INTRODUCTION

The Geological Survey of Canada carried out a program of systematic till sampling in the Ottawa area from 1980-1984 (Shilts, 1982; Kettles and Shilts, 1983). The project was designed to quantify regional variations in drift composition in order to provide baseline data that might be used in assessing the effects of acid rain. For this purpose two groups of compositional characteristics of till were mapped: (1) texture and carbonate composition (the buffering components) and (2) concentrations of naturally occurring trace and minor elements (potential sources of environmental contamination if released by acid leaching or by exchange reactions with groundwater). Till was observed at and collected from more than 1500 man-made and natural exposures along roads and streams and also from sand and gravel pits. Information obtained from this study pertaining to sedimentary characteristics and mineralogical composition of till are discussed in this report.

Bedrock geology

The till of the Ottawa and surrounding regions has inherited most of its physical and lithological properties from erosion of two contrasting bedrock lithologies. Precambrian metasediments and igneous rocks (Baer et al., 1977), referred to collectively as "crystalline" bedrock, underlie much of the area and are characterized by massive outcrops and sharp but low relief. Relatively flat-lying Paleozoic sedimentary rocks, dominated by carbonate lithologies, form flaggy outcrops in Ottawa Valley and east and west of Thousand Islands in the Central and West St. Lawrence Lowlands (Bostock, 1970; Fig. 2). Most Precambrian rocks are part of the Central Metasedimentary Belt of the Grenville Structural Province. This is characterized by extensive areas of carbonate metasediments (outlined in Fig. 6), felsic (less commonly mafic) plutons, and belts of metavolcanic and noncalcarenous metasedimentary rocks. The Central Metasedimentary Belt includes the Frontenac Arch, a prominent geological structure that connects the main body of the Canadian Shield in the north to the Adirondack Mountains south of St. Lawrence River (Fig. 2). The remainder of the crystalline terrain comprises gneisses of the Ontario Gneiss Belt.

Glacial geology

The predominant ice flow direction across the Ottawa region during the Late Wisconsinan was southerly down Gatineau River valley in Quebec and south-southwest over the southwestern part of the area (Fig. 3). During the last stages of glaciation, one lobe of ice flowed southwestward, retreating from Lake Ontario towards St. Lawrence Valley and another flowed south-southeastward and retreated up the Ottawa Valley (Richard, 1973a; Gadd, 1980a).

Figure 6. Map of carbonate (CaCO₃ equivalent) concentrations in silt and clay (<64 μm) fractions of till in the Ottawa region.
Stratigraphically, only one unit of till, which is associated with the last (Late Wisconsinan) glacial expansion of the Laurentide Ice Sheet, has been identified in the areas sampled (Gadd, 1963; Richard, 1975a). This till was referred to as Fort Covington till in the Merrickville map area at the eastern edge of the area covered by this work (Sharpe, 1979). It forms a persistent, but thin cover (<5 m) over both Precambrian and Paleozoic bedrock of the region but can be thicker in depressions, along valley walls, and on the up-ice side of bedrock ridges. Till is the most common surface deposit, except below 200 m elevation along Ottawa and St. Lawrence valleys where marine and lacustrine sediments predominate.

TILL SEDIMENTOLOGY

Sedimentary characteristics of till

The till of the Ottawa region is stony and sandy, similar to Canadian Shield tills in many other areas. The average texture of the <2 mm fraction of more than 800 samples is 67% sand (2 mm-64 µm), 26% silt (64-4 µm), and 7% clay (<4 µm) with ranges of 34-97%, 2-55%, and 1-29%, respectively (Fig. 7). In shallow exposures till is typically not very compact and fractures into small (<1 cm) angular "chunks" composed of sand and granules with a cohesive silt-clay matrix. In deeper exposures, till of similar texture can be fairly compact, but the origin of its compactness cannot be ascribed confidently to its mode of deposition. Increasing compactness with depth may simply reflect compaction by the overlying sediment combined with desiccation on exposure to the air.

In good near-surface exposures, till usually can be seen to contain stringers or clasts of water-sorted sediment, suggesting that it was emplaced by slumping or melting from a supraglacial position (Boulton and Deynoux, 1981). In deeper sections, the compactness, faint evidence of subhorizontal discontinuities, interbedded waterlaid sediments, and sediment-filled reticulate fractures may indicate that till melted out from a subglacial or englacial position, possibly from stagnant ice.

In many pits the surface of ice contact gravels and sands is mantled by a till-like diamicton which contains structures and has a distribution that indicates that the material flowed from ice onto or into the deposit. Because this "flow till" is present in or on so many glaciofluvial deposits, it probably also is present at the surface of much of the rest of the area. This diamicton, however, can only be recognized as a distinct deposit where it overlies sorted sediments.

Till composition

Carbonate minerals. The distribution pattern of carbonate minerals in till (Fig. 6) is determined from carbonate content of the silt plus clay-sized (<64 µm) fraction. Carbonate content was determined using a Leco carbon analyzer to measure carbon concentrations which were converted to %CaCO₃ equivalent. The distribution patterns of carbonate in the fine sand fraction (64-250 µm) and weight per cent Paleozoic limestone and dolomite erratics in the total granule (2-6 mm) fraction produce patterns that have similar configurations.

The geographic distribution of till characteristics may be divided into three zones (Fig. 6) based on carbonate content of till matrix and on the structure and lithology of underlying bedrock: 1) Low lying areas east and south of the Frontenac Arch which are underlain by flat-lying Paleozoic rocks characterized by a basal quartz sandstone overlain by carbonates with minor shales. The carbonate content of the silt-clay fraction of till in this region is high (generally >10%). 2) The Gatineau River valley region of Quebec and an area which extends southwestward across the western part of the Frontenac Arch from Barry's Bay to Minden (Gatineau-Minden area). This zone is underlain by crystalline bedrock of the Central Metasedimentary Belt and the Ontario Gneiss Belt. Till in this region has low carbonate content (<5% and commonly <2%) even where it overlies areas underlain by marble. 3) The eastern and southern parts of the Frontenac Arch, which are also underlain by lithologies similar to those underlying Zone 2 but in this area the carbonate content of till is high (>5% and commonly >15%).

Texture. Textural analyses of samples collected in each of the three zones have been plotted on ternary diagrams (Fig. 7). The low carbonate till of the Gatineau and Minden areas (Zone 2) generally has a smaller component of silt and clay-sized material than carbonate-rich till from the other two areas. There appears to be little difference in sand-silt-clay ratios between carbonate-rich till overlying the Paleozoic sedimentary rocks (Zone 1) and carbonate-rich tills overlying Precambrian crystalline rocks (Zone 3).

Figure 7. Ternary diagrams showing the texture of the <2 mm fraction of tills in the Ottawa region. Zones refer to areas outlined in Fig. 6.
Trace elements. The clay-sized (<4 μm) fraction of till has been analyzed for 14 trace and minor elements (Kettles and Shilts, 1983). With the possible exception of U (not shown here), the geographic distribution of trace element characteristics in till appears related to underlying bedrock and does not correspond to the distribution patterns of texture and carbonate concentrations. The lowest concentrations of U appear to be associated with carbonate-rich till of the first and second zones.

On a regional scale, high levels of various elements are preferentially associated with the Frontenac Arch. High levels of Zn, As, Fe, Pb, Mn, Cd, Mo, Hg, and sometimes Co are related to the northeast-southwest striking belts of metasedimentary and metavolcanic rocks, whereas others such as Cu, Cr, and Ni are commonly associated with some large basic plutons which are also part of the Arch.

The dispersal of arsenic in till will be discussed here because its provenance can be related easily to geological features within the region. Major areas of arsenic-enriched till occur within a triangle, the apices of which are the towns of Flower Station, Coe Hill, and Madoc (Fig. 8). This triangle encompasses the original Ontario gold mining belt that was the site of active mining of arsenical gold in the late 1800s and early 1900s. The areas of As enrichment outline metasedimentary and metavolcanic belts within shear zones and fractures contain abundant deposits of arsenic sulphides, some of which are host to gold-bearing veins (Carter et al., 1980).

Weathering and postdepositional modification. The postglacial soil profile is commonly about 1 m thick. Below this, till usually shows some evidence of minor weathering such as a tan (presumably oxidized) colour, staining from iron and manganese oxide precipitates, and the common presence of disaggregated, coarsely crystalline clasts of marble and/or granitoid rocks. Although signs of oxidation can be found to considerable depths, carbonate leaching is rarely deeper than the base of the solum. Also, secondary carbonate is commonly observed around root casts and along joints in till less than 1 m from the surface.

In the most sandy, permeable tills there has been a considerable amount of downward translocation of silt- and clay-sized particles by percolating ground water. Undisturbed exposures commonly reveal <1 mm-thick coatings of silt and clay on the tops of clasts, apparently washed down from the higher parts of the section. Below the local water table, chemical weathering does not seem to accompany these phenomena.

Glacial erosion insights from carbonate and trace element data

There is a high frequency of Paleozoic erratics in carbonate-rich till overlying crystalline rocks of the eastern and southern part of the Frontenac Arch, and a low concentration of carbonate minerals in till overlying the marble belts of the Gatineau-Minden area. This suggests that carbonate components were more readily glacially eroded from the flaggy, flat-lying metamorphosed rocks of the Paleozoic basins than from the massive, little fractured Precambrian marble. The carbonate derived from Paleozoic rocks south of Ottawa has been transported more than 70 km southwestward over the relatively low eastern part of the Frontenac Arch. In the western part of the area, carbonate debris has been moved up the larger river valleys (the Madawaska and Mississippi) and their tributaries) into areas underlain by Precambrian crystalline rocks. Also, along the southern edge of the Frontenac Arch the carbonate content of till abruptly increases from 5% to 10% and is commonly >30% directly down ice from numerous Paleozoic inliers that occur in this area. In contrast, in all areas where carbonate-poor material was carried from the Shield onto Paleozoic rocks, it was quickly diluted by large quantities of Paleozoic debris.

The strong influence of the Paleozoic lithologies on till composition over a wide area can be attributed to physical characteristics of these strata. These sedimentary rocks, composed largely of fine grained "soft" minerals, calcite and dolomite, are jointed and thinly bedded and consequently highly susceptible to plucking, the most effective form of glacial erosion. Once dense concentrations of these blocks were entrained in the basal parts of the glacier, they were broken up and abraded by collisions with each other and the underlying bedrock. The breakdown process would be further enhanced as the blocks moved over the coarse grained, structurally massive crystalline rock of the Frontenac Arch, composed largely of more erosion resistant minerals such as quartz and felspar. Although the marbles of the Frontenac Arch are also composed largely of calcite and dolomite, their components were not so readily entrained because they occur in massive outcrops, which were not as susceptible to erosion by plucking as were the Paleozoic outcrops. Erosion of marble outcrops has produced characteristic moulded forms, but relatively little debris coarser than sand size. Thus, the secondary comminution that occurred through clast-to-clast contact during transport of high concentrations of Paleozoic erratics near the base of the ice was not an important process down ice from marble outcrops. The presence of fine carbonate detritus most likely accounts for the larger component of silt- and clay-sized material (Fig. 7) in carbonate-rich till (zones 1 and 2) because the terminal grain size of calcite and dolomite is silt- and fine sand-size (Dreimanis and Vagners, 1971).

A broad arsenic anomaly is clearly outlined over the Frontenac Arch (Fig. 8). One known source of arsenic is small sulphide deposits, some of which have hosted gold, that are associated in fractures and shear zones of metasedimentary and metavolcanic rocks of this area. Other possible sources are the metasedimentary and metavolcanic rocks themselves which may have high background concentrations of As in the Frontenac Arch area. In either case, the area covered by
As-rich till is large compared to the area underlain by either type of source rock and illustrates how high concentrations of As might have been homogenized and dispersed over a wide area through glacial transport.

CONCLUSIONS AND SUMMARY

The ubiquitous presence of clasts, stringers, and lenses of waterlain material in till, subhorizontal discontinuities in the deeper parts of sections, and till-like diamictons in ice contact sand and gravel sediments, all suggest that much of the till of this region was emplaced during deglaciation when debris melted out of or slumped off retreating or stagnating ice at the glacier margin. A similar conclusion was reached by Kaszycki (1983) for the Haliburton area at the western edge of this region.

The effects of glacial erosion and transport on the geographic distribution of till characteristics are readily apparent. Over the eastern and southern parts of the Frontenac Arch the composition of till is strikingly different from that of underlying bedrock. Large concentrations of carbonate minerals derived from the extensive Paleozoic terranes of the Ottawa and St. Lawrence valleys have been dispersed over a variety of noncalcareous rocks which comprise part of the Frontenac Arch.

On a smaller scale, arsenic-rich debris, derived from small source areas of arsenic sulphides or possibly from high background concentrations of arsenic in metasedimentary and metavolcanic rocks of the Frontenac Arch, is dispersed over much larger areas by glacial processes of homogenization through transport of debris.
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