# Mesozoic-Cenozoic Stratigraphy of the Lowlands of Southwest Cape Breton Island (NTS 11F/11, 11F/14)[1]

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## Introduction

The Mesozoic-Cenozoic stratigraphy of the lowlands of southwestern Cape Breton Island records the history of formation of the present landscape. Unconsolidated surficial deposits that make up the present valley fill range in age from Early Cretaceous to recent. The greatest thickness of sediment was deposited in a succession of glacial lakes that filled valleys at various times during the Wisconsinan glaciation. In the River Denys Basin as much as 50 m of fine-grained silty clay was deposited. The purpose of this paper is to describe the deposits in their stratigraphic context, interpret the environments of deposition, and reconstruct the ice sheets that produced the deposits.

The project is part of the Targeted Geoscience Initiative (TGI), jointly funded through the Geological Survey of Canada (GSC) and the Nova Scotia Department of Natural Resources (NSDNR), and aimed at stimulating mineral resource development in Cape Breton Island. The main goal of the project is to broaden geoscience knowledge in the area, with a focus on the economic potential of Carboniferous bedrock and the overlying Mesozoic and Cenozoic sediments. Of particular interest is the search for hidden outliers of Mesozoic sediments, including valuable kaolin and silica sand, preserved in fault-bound basins and obscured by Quaternary cover (Stea and Pullan, 2001). This report will summarize the results from drilling and seismic surveys conducted during 2000 and 2001.

## Physiography and General Geology

The study area can be divided into two major lowland basins flanked on either side by highland areas (Fig. 1). Creignish Hills and North Mountain are upland massifs composed of igneous and metamorphic rocks ranging in age from Proterozoic to lower Devonian (Kelley, 1967; Lynch and Brisson, 1996). The lowland areas are defined as the River Denys Basin (Kelley, 1967) and the River Inhabitants Lowland (this study), separated from each other by an intermediate upland area underlain by Mabou Group clastic rocks termed the Maple Brook Syncline (Kelley, 1967). The River Denys Basin is a broad and rolling lowland plain to the north of the Maple Brook syncline, underlain primarily by clastic and evaporitic rocks of the Windsor Group. Inset in the River Denys Basin in the vicinity of River Denys Centre is a flatter and lower region of nearly rectangular shape which will be called the Big Marsh lowland (Fig. 1). The River Inhabitants Lowland is a north-south basin which encloses the floodplain of the River Inhabitants (Grant, 1994).

## Methods

### Mapping and Stratigraphic Studies

Road, stream and coastline traverses were conducted to describe and classify the various types of surficial sediments in the map area. Surficial

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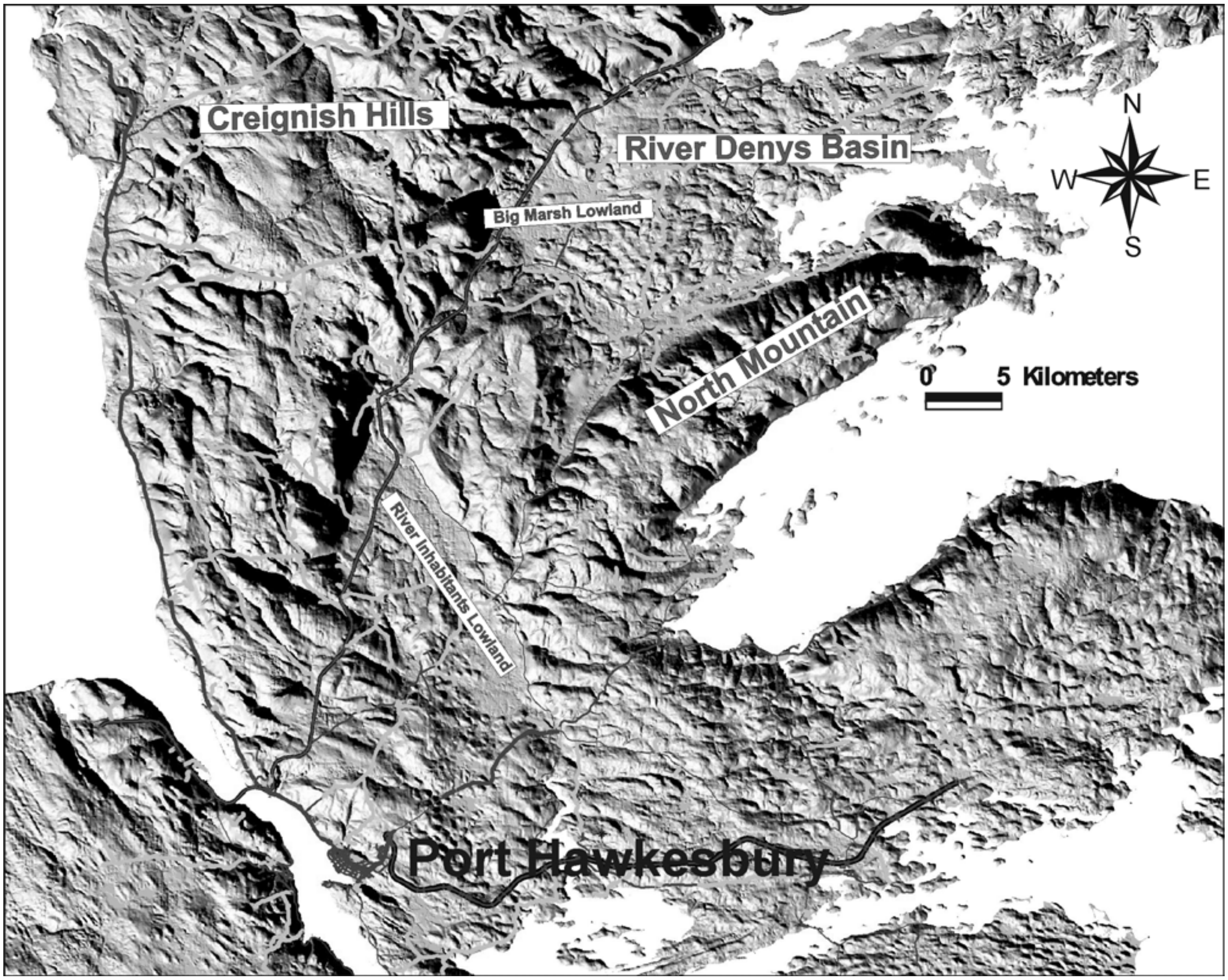


**Figure 1.** Physiography and location of the study regions of the Targeted Geoscience Initiative (TGI), Southwest Cape Breton Island.

units were delineated by matching the surficial deposits (e.g. till, fluvial, and colluvial deposits) with identifiable landforms traceable on air photographs and on digital terrain models. These data were integrated with other data sources (previous maps, well log data, etc.) in a GIS platform for final map production. Detailed stratigraphic sections were measured on coastline, road and stream exposures, and in the recently opened Sugar Camp quarry. Till fabric measurements were conducted using a standard methodology (e.g. Evenson, 1971) with the bearing and plunge of the long axes of 30-50 pebbles measured and plotted on a Schmidt net. Stratigraphic logs of all measured sections were constructed using LOGPLOT 98.

## Drilling

The drilling methodology was similar to that undertaken in the Musquodoboit Valley, which defined large areas of previously unknown Mesozoic silica sand and kaolin clay (Finck *et al.,* 1995; Gillis, 1998). For the first phase of drilling (March 2001) a large track-mounted drill equipped with a wire line coring system was used. It was designed to give high recovery in unconsolidated sand and clay, and was extremely mobile. Materials could be quickly triconed if core was not desired. In the fall of 2001 a second phase of drilling was conducted using a smaller, more versatile, track-mounted rotary drill. This multi-purpose drill allowed for a variety of sampling techniques including augering, split spooning and coring. Standard augers with a 4.5 inch diameter could be used to quickly drill down through surface clay, sand, and gravel. Grab samples could be taken at 5-foot intervals along each auger. Alternatively, a 1.5-inch diameter, 2 foot long split spoon sample could be obtained by driving a sampler ahead of the auger at the base of the hole. The drill was equipped with a 140 lb. hammer with a 30-inch drop. If ground conditions became unfavourable for auguring or split spooning, the drill was switched to diamond drilling. Cored holes were cased with 3.9 inch HW steel pipe to prevent caving. A HQ core barrel and rods were used to obtain a 2.5-inch core sample. All holes were drilled vertically, and the steel casing was removed upon completion.

## Down-hole Geophysics

An extensive suite of downhole geophysical logs has been acquired in eight of the boreholes drilled in 2001. These boreholes were cased with PVC pipe (6-7.5 cm inner diameter) to preserve borehole access and to permit downhole electrical/magnetic geophysical logging. The data set includes natural gamma, inductive conductivity, and magnetic susceptibility logs acquired using a Geonics EM-39. Further information on this instrumentation and the resulting geophysical logs may be found at http://sts.gsc.nrcan.gc.ca/clf/borehole_geophysic.asp or in Douma *et al.* (1999).

The natural gamma, conductivity and magnetic susceptibility logs are very useful in identifying varying lithologies downhole. The logs provide a qualitative estimate of grain size and allow the identification of geophysical signatures that can be used for hole-to-hole or regional correlations. In most sedimentary environments, high natural gamma count rates are associated with fine-grained units such as silt and clay, whereas low count rates are associated with sand and gravel. The conductivity of a porous, unconsolidated material is a function of the combined electrical conductivity of the sediment and the pore fluid, and high conductivities (in the 100s of mS/m) are typically an indication of highly conductive (e.g. saline) porewater. Magnetic susceptibility is a dimensionless measure of the magnetization capacity of a material, and in unconsolidated earth materials most of the response results from small quantities of magnetite. Hence, anomalously large values of bulk magnetic susceptibility in a formation are an indirect indication of increased heavy mineral content.

# Lithostratigraphy of the River Denys Basin

Based on previous seismic reflection testing (Pullan *et al.,* 2001), eight holes were drilled in the southwest part of the River Denys Basin (Fig. 2) where surficial cover is commonly thick (up to >100 m). Areas of special interest are the Big Marsh lowlands and the western River Denys Basin margin. A generalized stratigraphic profile from northwest to southeast across the Big Marsh lowlands can be constructed using logs from drillholes URD-01, -02, MPR-01-1, and BM-01-1, -2, and -3 (Figs. 2, 3). The Big Brook quarry in the River Denys Basin provides another reference section for the region, where radiocarbon dating of interglacial and interstadial organic beds provides temporal control for the lithostratigraphic units (Fig. 4). The surficial units are described from the base or bedrock contact to the top.

# Bedrock and Breccias

Coarse-grained grey-white gypsum of the Windsor Group was encountered at the base of holes URD-01-1, MPR-01-1, BM-01-2, and BM-01-3 at depths of 80.8 m, 59.4 m, 56.3 m and 19.5 m, respectively. Gypsum texture ranges from massive mosaic to slightly nodular, commonly grading into a gypsum breccia infilled with grey clay. Steeply, dipping bands of black-brown carbonate are also evident in the drill core. Hole BM-01-1 bottomed in grey-white limestone at 92.2 m. Lying above competent bedrock in the deeper part of the basin (BM-01-1) is a series of alternating blue-grey and red-brown, strongly calcareous mudstones and breccias up to 20 m in thickness (interpreted as part of the Windsor Group).

## Lower Till

Drag line trenches in the Big Brook gypsum quarry (Fig. 2) revealed a complex Quaternary

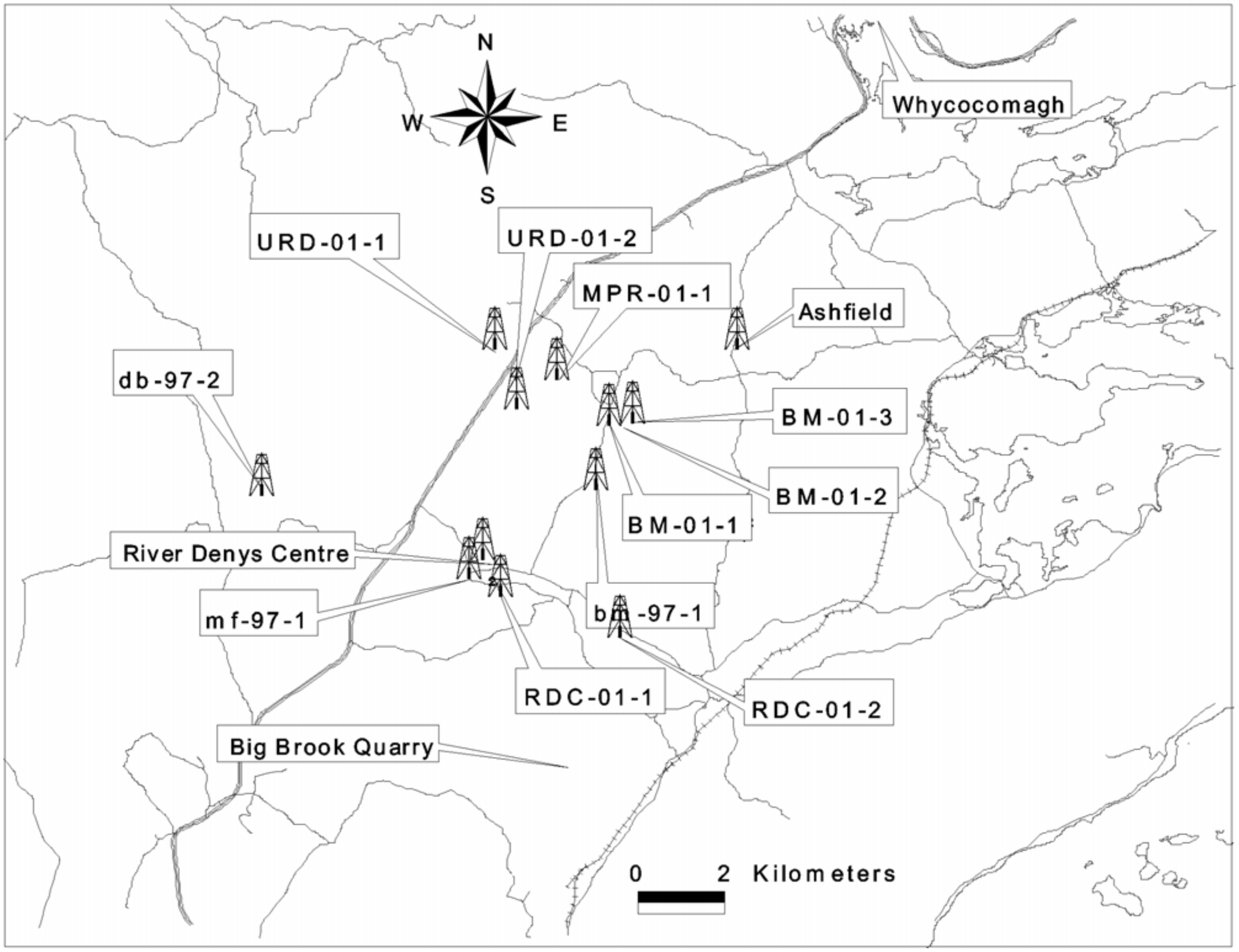


**Figure 2.** Location of reference sections and TGI diamond-drill holes in the River Denys Basin. Diamond-drill hole DB-97-2, at Diogenes (Grant) Brook encountered ~50 m of Early Cretaceous sediments.

stratigraphy, with an oxidized, greenish-grey silty till unit at the base, overlying the gypsum bedrock surface (Fig. 4). Large spruce wood fragments were found embedded in the grey lower till, providing radiocarbon dates of >49,000 (GSC-3289) and >52,000 (GSC-3880) yr B.P. Pollen from a levels organic layer sheared into the lower till was characterized by high of *Picea* (Spruce), *Alnus*, (alder) and fern spores, a boreal-forest type assemblage (R. J. Mott, unpublished palynological report 81-6). A mid-Wisconsinan date of 36,200±1280 yr B P (GSC-3206) was obtained from organic silt in a solution cavity beneath the lower till, but with a similar palynological signature (R. J. Mott, unpublished palynological report 80-12). The date is thought to be contaminated by "young carbon" (Mott and Grant, 1985), because it is apparently lower in stratigraphic position than the wood pieces dated as infinite in age. The wood fragments could either be inherited from an interglacial soil beneath the Lower Till or sheared into the unit from a younger soil by overriding ice. The later hypothesis is more likely as the Richmond Till was observed to intrude the lower till in large "till wedges". Interglacial wood from Nova Scotia at many localities dated by U-series disequilibrium methods did not produce ages in excess of 140 ka (de Vernal *et al.,* 1986). It is interesting to note that an undated organic silt just below the Richmond Till (Fig. 4) had a pollen profile significantly different than the lower sink-hole organics (R. J. Mott, unpublished palynological report 84-12).

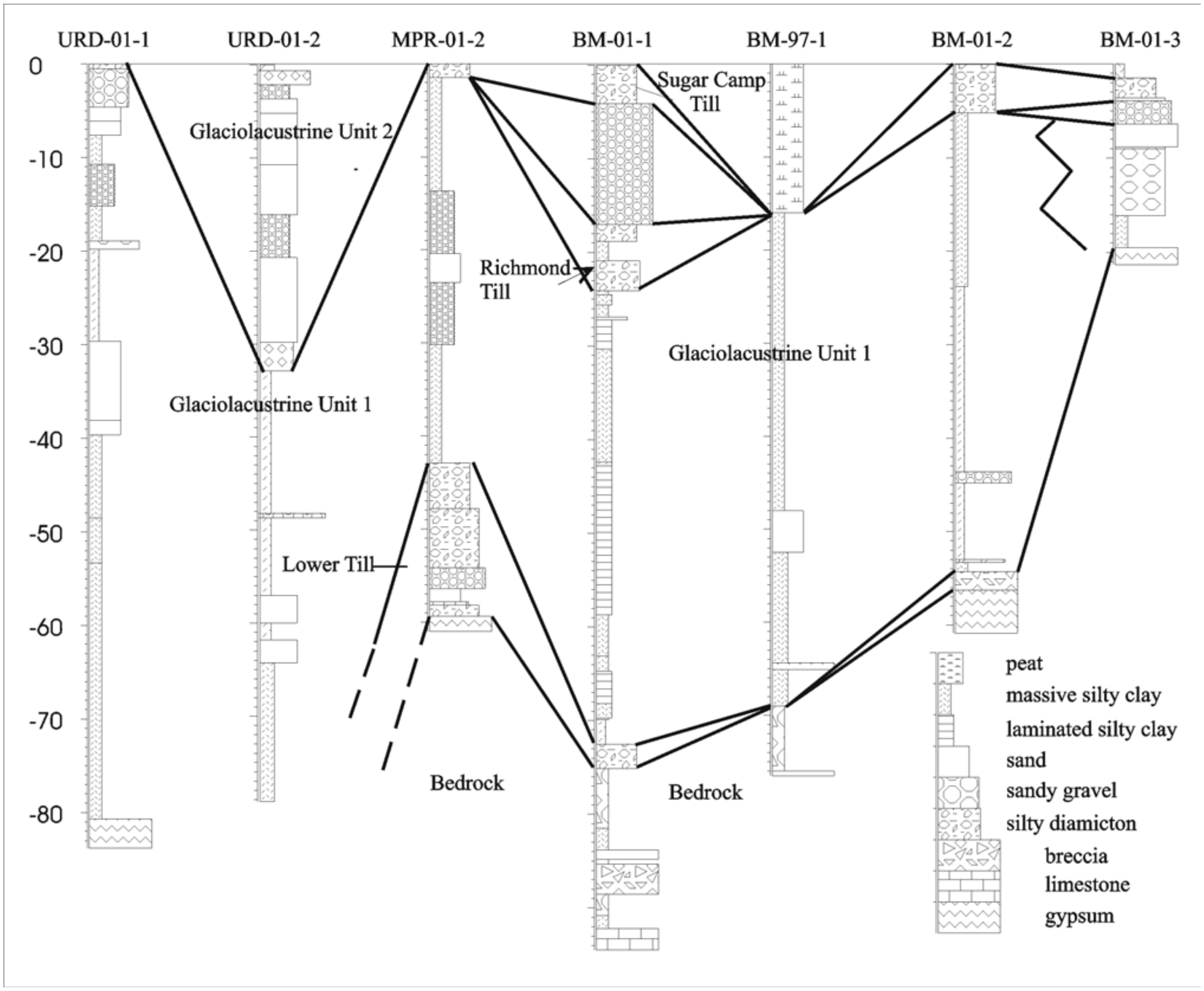


**Figure 3.** Stratigraphy and correlation of TGI drillholes within the Big Marsh lowlands.

A package of coarse gravel, sand, boulders and red-brown silty diamicton interpreted as a glacial till overlies Carboniferous bedrock and breccia in the deeper part of the Big Marsh lowlands to the north (MPR-01-1, and BM-01-1, and 2; Fig. 3). Thicknesses range from 0.3 m to 16.5 m, although the exact boundary of the lower till unit is sometimes difficult to establish. The till unit contains locally derived, angular clasts of white gypsum, black micritic limestone in a silty clay matrix, and also includes a high percentage of grey-green mafic, and white, pink and green granitic pebbles and cobbles.

## Interglacial Peat and Wood

D. G. Kelley (1955) noted a thin organic seam sandwiched between two tills in the village of Whycocomagh (Fig. 2). Mott and Prest (1967) described the organic section as containing wood fragments, intercalated with grey organic silty clay. A date of >44,000 yr B P(GSC-290) was obtained from a piece of wood in the peat section. Another till-buried organic site was discovered near Ashfield (Figs. 2, 6) and is described below.

# Glaciolacustrine Unit 1

Overlying the bedrock/breccia and the Lower Till in the River Denys Basin is a sequence consisting of red-brown and grey-brown clay, silty clay, and sand with minor gravel beds. This fine-grained unit ranges in thickness from 13 m to >40 m. Textures

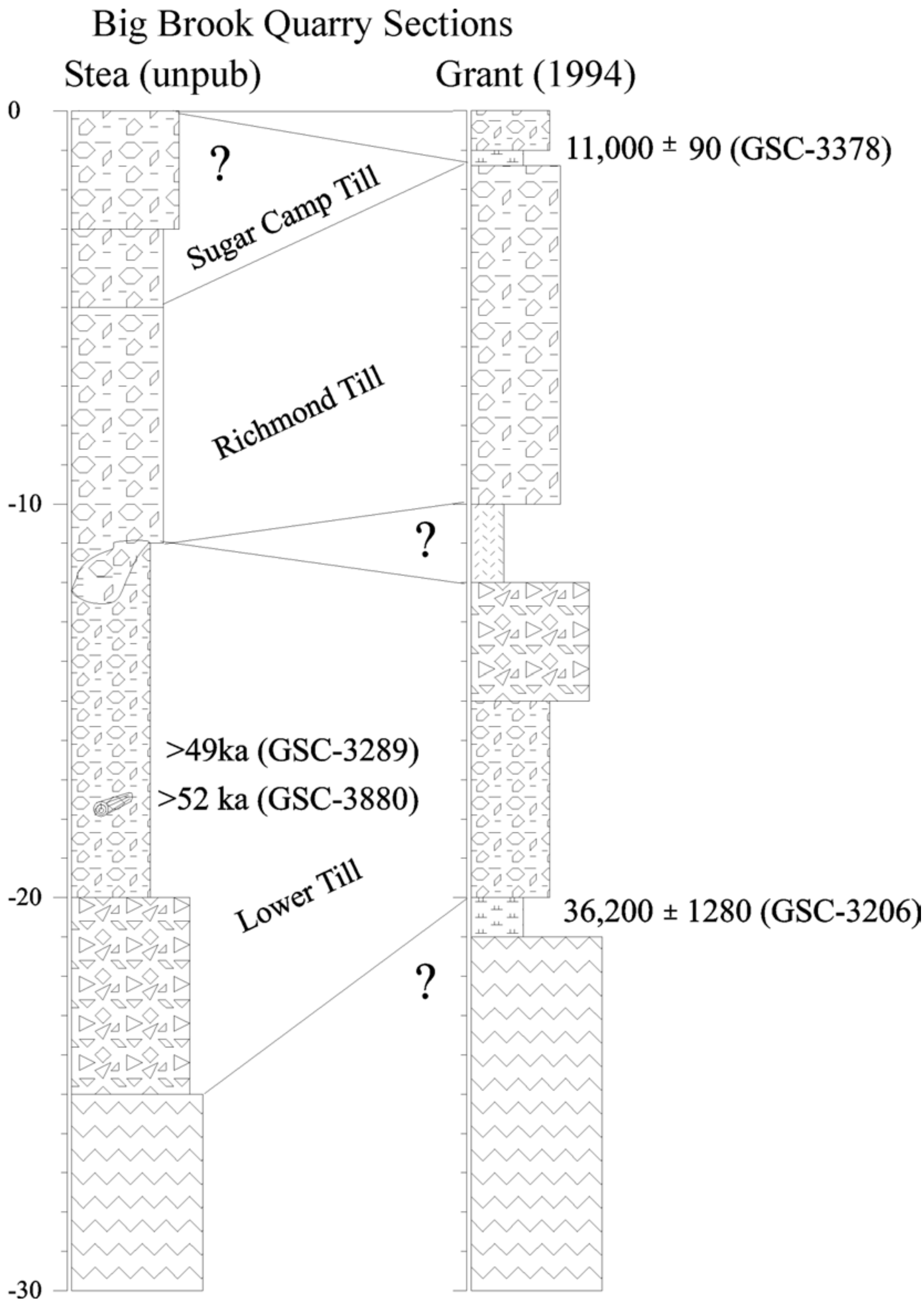


**Figure 4.** Stratigraphic sections and radiocarbon ages from the Cenozoic reference section at Big Brook (see facies legend, Fig. 3).

range from massive silty clay and clay to thinly laminated clay and silty clay, sometimes deformed by faulting or folding. Dropstones are rare throughout the unit, and occur as well rounded pebbles of various lithologies, but predominantly white quartz, grey and green siltstone, and sandstone. Sandy beds range from fine- to coarse-grained. Rhythmically bedded zones are present but rare. Magnetic susceptibility, natural gamma and conductivity geophysical logs (Fig. 5) demonstrate the inherent homogeneity of the unit by showing few excursions. The conductivity measurements in the order of 70-200 mS/m in unit 2 are indicative of glaciolacustrine sediments, based on a comparison of conductivity measurements with marine mud in the Champlain sea whose values are as high as 1200 mS/m (Hyde and Hunter, 1998). Conductivity is a good indicator of pore water salinity (Hyde and Hunter, 1998).

## Richmond Till

A reference section for the Richmond Till (Grant and King, 1984) occurs at Big Brook Quarry. At this locality a calcareous, greyish-red, matrix-supported diamicton with allocthonous igneous and metamorphic pebbles overlies the oxidized Lower Till, with an erosional/tectonic contact including southward-oriented wedges of till (Fig. 4).

A road cut just south of the town of Ashfield, Inverness County (Fig. 2), revealed 2-3 m of reddish-brown silty diamicton overlying a quartz-pebble gravel, yellowish medium sand, and black and grey, organic silty clay (Figs. 6a, 7). The surface diamicton intrudes the lower quartz gravel in a series of clastic wedges, trending southward. Clast fabric in the surface diamicton is reasonably well oriented and exhibits a shallow, preferred plunge direction, indicating a lodgment till origin (Fig. 7; Dreimanis, 1989). The direction of ice flow indicated by the till fabric is east-southeastward, and is further verified by the ~10% content of diorite erratics, derived from large dioritic plutons in the Creignish Hills to the northwest (Keppie, 2000). The clast fabric has a substantial scatter, explicable by later reworking, possibly through several ice flow phases (Stea and Finck, 2001). The quartz-pebble gravel at the Ashfield section is similar to Cretaceous outliers elsewhere in Nova Scotia which are dominantly quartz arenites (Stea and Pullan, 2001). It is difficult to conceive of Quaternary gravel containing such a high percentage of quartz, considering the varied local source areas. However, the lower organic material was found to contain a pollen assemblage indicating a Quaternary interglacial/interstadial deposition with abundant tree pollen, especially spruce (R. J. Mott, personal communication, 2003). The upper till is therefore correlative with the Richmond Till, and the quartz gravel may have been incorporated from formerly extensive Mesozoic deposits (Stea and Pullan, 2001).

Above glaciolacustrine unit 1 in drillhole BM-01-1 is a grey-red silty diamicton, interpreted as the Richmond Till (Fig. 3). It contains a high percentage of allocthonous, dark grey-green mafic rocks, including basalt (~14%), pink, green and white granite (12%), and local green and maroon siltstone and sandstone (70%).

Tang (1970) described three till units in the Mullach Brook Valley north of Whycocomagh which were being evaluated as a source of placer gold. The lowest till unit contained sandstone and shale clasts derived from southward to eastward flow across regions underlain by Carboniferous bedrock to the north of the site, and is therefore correlated with the Richmond Till.

## Sugar Camp Till (Big Brook Quarry)

At the Big Brook Quarry (“Stea section”; Fig. 4) the Richmond till is overlain by two brown till units, with high clast/matrix ratios, and a locally derived pebble lithology featuring limestone and shale clasts. The middle till is a correlative of the Sugar Camp Till, as defined in the Sugar Camp Quarry type section (see below).

At drillhole BM-01-1 (Fig. 3) in the River Denys Basin the surface unit in the region, a reddish-brown diamicton, occurs in many of the holes in this area, and is similar in texture and pebble assemblage to the underlying Richmond Till. Although it is most likely a reworked or hybrid till unit (cf. Stea and Finck, 2001) derived

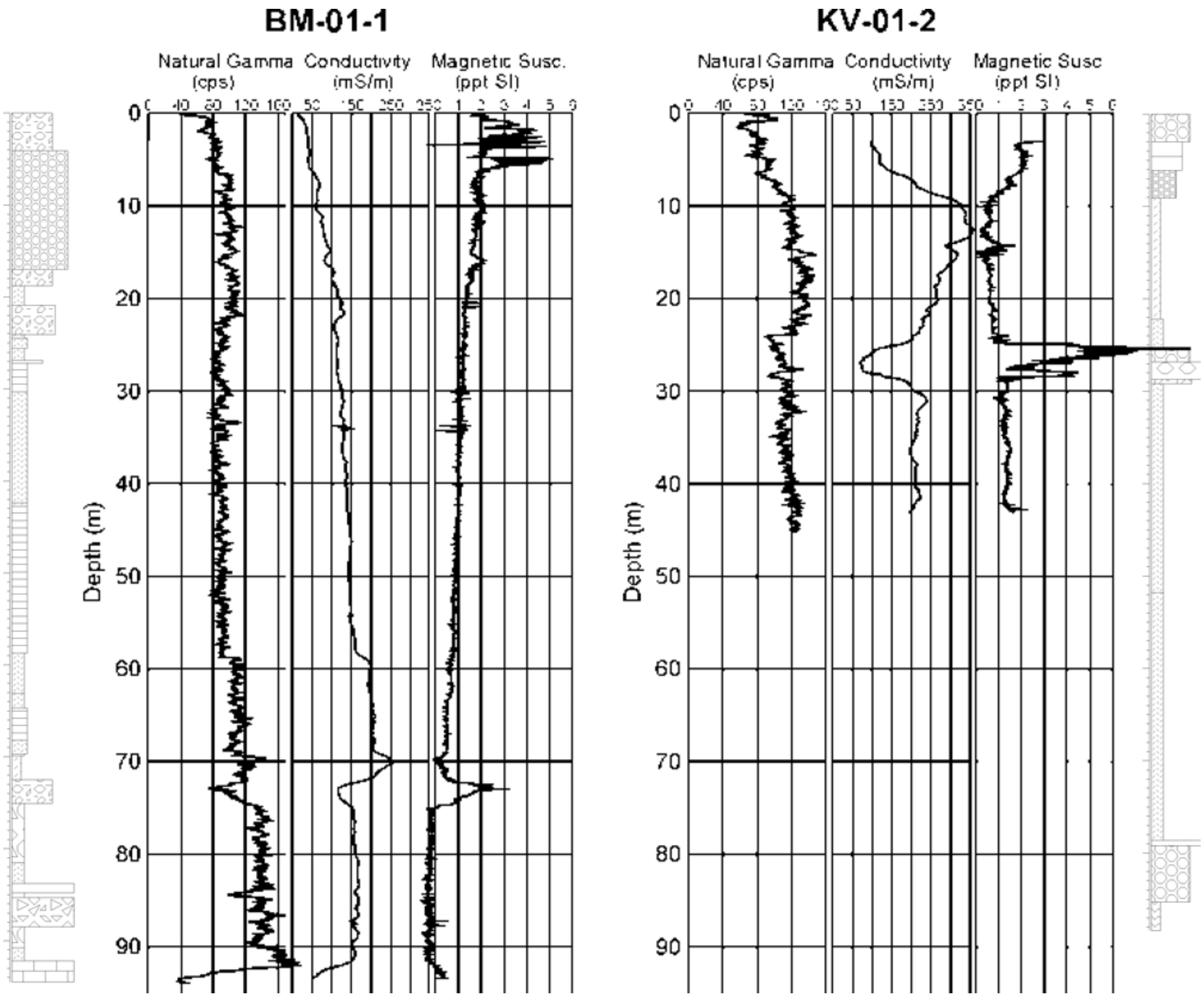


**Figure 5.** Geophysical logs from TGI diamond-drill holes in the River Denys Basin and River Inhabitants Lowlands.

from glacial mixing of the earlier Richmond Till during several ensuing glacial flow phases, it is also designated as the Sugar Camp Till. At BM-01-1 the Richmond Till correlative and the Sugar Camp Till units are separated by a thick gravel unit (Fig. 3). Total thickness of the two units ranges from a veneer along the western edge of the basin to 25 m at drillhhole BM-01-1.

Tang's (1970) middle till unit at Mullach Brook is composed of quartzite, diorite and granite clasts derived from highlands to the south and southwest, indicating a northward flow. Based on this evidence the middle till in Tang's sequence is considered a correlative of the Sugar Camp Till.

## Late-glacial Interstadial Peat and Wood and Overlying Till?

A 10 cm thick thin peat layer was found at the top of Big Brook section overlain by diamicton and grey clay (Fig. 4; R. J. Mott, personal communication, 2002). The organic peat layer yielded an age of 11,000 yr BP (GSC-3778) and had a pollen spectrum dominated by sedges and ferns with some willow and birch (Mott *et al.,* 1986; Grant, 1994). One metre of grey stony clay and reddish-brown stony clay diamicton overlies the peat, interpreted as a glaciolacustrine deposit (Grant, 1994). A road cut near River Denys Centre

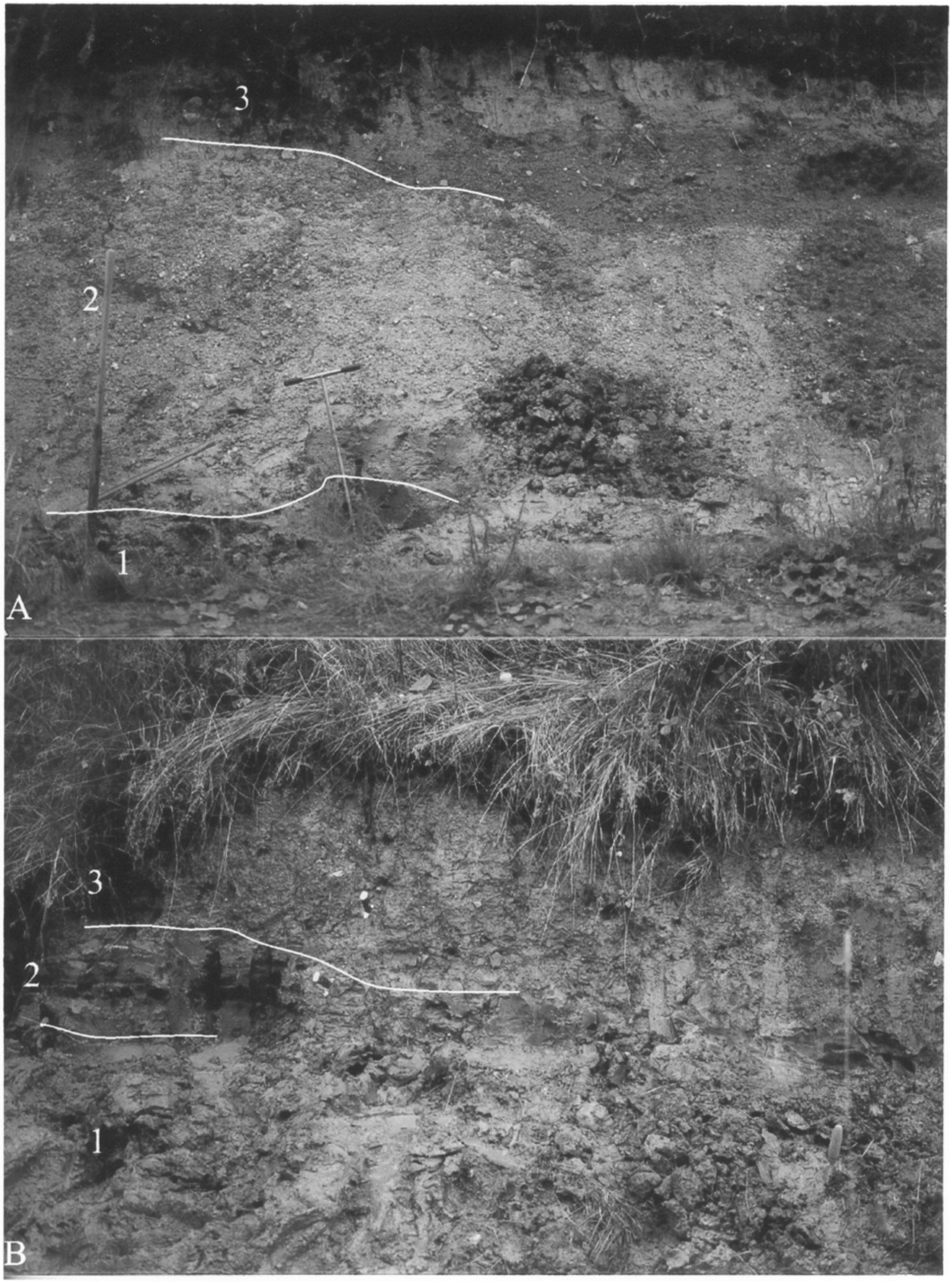


**Figure 6.** Photos from the (A) Ashfield section (Fig. 2); (1) lower interglacial organics, (2) quartz gravel, and (3) Richmond Till, (B) River Denys Centre; (1) till, (2) paleosol dated 11.4 ka, and (3) till?

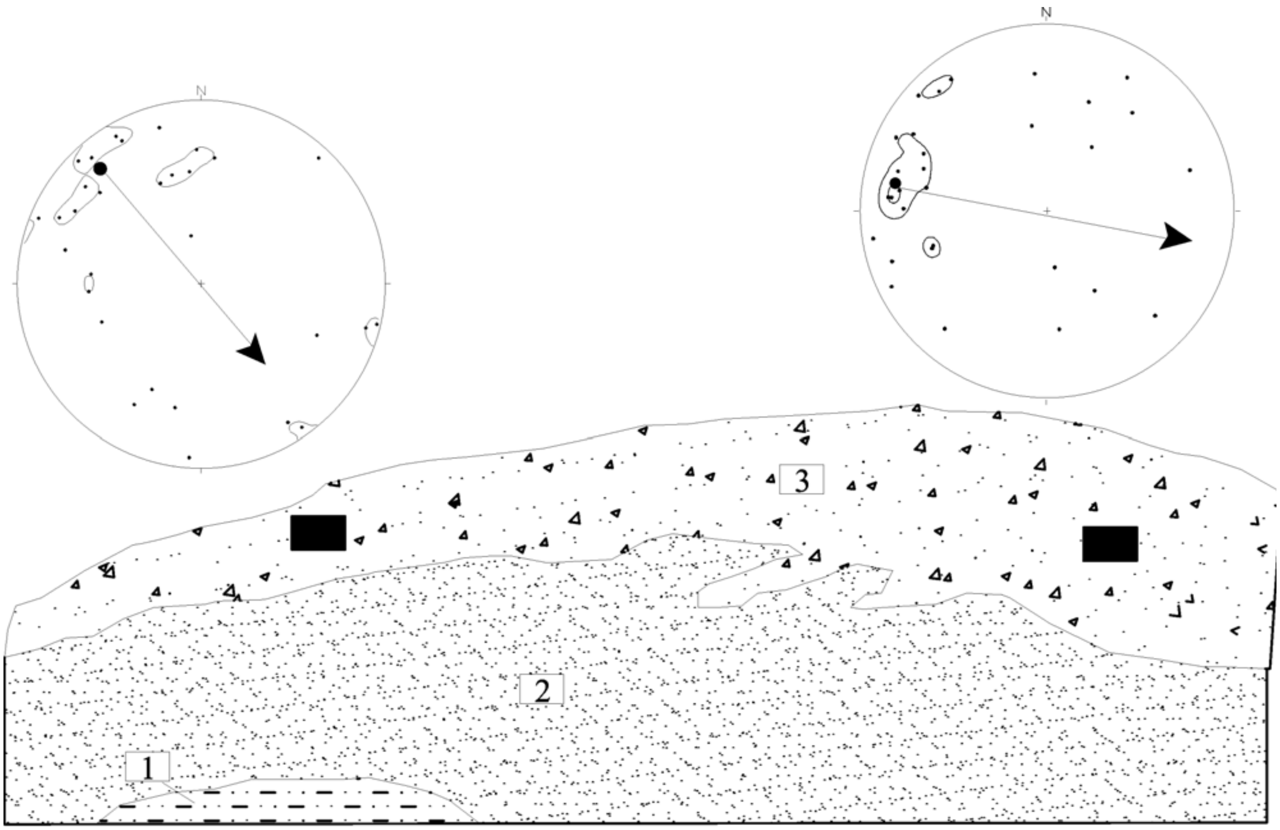


**Figure 7.** Schematic diagram of the Ashfield section, (1) lower interglacial organics, (2) quartz gravel, (3) Richmond Till. Stereo plots show till fabric from the Richmond Till with inferred glacial flow directions.

(Fig. 6b) revealed 1 m of reddish brown, silty clay diamicton over a 5-10 cm thick peat layer, sandwiched between ~10 cm thick layers of grey silty clay. The organic paleosol was dated at 11,400 ± 100 yr B P (GSC-6520). Pollen from the organic bed shows late-glacial assemblages and, therefore, the zone is correlative with the late-glacial organic zone at Big Brook (R. J. Mott, personal communication, 2002). The diamicton over the peat layer thickens upslope along the road exposure, while the nearly horizontal peat layer dips below the drainage trench. More data are needed to establish the genesis of this intriguing deposit.

# Lithostratigraphy of the River Inhabitants Lowlands

Based on seismic reflection testing (Pullan *et al.,* 2001) and previous indications of deep surficial cover, six drillholes were completed throughout the River Inhabitants Lowlands (Figs. 8, 9). A stratigraphic profile from north to south across the lowlands was constructed using drillholes KV-01-1, KV-01-2, DR-01-1, BR-01-1 and ML-01-1 (Fig. 9). Also within the lowland region is a previously described natural exposure of Quaternary sediments at River Inhabitants (Grant, 1994) and a new exposure at the Sugar Camp gypsum quarry. The Sugar Camp gypsum quarry (Fig. 10) is designated in this study as the type section for the Quaternary stratigraphic units of the lowland regions of southwest Cape Breton Island. The East Milford Quarry section (Mott and Grant, 1985; Stea *et al.,* 1992) is the equivalent stratigraphic section on mainland Nova Scotia.

## Bedrock

Windsor Group evaporites, biogenic and clastic rocks underlie most of the River Inhabitants Lowlands and are overlain by thick Quaternary sediments. In the southern part of the lowlands near Sugar Camp, grey-white carbonate-rich gypsum with nearly horizontal bedding was intersected at a

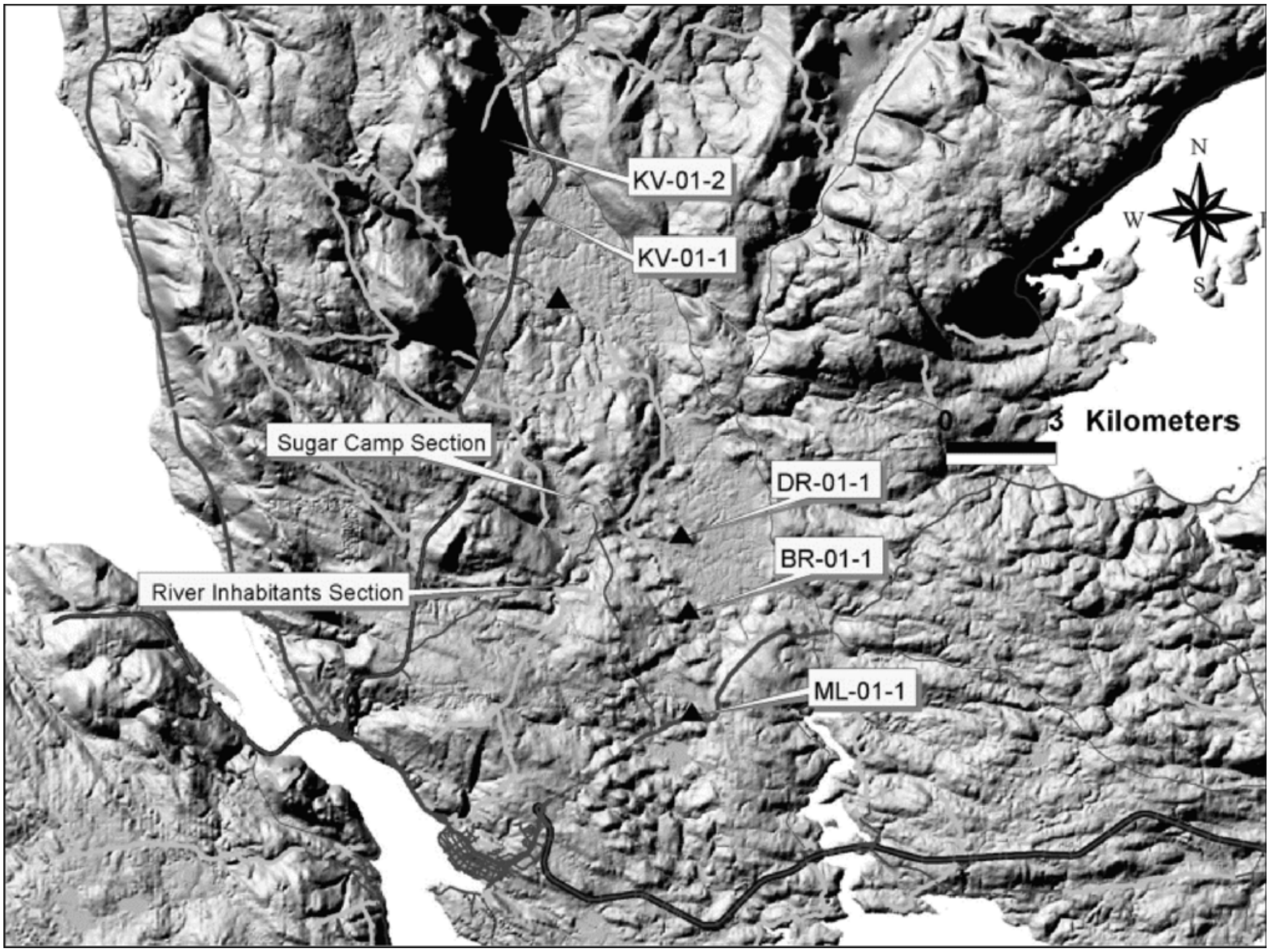


**Figure 8.** Location of reference sections and TGI diamond-drill holes in the River Inhabitants Lowlands.

depth of 14.2 m (ML-01-1) and at 53.6 m (BR-01-1) in the south (Fig. 9). At drillhole ML-01-1 near MacIntyre Lake, bedrock is an alternating green and maroon laminated mudstone with some mottling, characteristic of the Mabou Group (R. Boehner, personal communication, 2002).

None of the Kingsville area drillholes intersected bedrock (KV-01-1, 2; Fig. 9). The lowermost unit encountered was a light blue-grey silty clay and breccia containing pebbles of pink gypsum and satin spar veins near the base drillhole. In KV-01-1 this unit graded into a dark grey to black silty clay with abundant carbonate boulders. A sample from this unit was barren of palynomorphs (R. Fensome, personal communication, 2002). The maximum thickness of this unit is not known since two drillholes stopped short of intersecting bedrock.

## Lower Till

A grey-brown to dark grey, matrix-supported silty diamicton is found directly on top of gypsum bedrock in most of the Sugar Camp sections (Fig. 10). Locally, layers of woody debris including large pieces of wood are found within the till unit and in boulder layers. At the Barbarton Road drillhole, resting on bedrock at a core depth of -46.8 m is a matrix-supported blue-grey till with gypsum and limestone clasts (Fig. 9). Overlying this till is a laminated clayey silt, and an organic silty diamicton.

## Glaciolacustrine Unit 1

At Sugar Camp Quarry a brownish silty clay diamicton (Lower Till?) with few clasts overlies

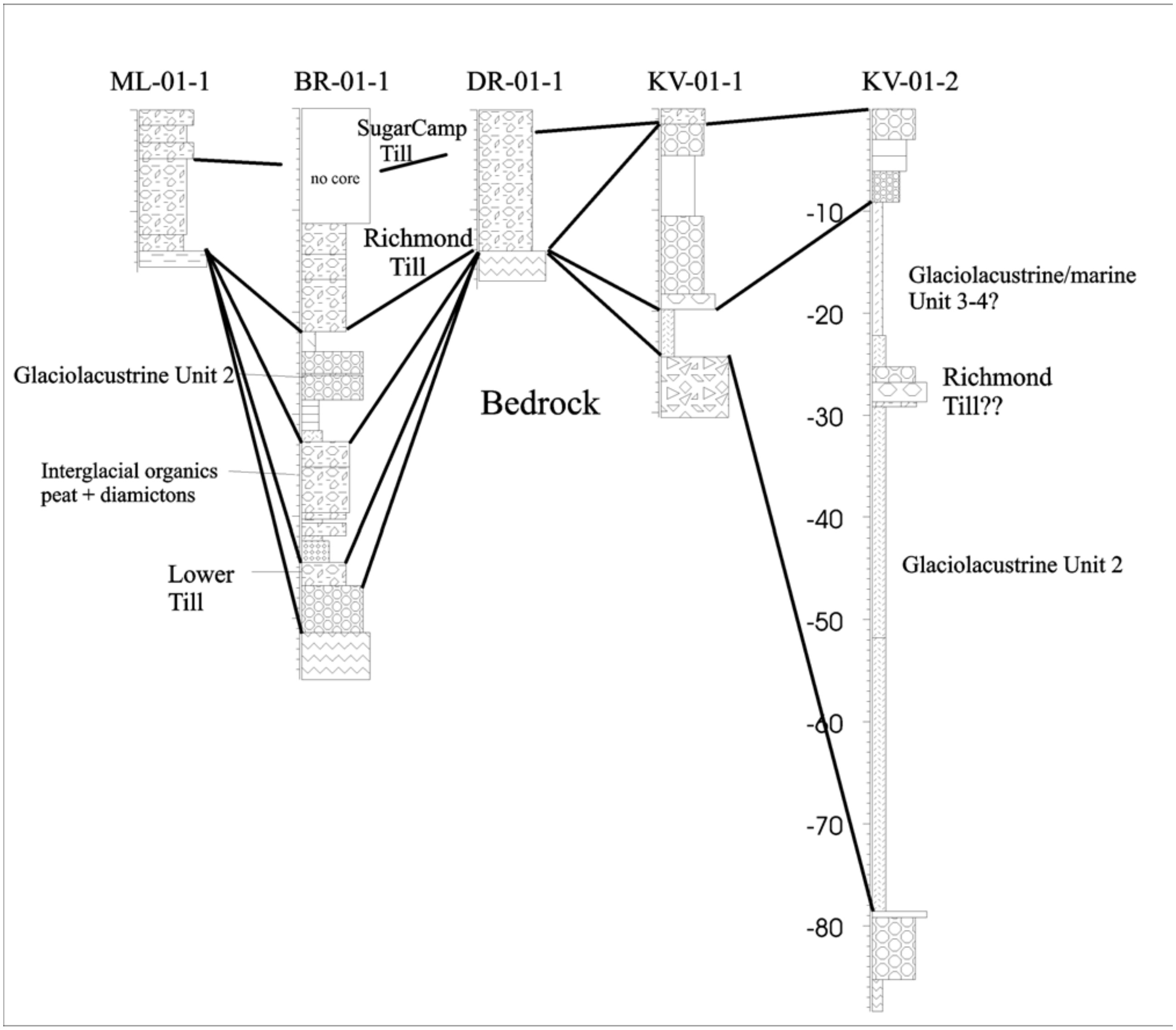


**Figure 9.** Stratigraphy and correlation of TGI drillholes within the River Inhabitants Lowlands (see facies legend, Fig. 3).

gypsum bedrock and develops gradually upsection into a rhythmically laminated silty clay and sand, with calcareous concretions (Fig. 10). This inorganic section is overlain by ~3 m of organic silty clay with layers of peat and woody debris. The interglacial organic horizon with wood fragments represents a marker horizon that can be used to stratigraphically separate similar glaciolacustrine facies.

## Interglacial Peat (Paleosol)

The River Inhabitants section was first described in 1855 by J. W. Dawson and later by Mott and Grant (1985) and Grant (1994). The river is carved into Carboniferous bedrock, except for the vicinity of the section were it has intersected an erosional channel infilled with Quaternary sediment. At the base of the section is a 2-4 m thick package of peat and wood layered with organic silty clay, dipping to the west. The peat layers are deformed, with boudinaged peat lenses (Grant, 1994). The organic zone is overlain and intercalated near the top of the sequence with locally derived, shaly, gravelly sand. Radiocarbon dating of balsam fir in the organic zone yielded an age of >39,000 yr BP (GSC-1402).

At Sugar Camp Quarry an organic zone of variable thicknesses with peat, wood and organic

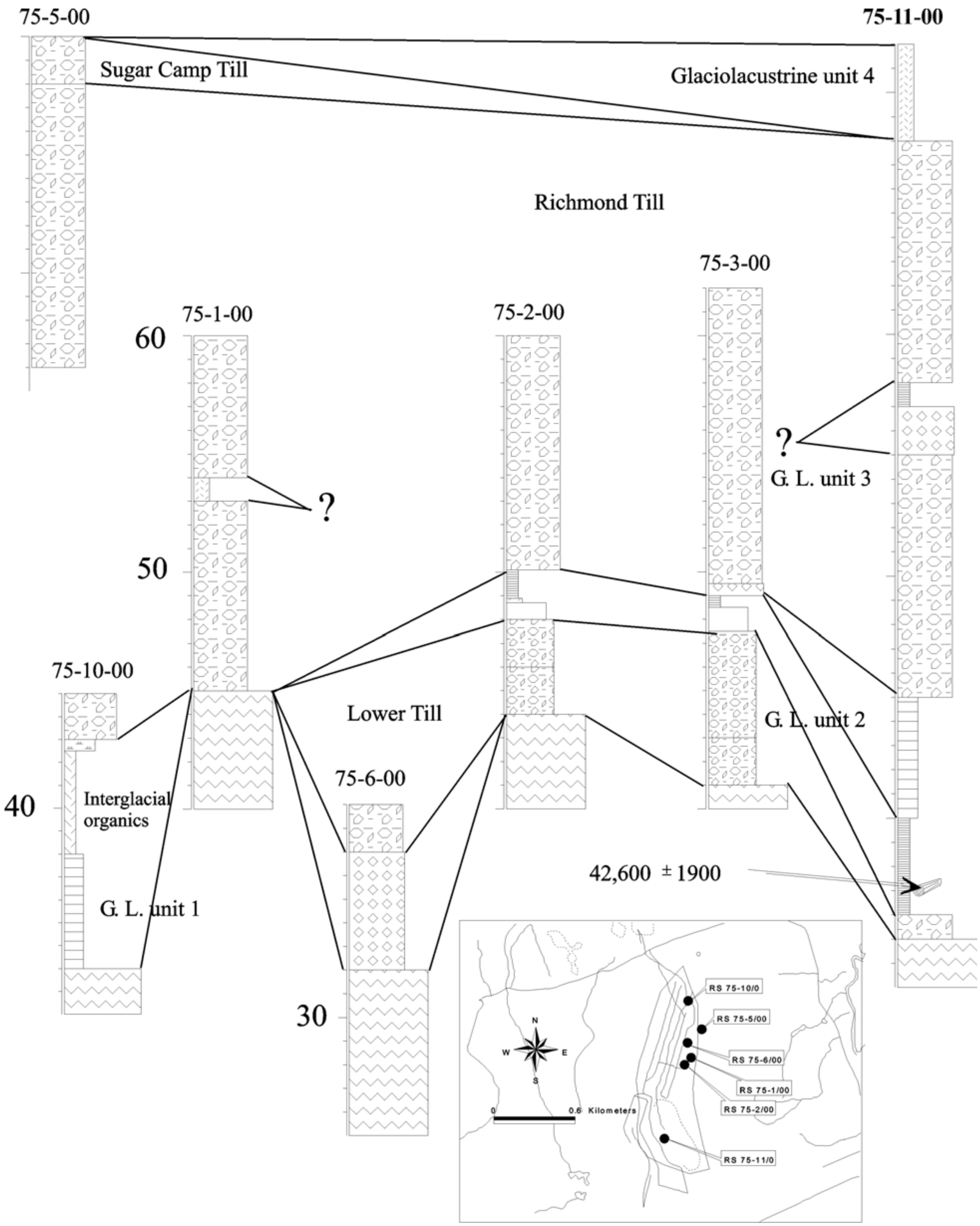


**Figure 10.** Stratigraphic sections from the Sugar Camp quarry (see facies legend, Fig. 3).

clay occurs near the base of the quarry section (e.g. 75-11-00; Fig. 10) both underlain and overlain by glaciolacustrine sediments (Figs. 10, 11). Large pieces of wood were recovered at several sites and identified as spruce *(Picea)* and fir (*Abies)* (R. J. Mott, personal communication, 2001). An accelerator mass spectrometry (AMS) radiocarbon date on one piece of wood produced a finite age of 42,600 ± 1900 yr B P (R. J. Mott, personal communication, 2001).

At the Barbarton Road drillhole section (BR-01–1; Fig. 9, 11) the lowest till unit is overlain by ~5 m of organic diamicton and silty clay, and a thin layer of peat and wood representing a non-glacial interval of unknown duration and paleoclimate. The similarity in stratigraphic sequences strongly suggests a correlation with the nonglacial units at the Sugar Camp and River Inhabitants sections.

## Glaciolacustrine Unit 2

At Sugar Camp Quarry ~4-6 m of rhythmically bedded silty clay and sand overlie interglacial grey organic clay (gyttja?) with wood fragments (Figs. 10, 11). The contact is gradational and conformable with organic grey clay in the rhythmically bedded couplets of coarse and fine sediment, gradually replaced upsection by inorganic reddish-brown silty clay.

Lying above organic diamicton facies in drillhole BR-01-1 is a ~10 m thick package of waterlain sediments and diamictons, beginning with red-brown highly deformed clayey silt, which becomes finely laminated (varved) upsection (Figs. 9, 11).

## Richmond Till

At the Sugar Camp quarry sections a massive grey-red, silty diamicton overlies the organic clay, rhythmites and oxidized sand and gravel with an erosional contact. A stripping wall section reveals a large wedge of Unit 2 intruding the lower organic-bearing diamicton (Unit 1). The massive, silty till has been called Richmond Till by Grant and King (1984), as it forms the core of many large drumlins in Richmond County. At the Sugar Camp quarry the pebble assemblage of the Richmond Till is dominated by grey, green and maroon siltstone, conglomerate, pink and white granite, diorite and gabbro and minor mafic and felsic volcanics. The most likely source area is the Creignish Hills to the west, which host NeoProterozoic granite, diorite and mafic volcanic rocks of the Devonian Fisset Brook Formation. The implied ice movement direction is east-southeastward.

At the Barbarton Road drillhole nearly 10 m of grey-red polymictic, matrix-supported diamicton overlies the organic layers (Figs. 9, 11). The unit is greyish-red and calcareous, with abundant granite, dioritic, and red and grey mudstone clasts, and is correlative with the Richmond Till.

## Glaciolacustrine Unit 3-4(?)

The Kingsville region of the River Inhabitants floodplain is underlain by ~6 m of sand, then nearly 15 m of reddish-brown massive silty clay (KV-01-1; Fig. 9). The stratigraphic position of this unit is unclear, as it overlies a polymictic till correlative with the Richmond Till, but is not apparently overlain by glacial advance deposits. Stream erosion could have removed till from the upper part of the section, making the unit a pre-glaciation deposit, but it is more likely that the unit postdates the last glacial retreat. The conductivity log of KV-01-1 (Fig. 5) shows a peak in the unit greater than 300 mS/m, suggesting brackish formational water within the unit (Douma and Nixon, 1993; Hyde and Hunter, 1998) and may indicate marine influence. An explanation based on underlying salt and gypsum bedrock may not be valid as high pore water conductivity values are not evident lower in the core and in other study boreholes overlying evaporitic bedrock (Fig. 5).

## Sugar Camp Till

At Sugar Camp Quarry a till overlying the Richmond Till (Fig. 10) is similar in texture and colour but can be differentiated from the Richmond Till by the abundance in robust marine shell fragments *(Mercenaria sp?)* and coal clasts. The source of coal is likely to be the upper Port Hood Formation, which outcrops around the south and eastern side of Inhabitants Bay. Shell fragments were described by Grant (1994) in tills along

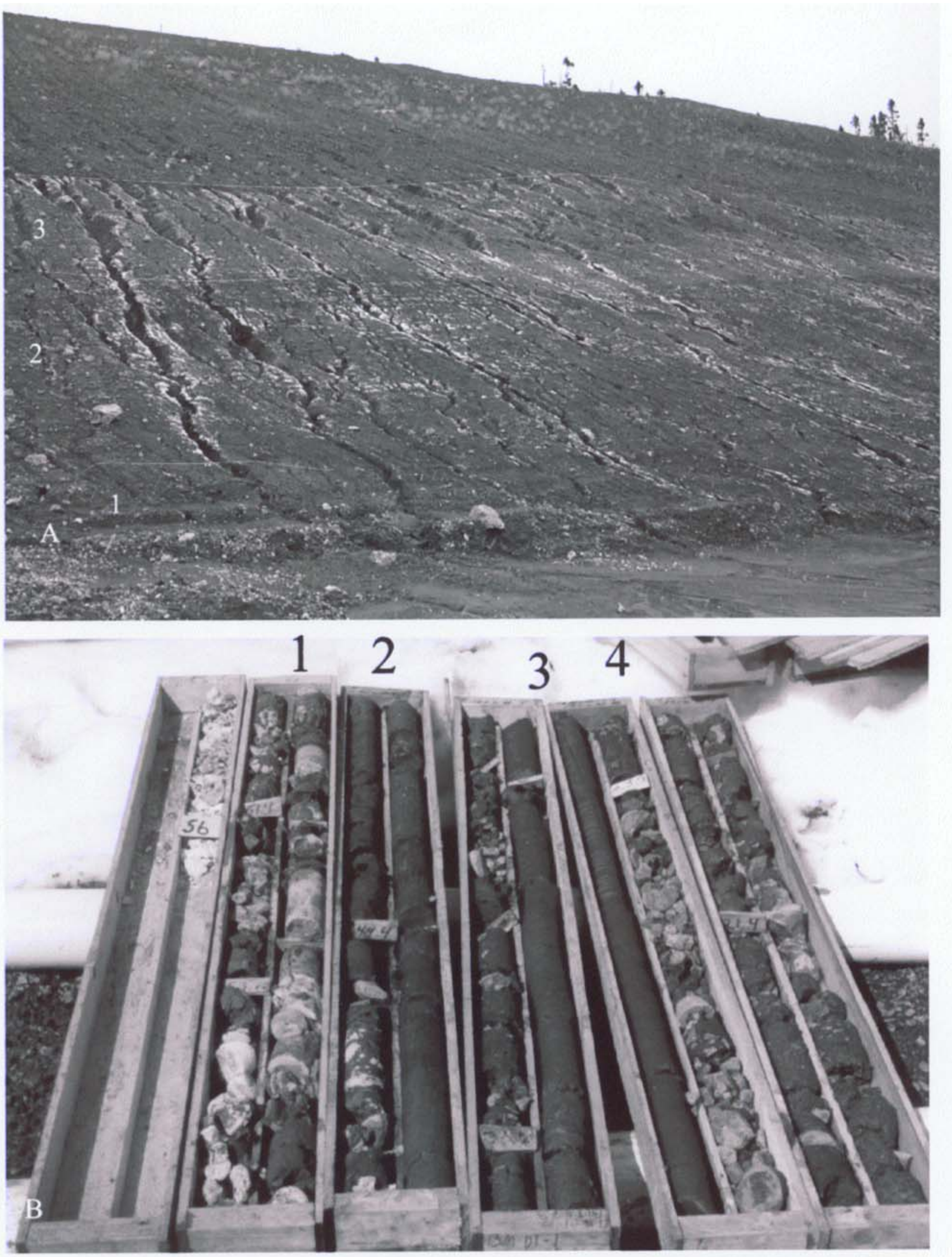


**Figure 11.** Photograph of the: (A) Sugar Camp section (1) lower till, (2) interglacial organic gyttja, (3) glaciolacustrine rhythmites (Unit 2), (4) Richmond Till. (B) Diamond-drill hole BR-01-1 (also see Fig. 9 for stratigraphy) (1) lower till, (2) interglacial peat, organic diamicton, (3) glaciolacustrine unit 2, (4) Richmond/Sugar Camp tills.

Janvrin Island as having been derived from onshore, northwestward ice flow. He also discovered that the shells are a temperate species, derived from interglacial deposits. These shell fragments must have been reworked from offshore marine areas as the Sugar Camp Till does not directly overlie interglacial beds in the study area.

## Glaciolacustrine Unit 4

The uppermost stratigraphic unit at the Sugar Camp Quarry (Fig. 10) is a brown, silty clay (G. L. Unit 4), which is also a widespread surficial deposit throughout the River Inhabitants Lowlands. This fine-grained waterlain unit is interpreted as a glaciolacustrine unit, based on a lack of fossils and the lack of any other evidence of late marine submergence in the area, with the possible exception of a brackish environment in drillhole KV-01-1.

# Interpretation

## Mesozoic and Pre-Quaternary Events

The surficial strata that blanket the valleys and hills in Cape Breton range in age from Early Cretaceous (120 Ma) to recent. The oldest unconsolidated deposits are found in the narrow valley of Diogenes or Glen Brook near River Denys Centre (Fig. 2). These are the youngest pre-Quaternary sediments preserved in the region and should define the age of valley erosion (Goldthwait, 1924, p. 59), assuming that these unconsolidated sediments were deposited in the valleys that they are presently found in. Dickie (1986) noted the correlation of Cretaceous outliers and faults and proposed that the sediments were deposited and preserved in pre-existing fault-bounded valleys or in karst depressions. Using high resolution reflection seismic profiling, Stea and Pullan (2001) demonstrated significant folding and faulting of Early Cretaceous deposits along the Rutherford Road fault zone in the Musquodoboit Valley of mainland Nova Scotia. Faulting of the Diogenes Brook Cretaceous sediments, and other mainland outliers, had been previously noted (Guernsey, 1929; Akande and Zentilli, 1984; Stea and Fowler, 1981) but the significance had not been elaborated. Grant (1994, p. 25) also suggested that the Diogenes Brook outlier was infaulted on a major thrust fault system that forms the contact between the Creignish Hills and River Denys Basin (Lynch and Brisson, 1996). If the Cretaceous sediments were deposited before faulting then the age of the thrust fault can be inferred as post-Early Cretaceous. The relatively young age (Mesozoic-Cenozoic) of basin margin tectonics was used by Stea and Pullan (2001) to develop the argument that most of the present topography is a Mesozoic structural remnant and not due to differential erosion, either by Tertiary fluvial incision and/or glacial erosion (cf. Goldthwait, 1924; Mathews, 1975; Grant, 1994). Recent discoveries of fault-bounded Cretaceous outliers in Antigonish (Stea *et al.,* 1986) and Sussex, New Brunswick (R. Fensome, personal communication, 2003), attest to the regional nature of this tectonic event.

Another important observation is the elevation of the Diogenes Brook outlier, between 100 and 130 m above present sea level. The preservation of this elevated Cretaceous outlier for ~100 million years suggests a substantial cover of post-Early Cretaceous sediment and it is significant that the highest outlier is also apparently the oldest (Dickie, 1986). The inference drawn from this observation is that much more cover had been stripped from this region than at other localities. The lack of a marine or terrestrial Late Cretaceous and Tertiary sedimentary record also implies regional uplift and erosion throughout these time periods, and is further evidence of exhumation of a substantial volume of Mesozoic sediment (Stea and Pullan, 2001). Evidence from thermal maturation studies of lignites (Hacquebard, 1984; Stea *et al.,* 1996) suggests a cover of between 600 m and 1 km, as does forward modelling of apatite fission track data (Arne *et al.,* 1989) assuming a geothermal gradient of 30°C/km. An estimate of cover thickness can be obtained by using an empirically derived Appalachian denudation rate (10 m/Ma; Stanford *et al.,* 2002) and multiplying by the length of erosional time (~100 million years). By this admittedly crude method we estimate a 1 km cover thickness of Early Cretaceous strata.

In summary, the development of uplands and lowlands in Cape Breton was largely a result of

Mesozoic-Cenozoic tectonism and subsequent unroofing of a thick blanket of Mesozoic sediments. Thrust tectonics evident in the Bay of Fundy (Withjack, 1998) and central Nova Scotia (Stea and Pullan, 2001) may be due to plate interactions in Cretaceous-early Tertiary times, when a regional extensional stress regime changed to an ENE-WSW-directed compressional stress field (Faure and Angelier, 1996). Regional uplift and erosion throughout the Tertiary can be explained by lithospheric flexure or forebulge migration due to subsiding offshore basins (King, 1972; Keen and Beaumont, 1990). This flexure model also explains later subsidence (e.g. Grant, 1994) that resulted in the lowering of terrestrial Early Cretaceous outliers in mainland Nova Scotia to well below present sea level (Stea and Pullan, 2001).

## Quaternary Events

During the Quaternary ice sheets advanced and retreated over Cape Breton Island during ~16 major glacial periods over ~2 million years. The record of glaciations however, span only the last 200,000 years of the Quaternary after most of the existing Cretaceous cover was removed, and the exhumed fault valleys began to be excavated by glaciers. The presence of a thick, sandy sediment cover of Mesozoic age may have helped to prevent glacier movement and deposition in the region by shunting basal water away from the incipient ice sheets.

### *Illinoian? Lower Till*

The age of the lower till has not been established directly, but assuming a last interglacial age for the overlying peat/paleosol, it would likely relate to the Illinoian glaciation or Marine Oxygen Isotope Stage 6 (~230 ka). At the Big Brook reference section, wood contained within the lower till could have either been inherited from older interglacial deposits (Yarmouthian?) or more likely tectonically emplaced or overprinted (e.g. Stea and Finck, 2001) into the lower till by glacial tectonics, which are clearly evident at the site.

### *Glacier Lake Grant*

After the Illinoian glacial advance that deposited the lower till, the ice sheet probably receded out of the isostatically depressed Bras d'Or Lakes, leaving a series of interconnected basins either open to the ocean or depending on the rate and mode of retreat, glacial lake basins (cf. Grant, 1994). In the Sugar Camp Quarry, rhythmites interpreted as glacio-lacustrine overlie the lower till and are conformably overlain by organic peat of the last interglacial. They therefore represent the formation of a glacial lake in the River Denys Basin at the end of the Illinoian glaciation. The name Glacial Lake Grant is used to denote this water body, which would have been the oldest precursor of the Bras d'Or Lakes. It is named after Douglas Grant who did much to establish the paleogeography and chronology of ice marginal lakes in Cape Breton.

### *Sangamon Interglaciation (MIS 5) Peat/paleosol and the Middle Wisconsinan Problem*

New specimens of organic material, including peat, organic clay and wood relating to the last interglacial period, were obtained from a drillhole (BR-01-1), the Sugar Camp gypsum quarry reference section and the Ashfield road section. These localities are added to the impressive number of sites in Cape Breton that feature non-glacial sediments of the warm period that pre-dates the Wisconsinan glaciation (Grant, 1994). The reference locality of these interglacial deposits in Cape Breton is at East Bay, where three layers of organics beds interrupted by fluvial gravel deposits record a progressively cooling climate from temperate to boreal/tundra (Mott and Grant, 1986; deVernal *et al.,* 1986; Grant, 1994). Wood from these sites generally produces ages with Carbon 14 activity that is not discernable from background radiation, but there are a growing number of Middle Wisconsinan ages including a finite date in this study of ~42 ka at Sugar Camp Quarry. The validity of these Middle Wisconsinan ages has been challenged based on the potential for contamination by minute quantities of young carbon from rootlets (Mott and Grant, 1986). U/Th disequilibrium dating of wood and peat from these beds has produced ages ranging from ~130 ka to 47 ka (de Vernal *et al.,* 1986), with most of the dates spanning Marine Oxygen Isotope Stage 5 (MIS 5; 128-74 ka). The youngest ages in the sequence were derived from beds where uranium migration is a distinct possibility, hence producing anomalously young ages (Stea *et al.,* 1992). The importance of the youngest ages is that they negate the concept of a significant MIS 4 ice advance in eastern Canada (e.g. Grant and King, 1984), and imply ice free conditions lasting throughout MIS 5, 4 and 3. A possible solution to this problem lies in the application of optically stimulated luminescence dating to interglacial organic gyttja and conformably overlying glaciolacustrine deposits at Sugar Camp. This alternative dating method can be used as a check on the anomalous Mid-Wisconsinan radiocarbon age obtained from the organics.

### *Glacial Lake Cameron*

At Sugar Camp Quarry, rhythmites overlie Sangamon (MIS 5) organic beds. The rhythmites formed in a glacial lake that developed both in the River Denys and in the River Inhabitants Lowlands. A similar concept was proposed by Grant (1994, p. 116) who termed the lake “Glacial Lake Cameron”. Grant’s evidence for the glacial lake in the Bras d’Or lowlands was primarily in coastal sections along East Bay that feature interbedded marine and lacustrine organic clays. Stea *et al.* (2002) interpreted these as interglacial marine deposits. Drillhole BM-01-1 in the River Denys lowlands, however, shows the development of 50-60 m thick deposits of glaciolacustrine clay and silt (GL Unit 1; Fig. 3) after deposition of the lower till. The development of a long-lived glacial lake in the River Denys lowlands, rimmed on three sides by highlands, would require an ice dam in the Bras d’Or Lakes, as was suggested by Grant (1994). The lack of dropstones implies that the ice dam was some distance away, and not in direct contact with the lake, a possibility if glacier expansion was first restricted to the Cape Breton Highlands (Fig. 12).

The concomitant development of a glacial lake predating till deposits in the River Inhabitants lowland, as seen at the Sugar Camp section (Fig. 12), would have to be explained by an ice dam in the lowlands to the south. This lake may not have been synchronous with the lake in the River Denys lowlands in the north, but drainage routes for the southern Glacial Lake Cameron would have presumably been through the northern and southern gaps of the Maple Brook Syncline (Fig. 12).

### *Caledonia Phase*

The first major glacial advance during the Wisconsinan glaciation was toward the east-southeast, depositing a thick silty till termed the Richmond Till (Grant and King, 1984). The provenance and fabric of Richmond Till in the River Denys and River Inhabitants lowlands implies an eastward flow (090°-120°; CP 1; Fig. 12) as does the orientation of drumlinized terrain in that area (Stea *et al.,* 2003). Later ice flow changed to a more southeastward orientation (140°-160°; CP 2; Fig. 12). A correlative silty till forms the core of many drumlins in southeast Cape Breton Island (McClenaghan and DiLabio, 1996; Grant, 1994). Stea *et al.* (1998) designated the early flow as the Caledonia Phase, deriving the term from Rampton *et al.* (1984), who proposed that a major southeast-ward ice flow (140°-160°) crossed the Caledonia Highlands of New Brunswick. Grant (1994) termed these early flow phases Phases B and C in Cape Breton Island. The provenance data from this study suggest that the early eastward flow (Caledonia Phase 1) was more extensive and consistent than in Grant’s (1994) reconstruction, which features a lobe of ice in the south that swings to the northwest in the study area.

Stea *et al.* (1992), Grant (1994) and Stea *et al.* (1998) hypothesized that the Caledonia Phase was initiated by ice growth in the northern Appalachians, perhaps the White Mountains area, an idea first suggested by Chalmers (1895). The extent and duration of the eastward flow event is in doubt, but it appears to have affected much of northern Nova Scotia and southeast New Brunswick (e.g. Rampton *et al.,* 1984; Stea and Finck, 1984) and there is some evidence that it may have affected west-central New Brunswick (Seaman, 2000). It may also be correlative with early eastward flow in northern New Brunswick (Parkhill and Doiron, 2003), which would certainly rule out a Laurentide source. It would seem likely that if the Cape Breton Highlands were a site of glacierization, as postulated by Grant (1994), then the higher northern Appalachians would also have nucleated a large ice sheet.

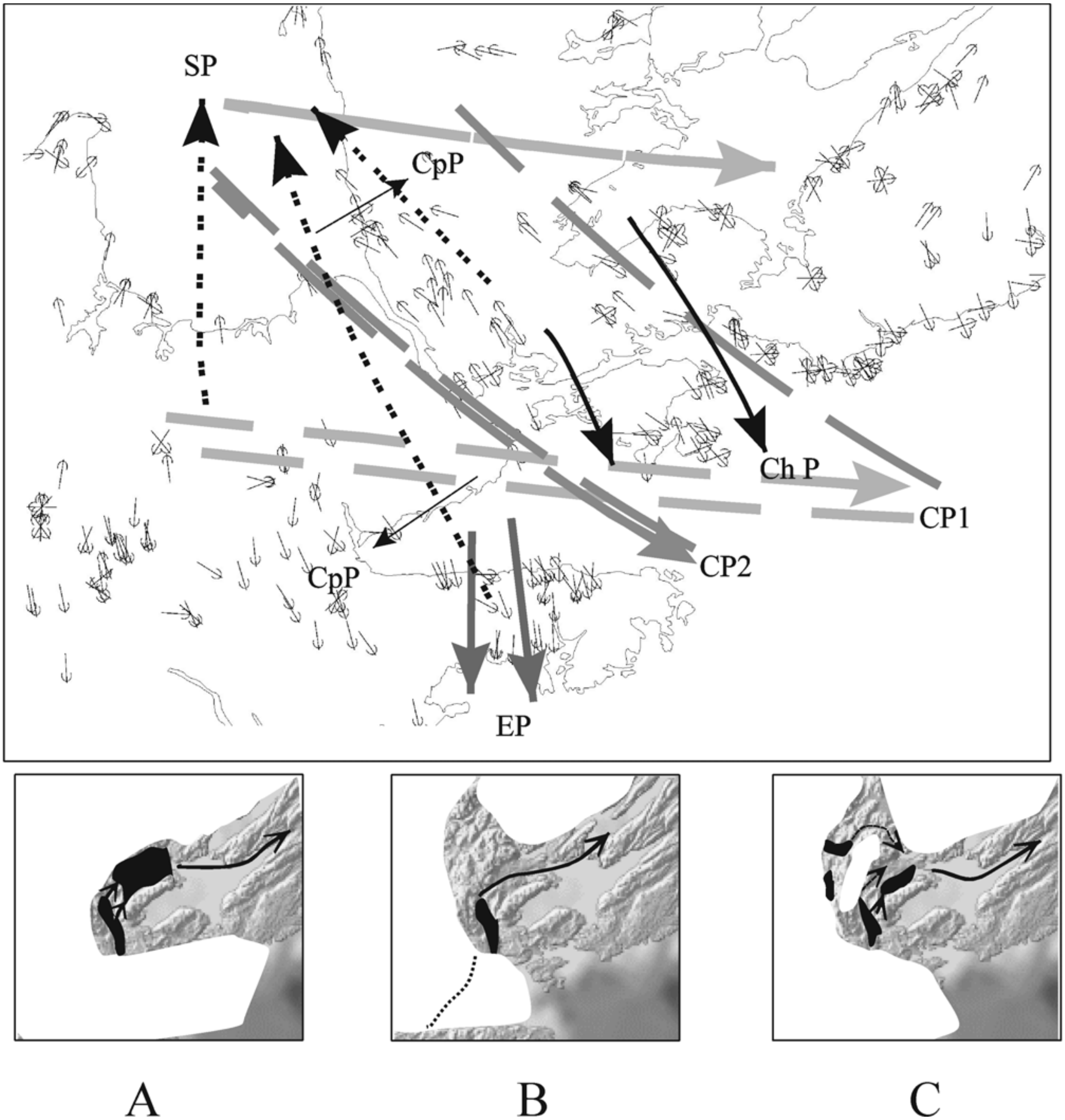


**Figure 12.** (A) Summary of ice flow phases and the development of glacial lakes in the study area. CP1, 2-Caledonia Phase; EP-Escuminac Phase; SP-Scotian Phase; ChP-Chignecto Phase; CpP-Collins Pond Phase. (B) (A) Glacial Lake Grant, Glacial Lake Cameron (1); (B) Glacial Lake Cameron (2). Dotted line represents an ice retreat margin when the lake basin becomes brackish. (C) Glacial Lake Dawson (1). Arrows are meltwater routes.

A later shift to the southeast is well documented by striae and till provenance on mainland Nova Scotia (e.g. Stea *et al.,* 1986; Stea and Finck, 2001), and in Cape Breton (Grant, 1994; Phase C2). McClenaghan and DiLabio (1995, 1996) interpreted the southeast flow phase to be derived from a local ice centre (Escuminac Ice Centre) over the Magdalen Shelf rather than the Laurentide Ice Sheet. A key point is the lack of Laurentide erratics in northern Nova Scotia (Stea *et al.,* 1998) and along the west coast of Cape Breton (Grant, 1994, p. 119). It is hypothesized that the local Appalachian ice caps "held off" the Laurentide ice sheet or directed it into the Laurentian Channel (Prest and Grant, 1969; Grant, 1994).

The age of this event is uncertain, but from the Sugar Camp Quarry section it is apparent that glacial lake development immediately post-dated the last interglacial, and was followed by emplacement of the Richmond Till. Deposits of the last interglacial have been dated by U/Th disequilibrium methods between ~130 and 80 ka (de Vernal *et al.,* 1986), if we discount the anomalous Mid-Wisconsinan ages. This would establish an Early Wisconsinan (MIS 4 ~75-64 ka) age for the till-forming event. A younger, bracketing age may be provided by the Bay St. Lawrence section in northern Cape Breton Island where a marine sand bed dated between 21 ka and 50 ka separates two till-like diamictons (Stea *et al.,* 1992; Grant, 1994; Stea *et al.,* 1998).

### *Glacial Lake Cameron (2)*

At drillhole KV-01-2 a thick sequence of silty clay overlies a till that can be correlated with the Richmond Till (Fig. 9). Evidence of brackish/ marine porewater from the conductivity logs suggests that the clay may have been deposited in a lake/estuary with some connection to the ocean. During the Middle Wisconsinan an ice sheet of considerable thickness was in retreat and at Bay St. Lawrence in northern Cape Breton, a marine shell-bearing sand between tills may represent that period of glaciomarine deposition on a submerged, recently deglaciated landscape. Also, there is no evidence of Late Wisconsinan submergence in the region. It is suggested that the silty clay unit in KV-O1-2 may have been deposited in a transitional glacial lake/glaciomarine estuary environment as ice retreat opened up an outlet to the Atlantic Ocean (Fig. 12). This conclusion is tentative and would have to be verified by age dating.

### *Scotian Phase*

The River Inhabitants and Sugar Camp Quarry sections exhibit two till units that can be related to regional ice flow events, mapped by striae and landform trends. The uppermost Sugar Camp Till unit at the sections provides evidence of a switch to southern provenance with the introduction of coal clasts derived from the Port Hood Formation outcropping around Inhabitants Bay. This flow direction also produced the Creignish Hills Till on the highlands of southwestern Cape Breton Island, associated with ribbed moraine, northwestward-trending striae and meltwater channels (Stea and Feetham, 2003) In southeast Cape Breton, McClenaghan and Dilabio (1995, 1996) clearly demonstrated that a till sheet was formed during this northward ice flow phase.

Northwestward flow across the study area can be traced across 300 m highlands and represents a major glacier flow phase that was directed into the Cape Breton Channel, possibly to merge with Laurentide ice in the Laurentian Channel (Stea *et al.,* 1998). Stea *et al.,* (1998) correlated these flow directions in southern Cape Breton (Grant, 1994; Phase D) with till-forming glacier flow on mainland Nova Scotia, also directed into the Cape Breton Channel through Georges Bay. They termed the event the Scotian Phase.

Stea (1995) and Stea *et al.* (1998) petrologically linked the till in mainland Nova Scotia formed during the Scotian Phase to the Scotian Shelf End Moraine complex which was dated between 15 and 18 ka (~18-21 ka (calibrated age); King, 1996). The extent and elevation of Scotian Phase erosional and depositional landforms is consistent with thick local ice (>1 km) over much of the region.

Till stratigraphy and provenance in mainland Nova Scotia indicate clearly that the main Late Wisconsinan flow that predated the Scotian Phase and extended out to the shelf edge was due to ice flow radiating from a centre in the Magdalen Shelf termed the Escuminac Ice Centre (Stea *et al.,* 1998). It is uncertain whether Escuminac flow was southeastward along a similar path to earlier flows across the island (McClenaghan and DiLabio, 1996), or whether Cape Breton Island was under an ice divide during the Escuminac Phase for part or all of the Late Wisconsinan and only produced southward flow recorded in northern mainland Nova Scotia (Stea *et al.,* 1998). Evidence of southward ice flow on the mainland of Nova Scotia suggests that latter possibility. Vigorous ice flow during the Scotian Phase may have overprinted much of the previously deposited Escuminac Phase till (e.g. Stea and Finck, 2001).

***Chignecto Phase***

Grant (1994) mapped a series of spatially separate glacier flow patterns (Phases E-F-G) that post-date the Scotian Phase. Similarly, Stea and Finck, (1984) mapped a southwestward ice flow phase (Ice Flow Phase 4) that postdates the Scotian Phase, and produced till and eskers in mainland Nova Scotia. Stea *et al.* (1998) termed the event the Chignecto Phase. At several localities southeastward striae (Grant, 1994; Phase E) postdate the strong northwestward flow (Scotian Phase). The youngest till sheet at Mullach Brook (Tang, 1970) and at Big Brook quarry (Fig. 4) may relate to one or more of these late flow phases, but lack of provenance data precludes any conclusions at this time.

The most likely scenario for these discordant flow patterns is a re-organization of ice to local centres and possible re-advances during this phase. The Chignecto Phase southwest flow pattern has been traced to a morainal belt off the eastern shore of mainland Nova Scotia, which was dated between 12.7 ka and 14 ka (~15-16.7 CAL; Stea *et al.,* 1996). Josenhans and Lehman (1999) presented evidence for a significant re-advance in the Cabot Strait ca. 13.2 ka (~15.8 CAL) which (Stea, 2001) linked to local glaciers by pebble lithology.

***Glacial Lake Dawson (1)***

Surface glaciolacustrine clay deposits in the River Inhabitants and River Denys lowlands relate to the retreat of Chignecto Phase glaciers from the Bras d'Or Lowlands. Grant (1994) envisioned remnant ice in the Bras d'Or Lakes and in southern Cape Breton, to explain ice-dammed lakes in these lowlands. The age of these lakes in western Cape Breton is just before 11.8 ka, based on radiocarbon dates of a paleosol overlying silty clay deposited in the lake (Stea and Mott, 1998). Radiocarbon dating of Chase Pond south of the Bras d'Or Lakes suggests an even earlier deglaciation (~13 ka), making a late remnant ice cap in the lakes a remote possibility (Stea and Mott, 1998). Another possibility is that ice remaining over Kelly Mountain, the Boisdale Hills and St. Andrews Channel forced meltwater through a higher outlet at East Bay (Fig. 12C). The elevation of this lake is uncertain, although there are glaciofluvial delta deposits near River Denys at ~30 m elevation (Stea and Feetham, 2003).

***Collins Pond Phase***

Near River Denys Centre a diamicton, possibly till, overlies a peat-paleosol dated to 11.4 ka (~13.4 CAL), suggesting a late re-advance of ice. This event is better represented in western Cape Breton where a glacial lake reformed as ice re-advanced and blocked the Gulf of St. Lawrence meltwater outlets (Stea and Mott, 1998). It is thought that much of the Cape Breton Highlands and the southern Gulf of St. Lawrence harboured a glacier during the Younger Dryas Chronozone (Stea and Mott, 1998).

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