In 1980 the Geological Survey of Canada undertook an acid rain research program on Precambrian terrain in eastern Ontario. The program was designed to investigate those aspects of composition and configuration of glacial and late glacial sediment which bear directly on the sensitivity of the terrain to the effects of acid rain. For this purpose two separate projects were initiated: one to study the subbottom lake sediments using sonar equipment (Klassen and Shilts, 1982; Shilts and Farrell, 1982; Shilts, 1984) and the other to quantify regional variation in drift composition (Shilts, 1982; Kettles and Shilts, 1983a, 1983b).

The impetus for the sonar work was the realization that in studying the potential effects of acid precipitation on aquatic systems, insufficient attention was being paid to the nature and thickness of soft sediments that lie beneath lake floors. Because both organic and inorganic fine grained sediment have high exchange capacity and large internal surface area, they react readily with the excess hydrogen ions accompanying acid precipitation. As a consequence, lakes underlain by a significant amount of fine grained sediment may be better able to buffer the effects of acid loading than lakes without sediment fills.

The second project was undertaken to provide much needed baseline data on patterns of variation in drift composition, which once defined can be used by other environmental scientists attempting to assess the potential effects of acid precipitation. Two groups of compositional characteristics were mapped: (1) texture and carbonate concentrations and (2) concentrations of naturally occurring trace and minor elements. The former serve to buffer acidity and the latter may be released to ground and surface waters in potentially noxious amounts by acid leaching and exchange reactions in areas where they are highly enriched in the drift.

Since this work began other important applications of information obtained from both projects have come to light. Sonar profiling is useful in studying late glacial sedimentation processes, glaciotectionism, paleoseismicity, neotectonism, groundwater processes, and the significance of certain geophysical anomalies in mineral exploration. Drift composition data generated as part of this work (Kettles and Shilts, 1983a) have led to the staking of mineral claims and further mineral exploration work in the Calabogie area.

Results of some of the work carried out near Ottawa as part of these two projects will be shown during this one day field trip. During the morning there will be a demonstration of sonar techniques on Lac Deschenes, a naturally ponded segment of the Ottawa River which is between Ottawa and Arnprior (Fig. L.1). Access to Lac Deschenes will be from the shore on the Pinhey Point Estate, a restored farmstead typical of those built in this area during the 19th century. The afternoon segment of the excursion includes stops to see basal and flow till and glaciofluvial deposits in the Madawaska Highland.

GEOLOGIC SETTING

The Ottawa area is underlain by a variety of chemically dissimilar rock types which makes it an ideal locality for research on the effects of acid rain. The Laurentian Highlands to the north, Madawaska Highland to the west and the Frontenac Arch or Axis to the south of Ottawa are underlain by Precambrian age granite, gneiss, metavolcanic rocks and belts of metasedimentary clastic and carbonate rock (Baer et al., 1977, Fig. 1). These areas are all part of the Canadian Shield. The Frontenac Arch is flanked on both the Ottawa Valley and Lake Ontario sides by unmetamorphosed, relatively flat-lying, largely calcareous Paleozoic sedimentary rock of the St. Lawrence Lowland.
Stratigraphically, only one unit of till is associated with the last (Wisconsinan) expansion of the Laurentide Ice Sheet in the area (Gadd, 1962; Richard, 1975). It forms a persistent, but relatively thin cover over both Precambrian and Paleozoic bedrock of the region and is thickest in depressions, along valley walls, and on the up-ice side of bedrock ridges. Predominant ice flow direction across the Ottawa region during the single Wisconsin stade recognized in the region, was south to south-southwestward. During the last stages of glaciation, a topographically deflected south-southeastward flowing lobe of ice retreated northwestward up the Ottawa Valley (Fig. 2). By 12 ka much of the area was inundated by the Champlain Sea which extended up the St. Lawrence and Ottawa Valleys (Richard, 1975; Gadd, 1980a).

Till is the most common surface deposit above 100 metres altitude in the area. Below 100 metres marine silty clay predominates, although marine limit is locally as high as 175 metres (Fig. 3). Above about 175 metres thick sequence of till, outwash, and kame-like ice contact gravels are common in the valleys of the Madawaska Highland.

Stop L-1: Lac Deschenes

South shore of Lac Deschenes on the Pinhey Point Estate which is located 1 km north of Berry Side Road which can be reached by taking Riddell Drive (becomes Regional Road 109) from near the corner of March Road and Dunrobin Road; Figure L.1; map 31 G/5; G.R. 255 320.

The level of Lac Deschenes (Fig. L.2) is controlled by a low ridge of Paleozoic sedimentary rock at Deschenes Rapids. Research first began in this lake because, as the largest basin containing a significant amount of acoustically transparent sediment fill in the Ottawa area, it is a convenient testing site for sonar equipment and techniques. As a result it is one of the best studied lakes in this region. In addition to abundant sonar profiles, a 30 and a 40 metre core of fine grained marine and freshwater sediment were obtained from this lake. Microfauna, chemistry, mineralogy, and texture of these cores have been studied in detail.

Subbottom sediment profiles were obtained using portable, low-frequency sonar equipment, deployed from a small inflatable boat as shown in Figure L.3 (Larocque and Shilts, in press). The system operates at either 3.5 or 7.0 kHz frequency and is powered by a standard 12 volt car battery. The transducer emits a low-frequency acoustic pulse which travels through the water column. When the pulse comes into contact with a medium of different density, for example, the sediment surface, some of the sound energy is reflected and some continues through the sediment. The travel time of the reflected pulse is measured and automatically converted to a trace on a strip chart that represents the depth of the reflecting surface. The record of these successive pulses on the moving chart produces profiles of the lake bottom and subbottom. The quality of the records depends mainly on the physical and chemical characteristics of the
sediments underlying the lake; the low frequencies of the system are especially suited to penetrating soft muddy sediments.

A series of profiles from the northern part of the lake are shown in Figure L.4 (Shilts, 1984). Two acoustically distinct units labelled "A" and "B" on Profile 2-5 can be traced over the entire lake basin. Core from the boreholes contained a layer of dense compact silty clay about 1 metre thick at the same depth that the distinct break between the acoustically laminated (B) and un laminated (A) units occurs. The remainder of the core was comprised of less dense un laminated to faintly laminated silty clay. Results of laboratory analyses showed that the marker layer is sandy, carbonate-rich and marks the transition between lower marine sediment carrying microfauna, indicating a high salinity environment, and upper-estuarine sediment, carrying microfauna that indicate progressively less saline conditions upward. Some trace elements and chloride concentration analyses also reflect this change.

All sediment but the thin (1-3 m) uppermost freshwater layer in the core is thought to have been deposited in the Champlain Sea between 12 and 10 ka. Rodrigues was able to distinguish from the microfaunal record the following depositional paleoenvironments, from bottom to top: (1) low salinity, (2) lower high salinity, (3) upper high salinity, (4) transition, and (5) low salinity. The lowermost low salinity environments of deposition probably formed when glacier ice stood in the sea, providing particularly large quantities of glacial meltwater. Later, from 11 to 10 ka glacial Lakes Algonquin and Barlow-Ojibway drained into the Ottawa Valley and this part of the Champlain Sea (Prest, 1970) contributing much freshwater at a time when relative sea level was falling, creating more estuarine conditions in this part of the Ottawa Valley.

The parallel reflectors which give the sediment package its laminated appearance in the records are caused by acoustic impedance differences related to differences in density among sedimentation units that make up the basin fill. The physical differences are in many places so slight that they cannot be related easily to visual or measurable properties of the cores. Each reflecting interface absorbs some of the acoustic energy so that the parallel reflectors generally become less distinct with increasing depth. The major acoustic reflector that marks the transition from open ocean, high salinity conditions to low salinity estuarine conditions absorbs so much energy that parallel reflectors below it are rarely well represented on the records.
These profiles from Lac Deschênes reveal unexpected geologic features in the northern part of the lake basin. A major channel labelled “C” in Figure L.4, which has formed since the deposition of units “A” and “B”, extends at least 8 kilometres along the western shore of the lake, and numerous small channels, some of which are labelled “D”, cut the flat surface of laminated sediment (B). The large channel is about 13 m deep at its eastern end and deepens westward to more than 40 m west of Dunrobin. It is floored by more than 2 m of sediment that is generally acoustically transparent (fine grained) and is presently a site of deposition rather than erosion. Its southern side is commonly a steep bedrock wall which extends for 5 metres or more above water level as low cliffs exposing Paleozoic bedrock.

How these channels formed is a mystery. The small ones may have been formed by ice scour while the large one may have cut through the underlying sediment during periods of increased water flow out of a major proglacial lake such as Lake Algonquin in the upper Ottawa Valley. A possible but controversial explanation, is that they all formed during a period of subaerial exposure before flooding of this part of the valley to form Lac Deschênes. If they were excavated in such a manner, their formation has important implications, with respect to postglacial history of the area. It suggests that this segment of the Ottawa Valley has been tilted down to the west, at right angles to the regional pattern of glaciotectonic uplift (Fulton and Richard, in press). If this hypothesis could be substantiated, it would mean that the Ottawa Valley has been subjected to major neotectonic movement. It is impossible to deduce from the information presently available whether such movement might have occurred during a short period or would have been ongoing. Several inferences from the sonar records support the conclusion that channels cut in the lake bottom were submerged and that this area has been tilted in postglacial time:

1. The major channel is cut into postglacial marine sediments which have bedding that intersects its side in a horizontal attitude (it therefore cannot be a hollow formed by sediment collapse over buried ice).
2. The major channel is cut over 45 m below the present bedrock barrier which controls the level of Lac Deschênes.
3. The major channel is presently the site of sediment deposition, suggesting that the current which cut it is not presently active.
Lac Deschénes

Figure L.4: Sonar profiles of Lac Deschénes west of Aylmer Island. Profiles are arranged from southeast (top) to northwest (bottom). See Figure L.2 for locations. A, B, C, and D are features mentioned in text (Stop L-1)
4. The channel deepens to the west, at a gradient opposite to the flow of the river.

5. The small channels that are cut into the flat surface of the laminated sediments are of a size and spacing reminiscent of gullies presently being cut into similar sediment onshore.

6. The small channels are draped by a sediment layer similar to that occurring in the large channel, suggesting that the forces that cut them are not presently active.

**Stop L-2: Burnstown Section**

*River bank cut immediately east of bridge of County Road 20, on south side of Madawaska River at Burnstown; Figure L.1; map 31 F/7; G.R. 766 267.*

The Burnstown Section is one of the best exposures of till in the Ottawa area. Exposures, some of which are over 20 metres high, consist of compact sandy till with sand bodies filling an angular pattern of fractures. At the base of the exposures the till is grey and it is leached and oxidized only in its upper metre. Disintegrated boulders of crystalline bedrock and marble may be found throughout the exposure. How these erratics came to be disaggregated is unknown. Unaltered, apparently similar lithologies appear to occur side-by-side with disaggregated clasts. Even though Precambrian marble and gneissic rock are exposed near the bridge, the till contains abundant erratics of Paleozoic sedimentary rock as well as those lithologies common to the Canadian Shield in this area.

No detailed sedimentological analysis of the till has been undertaken but it is thought to be part of a basal facies. It is very compact and is characterized by a lack of flow structures or other signs of soft sediment deformation. In addition some of the Paleozoic erratics examined within the till were found to have elongate tails radiating out in opposite directions on their top and bottom surfaces from small protrusions of more resistant material (rat-tail striae). Similarly oriented striae on pebbles of chromite-bearing serpentinized peridotite were previously discovered in till in some exposures in the Appalachian Highlands of Quebec. These striae are thought to have formed by differential movement within the debris-rich zone at the base of the glacier.

Samples collected in profile from this section were analysed for texture (finer than 2 mm), and their content of trace elements (finer than 2 µm), carbonate (finer than 63 µm) and Paleozoic granules and small pebbles (2-6 mm). The grain size composition was analyzed using standard sieve and hydrometer methods while carbonate concentrations were determined using Leco carbon analyzer (Foscolos and Barefoot, 1970). Trace element contents were determined using atomic absorption spectroscopy techniques for Cu, Pb, Zn, Co, Ni, Ag, Cr, Mo, Mn, Fe, Cd and Hg, colorimetric methods for As, and fluorometric techniques for U (Levinson, 1974). The component of Paleozoic rocks was separated from clasts of other compositions of the 2-6 mm fraction and its weight percent calculated.

Results (Table L.1) indicate that except for sample K which was collected in very oxidized till within a metre of the surface, chemical and textural composition varies little over the exposure. Much of the carbonate in the till is thought to be derived from Paleozoic limestone and dolomite underlying the St. Lawrence Lowlands to the east (Shilts, 1982; Kettles and Shilts, 1983b). Although there are marble erratics in the till and small outcrops of marble in the area, the one till sample at this section for which data are available contained 32% Paleozoic erratics compared to 11.5% marble. Similar concentrations of each were found at many other sections in the area. The flat-laying, thin-bedded, heavily jointed and therefore easily eroded Paleozoic sedimentary rocks of the St. Lawrence Lowlands provided a much larger volume of carbonate debris to the glacier than did the areally less significant, massive, coarsely crystalline outcrops of marble which underlie parts of the Canadian Shield.

Some work on chemical partitioning in till was undertaken for one sample from this section. To study carbonate partitioning the sample was divided into finer than 2 µm, 20-44 µm, 44-63 µm, .063-.125 mm, .125-.250 mm, .250-1.0 mm and 1.0-2.0 mm size fractions and analysed using the Leco technique. The variation of carbonate concentrations in the different fractions of till are illustrated in Figure L.5 which also contains results for till from near Thetford Mines in the Appalachian Highlands of Quebec for comparison (Shilts, 1982). Carbonate concentrations are relatively high in the gravel and silt sizes for both areas. Medium and fine sand size fractions of till from both sites contain roughly half as much carbonate as do the gravel and silt sizes. These results are predicted by the terminal mode concept of Dreimanis and Vagners (1971) which suggests that glacial crushing and abrasion produce a bimodal size distribution of carbonate minerals, a phenomenon related to the physical characteristics both of the carbonate minerals and of the rocks in which they occur. In the clay-size fraction, however, carbonate concentrations differ markedly between the two sections – levels decrease in the Thetford Mines section as would be expected with the terminal mode concept but increase sharply at the Burnstown section (Shilts, 1982). The high carbonate concentrations in the clay separated by centrifuging Burnstown till may be related to the presence of relatively large (coarser than 5 mm) carbonate-cemented aggregates of clay particles which were found to have stayed in suspension in the centrifuge decantate. Whatever the reason for their failure to sediment during centrifuging, their presence (determined through examining with a scanning electron microscope with X-ray dispersive capability) suggests that post- or syn-depositional precipitation of carbonate from ground or meltwater is at least in part responsible for the anomalous carbonate enrichment in the clay fraction. As a result, the total carbonate content of the Burnstown tills may not be solely the product of
Table L.1. Table of trace elements (finer than 2 µm), texture (finer than 2 µm) and carbonate (finer than .063 mm). Data from Burnstown Section and Black Donald Lake Pit.

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<th>Pb (ppm)</th>
<th>Zn (ppm)</th>
<th>Co (ppm)</th>
<th>Ni (ppm)</th>
<th>Ag (ppm)</th>
<th>Cr (ppm)</th>
<th>Mn (ppm)</th>
<th>Fe (ppm)</th>
<th>Cd (ppm)</th>
<th>As (ppm)</th>
<th>Hg (ppb)</th>
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<th>Texture*</th>
<th>Carbonate Composition**</th>
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*Texture: sand - 2.0 -.063 mm; silt - .063 -.004 mm; clay - <.004 mm
**Carbonate composition: silt plus clay - <.063 mm; fine sand - .25 - .125 mm

Samples from Burnstown Section and Black Donald Lake Pit are referred to as SAR0027 and SAR0042, respectively, in Kettles and Shilts (1983a).
Figure L.5: Distribution of carbonate (%CaCO₃ equivalent) in various size fractions of till with moderate (Burnstown) and low (Thetford Mines) carbonate concentration. Samples collected at ca. 3 m vertical intervals in Burnstown Section, at ca. 1 m intervals in section at Thetford Mines. Samples from Burnstown section are referred to as SAR0027 in Kettles and Shilts (1983).

glacial dispersal of clastic carbonate, as seems to be the cause with Appalachian tills, but may include a secondary component produced by chemical precipitation from groundwater circulation. The secondary chemical component is only important in analysis of separates containing the finest size fractions, such as the finer than 63 μm fraction. One possibility that should be further investigated is that the carbonate may be precipitated preferentially at the face of the exposure, a phenomenon observed on gravel pit faces in the region.

Trace element partitioning is discussed in the write-up for Stop L-5.

Stop L-3: Grassy Bay Pit

Small gravel pit 200 m south of Berryvale Road on an unnamed road that is 3.3 km west of Highway 511. Berryvale Road is 3.5 km south of Calabogie; Figure L.1; map 31 F/7, G.R. 655 136.

This pit has been excavated in bouldery gravels that were part of a late glacial ice contact delta or fan built at the ice front of a glacier retreating while standing in the Champlain Sea. This situation is considered to have been similar to those described in the Ottawa area by Rust and Romanelli (1975) and Cheel (1982). At this site meltwater drained out of the more rugged hills to the south into a late or postglacial higher level water body (marine?) in the Calabogie Lake basin.

Present in the gravels in the upper part of the pit are several large balls (.5 metres in diameter) of fine-grained, tough olive grey till, which contain a suite of erratics comprised largely of Paleozoic limestone (66%). The Paleozoic limestone erratics that occur within the gravels of the pit, comprise a smaller percentage of the total number of clasts – 48%. The higher incidence of Paleozoic erratics and the fine texture of the till in the balls compared to that in other nearby exposures suggest that the till in these balls was derived from a different source. For the balls of till to be preserved at all means that they were moved only short distances by water before being redeposited. The work of Lumbers (1982) indicates that there is a Paleozoic outlier on the southeast side of Calabogie Lake. It is possible the till in the balls was derived predominantly from this small local source. At the time of writing, however, no further work has been undertaken to test this idea or to determine other reasons for this compositional disparity.
Stop L-4: Black Donald Lake Pit

Borrow pit on the northwest side of the Graphite Bay Road; 0.6 km northwest of junction with Black Donald Hydro Dam Road; which is 14 km west of Calabogie on Highway 508; Figure L.1; map 31 F/2, G.R. 505 074.

This pit is located on an ice contact (?) terrace which for several kilometres follows a narrow abandoned drainage way which linked a narrow arm on the south shore of Black Donald Lake to the Madawaska River near the inlet at Norcan Lake. Exposed sediment in the pit consists of 1.5 metres of grey fissile till overlying at least 7 metres of light grey medium grained cross-bedded sand. Such thick sediment sequences characterize the valleys of the Madawaska Highland and like this one frequently take the form of ice-contact terraces along valley sides.

Although the till in this pit may have been deposited by ice overriding the underlying gravel it more likely was emplaced by the flow of glacial debris off ice. If ice had overridden the gravels it is unlikely that the terrace form of the deposit would have been preserved. Similar mantles of till-like diamicton are frequently found at the surface, or more rarely interbedded with sand and gravel, in many pits in the area. Commonly these till-like diamictons contain sedimentological structures that clearly indicate that the material flowed from ice onto or into the deposit. Flows of till are thought to have been relatively common events during deglaciation. Most flows however were reworked by later glaciofluvial action. Flows are in many places found overlying glaciofluvial deposits. This last flow is commonly preserved because it occurred after the ice walls which confined the waters which deposited the gravels melted back far enough to cause the water flow to be dissipated over a large area, allowing the last mudflow to be preserved. The prevalence of flow or remobilized till in glaciofluvial deposits supports the idea that much of the till at the surface in this area is composed of similar flows. However it is difficult to classify this as flow till because the material cannot clearly be related to a specific near-glacier sedimentary environment.

Samples from this section were analysed for texture and their contents of trace elements, carbonate and Paleozoic erratics using the methods previously described (Table L.1). Because concentrations of zinc in the clay fraction of till at this section is high (650 ppm) some trace element partitioning work was undertaken for one till sample from this section as well as another from the Burnstown Section. Bulk sample finer than 6 mm was fractionated into the following size fractions – finer than 1 µm, 1-4 µm, 4-44 µm, 44 µm-.250 mm, .25-2.0 mm, 2-6 mm and finer than 6 mm (bulk) – and analyzed after treatment with total (HF) leach. Results from both sites indicate that concentrations of zinc and most other trace elements are several to many times higher in material finer than 4 µm. This fraction comprises predominantly phyllosilicates and, in weathered samples, secondary clays, Fe and Mn-oxides-hydroxides (Table L.2).

For comparison the two finest fractions – finer than 1 µm and 1-4 µm were also analyzed using a hot leach (HNO₃-HCl) and two cold partial leaches (ammonium citrate and sodium dithionate). This hot leach is used routinely for trace element analyses by Quaternary geologists at the Geological Survey of Canada. The first partial leach removes easily soluble metals from clays while the second breaks down poorly crystallized Fe oxy-hydroxides without affecting colloidal aluminosilicates. Results (Table L.2) obtained using the hot leach were similar to those obtained using the total (HF) leach. In contrast, only a small percentage (less than 10%) of the metals stripped using HF and HNO₃-HCl leaches were stripped off using either partial leach. This indicates that in these samples, as well as in several dozen others for which partitioning studies have been carried out, most of the metals found in the clay-sized fraction are tied up within the structure of the aluminosilicate minerals.
Table L.2. Table of trace element partitioning data for Burnstown Section and Black Donald Lake Pit.

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<th>Cr</th>
<th>Fe</th>
<th>Mg</th>
<th>Mn</th>
<th>Ni</th>
<th>Pb</th>
<th>Zn</th>
<th>Cu</th>
<th>As</th>
<th>Cd</th>
<th>Hg</th>
<th>Ba</th>
<th>Cr</th>
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Note: Samples from Burnstown Section and Black Donald Lake Pit are referred to as SAR0027 and SAR0042, respectively, in Kettle and Shilts (1986).
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Canada Soil Survey Committee.

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