm	V ppm	Y ppm	Zn ppm	Zr ppm
96 MPB 6637	2.11	13	0.07	12	6	0.23	37	1.40	4	4	24	331	15	6	45	6	72	5
96 MPB 6638	2.21	6	0.46	31	6	0.28	28	1.16	3	14	26	1207	19	32	43	18	117	13
96 MPB 6639	2.38	6	0.11	9	56	0.07	13	0.35	2	6	6	274	11	15	18	6	55	5
96 MPB 6640	2.44	7	0.08	30	16	0.27	40	1.03	4	4	31	708	19	12	32	6	113	5
96 MPB 6641	1.93	8	0.26	28	8	0.16	18	0.90	3	11	19	1168	14	25	36	14	93	9
96 MPB 6642	4.56	6	0.03	571	234	0.26	46	1.19	4	5	14	621	23	52	45	6	268	10
96 MPB 6643	1.52	10	0.20	14	31	0.11	14	0.57	3	8	12	757	26	22	27	10	99	3
96 MPB 6644	2.76	9	0.12	19	41	0.18	35	0.88	4	4	23	549	45	17	34	5	197	3
96 MPB 6645	3.38	6	0.27	12	72	0.08	20	0.67	4	7	15	456	18	30	48	6	75	3
96 MPB 6646	3.31	-5	0.28	14	74	0.08	21	0.71	4	6	15	468	19	32	48	6	77	3
96 MPB 6647	1.75	-5	0.22	11	34	0.13	23	0.67	3	5	17	352	20	26	31	6	87	2
96 MPB 6648	2.88	8	0.11	11	72	0.09	35	0.44	4	5	21	369	39	15	37	6	115	2
96 MPB 6649	2.74	10	0.34	25	10	0.15	24	1.02	4	6	19	617	27	41	51	7	87	5
96 MPB 6650	5.43	6	0.21	19	104	0.07	26	0.51	5	8	10	374	12	31	55	7	58	5
96 MPB 6651	1.16	-5	0.14	2	10	0.04	2	0.10	1	2	-1	88	7	16	35	3	11	4
96 MPB 6652	1.94	-5	0.07	26	21	0.18	31	0.39	4	4	26	308	29	14	36	6	59	4
96 MPB 6653	2.20	8	0.21	43	26	0.06	19	1.06	3	6	21	895	19	18	43	7	72	3
96 MPB 6654	2.21	9	0.11	53	11	0.08	19	1.22	4	6	18	1189	7	9	44	9	55	5
96 MPB 6655	2.54	8	0.05	31	23	0.20	33	0.84	3	5	30	569	15	13	32	6	97	4
96 MPB 6656	3.19	12	0.19	13	92	0.22	38	1.26	6	18	23	6285	25	24	100	22	174	3
96 MPB 6657	3.28	7	0.08	50	197	0.17	34	0.73	6	36	25	4542	132	9	46	42	657	4
96 MPB 6658	2.44	10	0.43	15	68	0.10	20	0.70	3	8	13	390	12	49	41	7	49	6
96 MPB 6659	2.28	7	0.15	23	9	0.20	34	1.04	4	8	24	448	20	17	41	11	66	8
96 MPB 6673	2.25	6	0.19	22	15	0.26	59	0.21	4	8	36	429	7	27	42	10	38	3
96 MPB 6701	1.58	10	0.17	38	14	0.27	25	0.79	3	13	37	4204	403	1088	37	16	386	7
FIELD DUPLICATES																		
96 MPB 6615	3.22	9	0.50	63	47	0.05	24	2.14	4	9	21	1787	11	44	90	12	73	5
96 MPB 6616	3.14	11	0.56	66	39	0.05	22	2.00	4	9	17	1726	11	48	84	12	74	5
96 MPB 6645	3.38	6	0.27	12	72	0.08	20	0.67	4	7	15	456	18	30	48	6	75	3
96 MPB 6646	3.31	-5	0.28	14	74	0.08	21	0.71	4	6	15	468	19	32	48	6	77	3

APPENDIX 2-A: ICP-ES DATA

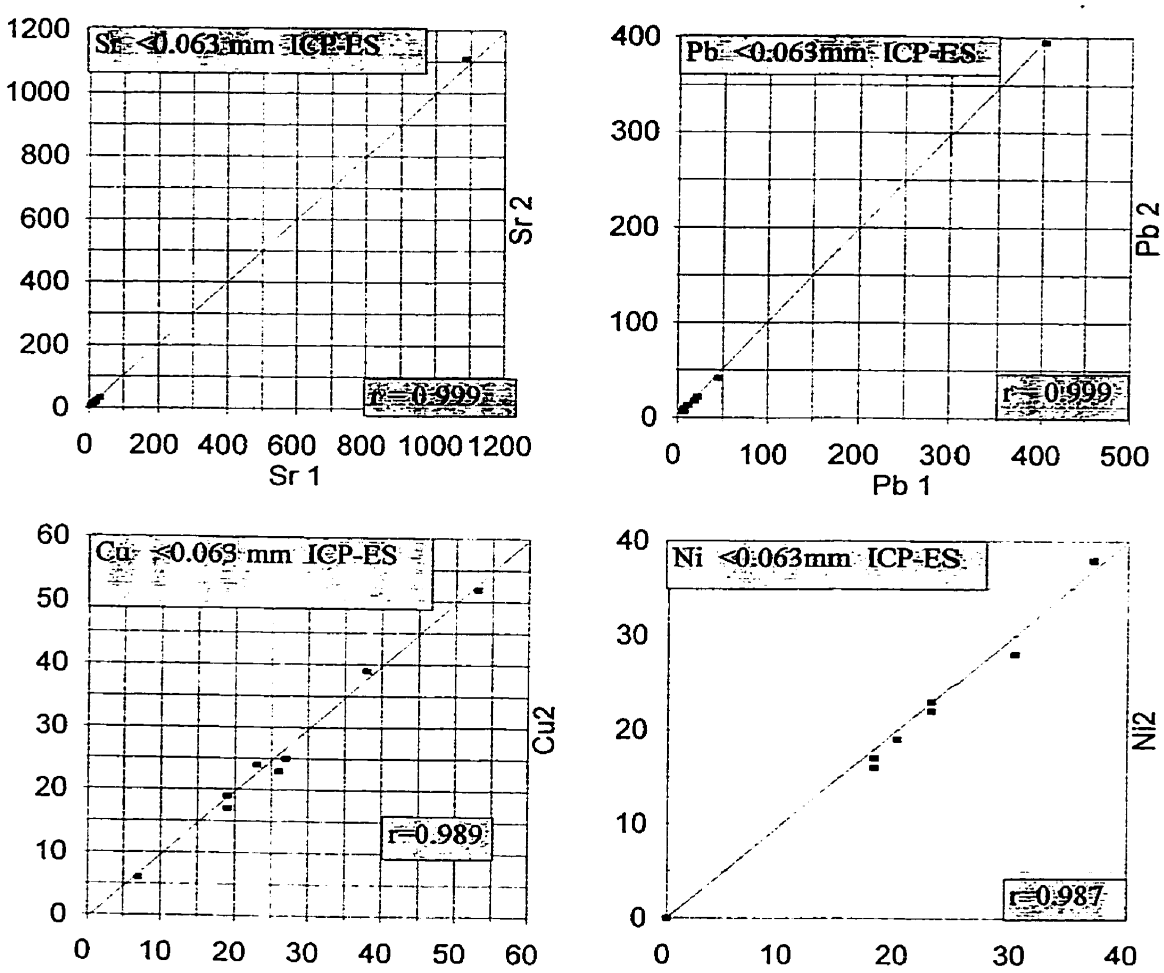
STANDARDS	Al	Bi	Ca	Cu	Hg	K	Li	Mg	Mo	Nb	Ni	Mn	Pb	Sr	V	Y	Zn	Zr
	%	ppm	%	ppm	ppb	%	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
96 MPB 6604A	0.82	6	0.43	26	32	0.05	7	0.42	2	7	15	211	5	19	26	8	27	8
96 MPB 6611A	0.83	8	0.43	27	25	0.05	8	0.42	2	7	15	213	6	19	26	8	26	8
96 MPB 6619A	0.84	7	0.43	28	29	0.05	8	0.43	1	7	15	217	5	19	26	8	26	8
96 MPB 6629A	0.81	-5	0.44	26	25	0.05	8	0.41	2	7	14	207	5	19	26	8	26	7
96 MPB 6634A	0.82	6	0.43	26	35	0.06	7	0.42	1	7	15	213	6	19	25	8	26	7
96 MPB 6639A	0.80	-5	0.42	26	22	0.05	8	0.40	1	7	14	207	6	19	25	8	26	7
96 MPB 6653A	0.81	6	0.42	26	35	0.05	8	0.41	1	6	14	213	6	19	25	8	26	7

DUPLICATES	Al	Bi	Ca	Cu	Hg	K	Li	Mg	Mo	Nb	Ni	Mn	Pb	Sr	V	Y	Zn	Zr
	%	ppm	%	ppm	ppb	%	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
96 MPB 6603	2.47	8	0.53	26	-5	0.29	37	1.24	4	12	30	994	22	32	43	16	123	13
96 PL 0270	2.27	-5	0.48	23	12	0.27	34	1.13	3	12	28	917	22	32	39	15	112	13
96 MPB 6610	2.09	7	0.18	19	28	0.12	19	0.76	3	6	18	1089	19	23	29	8	90	4
96 PL 0271	1.78	8	0.15	19	26	0.11	17	0.64	2	6	16	952	18	19	25	7	82	4
96 MPB 6619	2.12	8	0.16	27	15	0.09	17	0.95	3	6	20	820	12	23	37	8	63	3
96 PL 0272	1.99	8	0.16	25	8	0.09	16	0.88	3	6	19	761	13	23	34	7	58	3
96 MPB 6628	1.94	7	0.18	23	30	0.05	19	0.87	2	5	20	509	8	19	37	6	44	2
96 PL 0273	1.84	8	0.17	24	31	0.06	18	0.82	6	4	19	489	10	18	35	6	45	2
96 MPB 6636	1.72	-5	0.02	7	8	0.23	23	0.81	2	4	23	276	8	6	45	5	36	6
96 PL 0274	1.66	-5	0.02	6	6	0.22	23	0.80	3	3	23	276	8	6	44	5	33	5
96 MPB 6644	2.76	9	0.12	19	41	0.18	35	0.88	4	4	23	549	45	17	34	5	197	3
96 PL 0275	2.57	6	0.12	17	38	0.17	32	0.81	3	4	22	506	42	16	31	5	182	3
96 MPB 6654	2.21	9	0.11	53	11	0.08	19	1.22	4	6	18	1189	7	9	44	9	55	5
96 PL 0276	2.16	8	0.10	52	19	0.08	19	1.19	3	7	17	1160	7	9	43	9	55	5
96 MPB 6701	1.58	10	0.17	38	14	0.27	25	0.79	3	13	37	4204	403	1088	37	16	386	7
96 PL 0277	1.82	-5	0.18	39	16	0.29	25	0.85	4	14	38	4245	395	1109	40	16	383	7

APPENDIX 2-B

ICP-ES

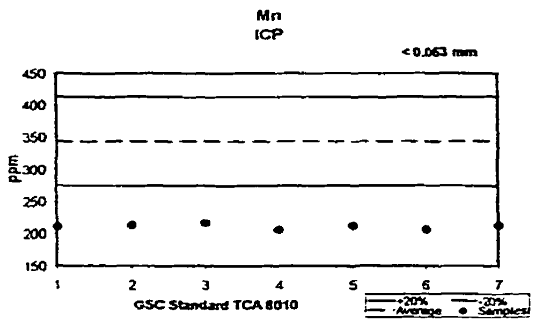
PRECISION GRAPHS

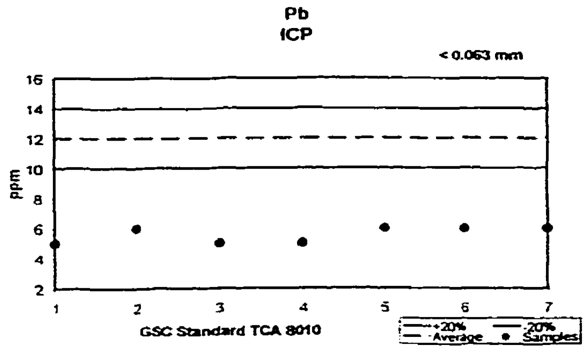


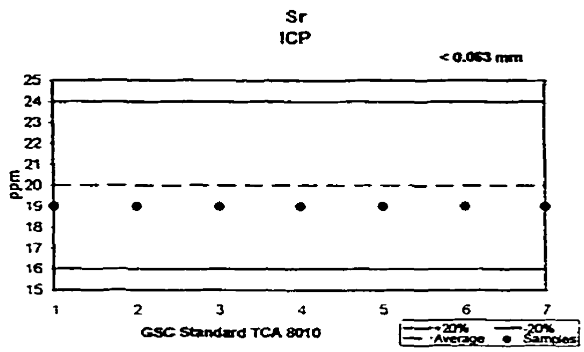
APPENDIX 2-C

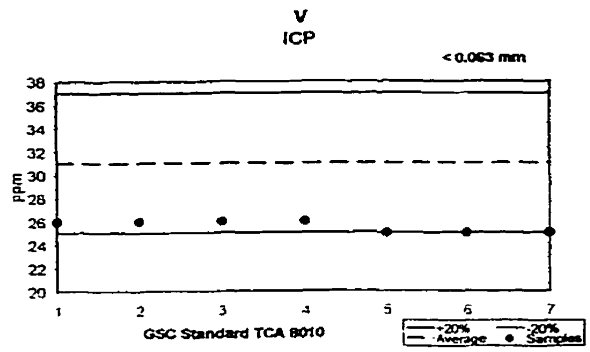
ICP-ES

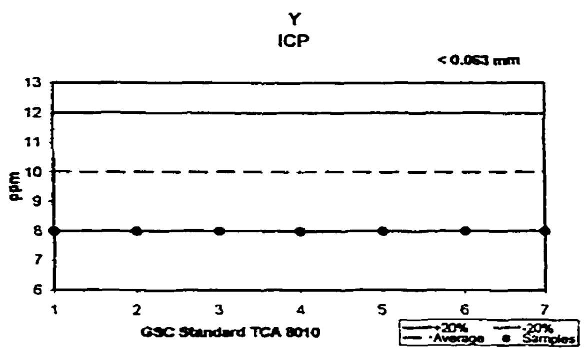
ACCURACY GRAPHS









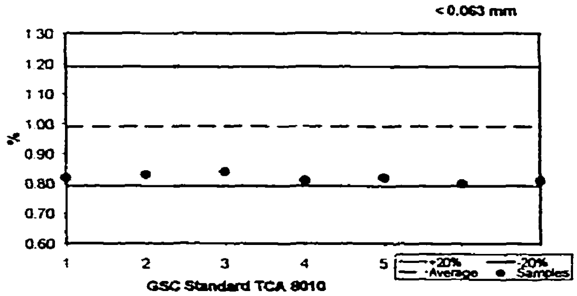


APPENDIX 2-C

ICP-ES

ACCURACY GRAPHS

Al
ICP



Bi
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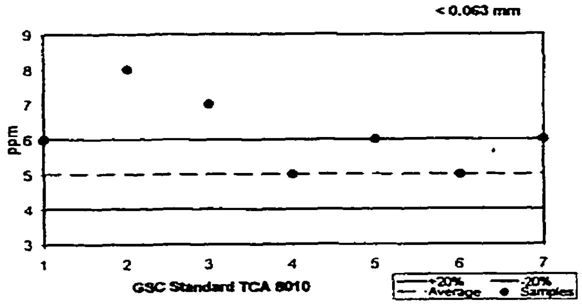

Ca
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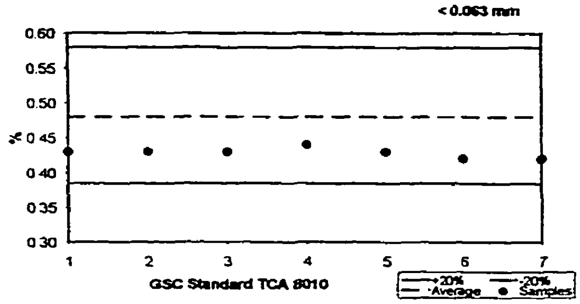

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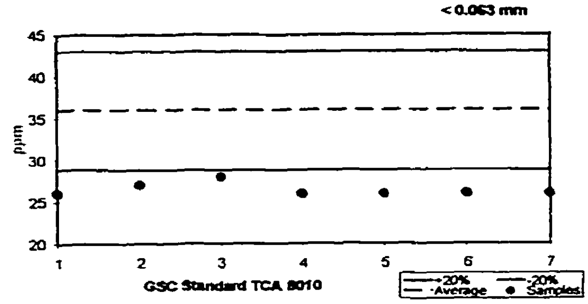

K
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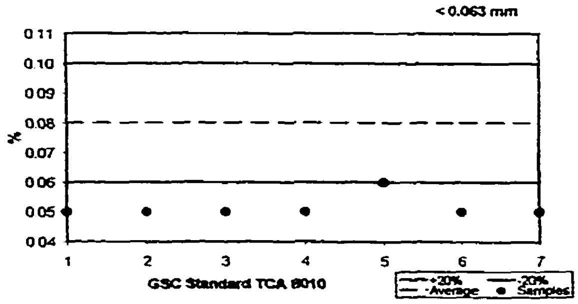
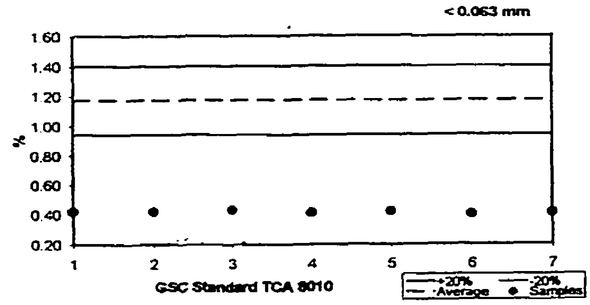


Mg
ICP



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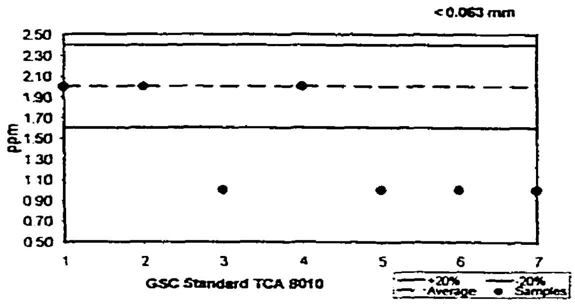

Ni
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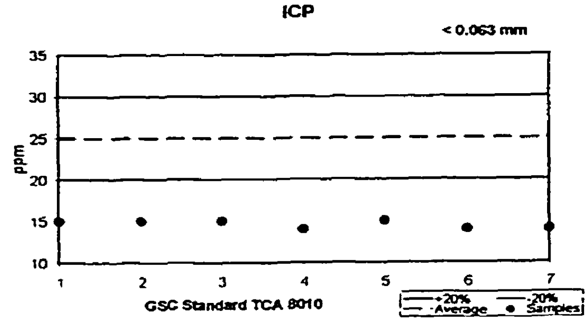


APPENDIX 3-A: INAA DATA

SAMPLE	As	Au	Ba	Br	Ce	Co	Cr	Cs	Eu	Fe	Hf	La	Lu	Na	Nd	Rb	Sb	Sc	Sm	Ta
Units	ppm	ppb	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm
Detect. Limit	0.5	2	50	0.5	3	1	5	1	0.2	0.01	1	0.5	0.05	0.01	5	15	0.1	0.1	0.1	0.5
96 MPB 6601	6.1	13	630	35	70	12	66	8	1.3	4.37	15	34	0.72	1.32	22	120	0.8	12	4.5	1.7
96 MPB 6602	6.2	16	490	90	120	11	48	8	1.3	3.78	11	34	0.56	1.30	18	110	2.1	12	5.0	1.7
96 MPB 6603	9.0	14	920	1.6	77	14	69	11	1.8	4.00	11	47	0.72	0.78	29	110	1.1	13	7.0	-0.5
96 MPB 6604	6.7	15	550	130	76	15	77	4	1.9	5.32	13	40	0.75	1.60	21	79	1.0	17	6.4	-0.5
96 MPB 6605	6.7	13	360	49	69	10	64	4	1.4	3.48	15	36	0.65	1.00	21	93	0.7	11	5.1	-0.5
96 MPB 6606	3.0	8	530	65	56	8	40	5	1.0	3.11	9	30	0.52	1.36	13	79	0.6	11	4.0	-0.5
96 MPB 6607	5.9	8	520	9.7	73	10	59	5	1.3	3.18	13	37	0.58	0.86	22	79	0.8	11	5.1	0.9
96 MPB 6608	9.4	8	460	54	62	10	73	6	1.2	4.97	10	38	0.54	0.39	22	110	0.9	12	4.8	1.7
96 MPB 6609	9.7	12	860	2.4	91	12	55	9	1.9	3.78	14	48	0.68	0.49	28	86	1.0	12	7.0	1.5
96 MPB 6610	4.0	13	680	38	86	12	50	4	1.5	3.45	12	44	0.66	1.96	24	100	1.0	11	5.6	-0.5
96 MPB 6611	1.4	7	490	8.3	74	7	39	2	1.4	2.54	12	40	0.70	2.32	24	68	0.5	10	5.5	1.3
96 MPB 6612	14.0	4	550	5.1	79	14	86	6	1.3	4.22	12	45	0.67	0.61	27	130	1.4	16	5.9	1.3
96 MPB 6613	4.9	-2	570	1	70	12	66	4	1.3	2.81	12	39	0.64	0.92	22	76	0.5	11	5.2	1.1
96 MPB 6614	4.2	-2	460	26	71	10	42	3	1.3	3.29	11	35	0.55	1.41	21	85	0.6	11	5.1	-0.5
96 MPB 6615	7.9	35	500	62	110	20	58	4	1.5	4.70	10	47	0.61	1.20	26	33	0.9	18	6.0	1.2
96 MPB 6616	7.4	20	490	57	94	19	49	3	1.4	4.50	11	48	0.61	1.21	26	60	0.9	18	6.2	1.0
96 MPB 6617	8.2	13	340	30	60	14	47	4	1.2	3.69	8	35	0.48	0.82	20	72	0.8	12	4.3	1.3
96 MPB 6618	3.5	11	380	40	48	13	67	-1	0.9	3.70	8	26	0.46	1.67	14	38	0.6	14	3.8	-0.5
96 MPB 6619	4.4	6	410	24	68	10	60	3	1.4	3.18	11	37	0.62	1.45	23	60	0.6	11	5.1	-0.5
96 MPB 6620	4.4	6	300	27	60	10	62	2	1.3	2.92	15	33	0.60	1.30	21	62	0.7	11	4.9	1.5
96 MPB 6621	4.4	18	260	94	61	9	61	2	1.2	3.32	12	33	0.50	1.30	23	52	0.9	10	4.7	-0.5
96 MPB 6623	3.3	13	560	39	54	7	37	4	1.2	3.11	9	32	0.45	1.61	15	70	0.8	12	4.1	-0.5
96 MPB 6624	2.8	9	620	48	66	10	36	9	1.1	2.97	9	34	0.62	1.44	16	95	0.9	10	4.5	1.3
96 MPB 6625	22.0	10	450	36	79	17	68	3	1.6	3.82	19	40	0.74	0.74	29	69	0.9	9.7	6.2	1.4
96 MPB 6626	12.0	6	670	22	87	15	87	4	1.7	4.24	11	51	0.67	0.61	29	120	0.8	13	6.7	1.9
96 MPB 6627	6.2	8	540	19	68	11	76	5	1.3	2.89	18	40	0.73	0.74	28	91	0.7	9.8	5.4	1.9
96 MPB 6628	8.3	-2	310	58	62	12	55	3	1.3	3.23	12	34	0.58	1.04	19	39	0.9	11	4.7	1.2
96 MPB 6629	4.0	8	290	49	61	11	54	2	1.2	2.87	14	29	0.53	1.41	17	49	0.5	10	4.1	1.0
96 MPB 6630	4.5	-2	520	10	72	11	56	2	1.5	3.31	9	41	0.56	1.33	24	66	0.5	13	5.7	1.4
96 MPB 6631	6.8	10	440	65	70	13	59	3	1.2	3.57	11	33	0.52	1.16	18	68	0.7	11	4.4	0.9
96 MPB 6632	11.0	-2	370	28	83	18	58	2	1.5	3.58	13	34	0.65	1.25	20	52	0.8	12	5.3	-0.5
96 MPB 6633	5.3	8	480	8.6	79	17	72	3	1.5	3.22	13	36	0.67	1.04	26	96	0.7	12	5.6	1.4
96 MPB 6634	18.0	32	370	30	100	21	54	2	1.4	3.45	12	37	0.57	0.96	24	63	0.7	11	5.5	1.0

APPENDIX 3-A: INAA DATA

SAMPLE	As	Au	Ba	Br	Ce	Co	Cr	Cs	Eu	Fe	Hf	La	Lu	Na	Nd	Rb	Sb	Sc	Sm	Ta
Units	ppm	ppb	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm
96 MPB 6635	11.0	12	590	4.3	80	19	86	6	1.3	4.49	9	46	0.61	0.77	26	130	0.9	16	5.7	0.8
96 MPB 6636	8.1	5	340	4.6	72	13	55	7	1.5	4.01	8	45	0.70	0.82	29	110	0.8	16	6.2	1.5
96 MPB 6637	9.9	3	360	9.3	69	13	62	13	1.3	4.44	8	44	0.61	1.11	22	120	1.1	15	4.9	-0.5
96 MPB 6638	5.7	13	810	-0.5	89	15	65	7	1.9	4.34	9	55	0.73	1.35	34	110	0.8	15	7.6	-0.5
96 MPB 6639	1.5	7	410	87	55	4	33	3	1.1	1.90	11	33	0.55	1.85	17	58	0.6	6.9	4.0	1.0
96 MPB 6640	9.5	13	530	4.7	84	15	81	5	1.4	4.15	14	46	0.70	0.56	27	110	0.9	14	5.8	1.4
96 MPB 6641	4.5	13	690	-0.5	84	10	57	6	1.8	3.61	10	52	0.70	1.70	29	93	1.0	13	7.0	1.2
96 MPB 6642	9.5	13	5300	63	84	16	65	11	1.1	3.47	11	50	0.67	0.75	25	89	1.0	12	4.5	0.9
96 MPB 6643	3.9	17	470	10	74	5	31	4	1.2	2.40	11	34	0.61	1.82	19	74	0.8	7.9	4.5	0.8
96 MPB 6644	6.7	8	510	28	64	10	68	5	1.1	3.12	15	37	0.61	0.74	21	100	0.7	9.7	4.7	1.2
96 MPB 6645	4.3	11	340	130	50	9	42	4	1.0	3.55	9	28	0.53	1.47	17	76	0.7	11	3.6	0.9
96 MPB 6646	2.9	-2	480	110	47	9	46	3	1.0	3.36	8	27	0.48	1.41	14	62	0.6	10	3.5	1.1
96 MPB 6647	3.7	10	480	13	61	8	59	4	1.2	2.76	17	33	0.68	1.07	21	96	0.6	10	4.5	1.1
96 MPB 6648	6.4	10	540	80	67	11	61	6	1.2	3.62	11	34	0.58	0.87	19	87	0.5	10	4.7	-0.5
96 MPB 6649	4.7	13	600	20	65	11	51	5	1.3	3.80	11	34	0.62	1.39	17	95	0.8	14	4.4	-0.5
96 MPB 6650	3.8	13	370	260	40	10	25	7	0.9	5.34	4	23	0.34	1.01	16	78	0.6	12	3.4	-0.5
96 MPB 6651	2.3	13	550	9.5	42	2	34	5	1.0	1.81	16	25	0.73	1.74	16	72	0.8	8.9	3.1	1.6
96 MPB 6652	15.0	14	520	6.2	83	12	99	14	1.3	4.64	11	49	0.64	0.48	26	170	1.6	17	5.5	1.3
96 MPB 6653	7.2	8	260	64	64	15	73	2	1.3	3.82	12	30	0.59	1.29	20	52	0.6	14	4.9	-0.5
96 MPB 6654	7.3	21	500	21	98	16	53	5	1.5	4.25	11	38	0.90	1.21	25	78	1.0	17	6.3	1.0
96 MPB 6655	11.0	18	590	13	82	13	88	9	1.5	4.29	13	47	0.70	0.64	31	140	1.0	15	6.2	1.2
96 MPB 6656	9.7	10	850	25	320	17	110	20	3.3	10.30	11	89	1.02	1.29	50	150	1.2	38	13.0	-0.5
96 MPB 6657	16.0	10	720	57	310	14	83	14	4.3	5.69	13	91	1.29	0.69	63	96	1.6	16	17.0	1.4
96 MPB 6658	4.6	11	580	110	65	12	52	9	1.3	5.41	9	33	0.65	1.49	19	110	1.0	14	4.9	1.5
96 MPB 6659	8.9	12	560	3.8	80	13	81	5	1.6	4.14	12	48	0.68	0.96	32	98	0.8	14	6.9	1.5
96 MPB 6673	8.9	19	730	2.5	110	23	140	35	1.8	5.19	3	65	0.60	0.28	38	240	2.0	24	7.7	-0.5
96 MPB 6701	11.0	14	1100	-0.5	110	12	64	12	2.2	4.37	14	56	0.76	0.49	36	100	1.0	15	9.0	1.0
FIELD																				
Duplicates																				
96 MPB 6615	7.9	35	500	62	110	20	58	4	1.5	4.70	10	47	0.61	1.20	26	33	0.9	18	6.0	1.2
96 MPB 6616	7.4	20	490	57	94	19	49	3	1.4	4.50	11	48	0.61	1.21	26	60	0.9	18	6.2	1.0
96 MPB 6645	4.3	11	340	130	50	9	42	4	1.0	3.55	9	28	0.53	1.47	17	76	0.7	11	3.6	0.9
96 MPB 6646	2.9	-2	480	110	47	9	46	3	1.0	3.36	8	27	0.48	1.41	14	62	0.6	10	3.5	1.1

APPENDIX 3-A: INAA DATA

TCA8010	As	Au	Ba	Br	Ce	Co	Cr	Cs	Eu	Fe	Hf	La	Lu	Na	Nd	Rb	Sb	Sc	Sm	Ta
Units	ppm	ppb	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm
Detection Limit	0,5	2	50	0,5	3	1	5	1	0,2	0.01	1	0,5	0,05	0,01	5	15	0,1	0,1	0,1	0,5
Standards																				
96 MPB 6604A	5,4	176	680	2,5	45	8	62	1	1,0	2,30	8	25	0,29	2,28	20	60	2,5	9,5	3,5	-0,5
96 MPB 6611A	4,9	178	670	2	45	9	55	1	1,1	2,25	8	28	0,27	2,24	18	58	2,6	9,9	3,7	0,7
96 MPB 6619A	5,3	173	650	2,1	38	8	56	1	1,1	2,25	8	26	0,28	2,19	19	58	2,3	9,3	3,4	0,7
96 MPB 6629A	5,8	186	610	1,7	44	8	58	1	1,0	2,25	8	27	0,28	2,14	17	55	2,4	9,8	3,6	0,6
96 MPB 6634A	5,4	205	650	1,7	41	8	48	1	1,0	2,19	7	27	0,26	2,12	18	69	2,4	9,6	3,5	0,8
96 MPB 6653A	5,5	176	640	2,4	43	8	50	1	1,0	2,27	8	27	0,30	2,13	17	58	2,4	9,8	3,5	0,7
Duplicates																				
96 MPB 6607	5,9	8	520	9,7	73	10	59	5	1,3	3,18	13	37	0,58	0,86	22	79	0,8	11	5,1	0,9
96 PL 0278	6,6	14	510	9,5	78	11	58	5	1,5	3,39	13	40	0,65	0,91	23	72	0,8	12	5,4	-0,5
96 MPB 6611	1,4	7	490	8,3	74	7	39	2	1,4	2,54	12	40	0,70	2,32	24	68	0,5	10	5,5	1,3
96 PL 0279	1,5	9	480	7	69	6	36	1	1,3	2,38	11	36	0,67	2,16	21	56	0,5	9,4	5,3	-0,5
96 MPB 6620	4,4	6	300	27	60	10	62	2	1,3	2,92	15	33	0,60	1,30	21	62	0,7	11	4,9	1,5
96 PL 0280	4,0	9	370	26	58	9	65	2	1,3	2,77	14	31	0,61	1,18	22	64	0,5	11	4,7	0,6
96 MPB 6623	3,3	13	560	39	54	7	37	4	1,2	3,11	9	32	0,45	1,61	15	70	0,8	12	4,1	-0,5
96 PL 0281	3,7	9	640	41	59	9	38	4	1,3	3,18	9	33	0,52	1,64	16	84	0,7	12	4,5	1,4
96 MPB 6632	11,0	-2	370	28	83	18	58	2	1,5	3,58	13	34	0,65	1,25	20	52	0,8	12	5,3	-0,5
96 PL 0282	10,0	13	500	28	89	17	59	2	1,5	3,67	14	34	0,66	1,22	20	56	0,9	12	5,6	-0,5
96 MPB 6643	3,9	17	470	10	74	5	31	4	1,2	2,40	11	34	0,61	1,82	19	74	0,8	7,9	4,5	0,8
96 PL 0283	4,6	8	440	10	71	6	34	3	1,2	2,36	11	33	0,63	1,78	20	66	0,9	7,6	4,5	1,4
96 MPB 6647	3,7	10	480	13	61	8	59	4	1,2	2,76	17	33	0,68	1,07	21	96	0,6	10	4,5	1,1
96 PL 0284	4,1	8	410	13	59	8	58	4	1,1	2,64	16	32	0,63	1,02	20	80	0,7	9,4	4,2	1,5
96 MPB 6651	2,3	13	550	9,5	42	2	34	5	1,0	1,81	16	25	0,73	1,74	16	72	0,8	8,9	3,1	1,6

APPENDIX 3-A: INAA DATA

Tb	Th	U	Yb	Zn	SAMPLE
ppm	ppm	ppm	ppm	ppm	Units
0.5	0.2	0.5	0.2	50	Detect. Limit
-0.5	15	4.8	3.8	101	96 MPB 6601
1.1	18	3.9	3.5	95	96 MPB 6602
1.1	14	3.7	4.1	175	96 MPB 6603
-0.5	13	2.9	4.2	168	96 MPB 6604
0.9	13	3.7	3.7	-50	96 MPB 6605
-0.5	14	3.4	2.9	133	96 MPB 6606
-0.5	12	3.9	3.3	119	96 MPB 6607
1.1	13	4.3	3.1	79	96 MPB 6608
1.1	12	4.6	4.1	364	96 MPB 6609
-0.5	16	3.9	4.3	76	96 MPB 6610
-0.5	9.7	3.2	4.0	77	96 MPB 6611
0.9	14	5.0	3.9	87	96 MPB 6612
0.9	11	3.3	3.9	86	96 MPB 6613
1.0	11	2.5	3.3	76	96 MPB 6614
-0.5	16	3.1	3.7	110	96 MPB 6615
-0.5	16	2.6	3.7	-50	96 MPB 6616
-0.5	9.7	2.4	3.0	-50	96 MPB 6617
-0.5	7.8	1.7	2.8	147	96 MPB 6618
0.9	11	3.4	3.7	94	96 MPB 6619
0.7	9.2	2.7	3.4	-50	96 MPB 6620
0.8	9.4	2.7	3.2	-50	96 MPB 6621
-0.5	11	3.4	2.8	76	96 MPB 6623
-0.5	15	3.6	3.6	74	96 MPB 6624
1.0	13	3.6	4.5	72	96 MPB 6625
-0.5	13	3.3	4.2	74	96 MPB 6626
0.9	13	3.7	4.4	72	96 MPB 6627
1.0	9	2.3	3.5	64	96 MPB 6628
0.7	8.1	2.6	3.0	63	96 MPB 6629
0.9	12	3.2	3.4	84	96 MPB 6630
1.2	11	3.5	3.2	-50	96 MPB 6631
0.9	9.7	2.4	4.0	84	96 MPB 6632
1.0	12	4.1	3.9	103	96 MPB 6633
1.0	11	2.9	3.4	59	96 MPB 6634

APPENDIX 3-A: INAA DATA

Tb	Th	U	Yb	Zn	SAMPLE
ppm	ppm	ppm	ppm	ppm	Units
1.0	13	3.3	3.7	110	96 MPB 6635
0.9	12	2.6	4.0	58	96 MPB 6636
-0.5	12	2.7	3.7	100	96 MPB 6637
1.2	13	3.5	4.6	166	96 MPB 6638
-0.5	8.9	2.6	3.2	83	96 MPB 6639
0.9	14	4.4	4.4	133	96 MPB 6640
1.0	13	3.1	4.2	101	96 MPB 6641
-0.5	15	4.9	3.8	326	96 MPB 6642
0.6	11	4.0	3.4	131	96 MPB 6643
0.8	13	4.5	3.6	252	96 MPB 6644
-0.5	13	3.4	2.9	52	96 MPB 6645
-0.5	13	4.1	2.9	89	96 MPB 6646
-0.5	12	4.7	3.9	110	96 MPB 6647
0.9	11	3.3	3.3	187	96 MPB 6648
0.8	14	4.0	3.3	101	96 MPB 6649
-0.5	8.4	2.3	1.9	84	96 MPB 6650
-0.5	12	4.9	3.8	-50	96 MPB 6651
0.9	16	4.8	3.9	88	96 MPB 6652
1.0	8.7	3.4	3.8	91	96 MPB 6653
1.4	11	2.2	5.8	105	96 MPB 6654
0.7	15	3.8	4.4	128	96 MPB 6655
2.2	21	3.5	6.1	276	96 MPB 6656
3.1	22	10.0	8.0	1030	96 MPB 6657
-0.5	12	3.7	3.6	69	96 MPB 6658
1.0	14	4.5	4.2	110	96 MPB 6659
1.0	17	4.5	3.5	111	96 MPB 6673
1.2	13	4.4	4.8	492	96 MPB 6701
					FIELD
					Duplicates
-0.5	16	3.1	3.7	110	96 MPB 6615
-0.5	16	2.6	3.7	-50	96 MPB 6616
-0.5	13	3.4	2.9	52	96 MPB 6645
-0.5	13	4.1	2.9	89	96 MPB 6646

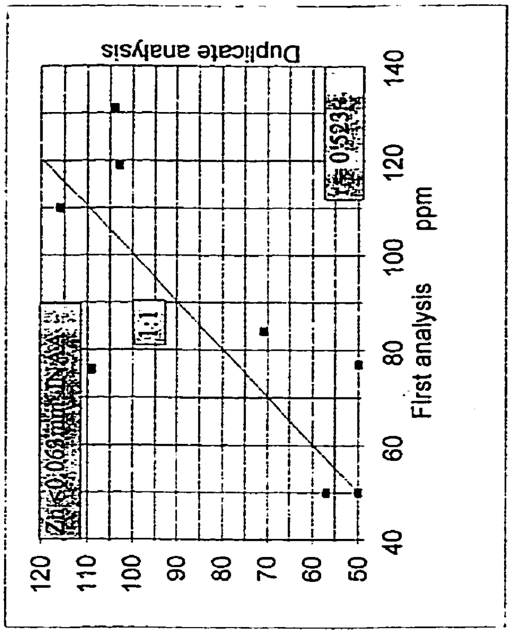
APPENDIX 3-A: INAA DATA

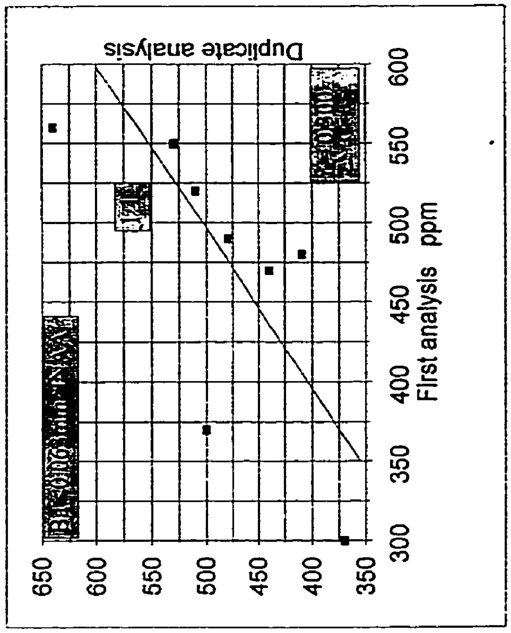
Tb	Th	U	Yb	Zn	TCA8010
ppm	ppm	ppm	ppm	ppm	Units
0.5	0.2	0.5	0.2	50	Detection Limit
					Standards
0.6	5.7	1.0	1.9	-50	96 MPB 6604A
0.6	5.8	1.3	1.7	56	96 MPB 6611A
0.5	5.4	0.9	1.8	-50	96 MPB 6619A
0.7	5.5	1.6	1.8	53	96 MPB 6629A
0.7	5.3	1.1	1.7	59	96 MPB 6634A
0.6	5.5	1.3	1.7	50	96 MPB 6653A
					Duplicates
-0.5	12	3.9	3.3	119	96 MPB 6607
0.8	12	3.7	3.7	103	96 PL 0278
-0.5	9.7	3.2	4.0	77	96 MPB 6611
0.8	8.9	2.7	4.0	-50	96 PL 0279
0.7	9.2	2.7	3.4	-50	96 MPB 6620
0.7	9	3.5	3.5	57	96 PL 0280
-0.5	11	3.4	2.8	76	96 MPB 6623
-0.5	12	3.8	3.3	109	96 PL 0281
0.9	9.7	2.4	4.0	84	96 MPB 6632
0.9	10	2.7	4.0	71	96 PL 0282
0.6	11	4.0	3.4	131	96 MPB 6643
-0.5	12	3.5	3.6	104	96 PL 0283
-0.5	12	4.7	3.9	110	96 MPB 6647
0.7	11	3.8	3.6	116	96 PL 0284
-0.5	12	4.9	3.8	-50	96 MPB 6651

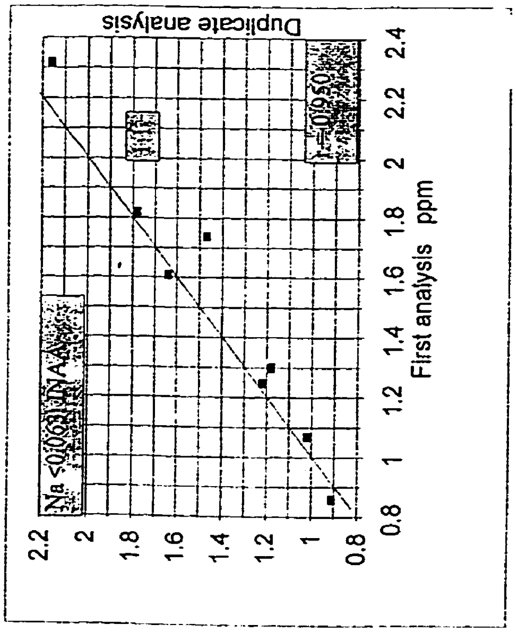
APPENDIX 3-B

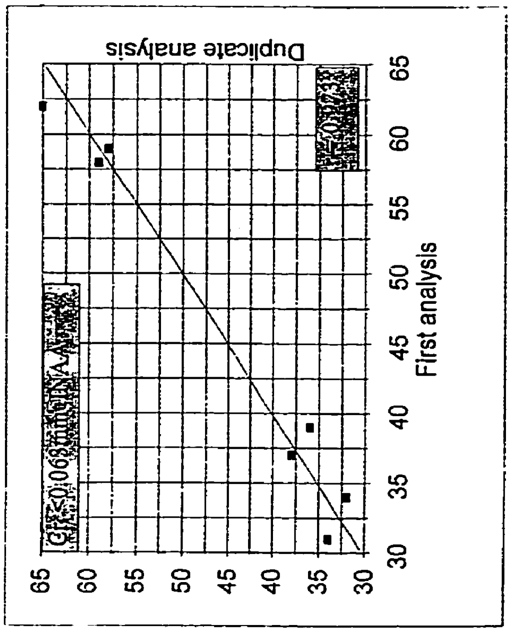
INAA

PRECISION GRAPHS





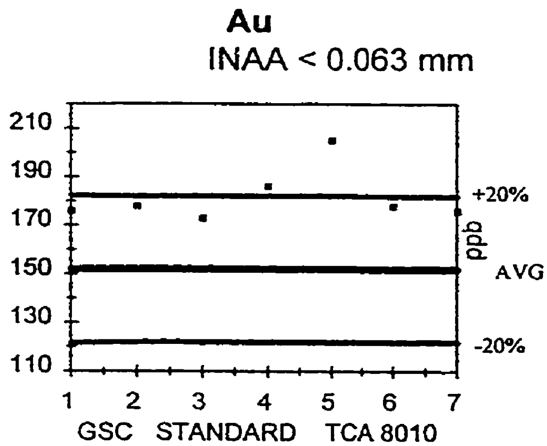


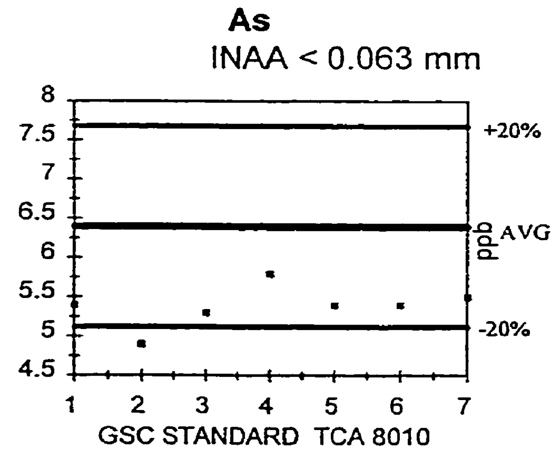


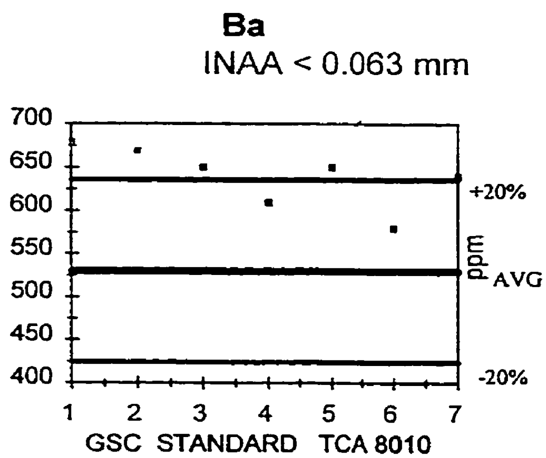
APPENDIX 3-C

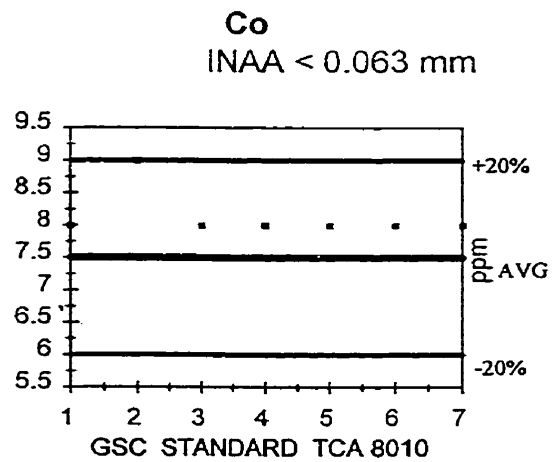
INAA

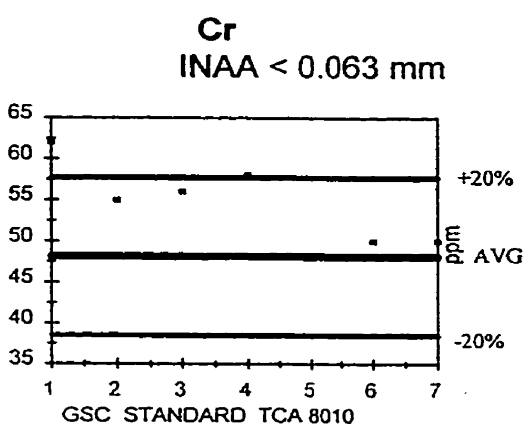
ACCURACY GRAPHS

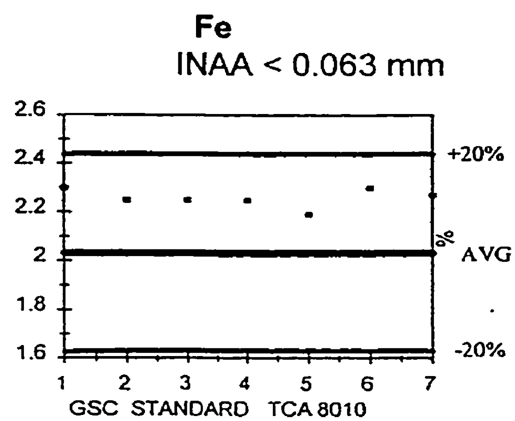












APPENDIX 4-A: PEBBLE COUNTS---PERCENTAGE DATA

Sample Number	n =	Mafic Volc	Felsic Volc	Mafic Por	Salmon River Rhy Por	Granite	Grand River Granite	Diorite	Gab bro	L'Ardoise Qtz SS	Vein Qtz	Red,Green Brown Seds	Grey, Black Seds	Lmst	Other	Total %
96-MPB-6601	153	0	13	1	0	81	0	3	0	0	0	2	0	0	0	100.0
96-MPB-6602	489	9	5	0	1	84	0	1	0	0	0	0	0	0	0	100.0
96-MPB-6603	157	25	50	0	0	7	0	1	0	2	3	10	0	2	1	100.0
96-MPB-6604	271	34	24	1	1	14	0	21	0	3	1	1	0	0	0	100.0
96-MPB-6605	277	12	18	0	0	18	0	8	0	23	0	21	0	0	0	100.0
96-MPB-6606	182	5	15	0	0	69	0	7	0	3	0	1	0	0	0	100.0
96-MPB-6607	189	10	14	0	0	17	0	2	0	5	1	50	0	0	0	100.0
96-MPB-6608	373	3	5	0	1	6	0	1	0	10	2	51	8	0	12	100.0
96-MPB-6609	107	11	21	0	2	38	0	6	0	3	0	6	14	0	0	100.0
96-MPB-6610	93	5	0	0	1	81	0	5	0	5	0	2	0	0	0	100.0
96-MPB-6611	28	14	4	0	0	79	0	0	0	4	0	0	0	0	0	100.0
96-MPB-6612	128	20	9	0	0	0	0	1	0	42	2	8	18	0	0	100.0
96-MPB-6613	170	6	3	0	0	4	0	0	0	36	0	28	22	0	0	100.0
96-MPB-6614	276	11	10	0	0	43	0	7	0	22	0	1	0	0	5	100.0
96-MPB-6615	465	29	3	0	0	68	0	0	0	0	0	0	0	0	0	100.0
96-MPB-6617	283	32	12	1	0	2	0	0	0	40	1	12	0	0	0	100.0
96-MPB-6618	174	31	21	2	0	34	0	1	0	7	0	0	0	0	5	100.6
96-MPB-6619	205	18	5	0	2	57	0	4	0	10	0	2	0	0	1	100.0
96-MPB-6620	196	23	7	0	0	33	0	1	0	24	1	5	0	0	8	100.0
96-MPB-6621	224	13	5	1	0	57	0	3	0	12	0	0	9	0	0	100.0
96-MPB-6623	156	31	57	1	0	10	0	0	0	0	0	0	0	0	0	100.0
96-MPB-6624	243	6	7	0	0	86	0	0	0	1	0	0	0	0	0	100.0
96-MPB-6625	301	0	1	0	0	2	0	0	0	71	0	19	6	0	0	100.0
96-MPB-6626	17	24	6	0	0	6	0	0	0	29	0	35	0	0	0	100.0
96-MPB-6627	146	31	14	0	0	1	0	0	0	40	0	14	0	0	0	100.0
96-MPB-6628	188	35	15	2	1	13	0	2	0	25	0	4	2	0	2	100.0
96-MPB-6629	216	36	24	3	0	20	0	1	0	12	0	3	0	0	0	100.0
96-MPB-6630	171	8	8	1	0	81	0	0	0	3	0	1	0	0	0	100.0

APPENDIX 4-A: PEBBLE COUNTS---PERCENTAGE DATA

Sample Number	n =	Mafic Volc	Felsic Volc	Mafic Por	Salmon River Rhy Por	Granite	Grand River Granite	Diorite	Gabbro	L'Ardoise Qtz SS	Vein Qtz	Red,Green Brown Seds	Grey, Black Seds	Lmst	Other	Total %
96-MPB-6631	352	32	20	0	0	23	0	0	0	22	3	1	0	0	0	100.0
96-MPB-6632	268	32	15	2	1	12	0	0	0	26	0	9	2	0	1	100.0
96-MPB-6633	36	0	36	0	0	11	0	6	0	31	0	14	3	0	0	100.0
96-MPB-6634	282	12	26	0	0	8	0	5	0	47	1	3	0	0	0	100.0
96-MPB-6635	66	35	8	0	0	11	0	0	0	12	3	32	0	0	0	100.0
96-MPB-6636	176	0	2	0	0	1	0	0	0	5	0	92	0	0	0	100.0
96-MPB-6637	129	12	13	0	0	8	0	0	0	1	0	66	0	0	0	100.0
96-MPB-6638	128	23	2	1	0	54	0	2	7	9	0	2	0	0	0	100.0
96-MPB-6639	101	3	3	1	0	67	0	9	0	15	1	1	0	0	0	100.0
96-MPB-6640	109	0	11	3	1	18	0	5	0	49	3	10	0	0	1	100.0
96-MPB-6641	53	21	2	0	0	64	0	6	0	6	0	0	0	0	2	100.0
96-MPB-6642	143	0	0	0	0	0	0	0	0	0	0	22	78	0	0	100.0
96-MPB-6643	309	8	8	0	5	57	0	8	0	6	1	0	1	0	6	100.0
96-MPB-6644	11	18	36	0	0	18	0	0	0	18	0	9	0	0	0	100.0
96-MPB-6645	154	26	13	0	1	55	0	5	0	0	0	0	0	0	0	100.0
96-MPB-6647	46	2	26	4	4	52	0	9	0	0	0	2	0	0	0	100.0
96-MPB-6648	189	8	11	1	1	25	0	1	0	1	0	0	52	0	0	100.0
96-MPB-6649	180	31	16	0	0	42	0	9	0	1	0	2	0	0	0	100.0
96-MPB-6650	323	93	2	0	0	2	0	0	0	1	1	0	0	0	0	100.0
96-MPB-6651	101	16	22	0	2	47	0	8	0	0	0	0	0	0	6	100.0
96-MPB-6652	128	9	10	1	0	25	0	1	0	3	0	51	0	0	0	100.0
96-MPB-6653	265	33	24	0	0	10	0	0	0	21	1	3	0	0	8	100.0
96-MPB-6654	294	37	0	0	0	0	63	0	0	0	0	0	0	0	0	100.0
96-MPB-6655	137	23	18	0	0	15	0	2	0	37	0	0	0	0	4	100.0
96-MPB-6656	310	30	26	0	0	27	0	4	0	7	0	6	0	0	0	100.0
96-MPB-6657	277	4	9	0	12	55	0	7	0	5	0	5	0	0	3	100.0
96-MPB-6658	187	60	32	0	0	7	0	0	0	1	1	0	0	0	0	100.0
96-MPB-6659	64	42	25	0	2	13	0	0	0	5	3	11	0	0	0	100.0
97-DS-002	154	7	8	2	1	19	0	1	0	4	0	3	4	52	0	100.0

APPENDIX 4-B: PEBBLE COUNTS --- COUNT DATA

Sample Number	n =	Mafic Volc	Felsic Volc	Mafic Por	S.R. Rhy Por	Granite	Grand R. Granite	Diorite	Gabbro	L'Ardoise Qtz SS	Vein Qtz	Red,Green Brown Seds	Grey, Black Seds	Lmst	Other	Total
96-MPB-6601	153		20	1		124		5				3				153
96-MPB-6602	489	43	25		5	413		3								489
96-MPB-6603	157	40	78			11		1		3	4	15		3	2	157
96-MPB-6604	271	91	65	3	2	38		58		9	2	3				271
96-MPB-6605	277	34	50		1	49		22		63	1	57				277
96-MPB-6606	182	9	28			126		12		5		2				182
96-MPB-6607	189	19	27			33		4		10	2	94				189
96-MPB-6608	373	11	20		2	24		4		39	8	190	31		44	373
96-MPB-6609	107	12	22		2	41		6		3		6	15			107
96-MPB-6610	93	5			1	75		5		5		2				93
96-MPB-6611	28	4	1			22				1						28
96-MPB-6612	128	26	12					1		54	2	10	23			128
96-MPB-6613	170	11	5			7				61		48	38			170
96-MPB-6614	276	31	28			118		18		62		4			15	276
96-MPB-6615	465	136	13			315				1						465
96-MPB-6616		duplicate														0
96-MPB-6617	283	90	33	3		6		1		112	3	35				283
96-MPB-6618	174	54	36	4		60		1		12					8	175
96-MPB-6619	205	37	11	1	4	116		9		20		4			3	205
96-MPB-6620	196	46	13			64		1		47	1	9			15	196
96-MPB-6621	224	30	12	2		128		6		26			20			224
96-MPB-6622		no sample														0
96-MPB-6623	156	49	89	2		16										156
96-MPB-6624	243	14	18			209				2						243
96-MPB-6625	301		4			6		1		215		58	17			301
96-MPB-6626	17	4	1			1				5		6				17
96-MPB-6627	146	45	21			2				58		20				146
96-MPB-6628	188	65	28	4	1	25		4		47		7	3		4	188
96-MPB-6629	216	78	52	6	1	44		2		26		7				216
96-MPB-6630	171	13	13	1		138				5		1				171
96-MPB-6631	352	111	69			81				77	9	5				352
96-MPB-6632	268	86	41	5	2	31				71		25	5		2	268

APPENDIX 4-B: PEBBLE COUNTS --- COUNT DATA

Sample Number	n =	Mafic Volc	Felsic Volc	Mafic Por	S.R. Rhy Por	Granite	Grand R. Granite	Diorite	Gabbro	L'Ardoise Qtz SS	Vein Qtz	Red,Green Brown Seds	Grey, Black Seds	Lmst	Other	Total
96-MPB-6633	36		13			4		2		11		5	1			36
96-MPB-6634	282	33	72			22		13		132	2	8				282
96-MPB-6635	66	23	5			7				8	2	21				66
96-MPB-6636	176		4			1				9		162				176
96-MPB-6637	129	16	17			10				1		85				129
96-MPB-6638	128	30	3	1		69		3	9	11		2				128
96-MPB-6639	101	3	3	1		68		9		15	1	1				101
96-MPB-6640	109		12	3	1	20		5		53	3	11			1	109
96-MPB-6641	53	11	1			34		3		3					1	53
96-MPB-6642	143											32	111			143
96-MPB-6643	309	26	26		16	175		24		17	3		4		18	309
96-MPB-6644	11	2	4			2				2		1				11
96-MPB-6645	154	40	20		1	85		8								154
96-MPB-6646		duplicate														0
96-MPB-6647	46	1	12	2	2	24		4				1				46
96-MPB-6648	189	16	20	2	1	48		2		2			98			189
96-MPB-6649	180	55	28			75		17		2		3				180
96-MPB-6650	323	302	7			7				4	3					323
96-MPB-6651	101	16	22		2	47		8							6	101
96-MPB-6652	128	12	13	1		32		1		4		65				128
96-MPB-6653	265	87	64			27		1		56	2	7			21	265
96-MPB-6654	294	110					184									294
96-MPB-6655	137	31	25			21		3		51					6	137
96-MPB-6656	310	93	82			83		11		22		19				310
96-MPB-6657	277	10	25	1	34	151		20		13		15			8	277
96-MPB-6658	187	112	59			14				1	1					187
96-MPB-6659	64	27	16		1	8				3	2	7				64
97-DS-002	154	11	12	3	1	30		1		6		4	6	80		154

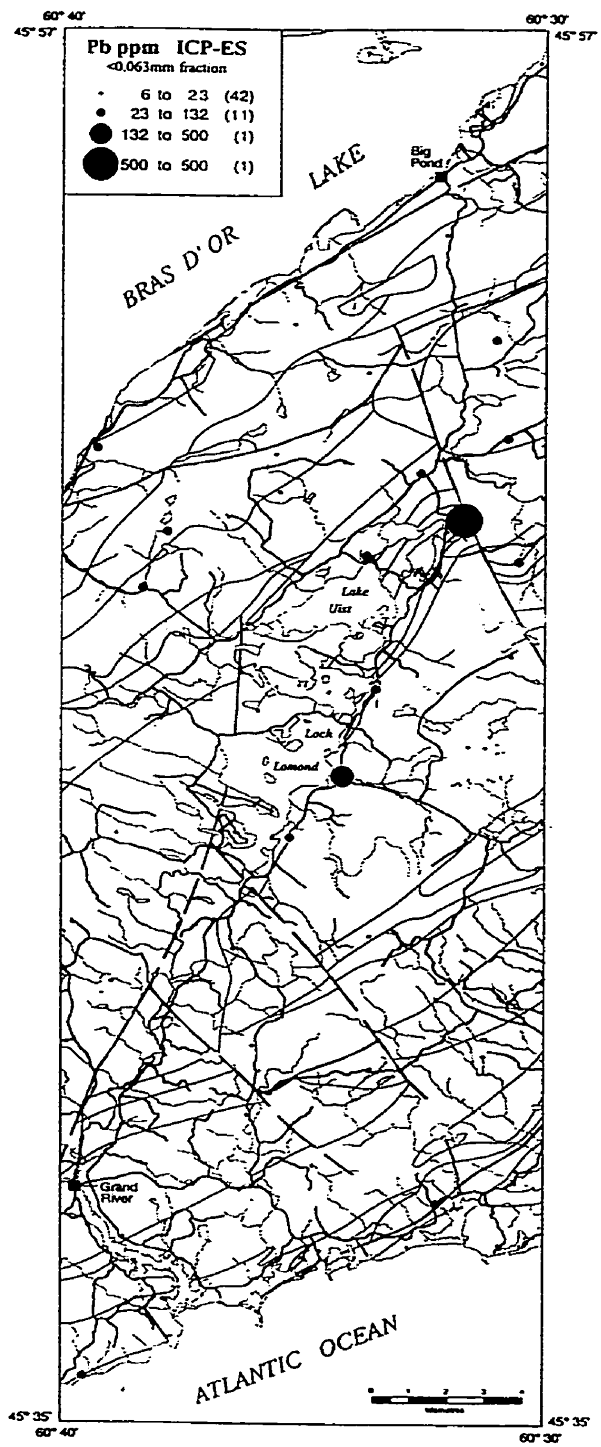
APPENDIX 5: Textural analysis of < 2.00 mm till fraction

SAMPLE	SAND %	SILT %	CLAY %	SAMPLE	SAND %	SILT %	CLAY %
6601	82.5	11.2	6.3	6632	75.4	22.0	2.6
6602	71.3	22.1	6.6	6633	58.7	30.8	10.5
6603	29.5	42.7	27.8	6634	71.7	24.4	3.9
6604	70.8	23.1	6.1	6635	26.0	44.5	29.5
6605	56.2	33.7	10.2	6636	21.7	58.1	20.2
6606	46.9	38.8	14.2	6637	51.9	34.3	13.8
6607	44.7	40.4	14.9	6638	39.4	36.9	23.7
6608	40.1	33.0	26.9	6639	62.3	29.6	8.1
6609	45.8	43.6	10.5	6640	31.3	43.3	25.4
6610	51.8	34.9	13.3	6641	50.1	38.4	11.5
6611	49.8	45.8	4.4	6642	71.6	21.1	7.2
6612	44.9	33.8	21.4	6643	54.8	36.9	8.2
6613	38.1	52.4	9.5	6644	45.1	36.5	18.3
6614	59.8	29.9	10.3	6645	46.6	42.3	11.1
6615	80.9	15.7	3.4	6646	47.0	43.0	10.0
6616	82.5	13.7	3.9	6647	59.2	31.7	9.0
6617	69.0	26.3	4.7	6648	39.9	44.1	16.0
6618	58.4	34.2	7.5	6649	42.6	36.9	20.5
6619	50.7	37.9	11.4	6650	55.7	37.7	6.6
6620	61.4	28.5	10.2	6651	35.8	55.9	8.3
6621	75.0	22.6	2.4	6652	28.8	43.9	27.3
6623	43.5	45.7	10.9	6653	72.1	24.8	3.0
6624	66.1	25.6	8.3	6654	68.3	26.8	4.9
6625	66.7	28.5	4.8	6655	36.6	37.3	26.1
6626	45.7	41.7	12.6	6656	79.7	14.1	6.2
6627	54.4	34.0	11.6	6657	80.1	13.8	6.1
6628	62.1	34.6	3.3	6658	54.7	33.4	11.8
6629	74.0	24.1	1.9	6659	42.0	36.9	21.1
6630	57.0	38.7	4.3	6673	43.1	37.2	19.7
6631	48.8	40.0	11.1	6701	45.5	40.3	14.2

APPENDIX 6

TILL GEOCHEMICAL PLOTS

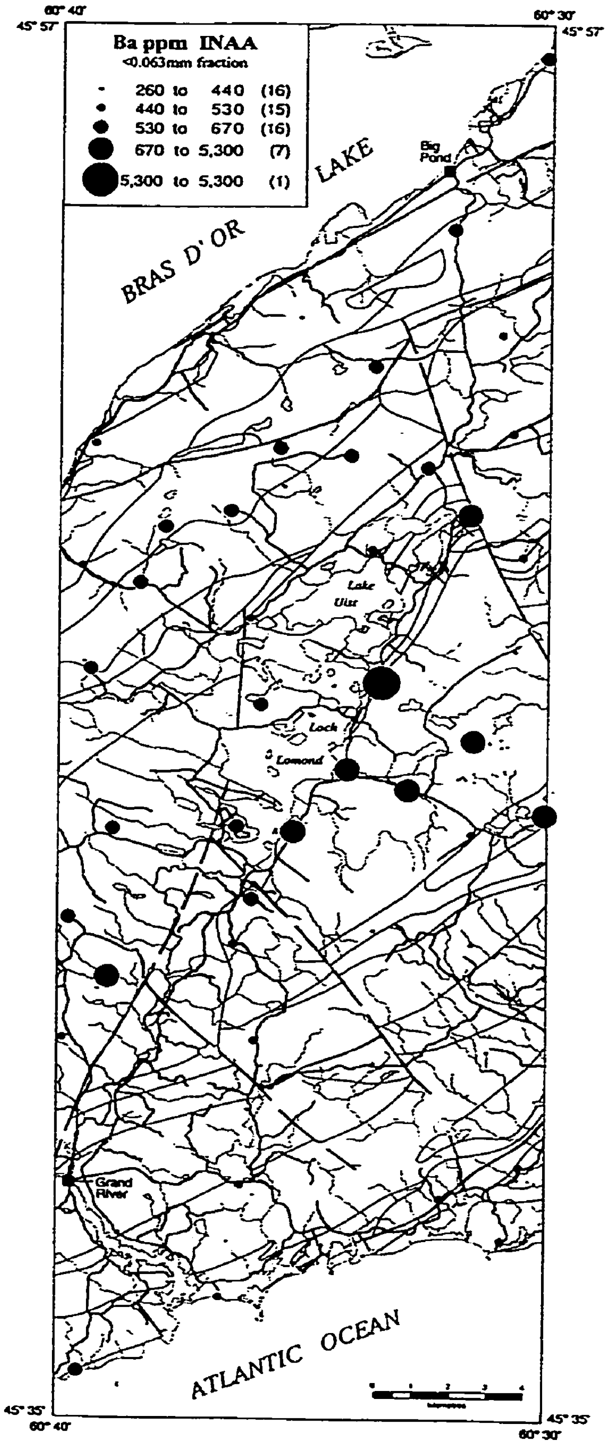
Pb



APPENDIX 6

TILL GEOCHEMICAL PLOTS

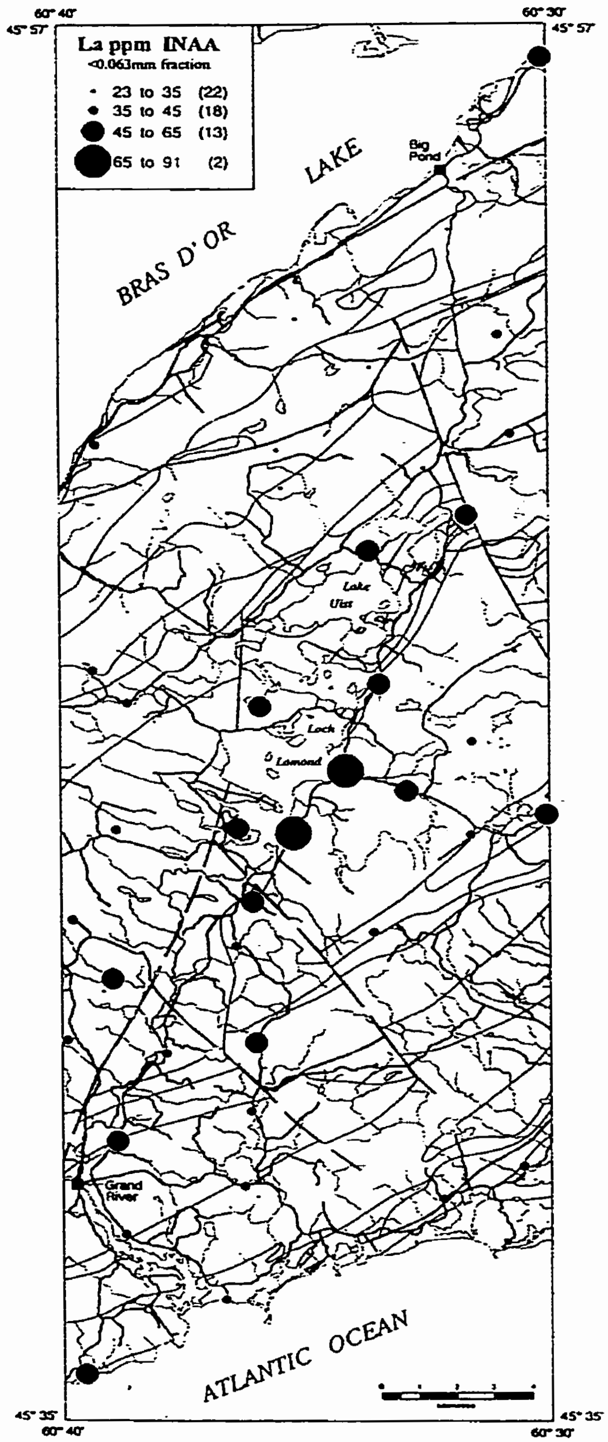
Ba



APPENDIX 6

TILL GEOCHEMICAL PLOTS

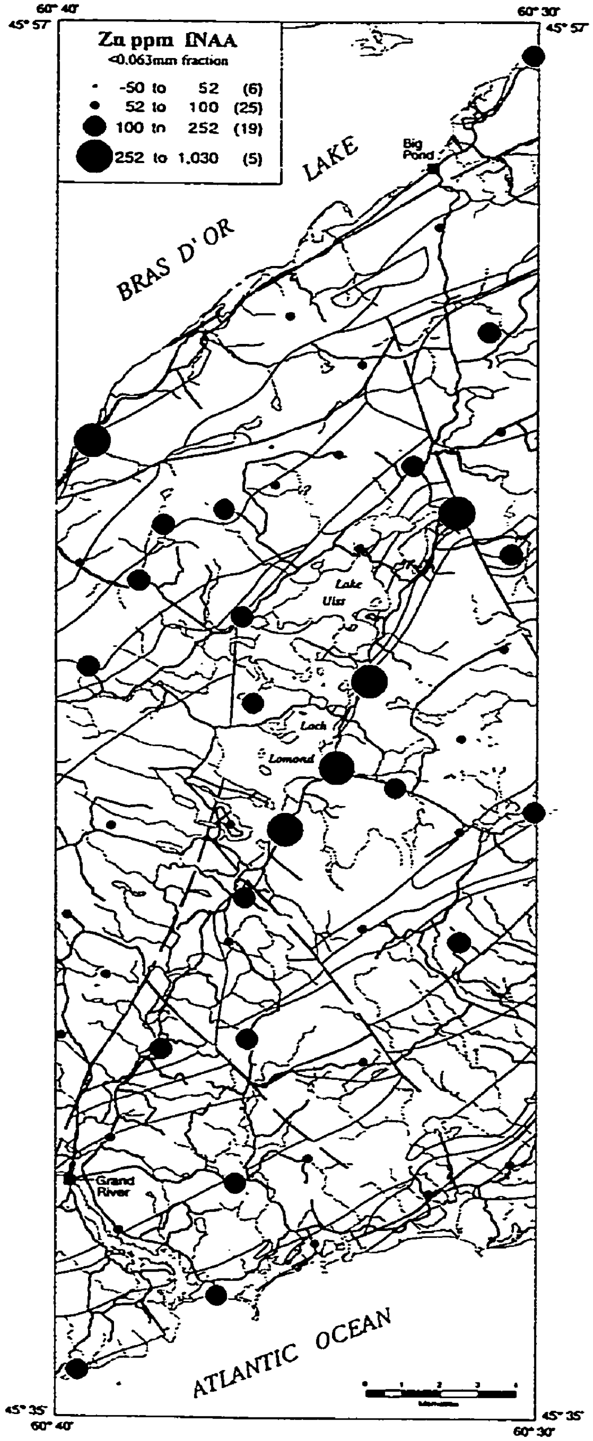
La



APPENDIX 6

TILL GEOCHEMICAL PLOTS

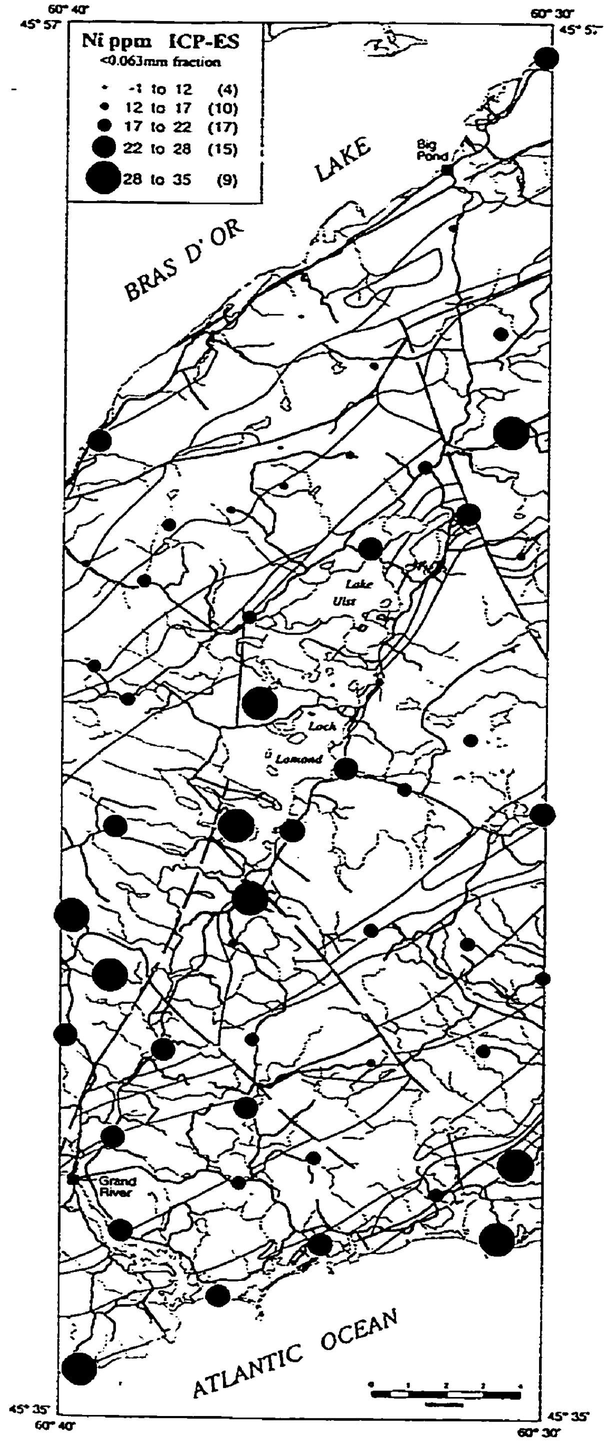
Zn



APPENDIX 6

TILL GEOCHEMICAL PLOTS

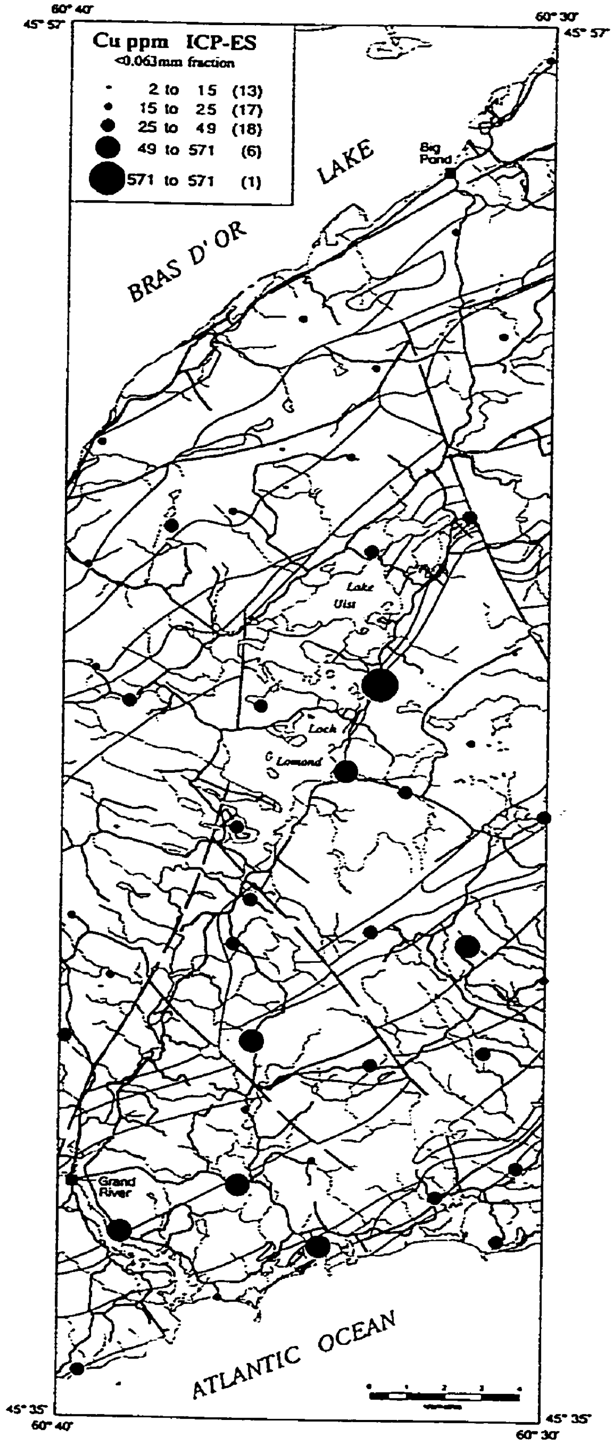
Ni



APPENDIX 6

TILL GEOCHEMICAL PLOTS

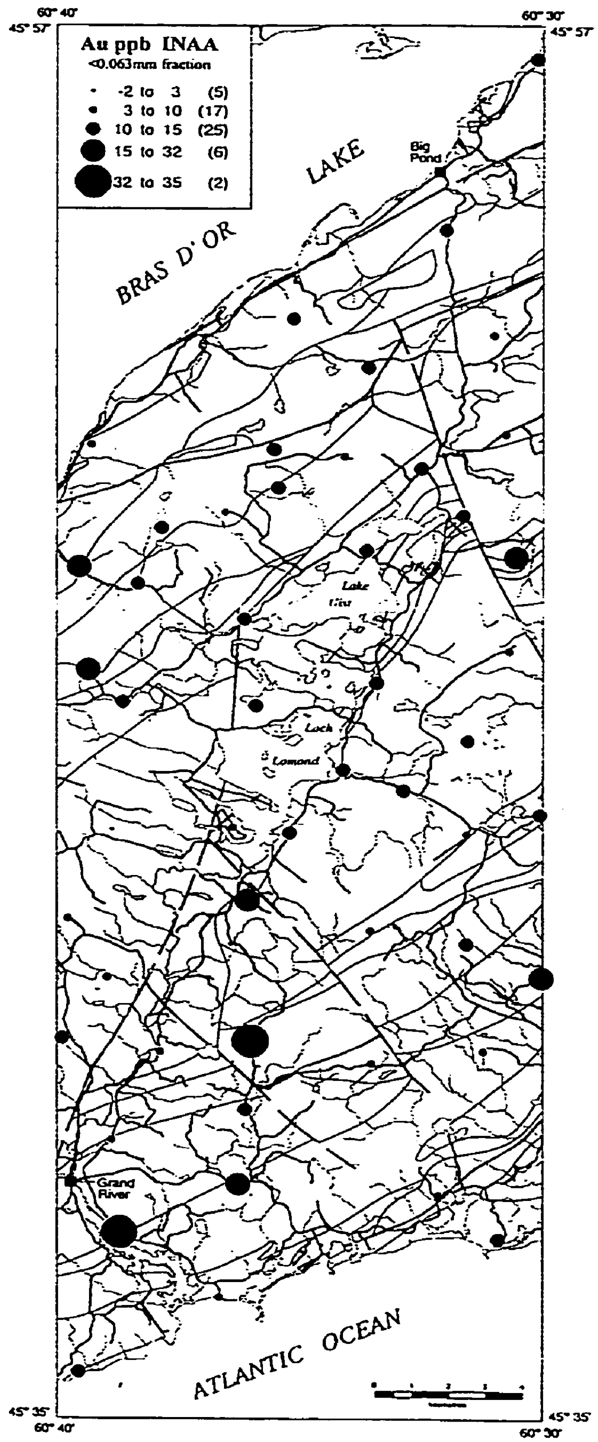
Cu



APPENDIX 6

TILL GEOCHEMICAL PLOTS

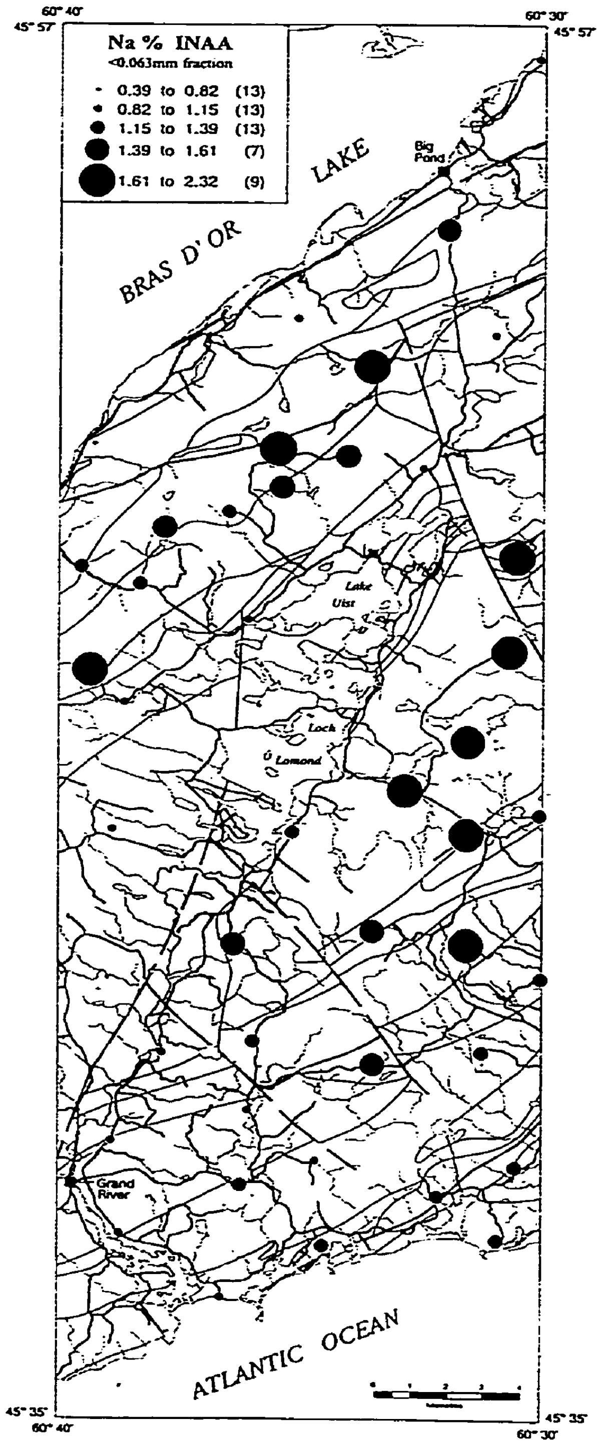
Au



APPENDIX 6

TILL GEOCHEMICAL PLOTS

Na



APPENDIX 7

AGE DATE CERTIFICATE OF ANALYSIS

GEOCHRON LABORATORIES a division of
KRUEGER ENTERPRISES, INC.

711 CONCORD AVENUE • CAMBRIDGE, MASSACHUSETTS 02138 • U S A
TELEPHONE (617) 876-3691 TELEFAX: (617) 661-0148

RADIOCARBON AGE DETERMINATION — **REPORT OF ANALYTICAL WORK**

Our Sample No.	GX-22226	Date Received:	08/27/96
Your Reference:	letter rec'd 08/27/96	Date Reported:	01/02/97

Submitted by: Prof. Ian Spooner
Department of Geology
Acadia University
Wolfville, Nova Scotia
Canada B0P 1X0

Sample Name: BP1D-96 (Big Pond)
organic material

AGE = >36,280 C-14 years BP (C-13 corrected).

Description: Sample of wood.

Pretreatment: The wood sample was cleaned of dirt or other foreign material and was split into small pieces. It was then treated with hot dilute HCl to remove any carbonates and with hot dilute NaOH to remove humic acids and other organic contaminants. After washing and drying, it was combusted to recover carbon dioxide for the analysis.

Comment:

$\delta^{13}C_{PDB}$ = -26.7 ‰

Notes: This date is based upon the Libby half life (5570 years) for ^{14}C. The error stated is $\pm 1\sigma$ as judged by the analytical data alone. Our modern standard is 95% of the activity of N.B.S. Oxalic Acid. The age is referenced to the year A.D. 1950.

APPENDIX 8

Differentiation of samples to till type with confidence factor (1 - 4).

OW - Outwash LL-6
LS - Local stony till LL-5
H - Hybrid till LL-3, 4
RR- Regional red till LL-2
* - Basal grey till LL-1
Confidence Factor 1 - Low 4 - High

No.	RR	LS	H	OW	No.	RR	LS	H	OW
6601		4			6633				2
6602		2.5			6634		4		
6603	4				6635	3.5			
6604			3		6636	4			
6605			2		6637			3	
6606	3				6638	3.5			
6607	3				6639		3		
6608	3				6640	4			
6609			3		6641			3	
6610		3			6642		4		
6611			3		6643		2	2	
6612	4				6644	3		1	
6613			3		6645		2	2	
6614		4			6646		2	2	
6615		4			6647	2		2	
6616		4			6648	2		1	
6617		4			6649			2	
6618		3			6650		4		
6619	2				6651		4		
6620			2		6652	4			
6621		4			6653				3

6623		3				6654		3		
No.	**RR**	**LS**	**H**	**OW**		**No.**	**RR**	**LS**	**H**	**OW**
6624		3				6655	4			
6625		4				6656		3	1	
6626		3				6657				4+
6627			2			6658		2.5		
6628		4				6659	4			
6629				2		6673	* (4)			
6630		4				6701		3	1	
6631				1						
6632				2						

Appendix 8 con't

APPENDIX 9

HEAVY MINERAL ANALYSIS

Au Grain Determination

PAGE 1 GSC: BETH McCLENAGHAN 02/18/97

GSC\GSBMIFEB.WR2
TOTAL # OF SAMPLES IN THIS REPORT = 2

OVERBURDEN DRILLING MANAGEMENT LIMITED

LABORATORY SAMPLE LOG

SAMPLE NO.	WEIGHT (KG. WET) TABLE SPLIT	+2 mm CHIPS	WEIGHT (GRAMS DRY) TABLE FEED	TABLE CONC	M.I. LIGHTS	M. I. CONC: CONC. TOTAL	NON MAG	MAG	DESCRIPTION: CLAST SIZE	% V/S	% GR	% LS	% OT	MATRIX S/U	SD	ST	CY	COLOUR SD	COLOUR CY	OR	CLASS
96-MPB																					
6617-HM	10.7	4.2	6.5	348.6	318.2	30.4	29.9	0.5	P	95	5	0	NA	U	Y	Y	Y	OC	OC		TILL
6609-HM	13.2	4.5	8.7	268.9	254.7	14.2	13.8	0.4	P	90	10	0	NA	U	Y	Y	Y	OC	OC		TILL

Remark: The HMC's from both samples consists mainly of limonite/goethite. Trace of barite (confirmed by SEM) in both samples. SEM showed minor strontium in one of the six grians checked.

APPENDIX 10 : MINERAL OCCURENCES (from NSDNR files)

TRACT	CLAIM	MAP	COMMODITIES	UTM NORTH	UTM EAST	NAME of OCCURRENCE	NSDNR NUMBER
25	J	11F/10D	Au,Cu,Fe,Zn	5059350	694430	Taylors Brook Au,Cu,Zn	F10-003
106	O	11F/10D	Fe,Mn,Cu,Co,Ni	5068450	678730	Toms Brook (Hay Cove)	F10-006
95	G	11F/10D	Cu, Fe, Zn	5066340	692230	Michaelson & Loch Lomond	F10-013
72	A	11F/10D	Cu, Fe	5062950	692550	Stirling Area Cu, Fe	F10-014
49	J	11F/10D	Cu, Fe	5062340	694300	Stirling area Cu, Pb	F10-015
85	N	11F/10D	Cu,Ag, Au	5066290	655750	Campbell Mountain Cu, Ag,Au	F10-021
84	O	11F/10D	F	5065160	675570	Detter Creek Fluorite	F10-025
59	C	11F/15A	Cu	5075000	677100	Johnston Cu	F10-001
46	K	11F/15A	Fe,Mn,Pb,Zn	5074730	690410	MacVicar Fe,Mn,Pb,Zn	F10-004
38	P	11F/15A	Ba, Fe	5074640	677570	Johnstown Ba, Fe	F10-005
49	H	11F/15A	Mn	5075700	693860	McCuish Mine Mn	F10-009
95	N	11F/15A	Mn	5081220	691060	Terra Nova Mn	F10-010
94	F	11F/15A	Fe, Pb, Zn	5080350	689970	Terra Nove Fe, Pb, Zn prospect	F10-011
22	E	11F/15A	Cu,Pb, Zn	5071080	689920	Shaw Lakes Cu, Pb, Zn	F10-016
53	C	11F/15A	Pb, Zn	5075200	687000	MacDonald Brook (Snake Brook	F10-017
50	M	11F/15A	Mn	5076150	691240	Enon Lake Mn	F10-018
27	P	11F/15A	Fe	5073100	690200	Little MacLeod Brook Fe	F10-019
44	B	11F/15A	Pb,	5073920	687200	Lake Uist Pb (trench)	F10-020
27	E	11F/15A	Pb, Zn	5073500	690000	Lake Uist Pb, Zn	F10-021
22	N	11F/15A	Pb, Sr, Zn	5071950	689600	Loch Lomond Lake Pb, Sr, Zn	F10-022
51	A	11F/15A	Pb, Sr,Zn,Cu	5076000	691500	MacRae Pit (Lake Enon)	F10-023
31	Q	11F/15A	Ba,Cu,Pb,Zn	5073300	684550	Pine Brook Ba,Cu,Pb,Zn	F10-024
49	F	11F/15D	Fe	5089660	692940	Ben Eoin Fe Occurrence	F10-025
97	G	11F/15D	Cu,Pb,Zn,Fe,Ag,Au,Cd,Ni	5095950	693180	MacIntosh Brook Cu,Pb,Zn	F10-026
50	F	11F/15A	Sr	5075810	691620	Loch Lomond Celestite Deposit	F10-039
30	N	11F/15A	Ba	5073070	684680	Pine Brook Barite	F10-040