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The Clay Products Industry and Shale Resources in Southern Ontario

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By

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ABSTRACT

The heavy clay products industry of southern Ontario relies on the shales of the Georgian Bay and Queenston formations and, to a lesser extent, the Arkona formation for raw material in the manufacture of bricks. Gaining access to these shale resources especially in the Toronto-Hamilton region, is becoming increasingly difficult due to urbanization and socio-environmental pressures. These constraints are forcing operators to find alternate sites for shale extraction and production facilities.

This study was designed to assist the clay brick industry in the exploration of shale resources by drilling and testing shale bedrock.

Six sites were selected for shallow (48.2 m maximum depth) drilling. Five of these sites located near Niagara-on-the-Lake, Milton, Streetsville, Brampton and Rosemont, intersected the Queenston and/or Georgian Bay formations. A drill hole near Thedford in southwestern Ontario, intersected the Arkona, Rockport Quarry and Bell formations of the Hamilton Group.

Visual examination of the drill cores and chemical analyses of representative shale samples were performed to give an indication of suitability as a raw material. Forty-eight samples were tested for major elements; 22 of these were also tested for CI and F, the presence of which is of environmental concern in the production process. Ceramic testing to determine behavior of these shales under firing is needed before the value of these shales as a raw material is known.

Overburden thicknesses encountered during drilling ranged from 0 to 17.7 m. The Milton borehole intercepted 8 m more overburden than was expected demonstrating the need for revising existing drift thickness maps.

The Clay Products Industry and Shale Resources in Southern Ontario,

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INTRODUCTION

Background and Purpose of Study

Ontario's heavy clay products industry, which manufactures construction materials, such as bricks, tiles, sewer pipes and flue liners derives its raw material predominantly from shales. Shale deposits are plentiful in southern Ontario and conveniently underlie the areas of greatest market demand: the Niagara Falls-Toronto-Collingwood, Sarnia-London-Chatham, and Ottawa regions. Of the 17 Paleozoic shale units present in southern Ontario, only 3 of these—the Georgian Bay, Queenston and Arkona formations—have been or are presently being used in the production of heavy clay products (Guillet and Joyce 1989). The Queenston and Georgian Bay shales are the principal sources of raw material for the brick industry, while the Arkona shale, also once utilized by this industry, is now primarily used in the manufacture of tiles and flue liners (Guillet and Joyce 1989).

The Queenston and Georgian Bay formations are thick and laterally extensive units, underlying the area of greatest urban development in Ontario, the Toronto-Hamilton region. The accessibility and good ceramic quality of these shales in this area has made the Toronto-Hamilton area one of the major producers of shale products in Canada. However, due to urbanization (resulting in intense competition for land use) and increasing socio-environmental pressures, access to shale lands is being jeopardized, forcing the industry to find alternate sources away from the Toronto-Hamilton area. One favoured site of relocation is along the base of the Niagara Escarpment, where good quality shale exists; however, land use restrictions imposed by the Niagara Escarpment Plan severely limit access to these lands. A partial, though temporary, solution in recent years has been to make material from construction excavations available to a brick manufacturer, thereby extending the life of one operation. The brick industry, 90% of whose brick sales are to the residential market, is experiencing additional pressure from the increasing use and acceptance of alternate cladding materials, such as concrete (or "calcite") bricks, which attempt to duplicate the appearance of clay bricks, and which sell at 20 to 30% less (Gartner Lee Limited et al. 1988).

The long term need for additional shale resources to meet future demand for bricks has prompted studies of shales in southern Ontario. Preliminary studies by Proctor and Redfern Limited (1978) for the Clay Brick Association of Canada, and Gartner Lee Limited et al. (1988) for the Niagara Escarpment Commission, have shown that large areas of shale lands are potentially available. The term potentially available refers to deposits of shale that underlie areas of thin overburden (thicknesses of less than 3 m are generally preferred; Gartner Lee Limited et al. 1988) that are "still available after the imposition of various natural, cultural, and legal restrictions" (Guillet 1982). These shale lands, however, need to be drilled and tested to determine shale quality, thereby providing essential information to quarry operators who are considering relocation.

This report presents the results of a drilling program designed to assist in the exploration for resources for future development. Deposits of the Georgian Bay, Queenston and Arkona formations over a wide geographic area have been drilled. Shale samples have been analyzed to determine their chemical composition, which is the first indication of potential suitability as a ceramic raw material. Ceramic testing of the shales was not done. Ceramic properties of surface samples from some of the drilled areas have been tested previously, however, by Kwong et al. (1985). The present study also fills information gaps on the regional stratigraphic trends of the Georgian Bay and Queenston formations between existing Ontario Geological Survey (OGS) deep drill holes at Clarkson (OGS-83-2; Johnson 1983), Milton (OGS-83-1; Johnson 1983), Corbetton (Johnson et al. 1983) and Wiarton (OGS-83-4; Johnson et al. 1985).

Cores from this drilling project are housed in the OGS core room in Sudbury. Samples of core can be made available to interested parties for further analysis provided that test results become part of the public domain.

Methodology

Drill Site Selection

The selection of the 6 drill sites for this study was governed by the project's 2 main objectives: 1) to investigate alternate source areas of shale and conduct preliminary testing to determine if material might be of suitable quality for use by the brick industry; and 2) to obtain information on the regional trends in lithological, mineralogical and chemical composition of selected shale formations.

Areas considered for drilling were based on the results of a survey prepared for the Niagara Escarpment Commission by Gartner Lee Limited et al. (1988). In this survey, potentially available shale resources were identified after the imposition of a number of physical, environmental and economic constraints. Factors taken into consideration included: 1) accessibility, with respect to thickness of overburden; 2) availability, with respect to access to suburban and rural lands; and 3) economic viability, with respect to location of facilities and markets. Not included, however, was a consideration of land values and local shale quality.

For the present study, the widest possible geographic distribution of holes was attempted on the shale lands designated as potentially available. The 6 sites selected for drilling were (Figure 1): 1) Brampton/Norval (OGS-89-05a), Highway 7 right-of-way; 2) Rosemont (OGS-89-06), Mono Township, rural road right-of-way; 3) Milton (OGS-89-08), Hydro Transfer Station property; 4) Niagara-on-the-Lake (OGS-89-09), Canada Brick Quarry property; 5) Streetsville (OGS-89-10), Canada Brick Britannia Quarry; 6) Thedford (OGS-89-11), Alan Hawkins (previously G. Coultis) Quarry. Boreholes OGS-89-05a to 89-10 intersect either or both of the Georgian Bay and Queenston formations. Borehole OGS-89-11 (Thedford) intersects the Arkona, Rockport Quarry and Bell formations of the Hamilton Group. Detailed location maps for these sites are provided in Appendix 1.

The drill holes encountered overburden thicknesses ranging from 0 to 6.7 m. The Milton borehole, however, intercepted 17.7 m of overburden, 8 m more than had been expected.

Sampling and Testing Procedures

Evaluation of shale as ceramic raw material requires chemical analysis and physical testing of moulding behaviour and firing characteristics; the 3-inch diameter drill core chosen for this project provides sufficient material to achieve both.

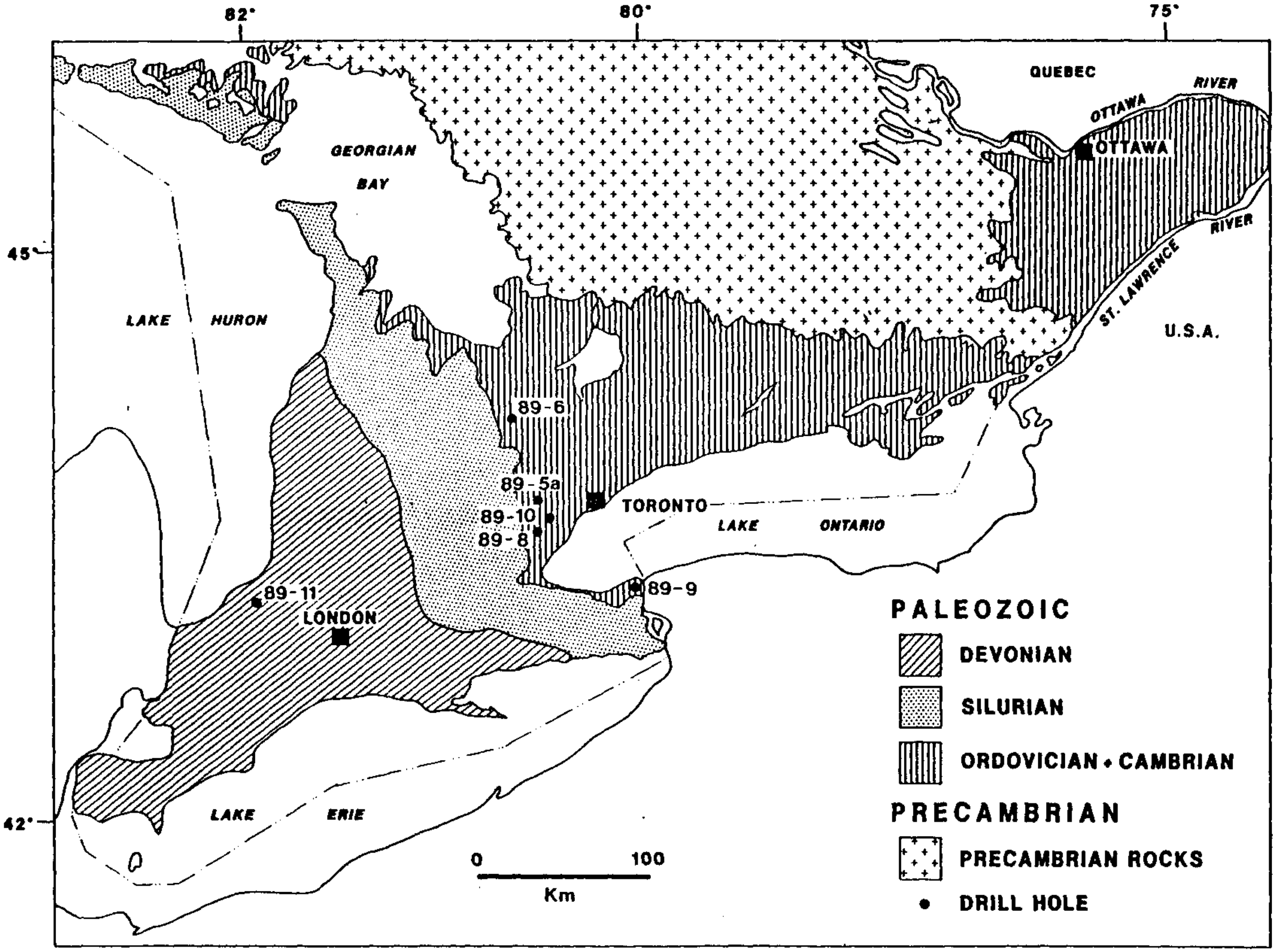


Figure 1. Location of drill sites.

At the drill sites, core was logged visually and tested for calcium carbonate content with dilute hydrochloric acid. Core recovery was excellent once bedrock had been reached and casing was installed. Shale was occasionally retrieved in a single piece from the 1.5 m core barrel. Use of the triple walled core barrels available on site was rarely necessary.

Standard sampling procedures for the evaluation of ceramic raw material, whereby samples are taken at regular intervals and are combined to form one bulk sample, were followed in this project to ensure representation of the shale formation. Shale chips were taken at 30 to 60 cm intervals along the core. Within the upper 13.7 m of each borehole, chips were combined to form 1 sample per 2.1 m of core. These samples were analyzed for major rock-forming elements and for the presence of CI and F, which is of environmental concern in the production process. Below 13.7 m, shale samples, representing larger intervals of core, generally one sample per 4.3 or 9.1 m, were analyzed for major elements only. In addition to these chemical analyses, four samples where analyzed for clay mineralogy. The sampled intervals of each drill core, along with some of the results of the chemical analyses, are shown on the lithologs presented in the results and discussion section.

HISTORICAL NOTES

Brick-making has been a feature of Ontario history from the time of the earliest settlement. The technology of brick-making and building with natural stone was brought over from England and Scotland. Until the early part of this century, these materials were the most commonly used load-bearing materials for construction purposes.

In 1906 Miller, Ontario's Provincial Geologist, in his foreword to the study of "Clay and the Clay Industry of Ontario" by M.B. Baker (1906), draws attention to the value of the industry to the public good of Ontario. He states: "Moreover, it should be remembered that a high percentage of the receipts from the clay industry are expended on labour and supplies. From this point of view no mineral industry can be claimed to benefit a community or a country more than that whose raw material is clay". At that time, clay products, manufactured from at least 186 production facilities, represented nearly 20% of the total output of the mineral industry in Ontario (Baker 1906). Both clays and shales were used by these plants to produce a variety of clay products: brick (90% common bricks, 10% pressed bricks; Gibson 1906), hollow block, terra cotta, roofing tile, drain tile, sewer pipe, paving brick, chimney flues, terra cotta lumber, and pottery. Three methods of brick production were employed: 1) soft-mud; 2) stiff-mud; and 3) dry-press. Shale was predominantly used in the latter.

Significant changes have occurred in all aspects of the brick-making industry over the years. Brick production reached a peak in 1910 of 350 million bricks, but dropped sharply between the years 1910 and 1945 reaching a low in 1935 of 50 million bricks. After World War II, production gradually recovered. Improved brick-making technology and increased efficiency of larger plants saw a dramatic decrease in the number of manufacturing plants. In 1987, production from 10 plants (owned primarily by two companies) amounted to twice the volume (about 603 million bricks) of that produced by 186 plants in 1906 (Gartner Lee Limited et al. 1988).

In the new plants the amount of manual labour is greatly reduced by automatization, allowing clay brick producers to compete with concrete brick and other building materials. Production is mainly by forced extrusion of a clay column under vacuum; bricks of desired size are cut from this column in a continuous process, or, alternatively, sections of this column are advanced forcefully through a stationary bank of cutting wires. New state-of-the-art facilities have been built by the major producers. Production from these plants will meet future demands and probably reverse the trend of importing bricks that developed in 1987 when an excess of 600 million clay bricks were used in Ontario.

An estimated 90% of clay bricks (bricks made from shale are still referred to as "clay bricks") produced goes into residential construction (Guillet and Joyce 1989). A high rate of construction and the building of larger prestige dwellings in suburban developments have increased Ontario consumption to its present level. In fact, large imports, at least 100 million bricks in 1987, from other provinces and the United States are required to satisfy the demand. Recent trends in the development of the industry are discussed by the Institute for Research in Construction and Matex Comsultants Inc. (1990). In this paper (p. 102), it is stated that... "Unquestionably, the preferred exterior finish for housing in most of southern Ontario is clay brick. Elsewhere in the province, wood, stone, aluminum and plastic are alternative cladding materials which, for reasons of aesthetics or local availability, may be used in place of bricks". Bricks no longer have a load bearing function in modern house construction; they serve as an aesthetic veneer to cover the structural frame and have an added value as insulation against rain and cold. Major competition to the use of clay brick is from imitation concrete brick which is similar in most respects.

GEOLOGY OF SHALE RESOURCES IN ONTARIO

Geological Setting

Southern Ontario occupies an interbasinal position between the clastic-dominated, foreland Appalachian Basin and the carbonate-dominated, intracratonic Michigan Basin (Figure 2). Separating the two basins and trending northeast-southwest through the centre of the southern Ontario peninsula is the Algonquin Arch. Throughout the Paleozoic Era the arch intermittently affected sedimentation patterns within southwestern Ontario. Although it is unlikely that the arch ever actually acted as a complete barrier to sedimentation, complex facies changes occur in some units across this structural feature.

During the Paleozoic, three major periods of orogenic activity (the Middle to Late Ordovician Taconic, the Middle Devonian Acadian and the Pennsylvanian Alleghanian orogenies), centred along the present day Appalachian Mountains, resulted in large volumes of clastic material, primarily sandstones and shales, being shed northwestward into the centre and outer margins of the Appalachian Basin. During periods of tectonic quiescence carbonate depositional environments similar to those then occurring in the Michigan Basin, prevailed over southern Ontario. The complex interaction between these two sedimentary basins throughout the Paleozoic has resulted in a stratigraphic succession (Figure 3) in southern Ontario that is approximately 1525 m thick and which consists predominantly of shallow marine sandstones, shales, carbonates (limestones and dolostones) and evaporites (Winder and Sanford 1972).

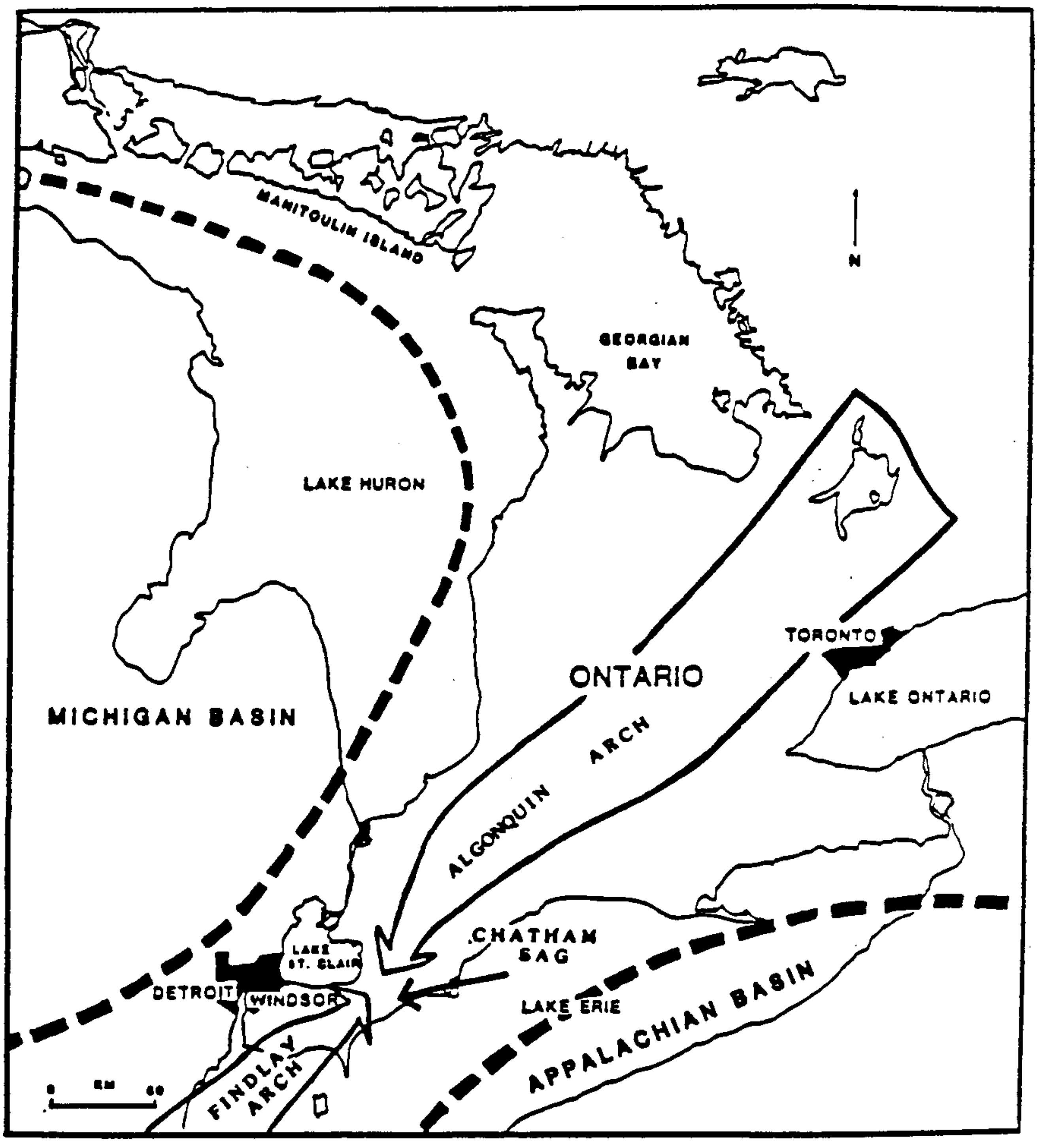


Figure 2. Major structural elements of Southern Ontario.

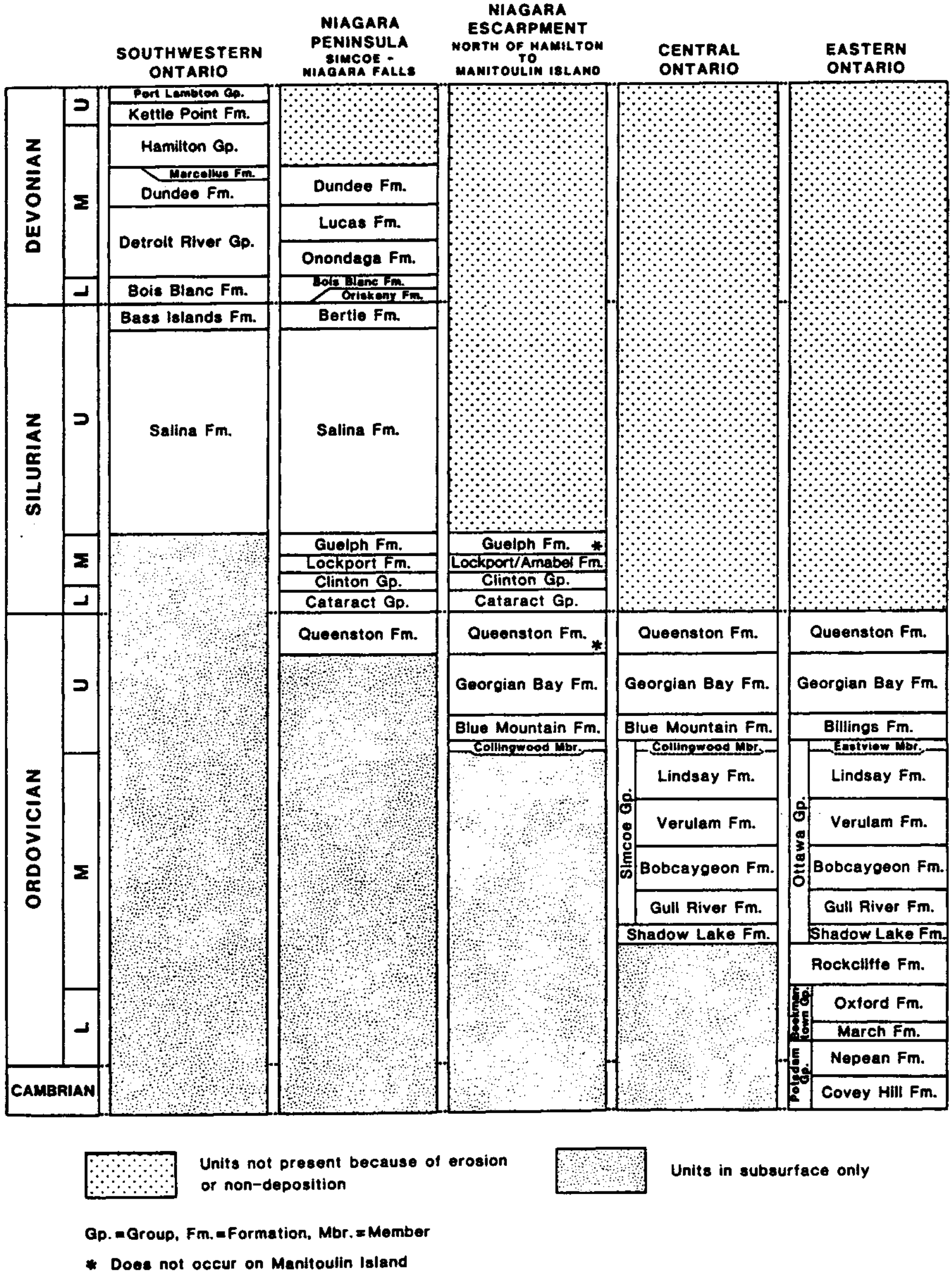


Figure 3. Stratigraphic chart of Paleozoic units in southern Ontario.

The Paleozoic strata of southern Ontario show little evidence of structural disturbance and are essentially flat-lying with gentle dips of between 5.5 to 8.5 m/km towards the south-southwest (Winder and Sanford 1972). As a result of this attitude, the rocks are exposed at surface in northwest trending bands (Figure 4), with successively older rocks being exposed towards the east. The Niagara Escarpment, an erosional feature formed by the differential erosion of resistant limestones, dolostones and sandstones and less resistant shales, is an expression of this attitude (Figure 4).

The Upper Ordovician Georgian Bay and Queenston formations, the main focus of this study, underlie a narrow, wedge-shaped, northwest trending area lying immediately east of the Niagara Escarpment, extending from the Bruce Peninsula southward to the Toronto-Hamilton region (Figure 4). South of Lake Ontario, between Hamilton and Niagara Falls, the Queenston formation forms the bedrock of an area bounded by the Lake Ontario shoreline and the Niagara Escarpment. The Middle Devonian Arkona Formation is part of a group of limestones and shales constituting the Hamilton Group. The group underlies an irregular area extending across southwestern Ontario from Ipperwash Beach on Lake Huron southward to Port Glasgow on Lake Erie and eastward to Long Point (Figure 4).

Shale Resources of Southern Ontario

Shales of Ordovician through to Devonian age are thick and laterally extensive in southern Ontario, yet only a few of these are accessible (either exposed extensively at surface or covered by thin overburden) and have the qualities acceptable for use as a raw material in the ceramic industry. The lithologic character of Ontario shales and their

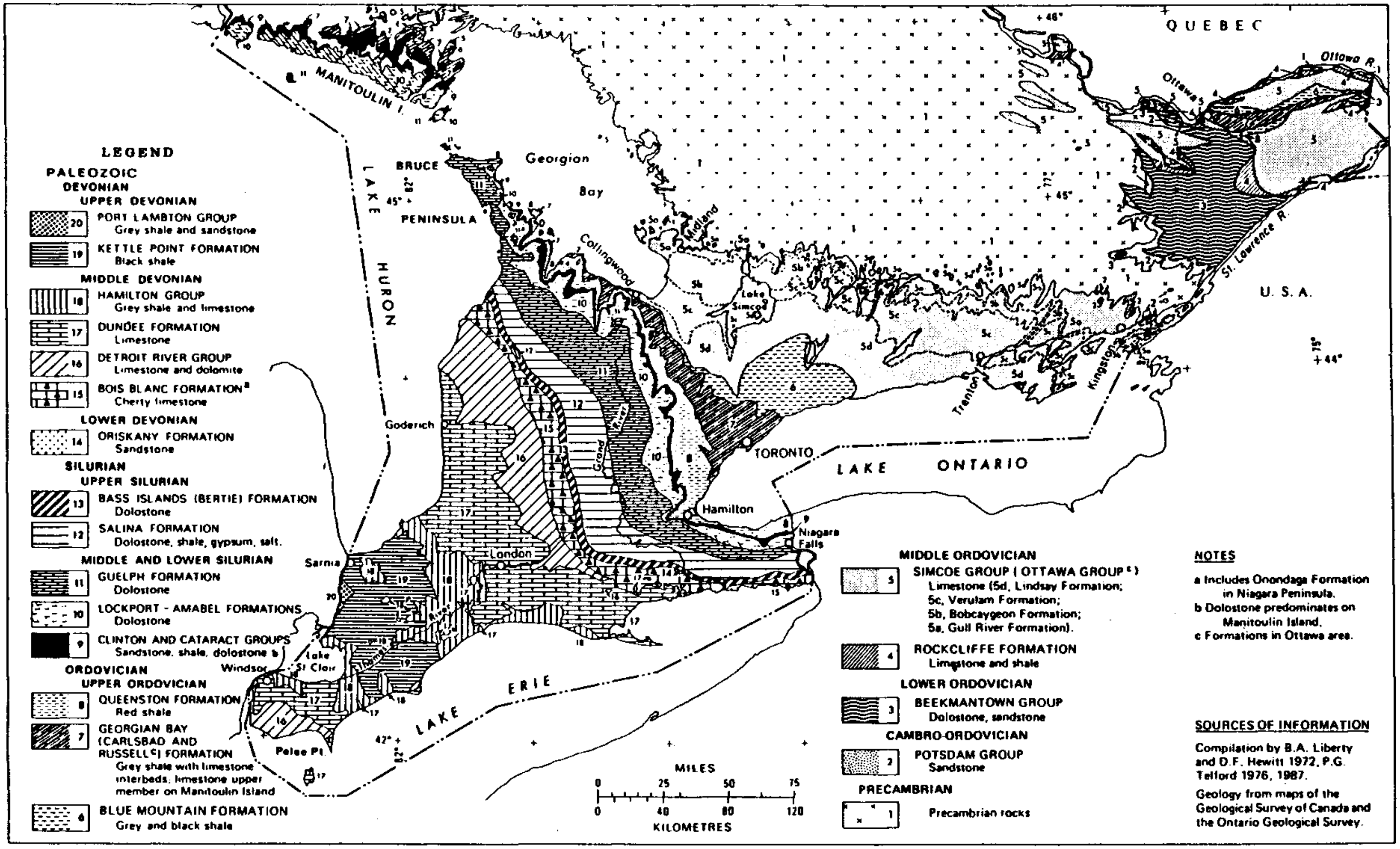


Figure 4. Paleozoic bedrock geology of southern Ontario.

potential as a raw material in the manufacture of ceramics has been discussed by a number of authors (Keele 1924; Montgomery 1930; Guillet 1967, 1977; Kwong et al. 1985; Martini and Kwong 1986). A brief summary of this information is contained in a report prepared for the Niagara Escarpment Commission by Gartner Lee Ltd. et al. (1988). The lithologic character and ceramic properties of the Georgian Bay, Queenston and Arkona formations are described below. Other shale formations are referred to, but are not dealt with in detail due to their limited use by the heavy clay products industry.

Georgian Bay Formation

Definition, distribution and stratigraphic relationships

The Upper Ordovician Georgian Bay Formation, formerly known by the names Meaford and Dundas, is the oldest shale unit used in the production of ceramics in southern Ontario. The formation forms part of a thick, shoaling upwards (deep water to deltaic environments) clastic wedge that was shed northwestward from highlands to the southeast during the Middle to Late Ordovician Taconic Orogeny. At the base of this clastic sequence are the organic-rich interbedded calcareous shales and limestones of the Colling wood member of the Lindsay Formation, followed by the black bituminous, sulphurous shales and soft uniform grey-blue shales of the Blue Mountain (former Whitby) Formation. The latter, according to Guillet (1977), are "... one of the most promising shales for heavy clay products in Ontario". These shales, however, have not been tested in production due to thick overburden cover. Overlying the Georgian Bay Formation, and forming the top of the fine-grained clastic sequence, are the red shales of the Queenston Formation.

Distribution of Georgian Bay Formation exposures is limited to a narrow band extending southward from the southern shoreline of Georgian Bay to the Toronto area *(see* Figure 4). Additional exposures can be found on Manitoulin Island, where two members can be recognised: a lower member, characterized by interbedded siliciclastic mudstones and crystalline to fossiliferous, bioclastic limestones; and an upper member, consisting predominantly of bioclastic limestones and dolostones (Liberty 1968; Byerley and Coniglio 1989). The upper part of the upper member is generally regarded as a lateral fades equivalent to the Queenston Formation. Southeast of Ottawa, equivalent shales to the Georgian Bay Formation comprise the Carlsbad Formation (Derry Michener Booth and Wahl and OGS 1989).

The Georgian Bay Formation consists of about 100 m of blue-grey and green-grey, soft, fissile shales with interbeds of calcareous, fossiliferous sandstone, green-grey siltstone, and grey argillaceous limestone (Bond et al. 1976; Guillet 1977; Czurda et al. 1973). The formation gradationally overlies the Blue Mountain Formation, the contact arbitrarily drawn at the lowermost occurrence of grey carbonate hard beds (Liberty 1969; Liberty and Bolton 1971). The upper contact with the Queenston Formation is also transitional, with the first occurrence of red mottled beds generally placed within the Queenston Formation.

<u>Lithological and sedimentological characteristics</u>

The sedimentology of the Georgian Bay Formation in the Toronto area has most recently been described by Kerr and Eyles (1990). The shales are generally sparsely fossiliferous, except for occasional fossiliferous horizons, and are weakly to intensely bioturbated with the traces of *Planolites, Teichichnus, Phycodes* and *Chondrites.* Sandstone, siltstone, or limestone interbeds are laterally extensive and display features typical of storm deposits. Internally, they commonly display a basal fossil hash layer overlain by horizontal, hummocky cross- and symmetrical cross-stratified divisions. On top and basal surfaces of the siltstone/sandstone interbeds, trace fossils of *Conostichnus, Diplocraterion* and *Teichichnus,* and of *Planolites* and *Palaeophycus,* respectively, are common.

The frequency of interbeds tends to be greater in the upper part of the formation (30% of the unit) than in the lower part (10 to 20%), and also greater in sections further north than in the south (Czurda et al. 1973; Guillet and Joyce 1989). The lime content of the shales tends to follow this trend, increasing with increasing frequency of interbeds. The thickness of the "hard layers" is variable, generally ranging from less than 1 to 20 cm, although thicknesses of over 50 cm are not uncommon, particularly near the top of the formation (Czurda et al. 1973; Kerr and Eyles 1990). Shale layers have variable thicknesses and may reach up to 2 m in thickness (Czurda et al. 1973).

The paleontology of the Georgian Bay Formation has been the focus of a number of studies in the past (Foerste 1916, 1924; Dyer 1925a, 1925b; Parks 1925; Caley 1940; Davidson 1985). The unit contains an abundant and diverse fauna, the most significant of these being bryozoans, crinoids and brachiopods.

Although sedimentological characteristics of the Georgian Bay Formation appear to change very little regionally throughout southern Ontario, mineralogical studies have shown that there are regional variations in composition of the shales (Czurda et al. 1973).

At Meaford, on the southern shoreline of Georgian Bay, the shales tend to have a higher quartz (40%) and lower clay (50%), content than shales in the Toronto area, which contain 17% and 70%, respectively. Illite is the dominant clay mineral, constituting 70 to 80% of the clay fraction at Meaford, increasing to 80 to 85% in the Toronto area. Additionally, shales at Meaford have a greater amount and variety of heavy minerals than shales to the south. Carbon content appears to remain the same, about 6%. Czurda et al. (1973) attribute these regional variations in shale composition to the presence of a secondary source area, the Canadian Shield to the north: "The main source area for the clay minerals would seem to have been the Taconic orogen, which rose during the Upper Ordovician. The relatively high quartz content and the heavy minerals in the east (Toronto) can be attributed to the high sediment delivery rate from the Appalachians. The even higher quartz content and the greater variety of heavy minerals in the northern parts of the area (Meaford) suggest derivation from the neighbouring Canadian Shield, although selective sorting may have caused local variations in mineral concentration."

Depositional Environment

The sedimentological, ichnological and paleontological characteristics of the Georgian Bay Formation, and its gradational relationships with the underlying deep water Blue Mountain Formation (Brett and Brookfield 1984) and the overlying intertidal to supratidal mudflat deposits of the Queenston Formation (Brogly 1984, Brogly and Martini 1990), suggest that deposition occurred on a shallow, warm, muddy storm-influenced middle to outer shelf setting (Martini and Kwong 1986; Kerr and Eyles 1990).

Ceramic properties

The shales of the Georgian Bay Formation have been used extensively and successfully as a ceramic raw material in the Toronto area, and will remain in use as long as they remain accessible in an encroaching urban environment. Ceramic performance, colour and plasticity are improved by reducing or eliminating hard layers, usually by manual or mechanical means. The shale has a moderate firing range and burns to a salmon-red colour. Gypsum and pyrite, present in minor amounts in the Georgian Bay shale, require neutralizing to prevent scum and efflorescence.

Two drill holes intersected the Georgian Bay Formation in the present drill program: OGS-89-06 at Rosemont, and OGS-89-10 at Streetsville. See Appendix 1 (Figures 19 and 22) for location of drill sites.

Queenston Formation

Definition, distribution and stratigraphic relationships

The Queenston Formation in southern Ontario typically consists of up to 300 m of maroon-coloured, hematitic, thin- to thick-bedded, moderately soft, sandy, argillaceous and calcareous shale with thin interlayers of grey-green shale, grey-green (sometimes red), fine crystalline argillaceous limestone, bioclastic and silty limestone and calcareous siltstone (Caley 1940; Sanford 1961; Guillet 1967,1977; Brogly 1984; Bond et al. 1976). The formation is Late Ordovician (Maysvillian to Richmondian) in age and occupies the top of the Ordovician System in southern Ontario. The contact with the underlying grey shales and limestones/sandstones of the Georgian Bay Formation is transitional, displaying interbedded red shale and limestone/siltstone over a thickness of about 6 m;

the contact is generally drawn at the lowest occurrence of red shale (Caley 1940). The upper contact with the light grey, quartzose sandstones of the Lower Silurian Whirlpool Formation (southeast of Duntroon) or the grey and brown dolostones of the Manitoulin Formation (northwest of Duntroon and in the subsurface of southwestern Ontario), both of the Cataract Group, is sharp and unconformable.

The Queenston Formation is part of a large fluvio-deltaic complex commonly referred to as the Queenston Delta, which formed at the culmination of the Taconic Orogeny. Other formations comprising this complex and which are lateral equivalents to the Queenston Formation, include the Juniata and Sequatchie Formations of the northeastern United States. Areal distribution of this complex is extensive, covering much of the Appalachian Basin and spilling out into basin margin areas (Dennison 1976). In Ontario, the Queenston Formation is present in the subsurface over the entire southwestern Ontario Peninsula. The formation thins in a northwestwardly direction from a maximum of about 300 m in east-central Lake Erie (Sanford 1961) to about 40 m at the northern tip of the Bruce Peninsula, shortly north of which the Queenston Formation pinches out. Outcrops of the Queenston Formation are found at the base of the Niagara Escarpment and within a narrow, northwest-trending area of land lying east of the Escarpment, extending from Niagara Falls northward to Cape Croker, on the Bruce Peninsula (Figure 4; Liberty and Bolton 1971). Additional exposures of the Formation occur in the Ottawa area, where it has a maximum thickness of about 50 m (Wilson 1946; Derry Michener Booth and Wahl and OGS 1989). On Manitoulin Island, the dolostones and limestones forming the top of the Georgian Bay Formation are commonly considered to be lateral fades equivalents to the Queenston Formation.

The Queenston Formation is the primary source of raw material for the heavy clay products industry in southern Ontario (Gartner Lee Limited et al. 1988; Guillet and Joyce 1989), and is quarried in several locations and at various stratigraphic levels of the formation. Due to its use by the ceramic industry, a considerable amount of literature exists on the chemical and mineral composition and the ceramic properties of this shale (Keele 1924; Montgomery 1930; Guillet 1967, 1977; Kwong et al. 1985; Martini and Kwong 1986; Guillet and Joyce 1989).

Lithological and sedimentological characteristics

The number of detailed sedimentological studies on the Queenston Formation have, until recently, been rather meagre. Among some of the early studies on the unit include Foerste (1916), Caley (1940), Liberty (1969), and Liberty and Bolton (1971). Recent studies, concentrating on the sedimentological aspects of the formation (Brogly 1984, Martini and Kwong 1986, Brogly and Martini 1990) have greatly improved the understanding of the depositional environment of the Queenston Formation in Ontario.

On a regional scale, the Queenston Formation displays considerable lateral variations in fades, reflecting changes from proximal to distal environments. In New York State, the formation is characterised by red shale interlayered with channelized sandstone. In southern Ontario, the formation consists primarily of red shale with minor interbeds of limestones and siltstones, while on Manitoulin Island, the lateral equivalent consists of dolostones, limestones, and minor grey-blue shales (Byerley and Coniglio 1989; Liberty 1968).

In southern Ontario, the Queenston Formation maintains a fairly uniform lithological and sedimentological character, both vertically and laterally. Detailed descriptions of Queenston Formation sections in the Hamilton-Georgetown region have been given by Guillet (1967) Brogly (1984), and Martini and Kwong (1986). General lithological and sedimentological characteristics of the formation at these sections are summarized below:

1. The red shales of the Queenston Formation are generally hard and well cemented by calcite and quartz (Russell 1982). Sand content in the shales decreases upward from about 10% near the base of the formation, to about 2% near the top.
2. Interlayers of grey-green calcareous shale, siltstone and minor limestone range from less than 1 to 25 cm in thickness, and generally comprise 20 to 25% of the Queenston Formation in section. Frequency of interlayers tends to be highest in the middle (40%) and lower part of the formation than in the upper part (< 5%), near the Whirlpool Formationcontact.
3. Grey-green shale interlayers are harder and have a higher carbonate content than the red shales. Grey-green coloration of the shales also occurs as mottlings, specks, and as bands along joints oriented at high angles to the bedding plane. A bleaching by acidic groundwaters is believed to be the cause of this coloration (Caley 1940).
4. Gypsum, in nodules and botryoidal masses up to 30 cm in diameter (Guillet 1967) and in lenses up to 2.5 cm thick, is common in the lower part of the formation.
5. Interlayers of grey-green siltstone become thinner and softer toward the top of the formation. Internally, the siltstone beds exhibit a vertical transition from shale intraclasts at the base to horizontal lamination to occasional ripple cross-

lamination at the top. Wrinkle marks and desiccation cracks are occasionally present. Fossils, usually brachiopods, pellets, and ooids, are commonly present.

6. The carbonate interlayers occur in the middle and lower parts of the formation, and are of algal, oolitic, and pelletoidal origin. Vertical burrows, mainly *Diplocraterion,* are common.

Mineral and chemical composition

The mineral and chemical composition of the Queenston Formation has been reviewed by Guillet (1967,1977), Kwong et al. (1985) and Martini and Kwong (1986). The shales consist of about 60% clay (primarily illite) and 40% non-clay minerals (predominantly quartz and calcite). The grey-green interlayers tend to have a higher lime (CaO) content and are harder than the red shales. Generally very little variation, either vertically or laterally, occurs in the chemical and mineral composition of the red shales. Lime content, commonly varying proportionally to the percentage of grey-green shale interlayers in the section, is most variable, generally it increases towards the middle of the formation and, on a regional scale, towards the northwest (Sanford 1961; Guillet 1967,1977; Kwong et al. 1985).

Depositional environment

Due to its red colour, apparent absence of fossils, and stratigraphic position at the top of a large clastic wedge (which includes the Blue Mountain through to Queenston formations) that formed in front of the Taconic Highlands, the Queenston Formation in Ontario has long been interpreted as a subaerial deposit associated with deltaic deposition (Grabau 1909; Foerste 1916; Caley 1940). More recent sedimentological work

(Brogly 1984; Martini and Kwong 1986; Middleton 1987; Brogly and Martini 1990), however, indicates that the Queenston Formation, at least in Ontario, was likely deposited under warm, seasonally arid climatic conditions in a prograding, storm-influenced, muddy shelf to shoreline environment. Body fossils, trace fossils, sedimentary structures, and carbonate interbeds in the lower part of the unit suggest deposition on a storm-influenced shallow, muddy shelf, at or near wave base (Martini and Kwong 1986). Periodic emergence due to differential sediment supply from the Taconic orogen and possible glacio-eustatic changes in sea level (Dennison 1976) resulted in the local development of intertidal and supratidal mudflat areas, where evaporitic deposits were formed. The top of the Queenston Formation is knife-sharp and mudcracked, and indicates a considerable period (much of the Gamachian Stage; Barnes et al. 1981) of subaerial exposure prior to deposition of the fluvial sandstones Whirlpool Formation.

Ceramic properties

Queenston Formation shales are used extensively and successfully as a ceramic raw material. Ceramic tests results on the shale are given by Keele (1924), Montgomery (1930), Brady and Dean (1966), Guillet (1967, 1977), Kwong et al. (1985), Martini and Kwong (1986) and Guillet and Joyce (1989). Unweathered Queenston Formation shale is characterised by a short to moderate firing range and a light-red fired colour. Local concentrations of gypsum increase the likelihood of scum formation and efflorescence on the finished brick. The porosity and redness of the fired ware varies proportionally with the amount of green shale, which, because of its higher lime content, tends to be buff burning. The green shale is also generally harder and less plastic than the red shale. Weathered Queenston Formation shale has superior ceramic properties due to the reduction of lime content during the weathering process. Weathering of the shale results in improved plasticity of the shale, a longer firing range, and a lower porosity and deeper red colour of the fired ware. Selective quarrying or sorting to reduce the amount of green shale and gypsum can be done to control the final colour of the bricks and ceramic performance of the finished product.

In the present drill program, the Queenston Formation was intersected in the Brampton (OGS-89-05a), Milton (OGS-89-08), Niagara-on-the-Lake (OGS-89-09), and Streetsville (OGS-89-10) boreholes. See Appendix 1 (Figures 18, 20, 21 and 22) for location of drill sites.

Silurian Shales

Following the intense tectonic activity of the Ordovician Period the Silurian was, in comparison, a time of tectonic quiescence in the Appalachian Basin. Local tectonic movements associated with the lithosphere's readjustment to reduced overthrust loading in the Taconic orogen, combined with eustatic processes, did, however, result in considerable sea level fluctuations over southern Ontario (Brett et al. 1990). Alternations of carbonate and clastic environments resulted in a Silurian stratigraphic succession consisting predominantly of dolostones, limestones, and minor sandstones and shales.

Shales of the Lower Silurian Cataract Group (Cabot Head Formation) and of the Middle Silurian Clinton Group (Neahga and Rochester formations) have an extensive and limited distribution, respectively, throughout southern Ontario. Natural exposures of the shales are limited, generally restricted to the steep face of the Niagara Escarpment.

The composition and ceramic properties of these shales are discussed by Guillet (1977). Generally, these shales have a high lime content and low plasticity, resulting in an inferior ceramic product. The poor quality, limited exposure, and inaccessibility are the main reasons for the lack of production from these Silurian shales. For similar reasons, the shales of the Upper Silurian Salina Formation are not used as a raw material by the ceramic industry. These shales have a high dolomite content, producing a fired product that is porous, weak and chalky.

Arkona Formation

Definition, distribution and stratigraphic relationships

The Arkona Formation is the only Devonian shale in southern Ontario that is of interest as a ceramic raw material. The formation is middle Devonian in age and forms a small part of the Devonian stratigraphic succession, which, in southwestern Ontario, has a maximum thickness of about 305 m and consists predominantly of limestones and shales with minor dolostones and sandstones (Sanford 1968).

The Arkona Formation constitutes part of the Hamilton Group of limestones and shales. The group has a maximum thickness in southwestern Ontario of 93 m (Winder and Sanford 1972) and consists of the following formations (listed in ascending stratigraphic order and shown with thicknesses measured in a borehole at Lambton (OGS-82-1; Johnson et al. 1985): the Bell (14.6 m; calcareous shale), Rockport Quarry (5.8 m; limestone with occasional thin shale interlayers), Arkona (32 m; shale with occasional limestone lenses), Hungry Hollow (2 m; interbedded fossiliferous shale and bioclastic limestone), Widder (21.4 m; calcareous shale interbedded with argillaceous crinoidal and nodular limestone), and the Ipperwash (2 m; bioclastic limestone) formations (Uyeno et al. 1982). Three of these, the Bell, Rockport Quarry and Arkona formations, were intersected in the present drilling program by borehole OGS-89-11 at Thedford. The Hamilton Group is disconformably underlain, on the northwestern side of the Algonquin Arch, by the fossiliferous, micritic limestones of the Dundee Formation, and on the southeastern side of the arch, by the black bituminous shales of the Marcellus Formation *(see* Figure 3). The black, fissile, bituminous shales of the Upper Devonian Kettle Point Formation conformably overlie the Hamilton Group.

The Marcellus Formation is not exposed at surface in Ontario and is therefore not available for use as a ceramic raw material. The Kettle Point Formation has the lowest lime content of any of the Paleozoic shales in Ontario; however, its high organic and sulphur content discourages its use by the clay products industry (Guillet 1977).

The Hamilton Group forms the bedrock of a narrow, irregular area extending across the southwestern Ontario Peninsula from Ipperwash Beach on Lake Huron to Port Glasgow on Lake Erie. Natural exposures of the Arkona Formation occur along the banks of the Ausable River east of Arkona, at Hungry Hollow, and at Decker Creek north of Thedford. The unit is also exposed in quarries/pits at Thedford (Alan Hawkins, former Coultis, Quarry), Hungry Hollow, and Parkhill (Martini and Kwong 1985; Guillet and Joyce 1989).

Lithological and sedimentological characteristics

Descriptions of the Arkona Formation are given by Guillet (1967, 1977), Uyeno et al.

(1982), Martini and Kwong (1986) and Guillet and Joyce (1989). The formation consists of up to to 43.5 m of blue-grey, soft, easily weathered, plastic, calcareous shale with occasional thin, laterally discontinuous, argillaceous limestone lenses, particularly in the lower and middle parts of the unit. The unit is poorly fossiliferous except for local, thin concentrations of well preserved fossils, primarily brachiopods with minor bryozoans, crinoids, and tentaculids. The Arkona Formation has a gradational contact with the underlying Rockport Quarry Formation.

From a borehole and exposures in the Hungry Hollow pit located just east of Arkona, Martini and Kwong (1986) describe the Arkona Formation as consisting of: a lower calcareous shale facies with occasional isolated fossils or fossiliferous layers displaying intense pyritization; a middle shale facies with abundant, thin bioclastic interlayers composed mostly of brachiopods; and an upper unit characterized by light grey shale with occasional thin fossiliferous layers.

Depositional environment

The Arkona Formation forms a small and distal part of a thick and extensive terrigenous clastic wedge known as the Catskill Delta Complex, which was shed into the Appalachian Basin from highlands produced by the Middle Devonian Acadian Orogeny. Catskill Delta deposition was largely confined to the central portion of the Appalachian Basin, in Pennsylvania, Central New York, eastern Ohio, and West Virginia (Faill 1985); however, pulses of fine-grained sediment, particularly during the Late Devonian, managed to spill out into the outer margins of the basin and over the Algonquin Arch to intertongue with the carbonate sediments of the Michigan Basin. In such a setting, on the northwestern flank of the Algonquin Arch, the shales of the Arkona Formation were deposited in warm, muddy, shallow subtropical seas (Martini and Kwong 1986). Organisms flourished at times, resulting in thin biostromal deposits.

Ceramic properties

The Arkona Formation shale is becoming an important raw material for the heavy clay products industry. Buff brick, flue liners, drain tile and pottery have all been successfully produced from the unit and, with the exception of drain tile, are still in production.

The ceramic properties and the chemical and mineralogical composition of the Arkona Formation shale have been studied most recently by Martini and Kwong (1986) and Guillet and Joyce (1989). The fired ware produced from shales in the upper part of the unit has a tendency toward significant scumming and efflorescence. This may be due to a greater accumulation of soluble salts in the upper part of the formation than in the lower. The shale appears to have a narrow firing range for the manufacture of dense products, such as roofing tiles (Martini and Kwong 1986). Improvements to lower the absorption value, may be possible by blending Arkona Formation shale with other shales, such as the Cabot Head Formation shale.

The Arkona Formation, along with the Rockport Quarry and the Bell formations were intersected in the Thedford borehole (OGS-89-11). See Appendix 1 (Figure 23) for the location of the drill site.

RESULTS AND DISCUSSION

Descriptions, lithologs, and results of the chemical analyses of the shale formations intersected by the 6 drill holes in this study are presented below. Table 1 summarizes the results of the drilling program showing overburden and formation thicknesses intersected and the total depth of each drill hole.

Lithologs of the drill holes include brief descriptions of the drill holes, locations of gypsum nodules /layers and fossiliferous horizons, and graphs showing the percentage (visually estimated) of grey-green shale or siltstone interlayers for the Queenston Formation, or the percentage of siltstone and limestone interlayers for the Georgian Bay Formation. Gypsum is an undesirable component due to its tendency to cause scumming and efflorescence. Shale intervals characterized by fossiliferous horizons and abundant interlayers of grey-green shale, which is harder and has a higher carbonate content than red shale, tend to be high in lime content. This can affect colour (by weakening the red colour), absorption and porosity of the ceramic product.

Results of the chemical analyses are reproduced in Table 2. A total of 48 shale samples were analyzed for major elements. Twenty-two of these samples, representing sampled shales from within the upper 13.7 m of each core, were also analyzed for CI and F, the presence of which is a cause for environmental concern during the production process. Gaseous fluoride emissions during the kiln firing process have been attributed to the action of heat on fluoride and fluorosilicate minerals present in trace amounts in the raw material; Guillet and Joyce 1989.

To give a better visual representation of the variability in chemical composition of the shale units, some of the results of the chemical analysis, those that are most likely

HOLE	LOCATION	THICKNESS (m)						TOTAL DEPTH
		Overburden	Hamilton Group			Queenston	Georgian Bay	
			Arkona	RQ	Bell			
OGS-89-05a	Brampton/Norval	3.7	-	-	-	43.5	-	47.2
OGS-89-06	Rosemont	6.4	-	-	-	_	26.8	33.2
OGS-89-08	Milton	17.7	-	-	-	24.4	-	42.1
OGS-89-09	Niag.-on-the-Lake	4.7	-	-	-	34.3	-	39.0
OGS-89-10	Streetsville	6.7	-	-	-	9.7	13.2	29.6
OGS-89-11	Thedford	0.0	38.1	2.6	7.5	-	-	48.2

CHEMICAL COMPOSITION (%)

Sample #	SiO2	Al2O3	Fe2O3	MgO	CaO	Na2O	K2O	TiO2	P2O5	MnO	CO2	S	L.O.I.	Total	Cl	F
1	41.8	9.57	4.06	1.86	19.00	0.73	2.74	0.55	0.15	0.12	15.00	0.02	18.2	98.8	1080	470
2	43.3	11.10	4.85	2.20	16.10	0.66	3.24	0.56	0.15	0.12	12.80	0.02	17.4	99.7	170	580
3 *	38.2	9.37	4.41	1.55	9.19	0.61	2.55	0.29	0.12	0.08	7.81	3.70	10.8	77.2	110	440
4	41.8	11.30	4.63	2.31	16.70	0.41	3.31	0.60	0.14	0.12	13.50	0.04	17.1	98.4	1080	550
5	44.9	11.90	5.50	2.43	13.90	0.54	3.40	0.65	0.15	0.10	11.50	0.04	14.8	98.3	220	570
6	45.3	9.07	3.87	3.14	16.20	0.46	2.66	0.59	0.17	0.13	14.60	0.11	16.8	98.4	1120	440
7	53.6	13.40	5.70	4.33	6.17	0.29	3.86	0.73	0.18	0.13	7.31	0.14	10.4	98.8	1020	600
8	55.9	12.20	5.12	3.86	6.81	0.45	3.44	0.68	0.21	0.12	7.54	0.06	10.1	98.9	1060	570
9	58.0	12.90	5.52	3.22	5.31	0.53	3.72	0.75	0.20	0.11	5.82	0.08	8.6	98.9	430	590
10	58.3	14.80	6.26	2.72	4.05	0.44	4.06	0.88	0.13	0.10	2.94	0.05	7.8	99.5	1060	540
11	57.4	15.60	7.58	2.79	3.21	0.05	4.50	0.86	0.16	0.09	2.42	0.01	7.1	99.3	1080	590
12	56.8	15.90	7.26	2.82	3.54	0.28	4.54	0.86	0.16	0.09	2.64	0.01	7.6	99.8	100	610
13	58.1	14.40	5.67	2.43	4.89	0.56	4.03	0.86	0.17	0.11	3.64	0.01	8.0	99.2	140	530
14	58.7	13.90	5.94	2.20	5.40	0.83	3.84	0.85	0.16	0.10	3.83	0.01	8.0	99.0	110	470
15	57.3	12.90	6.29	2.32	6.68	0.38	3.57	0.84	0.15	0.10	5.50	0.01	8.9	99.4	110	520
16	57.1	16.40	8.64	2.86	1.97	0.50	4.64	0.88	0.14	0.06	1.52	0.01	6.6	99.8	140	680
17	54.4	13.70	7.15	2.29	7.08	0.76	3.83	0.80	0.14	0.11	5.85	0.01	9.5	99.8	210	630
18	52.1	17.20	7.07	2.53	4.68	0.05	4.32	1.00	0.16	0.19	5.50	0.25	9.2	98.5	170	570
19	50.9	17.00	6.76	2.67	5.35	0.18	4.27	0.92	0.17	0.18	6.06	0.23	9.7	98.1	330	410
20	49.0	13.60	6.08	2.65	9.66	0.35	3.33	0.83	0.29	0.19	9.39	0.45	12.2	98.2	440	490
21	53.7	15.30	6.47	2.58	5.52	0.47	3.78	0.91	0.19	0.16	6.18	0.23	9.4	98.5	330	490
22	55.9	14.70	6.02	2.50	5.91	0.31	3.64	0.96	0.18	0.15	6.27	0.20	9.3	99.6	310	500
23	45.2	11.30	4.59	2.19	13.80	0.75	3.12	0.58	0.15	0.10	10.10	0.81	14.4	96.2		
24	48.7	13.30	6.20	2.50	10.40	0.70	3.82	0.65	0.17	0.10	8.64	0.03	12.4	98.9		
25	52.2	13.00	5.69	2.40	8.61	0.68	3.45	0.74	0.15	0.10	7.48	0.11	11.0	97.9		
26	53.3	14.30	5.84	3.78	5.39	0.41	4.06	0.67	0.16	0.11	5.42	0.14	10.1	98.1		
27	53.7	17.60	7.16	3.52	2.18	0.44	5.02	0.85	0.22	0.08	2.44	0.13	8.2	98.8		
28	52.8	16.60	7.05	3.76	3.36	0.34	4.78	0.83	0.21	0.10	3.69	0.11	9.0	99.0		
29	44.3	9.30	3.04	2.32	17.30	0.74	2.48	0.51	0.15	0.14	14.10	0.03	17.2	97.5		
30	48.0	13.10	5.89	2.90	10.30	0.61	3.75	0.64	0.17	0.10	8.83	0.03	12.8	98.3		
31	54.0	12.90	5.63	2.83	7.88	0.58	3.44	0.68	0.16	0.10	6.84	0.12	10.4	98.6		
32	56.2	15.90	7.28	2.73	3.69	0.46	4.40	0.81	0.16	0.09	2.85	0.01	7.2	98.9		
33	55.6	15.50	6.74	2.71	4.29	0.49	4.30	0.79	0.16	0.09	3.28	0.05	7.8	98.5		
34	51.6	13.50	5.85	2.26	7.15	0.61	3.64	0.70	0.16	0.08	3.17	1.89	9.3	94.7		
35	48.3	12.70	5.00	3.05	10.70	0.65	3.39	0.61	0.16	0.13	9.71	0.09	13.0	97.7		
36	55.2	12.90	4.89	3.49	6.48	0.76	3.20	0.64	0.16	0.13	7.26	0.21	10.2	98.1		
37	46.6	13.00	5.73	3.78	9.86	0.80	3.40	0.63	0.14	0.14	10.00	0.71	12.7	96.8		
38	54.1	18.10	6.63	2.28	3.53	0.26	4.34	0.78	0.14	0.09	3.83	0.46	8.3	98.6		
39	44.5	16.00	5.98	2.18	11.30	0.39	3.91	0.50	0.08	0.11	10.30	0.81	13.0	98.0		
40	46.9	16.50	5.82	2.27	8.97	0.52	4.04	0.55	0.08	0.09	9.01	0.75	12.1	97.8		
41	51.6	13.10	5.62	2.61	8.90	0.79	3.53	0.69	0.16	0.11	7.49	0.04	11.1	98.2		
42	54.0	13.20	5.69	2.79	7.70	0.59	3.53	0.70	0.15	0.10	5.45	0.03	9.9	98.4		
43	53.7	16.50	6.99	3.64	2.85	0.21	4.62	0.79	0.22	0.10	3.21	0.16	8.2	98.0		
44	52.5	13.10	5.73	2.84	8.22	0.88	3.51	0.69	0.18	0.10	6.58	0.02	10.7	98.5		
45	55.5	14.30	6.55	2.61	5.23	0.73	3.97	0.72	0.17	0.08	3.96	0.02	8.4	98.3		
46	58.1	14.40	5.88	2.63	4.54	0.65	3.88	0.77	0.17	0.09	3.43	0.13	7.5	98.6		
47	45.1	16.60	6.18	2.19	9.73	0.33	4.05	0.57	0.09	0.08	9.41	1.01	12.3	97.2		
48	42.9	16.40	5.40	2.22	11.70	0.25	4.03	0.56	0.11	0.05	10.90	0.87	13.4	97.0		

* Results may be unreliable. See text for explanation.

N.B.: H20+ and H20- values not shown; therefore, total of columns is less than that shown in 'total' column.

Table 2. Chemical composition of shale samples. See Figures 7, 9, 11, 13, 15 and 17 for stratigraphic locations of sampled intervals.

to be of interest, such as CaO, Fe_2O_3, SiO_2, to brick manufacturers in assessing the value of a raw material, are shown alongside the lithologs, at the corresponding sampled intervals.

Scumming and efflorescence are usually the result of minor amounts of gypsum in the raw material, but it may also be due to the presence of sulphates of magnesium, iron and alkalies, as well as to the reaction of sulphides (such as pyrite) with carbonates (Guillet 1967). Both lime (CaO) and iron (Fe_2O_3) influence the colour of the fired ware: lime, causing a buff-coloured brick, and iron, a red or black coloured brick under oxidizing and reducing conditions respectively (Guillet 1967). A high lime content also acts in reducing the porosity of the fired ware. Since the shales of the Georgian Bay, Queenston and Arkona formations are illitic, silica (SiO_2), acting as an inert filler, is generally a required ingredient in the raw material (Brownell 1976). However, if present in excessive amounts, silica may serve to reduce the plasticity of the batch (Guillet 1967).

It should be noted that sample #3, Brampton/Norval, OGS-89-05a yielded a low major element total percent (*see* Table 2). This may be due to high Ba and Sr values. As the results of the chemical analysis on sample #3 may be unreliable it is recommended that they be used with caution.

Clay mineralogical analysis was performed on four Georgian Bay Formation shale samples from the Rosemont (OGS-89-06) drill core.

Drill Core Descriptions and Compositional Trends

Borehole OGS-89-05a Brampton/Norval

The 43.5 m of Queenston Formation intersected by the Brampton/Norval borehole consists of red calcareous shale interlaminated to interbedded with grey-green shale, silty shale, green-grey argillaceous siltstone and siltstone (Figure 6). These "hardbands", which comprise up to 45% of the Queenston Formation at this location, are slightly more calcareous and harder than the red shales, and range in thickness from less than 1 to 15 cm. The grey-green shales and occasionally the red shales are wavy- to horizontally-laminated, in places fragmented, suggesting penecontemporaneous disturbance. Grey-green and red mottling of the red and grey-green shales, respectively, is common. Intraclasts, up to 1 cm in diameter of red and grey-green shale occur at various horizons. Siltstones are commonly cross- and horizontally-laminated. Gypsum, primarily present in layers 2 to 10 mm thick, is a minor component of the Queenston Formation at this site; yet it occurs frequently, particularly in the lower half of the hole. This suggests, along with the sedimentary structures, proximity to the contact between the Queenston and Georgian Bay formations.

Some minor trends in the chemical composition of the Queenston shale are apparent at this site (Figure 7). The percentage of both silica and alumina in the shales increase gradually down the hole, from 41.8 to 54% and 9.6 to 13.2%, respectively, while lime content decreases (from 19 to 7.7%). There does not appear to be a strong correlation between lime content and percentage of interlayers. Deviations from these trends are shown by the values belonging to sample #3; these values, as explained above, may be unreliable.

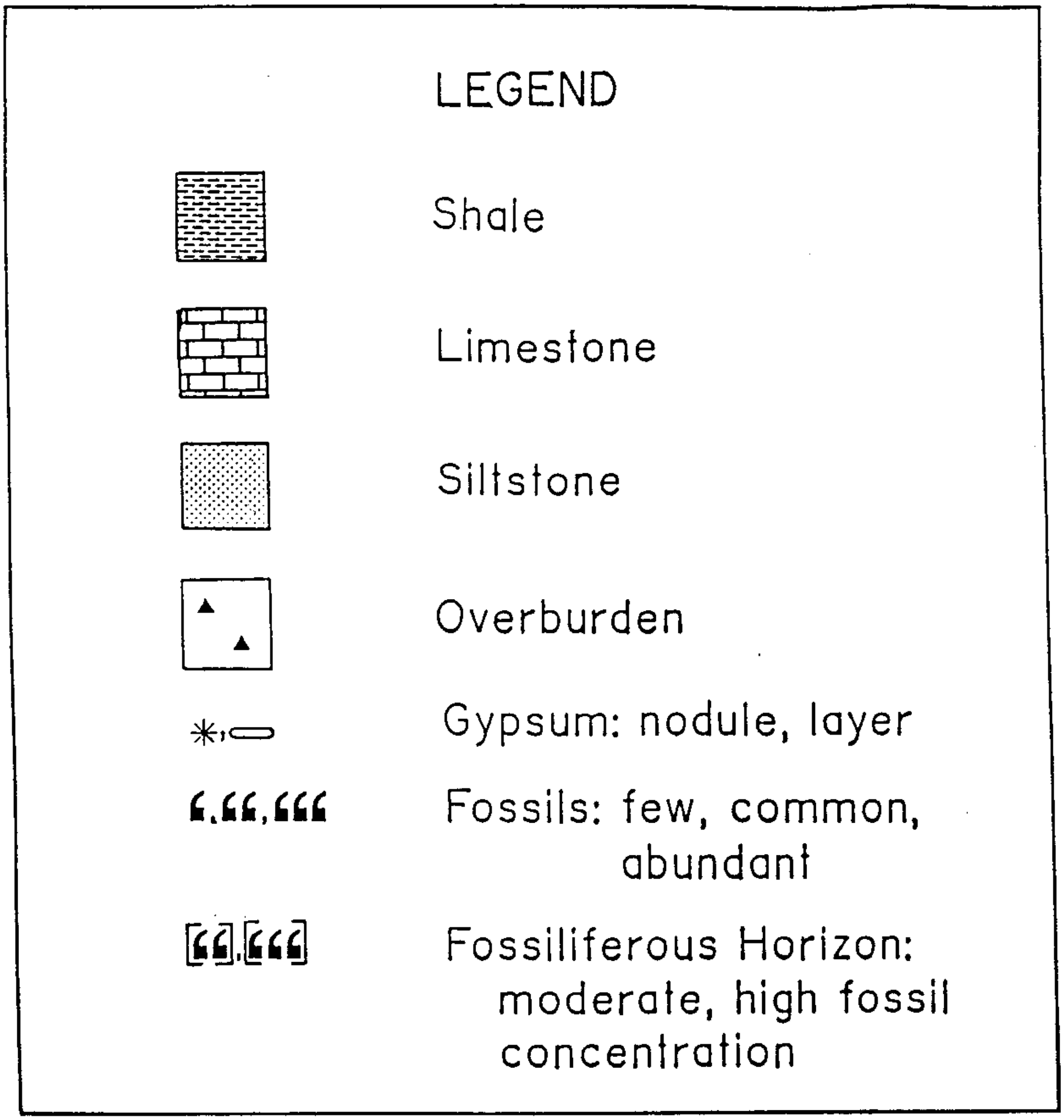


Figure 5. Legend for figures 6 to 17.

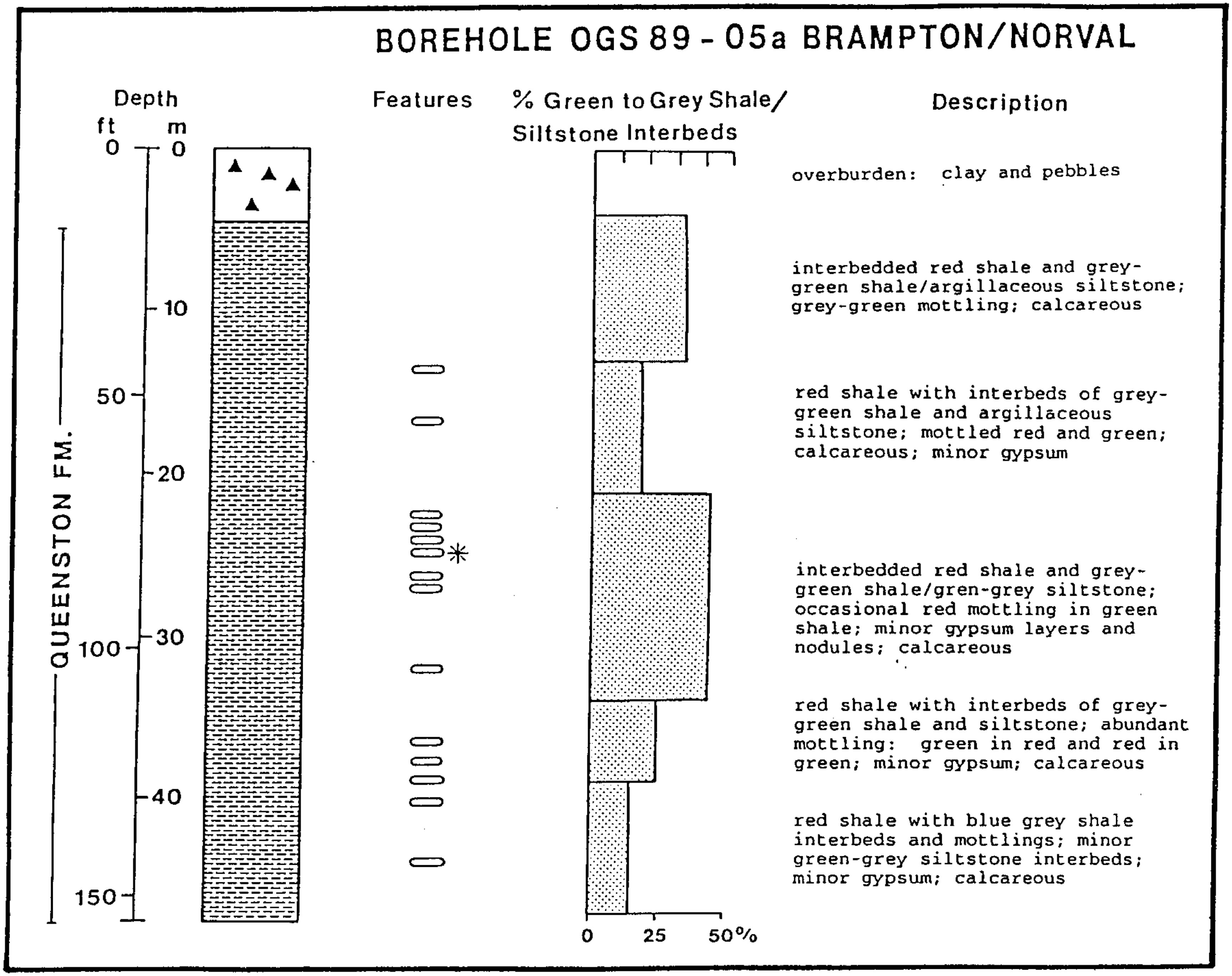
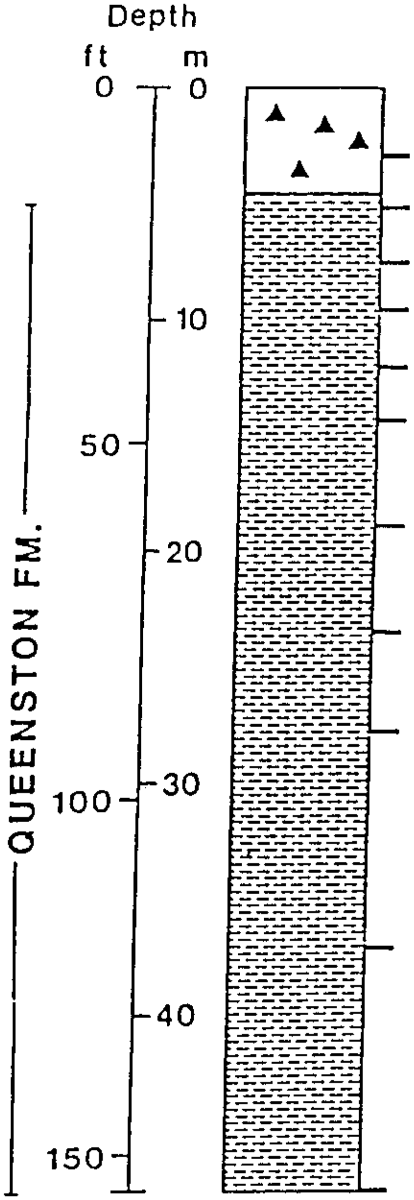


Figure 6. Brampton/Norval drill hole OGS-89-05a.

BOREHOLE OGS 89 - 05a BRAMPTON/NORVAL



Sample #	SiO_2 (Weight %)	Al_2O_3 (Weight %)	CaO (Weight %)	MgO (Weight %)	Fe_2O_3 (Weight %)	S (Weight %)	Cl (ppm)	F (ppm)
1	41.8	9.57	19.00	1.86	4.06	0.02	1080	470
2	43.3	11.10	16.10	2.20	4.85	0.02	170	580
3*	38.2	9.37	9.19	1.55	4.41	3.70	110	440
4	41.8	11.30	16.70	2.31	4.63	0.04	1080	550
5	44.9	11.90	13.90	2.43	5.50	0.04	220	570
23	45.2	11.30	13.80	2.19	4.59	0.81		
24	48.7	13.30	10.40	2.50	6.20	0.03		
25	52.2	13.00	8.61	2.40	5.69	0.11		
41	51.6	13.10	8.90	2.61	5.62	0.04		
42	54.0	13.20	7.70	2.79	5.69	0.03		

* Analytical results may be unreliable. See text for explanation

Figure 7. Brampton/Norval (OGS-89-05a) drill hole showing chemical composition of sample intervals.

Borehole OGS-89-06 Rosemont

The Georgian Bay Formation in borehole OGS-89-06 (Figure 8) is characterized by fine-grained, grey to dark grey, occasionally reddish shale interbedded with light grey argillaceous siltstone, siltstone, and fossiliferous limestone. The shales have a low carbonate content and are generally laminated, but low to moderate bioturbation occasionally obscures these laminations. Fossils, primarily bryozoans, occur occasionally in the shales and are in places concentrated in thin (<5 cm) layers. Siltstone interbeds, with thicknesses ranging from 1 to 40 cm and averaging about 2 to 5 cm, have a higher carbonate content than the host shales. The interbeds are frequently fossiliferous, internally stratified and display sedimentary features typical of storm beds: normally graded beds with shale intraclasts at the base, overlain by horizontal lamination, which in turn grades up into ripple cross-lamination. Limestone interbeds are up to 10 cm thick and contain a concentration of fossils, primarily bryozoans. Minor gypsum occurs in nodules and in layers 1 cm thick.

Although the upper surface of the Georgian Bay Formation at Rosemont occurs stratigraphically just beneath the contact with the Queenston Formation, the occurrence of a reddish hue frequently observed in the dark grey shale is likely unrelated to the proximity of this contact.

Minor trends in the chemical composition of the Georgian Bay Formation shale are present at the Rosemont site (Figure 9). The percentage of both alumina and iron in the shales exhibit an overall increase with depth. Lime content, appears to vary

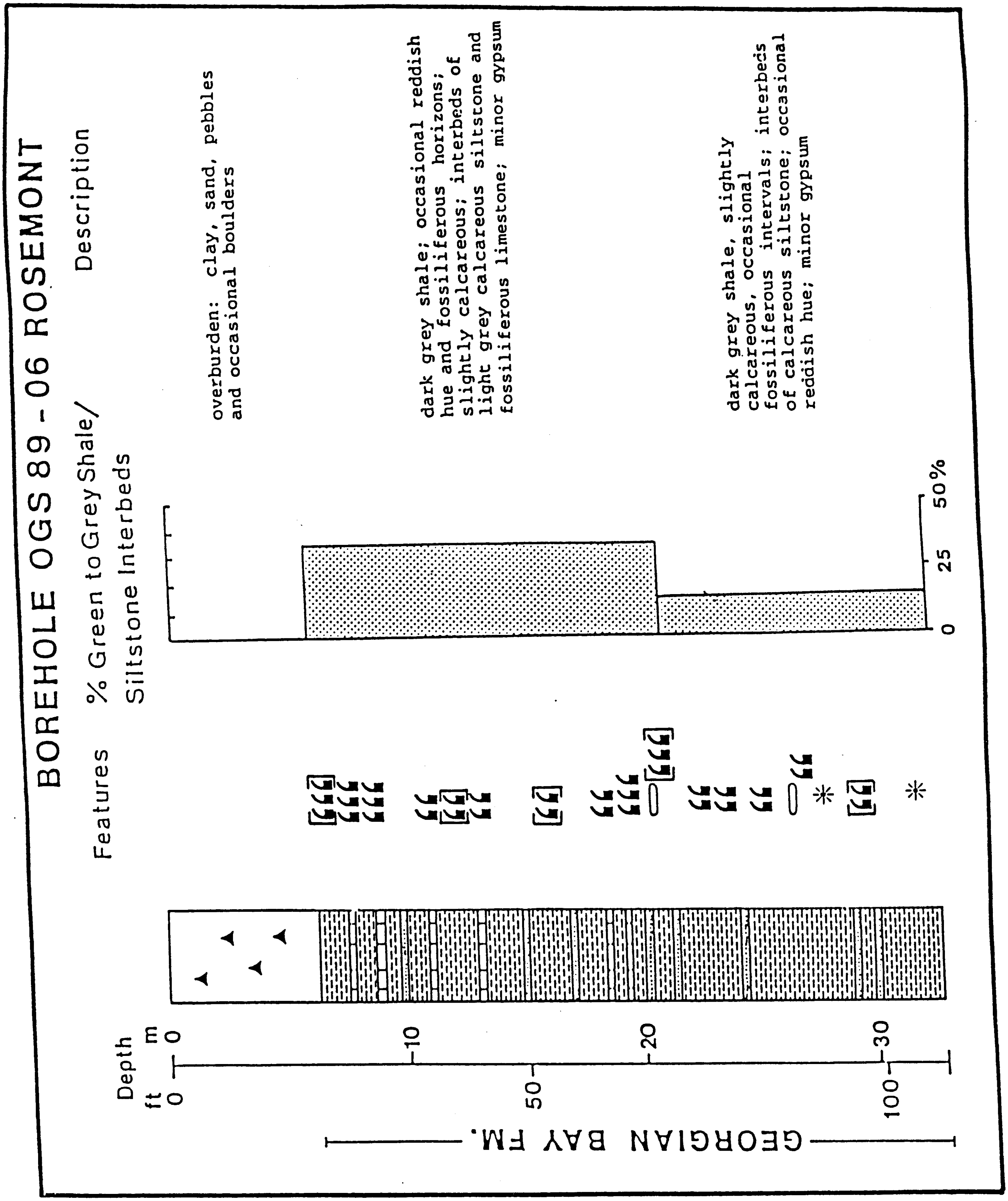


Figure 8. Rosemont drill hole (OGS-89-06).

BOREHOLE OGS 89 - 06 ROSEMONT

Sample #	SiO_2	Al_2O_3	CaO	MgO	Fe_2O_3	S	Cl	F
	WEIGHT %						ppm	
6	45.3	9.07	16.20	3.14	3.87	0.11	1120	440
7	53.6	13.40	6.17	4.33	5.70	0.14	1020	600
8	55.9	12.20	6.81	3.86	5.12	0.06	1060	570
9	58.0	12.90	5.31	3.22	5.52	0.08	430	590
26	53.3	14.30	5.39	3.78	5.84	0.14		
27	53.7	17.60	2.18	3.52	7.16	0.13		
28	52.8	16.60	3.36	3.76	7.05	0.11		
43	53.7	16.50	2.85	3.64	6.99	0.16		

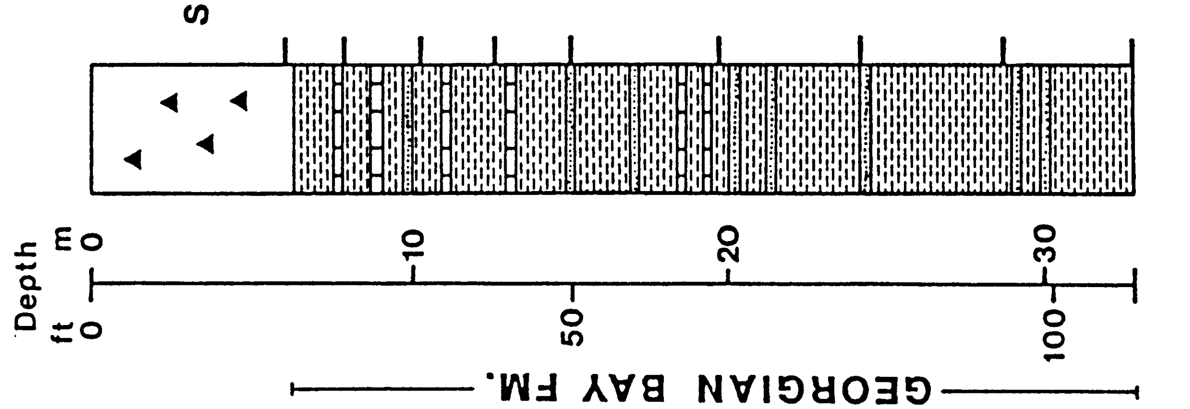


Figure 9. Rosemont (OGS-89-06) drill hole showing chemical composition of sample intervals.

proportionally to the percentage of siltstone/limestone interlayers and shows an overall decrease, from 16.2 to 2.9%, with depth. The overall content of lime is low, however, and in the basal portion of the drillhole, lower than magnesia. In view of high magnesia and alumina content in the lower part of the section, a grain size analysis and determination of clay mineral content would be desirable in addition to existing analyses.

Non-quantitative clay mineralogical analysis of four shale samples (samples #6, 7, 8, 9) show the shales in the upper 8.2 m of the formation to consist predominantly of chlorite, mica and quartz.

Borehole OGS-89-08 Milton

The Milton borehole (Figure 10) encountered a considerable thickness (17.7 m) of overburden, exceeding expectations by about 8 m. The 24.4 m of Queenston Formation intersected by this hole is characterised by very fine-grained red shale with interlayers of grey-green shale, silty shale, and argillaceous siltstone, constituting up to 40%, but generally less than 25%, of the section. Red shales are commonly mottled grey-green, with patches up to 10 cm in size. The red shales derive a medium to high calcium content from the grey-green mudstone interlayers. Grey-green shale intraclasts occur occasionally. The grey-green coloured interlayers, up to 13 cm in thickness, are harder and slightly more calcareous than the red shales, and where silt is present, display minor horizontal- and cross-lamination. The amount of gypsum in this borehole is minor, occurring as layers (1 cm thick) and nodules (8 cm in diameter) in the middle of the Queenston Formation intersection. The fine grain size of the Queenston Formation in this

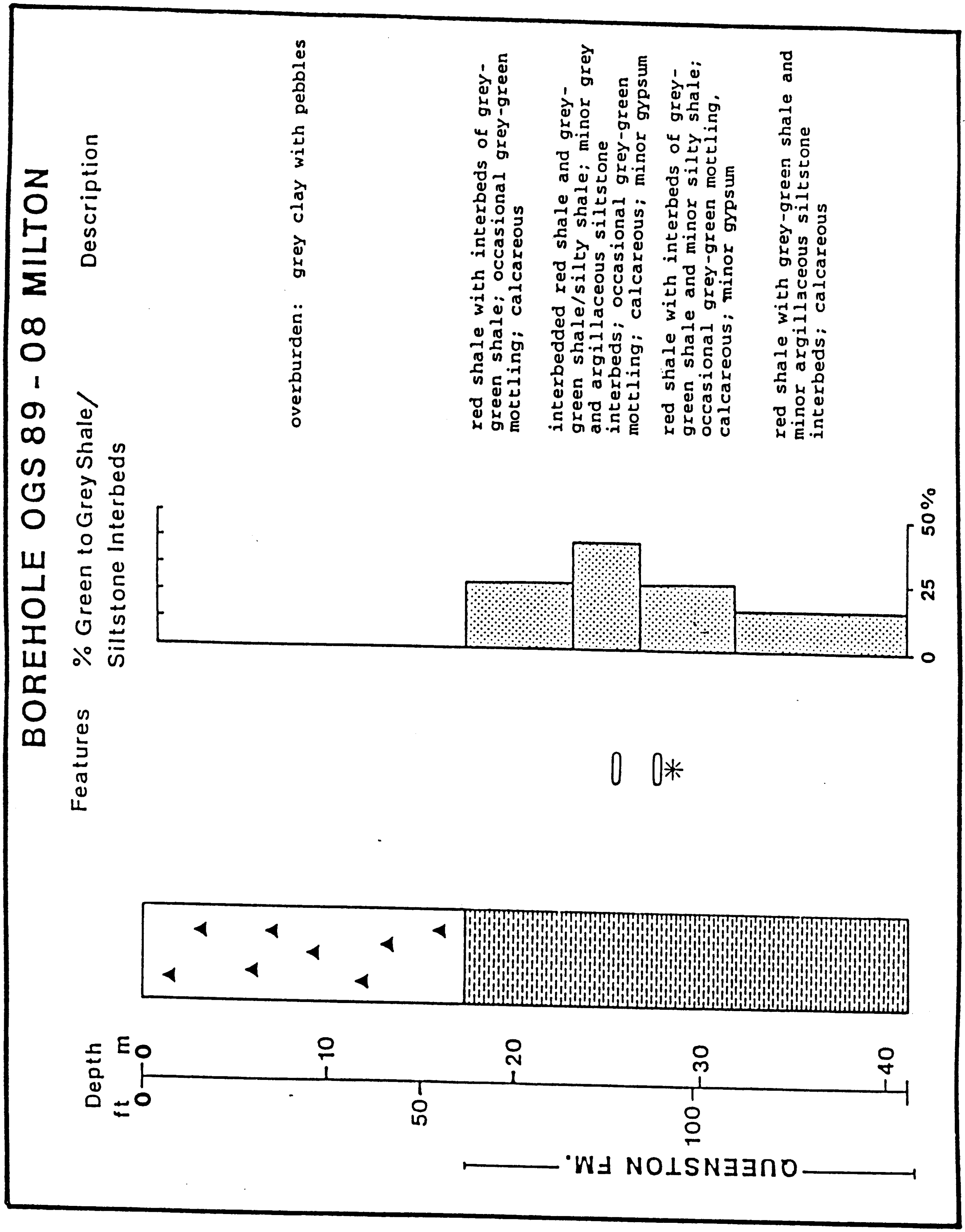


Figure 10. Milton drill hole (OGS-89-08).

BOREHOLE OGS 89 - 08 MILTON

WEIGHT %

Sample #	SiO_2	Al_2O_3	CaO	MgO	Fe_2O_3	S
29	44.3	9.30	17.3	2.32	3.04	0.03
30	48.0	13.10	10.3	2.90	5.89	0.03
31	54.0	12.90	7.88	2.83	5.63	0.12
44	52.5	13.10	8.22	2.84	5.73	0.02
45	55.5	14.30	5.23	2.61	6.55	0.02

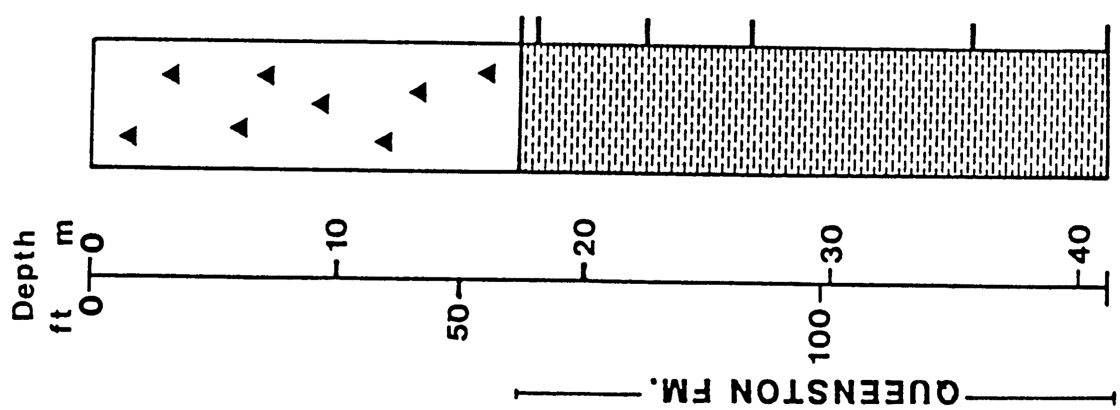


Figure 11. Milton (OGS-89-08) drill hole showing chemical composition of sample intervals.

hole indicates a position both higher stratigraphically and farther away from the source rocks than the shale intersected at Streetsville and Brampton/Norval.

Some minor trends in the chemical composition (Figuer 11) of the Queenstone Formation shales can be seen despite the reduced sampled interval compared to the other drill cores. Silica and iron content increases with depth from 44.3 to 55.5%, and from 3.0 to 6.6%, respectively. Lime content, possibly reflecting the percentage of green-grey shale/siltstone interlayers, decreases with depth from 17.3 to 5.2%.

The intersection in this hole of an unexpected thickness of 17.7 m of overburden reflects the difficulty and limitations involved in predicting overburden thicknesses, particularly in areas where abundant outcrop and water well data (used to construct overburden thickness maps) are lacking.

Borehole OGS-89-09 Niagara-on-the-Lake

The interval of the Queenston Formation intersected by borehole OGS-89-09 (Figure 12) consists predominantly of red shale with interlayers of grey-green mudstones. The Grey-green mudstones, with thicknesses up to 20 cm, comprise approximately 15% of the section and generally have a higher carbonate content than the red shales. Red shales display occasional grey-green mottling and contain minor grey-green mudstone intraclasts. In the upper part of this hole (4.7 to 21 m), the red and grey-green shales are fine-grained and massive in appearance. In the lower part of the hole (21 to 39 m), the red shale is occasionally laminated and is characterised by a slightly greater abundance

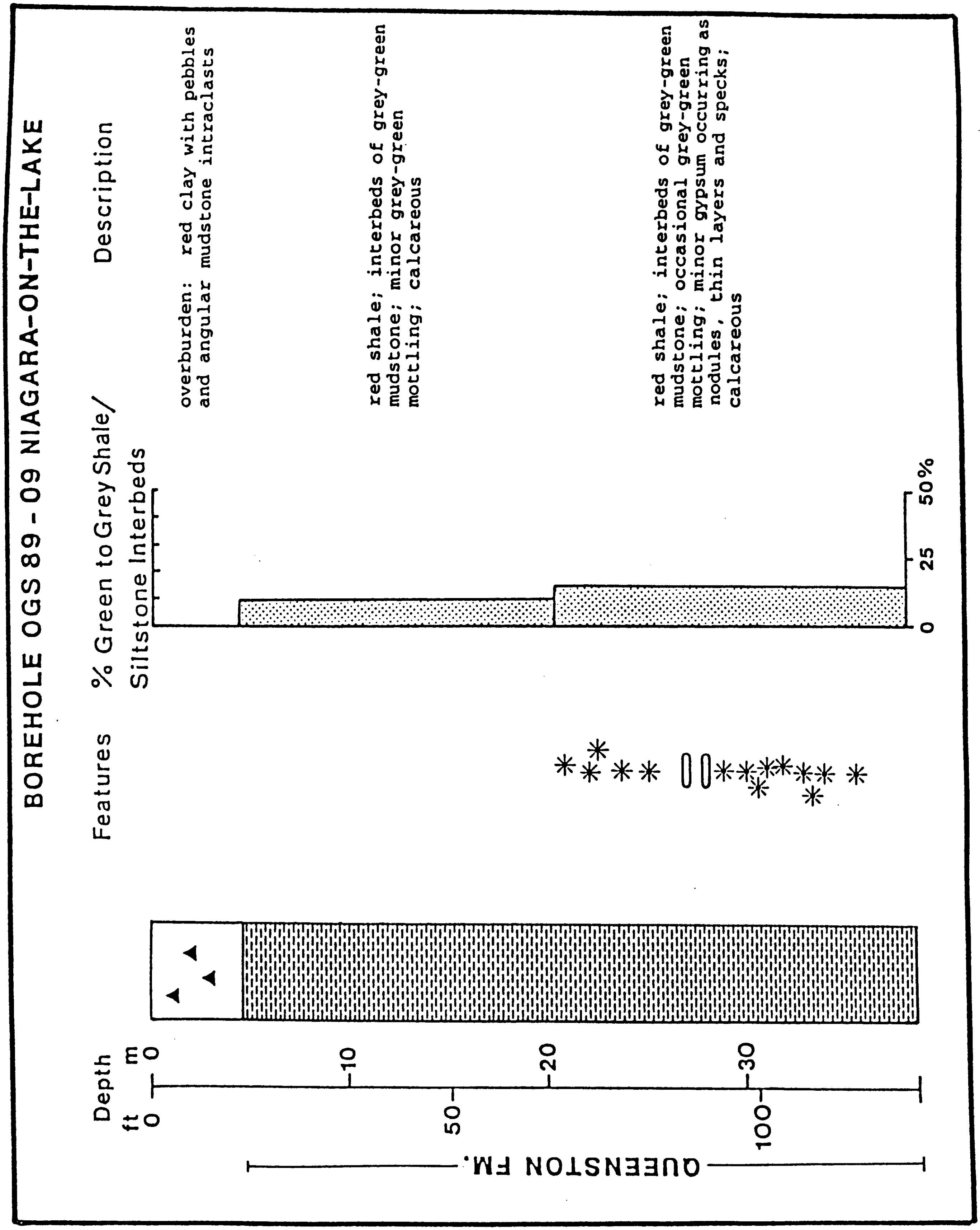


Figure 12. Niagara-on-the-Lake drill hole (OGS-89-09).

of grey-green mudstone interlayers and intraclasts. Minor gypsum occurs as specks, thin layers (1 to 2.5 cm), or nodules (2 to 7 cm in diameter).

The chemical composition of the Queenston Formation shales at this site is variable, showing no obvious trends down the hole (Figure 13). Sample #10 was taken from overburden in which shale from the bedrock had become incorporated into the glacial sediments; the sampled interval consists of red clay with pebbles and intraclasts of mudstone and weathered red shale.

Borehole OGS-89-10 Streetsville

Borehole OGS-89-10 (Figure 14) intersects 6.7 m of overburden, 9.7 m of Queenston Formation and 13.2 m of Georgian Bay Formation. The Queenston Formation is characterised by red shale interlaminated to interbedded with grey-green mudstone, silty mudstone, and grey to red argillaceous siltstone. The percentage of these hardbands within the secton is variable but is generally greatest within the basal 3.6 m representing the transition into the Georgian Bay Formation. The red shales bear the characteristics of their proximity to the Georgian Bay Formation. They are calcareous, horizontally-laminated, commonly wavy-bedded and, towards the base of the formation, contain fossils and minor gypsum nodules.

The Georgian Bay Formation at Streetsville is a grey, horizontal- to wavy-laminated shale with fossiliferous (corals), occasionally cross-laminated limestone or argillaceous limestone interbeds. Although dark grey, massive shale is present,

BOREHOLE OGS 89 - 09 NIAGARA-ON-THE-LAKE

Sample #	SiO_2	Al_2O_3	CaO	MgO	Fe_2O_3	S	Cl	F
	WEIGHT %						ppm	
10	58.3	14.80	4.05	2.72	6.26	0.05	1060	540
11	57.4	15.60	3.21	2.79	7.58	0.01	1080	590
12	56.8	15.90	3.54	2.82	7.26	0.01	100	610
13	58.1	14.40	4.89	2.43	5.67	0.01	140	530
14	58.7	13.90	5.40	2.20	5.94	0.01	110	470
32	56.2	15.90	3.69	2.73	7.28	0.01		
33	55.6	15.50	4.29	2.71	6.74	0.05		
34	51.6	13.50	7.15	2.26	5.85	1.89		
46	58.1	14.40	4.54	2.63	5.88	0.13		

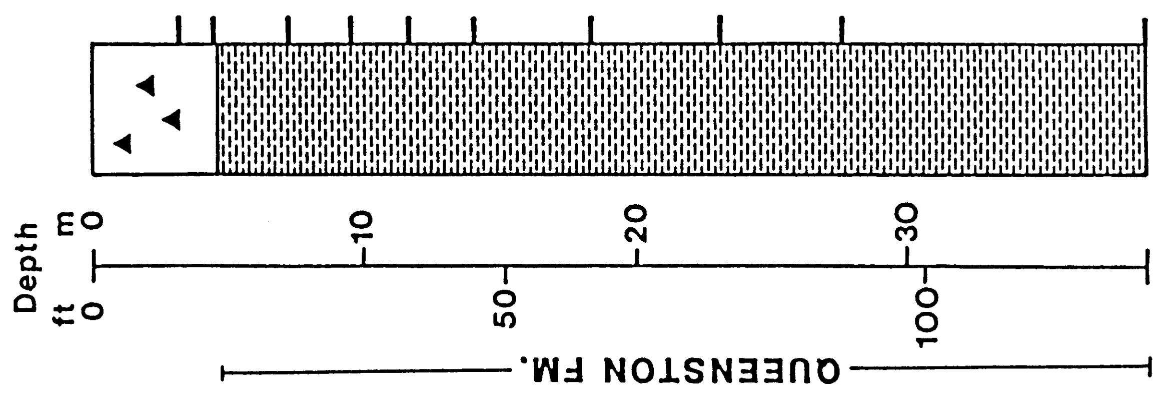


Figure 13. Niagara-on-the-Lake (OGS-89-09) drill hole showing chemical composition of sample intervals.

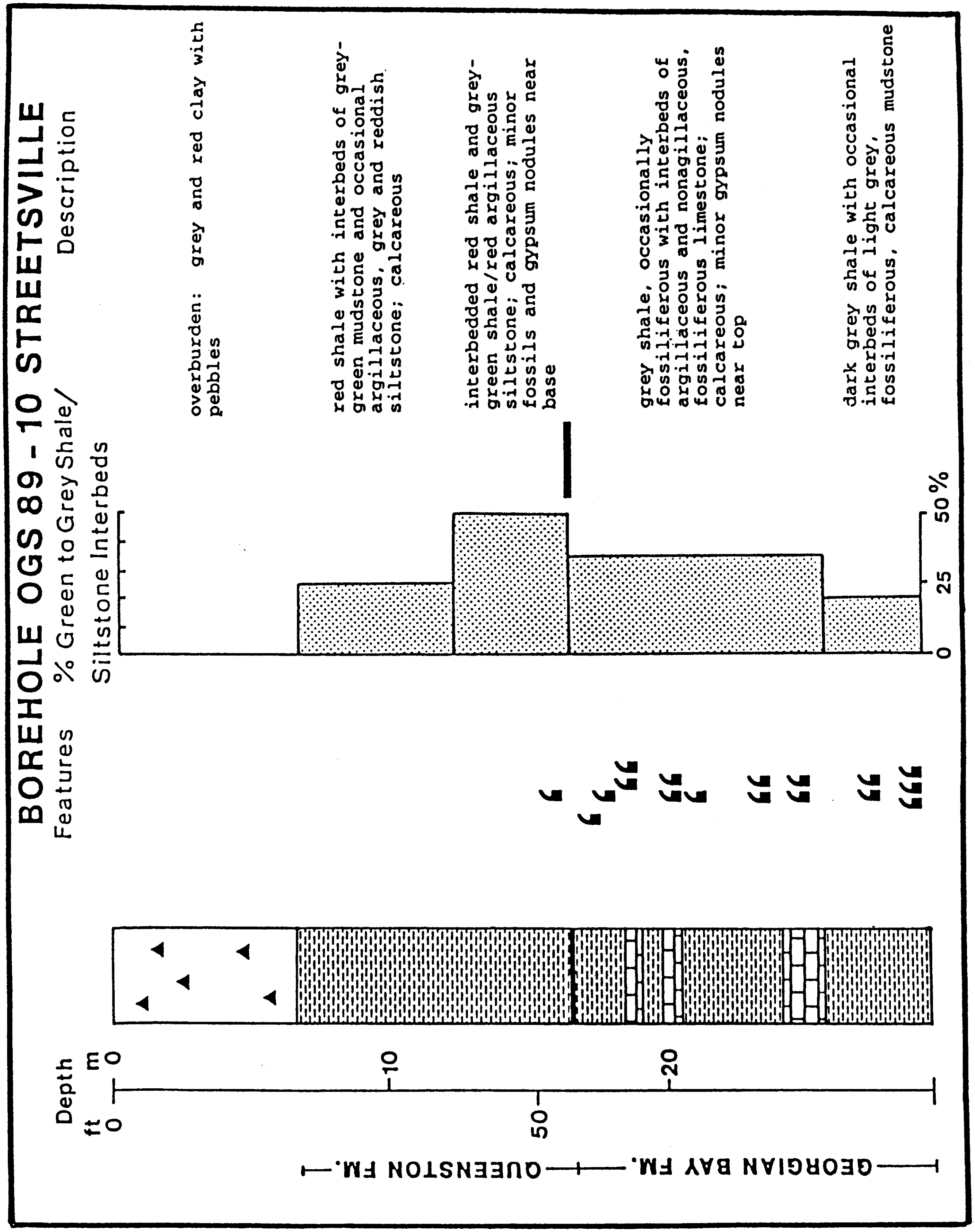


Figure 14. Streetsville drill hole (OGS-89-10).

fossiliferous and light grey, calcareous shale predominates in this section. Minor gypsum, in the form of nodules, occurs near the top of the formation.

The thicknesses of the Georgian Bay and Queenston formations intersected in this drill hole are too small to draw any substantial conclusions regarding any trends in the chemical composition of the shales (Figure 15). Of interest is the lack of any significant differences in chemical composition between the two formations; there tends to be, however, a slightly higher silica and iron content and a lower magnesia and sulphur content in the Queenston shales than in the shales of the Georgian Bay Formation.

Borehole OGS-89-11 Thedford

Three of the 6 formations composing the Hamilton Group—the Arkona, Rockport Quarry and Bell formations—were intersected by borehole OGS-89-11 (Figure 16). Of the 3 only the Rockport Quarry Formation has its full formational thickness present (2.6 m). Subdivision of the Hamilton Group, as shown on Figure 16, is tentative. The 38.1 m of Arkona Formation intersected by this hole consists predominantly of grey, calcareous, laminated shale with occasional intervals of light and dark grey, laminated shale. Fossils, primarily shell fragments, and trace fossils occur in the basal 11 m of the formation. Part of this interval may in fact belong to the underlying Rockport Quarry Formation. A paleontological study may be required to better define the placement of this contact. The Rockport Quarry Formation in this hole is characterised by grey, fossiliferous limestone with minor grey calcareous shale. The 7.5 m of Bell Formation consists of dark grey, calcareous shale. Fossils, primarily shell fragments, occur at a few horizons.

BOREHOLE OGS 89 - 10 STREETSVILLE

Sample #	SiO_2	Al_2O_3	CaO	MgO	Fe_2O_3	S	Cl	F
	WEIGHT %						ppm	
15	57.3	12.90	6.68	2.32	6.29	0.01	110	520
16	57.1	16.40	1.97	2.86	8.64	0.01	140	680
17	54.4	13.70	7.08	2.29	7.15	0.01	210	630
35	48.3	12.70	10.70	3.05	5.00	0.09		
36	55.2	12.90	6.48	3.49	4.89	0.21		
37	46.6	13.00	9.86	3.78	5.73	0.71		

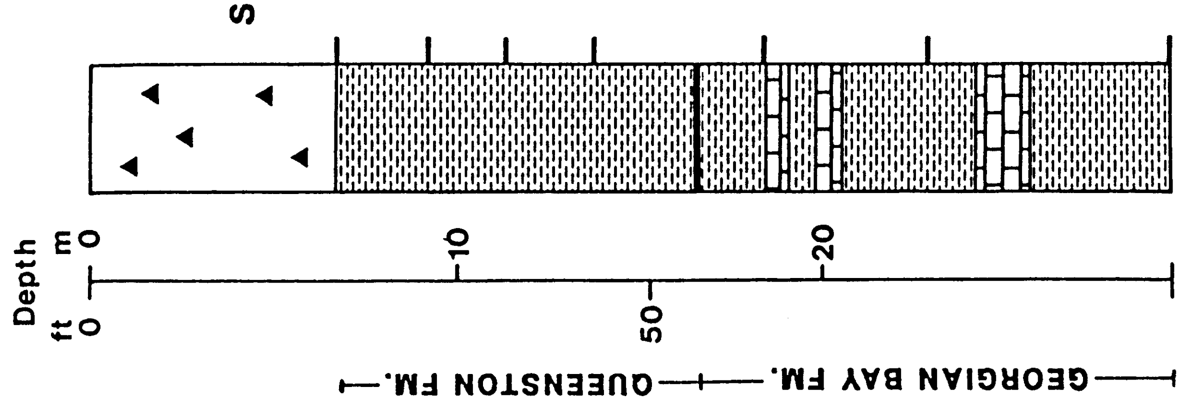


Figure 15. Streetsville (OGS-89-10) drill hole showing chemical composition of sample intervals.

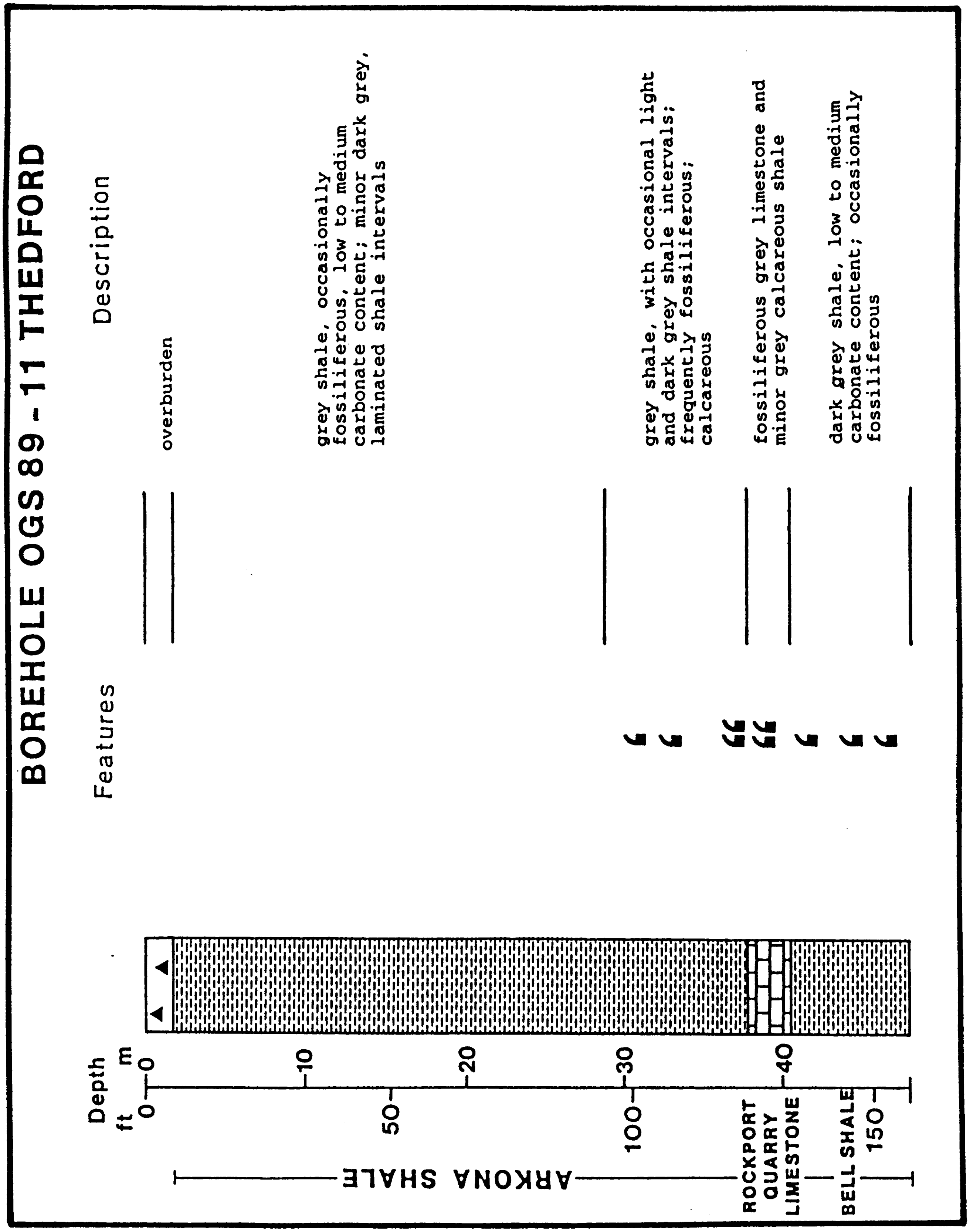


Figure 16. Thedford drill hole (OGS-89-11).

The Arkona Formation shales show minor variability in chemical composition vertically at this site (Figure 17). The upper half of the intersected Arkona Formation tends to have a higher silica content and a lower sulphur and lime content than the lower half. Inclusion **of** the Rockport Quarry Formation with the Bell Formation shale in chemical analysis #48 does not allow the essentially low to medium calcium content of the dark-grey Bell Formation shales at this location to be demonstrated.

Regional Trends in Shale Composition

Due to the relatively limited number of drill holes and the lack of stratigraphic control of this study, except for borehole OGS-89-10 (Streetsville), where the drill hole has intersected both the Georgian Bay and Queenston formations, it is difficult to come to any conclusions regarding regional trends in the chemical composition of either the Georgian Bay or Queenston Formation shales based on the results of this study. However, a few general comments can be made about the regional variation of the composition of the Queenston Formation shale within 50 m of the surface. The content of silica and alumina in the shale tends to be lower in the northern part of the study area (e.g., Brampton/Norval) than in the southern part (e.g., Niagara-on-the-Lake). Conversely lime content tends to be higher in the northern part as opposed to the southern part of the study area. These observations, particularly with respect to silica and lime, are consistent with other studies (Guillet 1967, 1977; Kwong et al. 1985).

BOREHOLE OGS 89 - 11 THEDFORD

Sample #	SiO_2	Al_2O_3	CaO	MgO	Fe_2O_3	S	Cl	F
	WEIGHT %						ppm	
18	52.1	17.20	4.68	2.53	7.07	0.25	170	570
19	50.9	17.00	5.35	2.67	6.76	0.23	330	410
20	49.0	13.60	9.66	2.65	6.08	0.45	440	490
21	53.7	15.30	5.52	2.58	6.47	0.23	330	490
22	55.9	14.70	5.91	2.50	6.02	0.20	310	500
38	54.1	18.10	3.53	2.28	6.63	0.46		
39	44.5	16.00	11.30	2.18	5.98	0.81		
40	46.9	16.50	8.97	2.27	5.82	0.75		
47	45.1	16.60	9.73	2.19	6.18	1.01		
48	42.9	16.40	11.7	2.22	5.4	0.87		

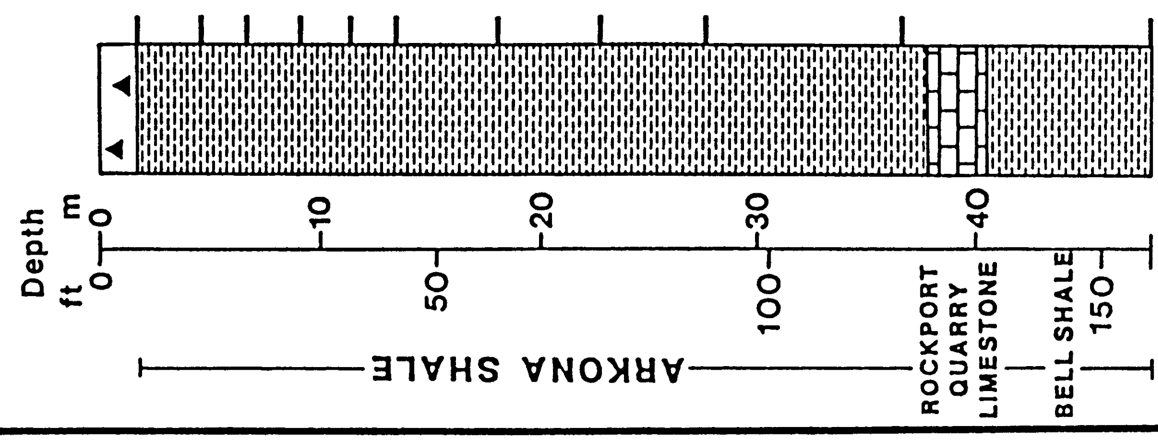


Figure 17. Thedford (OGS-89-11) drill hole showing chemical composition of sampled intervals.

SUMMARY AND CONCLUSIONS

Historically clay brick plants in southern Ontario have been located where resources and markets coincide. The great number of plants that once existed has now been reduced to a few large production facilities with modern, state-of-the-art, automated equipment. These plants equally depend on a strategic location with respect to resources and markets in view of competition from other building materials.

The continued popularity of clay brick promises a sustained demand, particularly in residential construction, where it serves mainly as a protective and decorative veneer on the structural frame. Clay brick is also popular in landscaping and patio construction.

The objective of the study was twofold: to locate source areas of shale and conduct preliminary testing to determine if the material might be of suitable quality for use by the brick industry, and to obtain information on regional trends in the composition of selected shale formations. The following is a summary of this study and its results:

1) Three formations—the Georgian Bay, Queenston and Arkona formations—were selected for study, due to their proven success as a raw material in brick-making.

2) Six shallow holes (maximum depth of 48.2 m) were drilled (OGS-89-05a, 06, 08, 09,10, and 11) at or near surface, one through the Arkona, and the remaining five through the Queenston and/or Georgian Bay formations.

3) Forty-eight shale samples were analysed for chemical composition. All were analysed for major rock-forming elements. Samples taken within the upper 13.7 m of each core, were also analysed for CI and F. Non-quantitative clay mineralogical analysis was performed on four samples from the upper 8.2 m of the Georgian Bay Formation from the Rosemont drill core.

4) In some of the drill cores (OGS-89-05a, 06 and 08), the following general trends in chemical composition of the Georgian Bay and Queenston Formation shales were observed: lime (CaO) content decreased with depth, while the content of silica (in drill cores OGS-89-05a, and 08), alumina (in OGS-89-05a and 06) and iron (in OGS-89-06 and 08) correspondingly increased. The Arkona Formation (OGS-89-11) is characterized by an increase in lime and sulphur content with depth and a corresponding decrease in silica content.

5) The limited size of the data base generated by this study is not sufficient to draw conclusions regarding regional trends in the chemical composition of the shales. However, it was noted that generally the shales of the Queenston Formation, within 50 m of the surface, tend to be higher in lime content but lower in alumina and silica in the northern part of the study area than in the southern part.

6) Results obtained during this study regarding the chemical composition of the shales will serve, at the drill locations, as a first indication of the potential suitability of the shales as a ceramic raw material. Physical characteristics and behaviour of the shales under firing need to be studied to further assess the value

of these materials.

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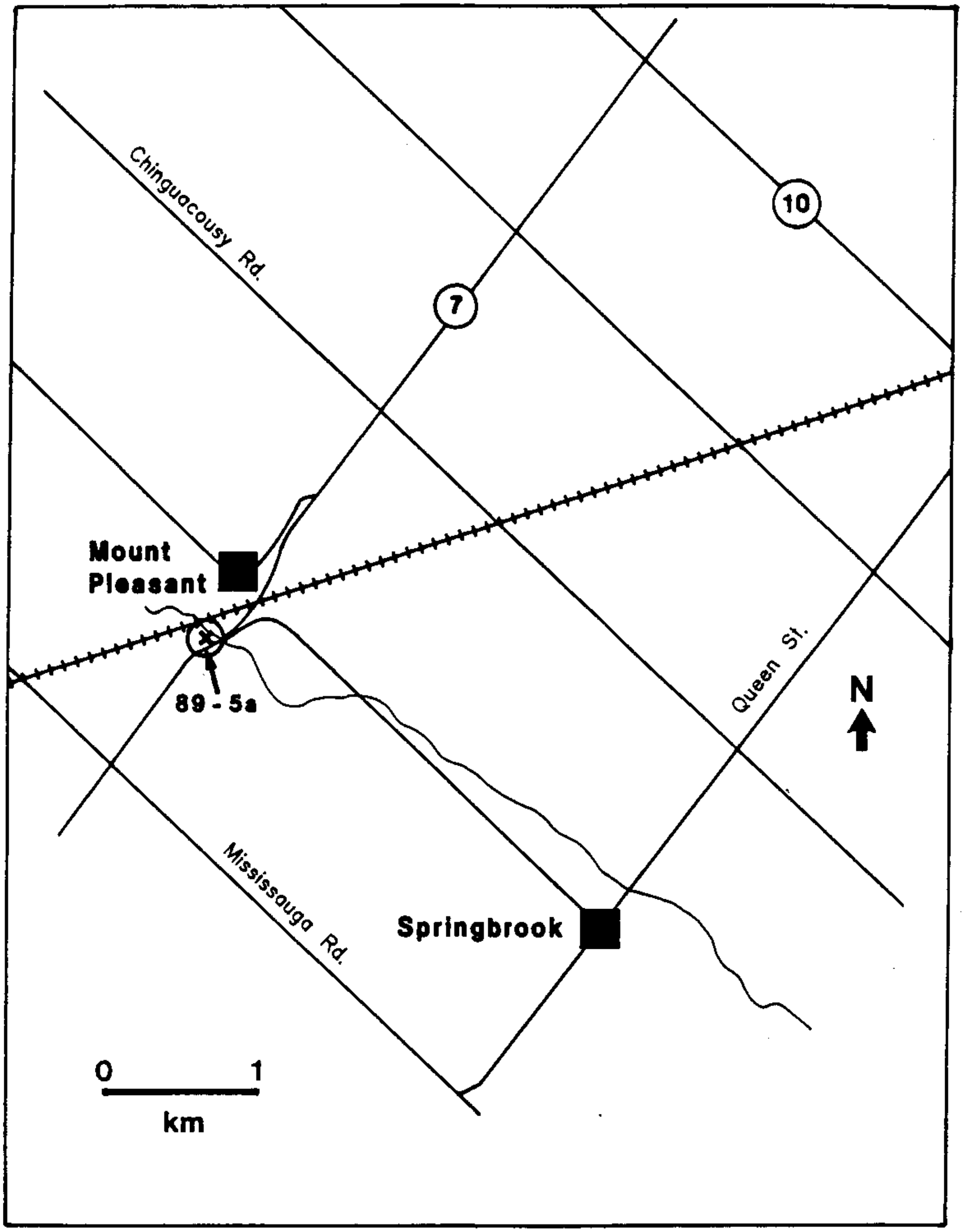
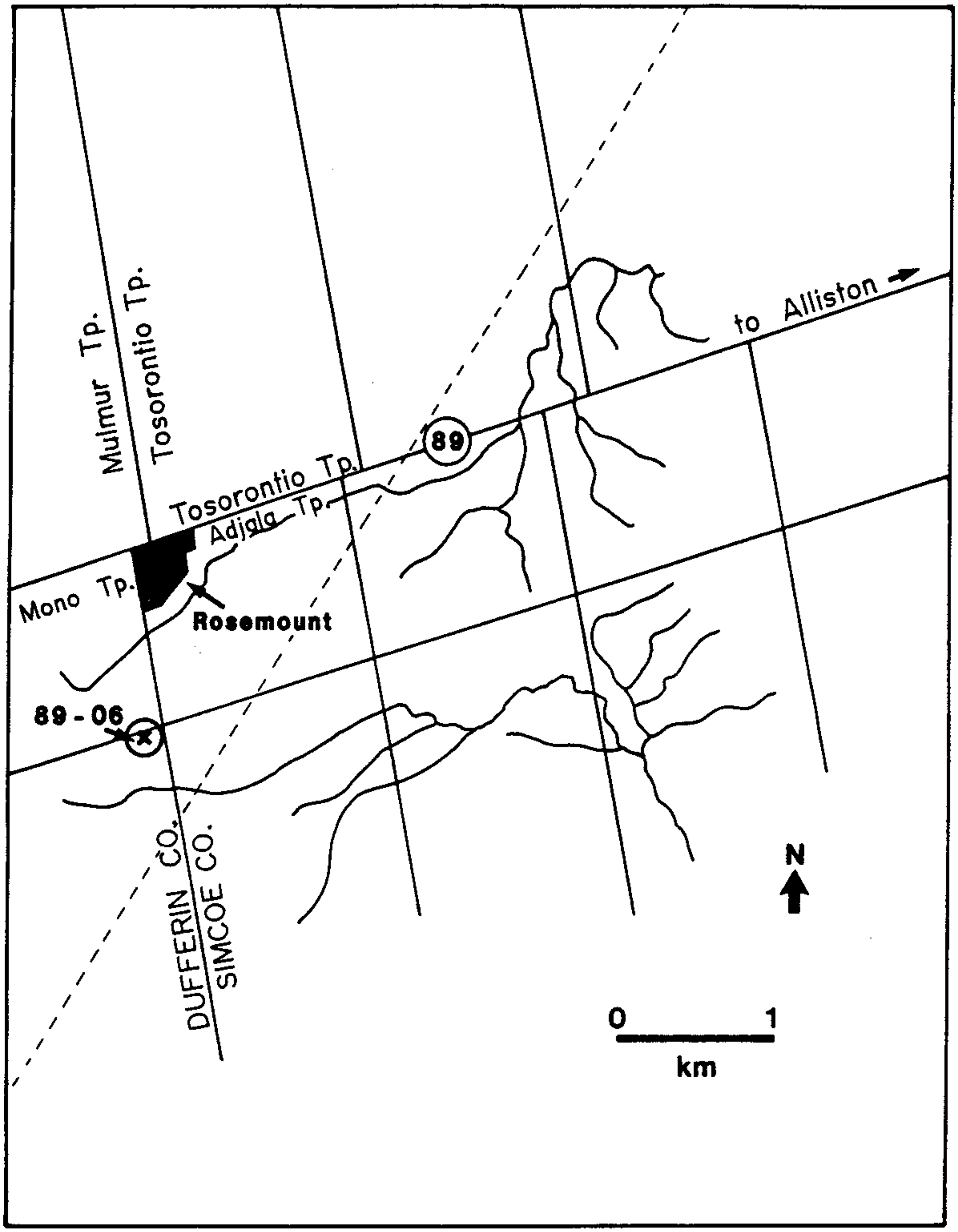
APPENDIX 1. Location of Boreholes



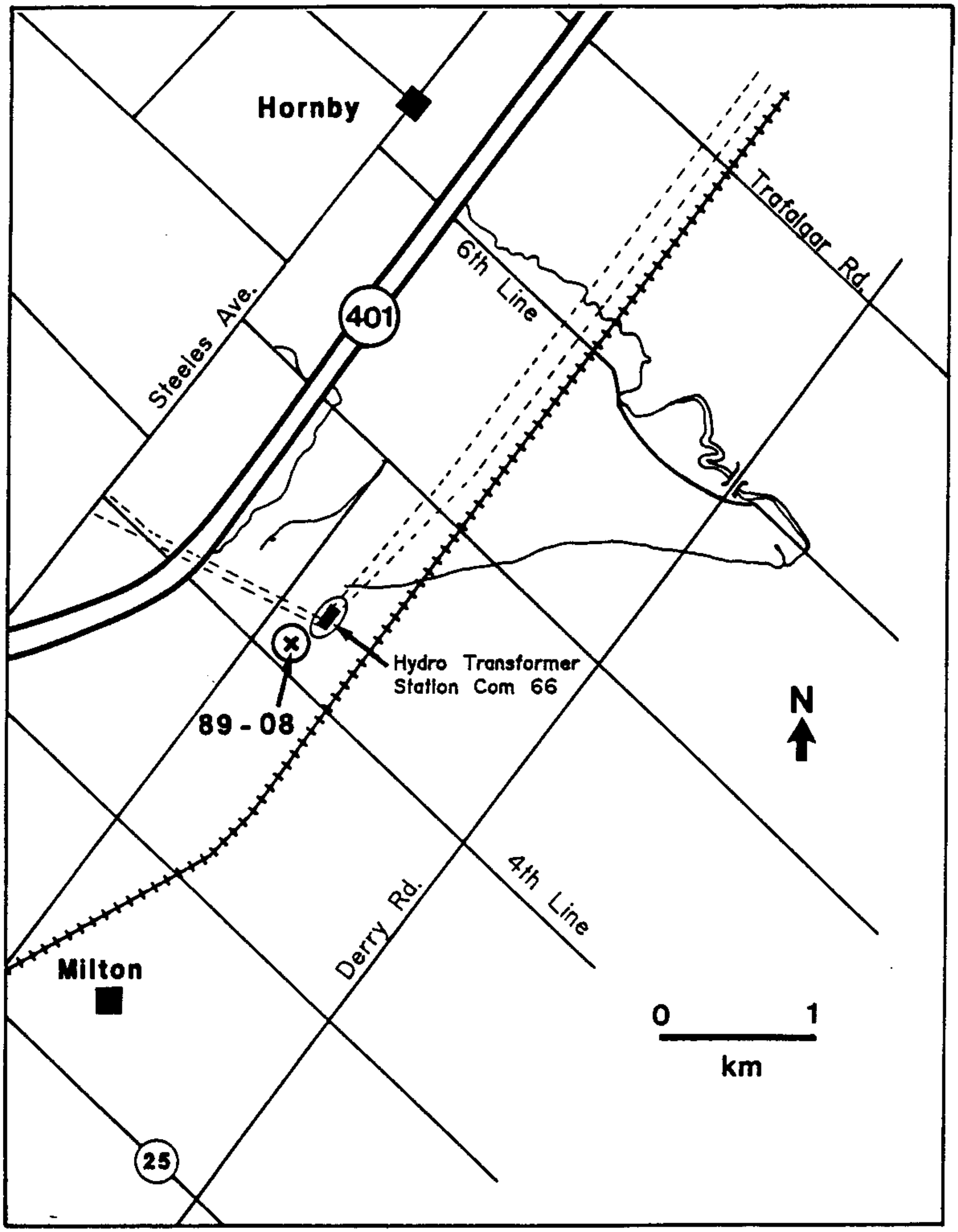
UTM Grid Zone:	17T	
Grid Reference:	4 836 048 m	Northing
	594 903 m	Easting

Figure 18. Location map and grid reference for the Brampton/Norval (OGS-89-05a) drill site, located on Highway 7 right-of-way, on an abandoned road bed section between lot 10 and lot 11 (concession IV), Municipality of Peel, City of Brampton.



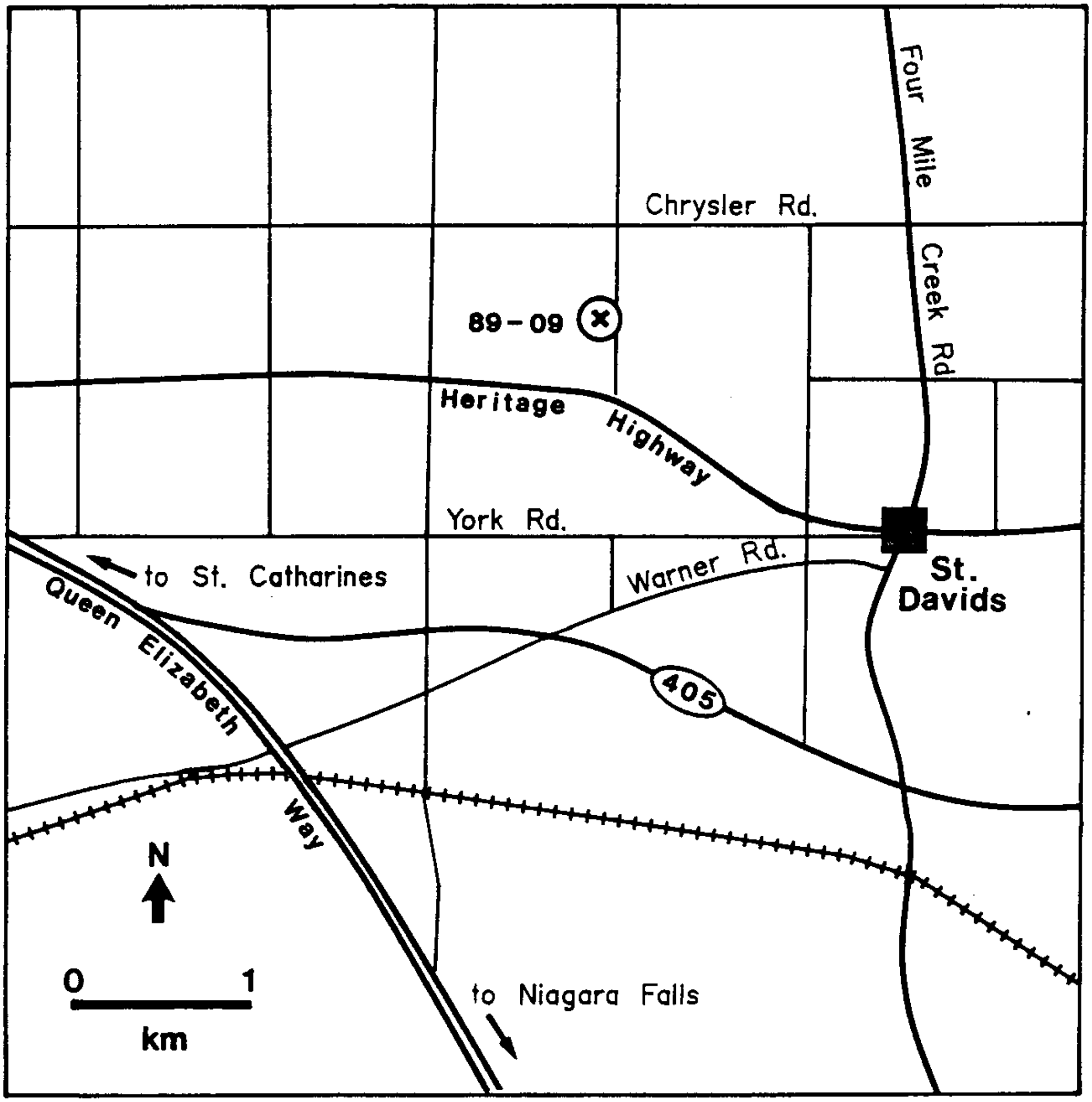
UTM Grid Zone:	17T		
Grid Reference:	4 884 645 m	Northing	
	580 548 m	Easting	

gure 19. Location map and grid reference for the Rosemont (OGS-89-06) drill site, :ated on a rural road right-of-way, County of Dufferin, Mono Township, lot 30, ncession VIII.



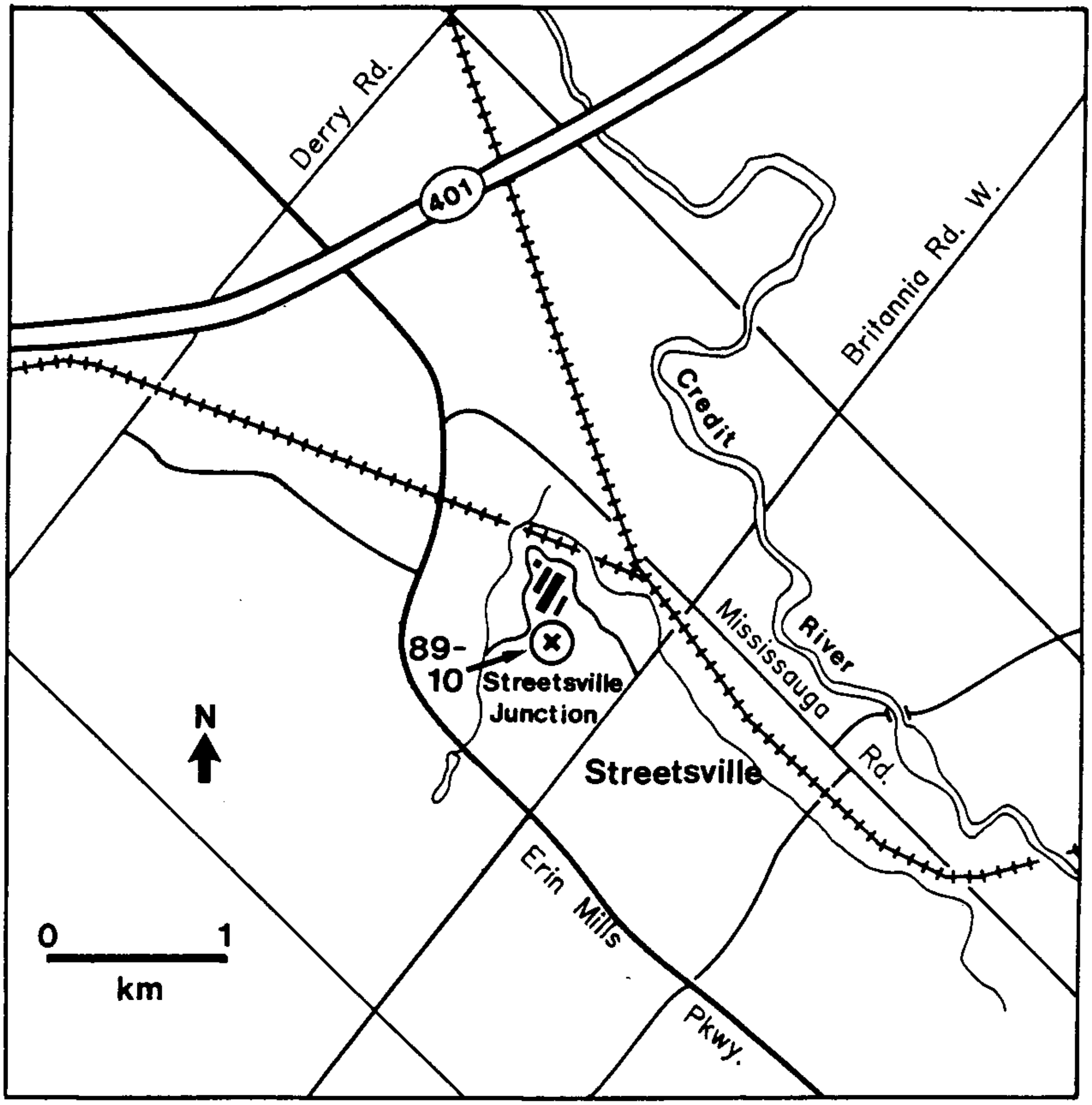
UTM Grid Zone:	17T	
Grid Reference:	4 820 968 m	Northing
	592 613 m	Easting

Figure 20. Location map and grid reference for the Milton (OGS-89-08) drill site, located on the north side of Ontario Hydr Transfer Station prpoerty, Municipality of Halton, Town of Milton, lot 13, concession V.



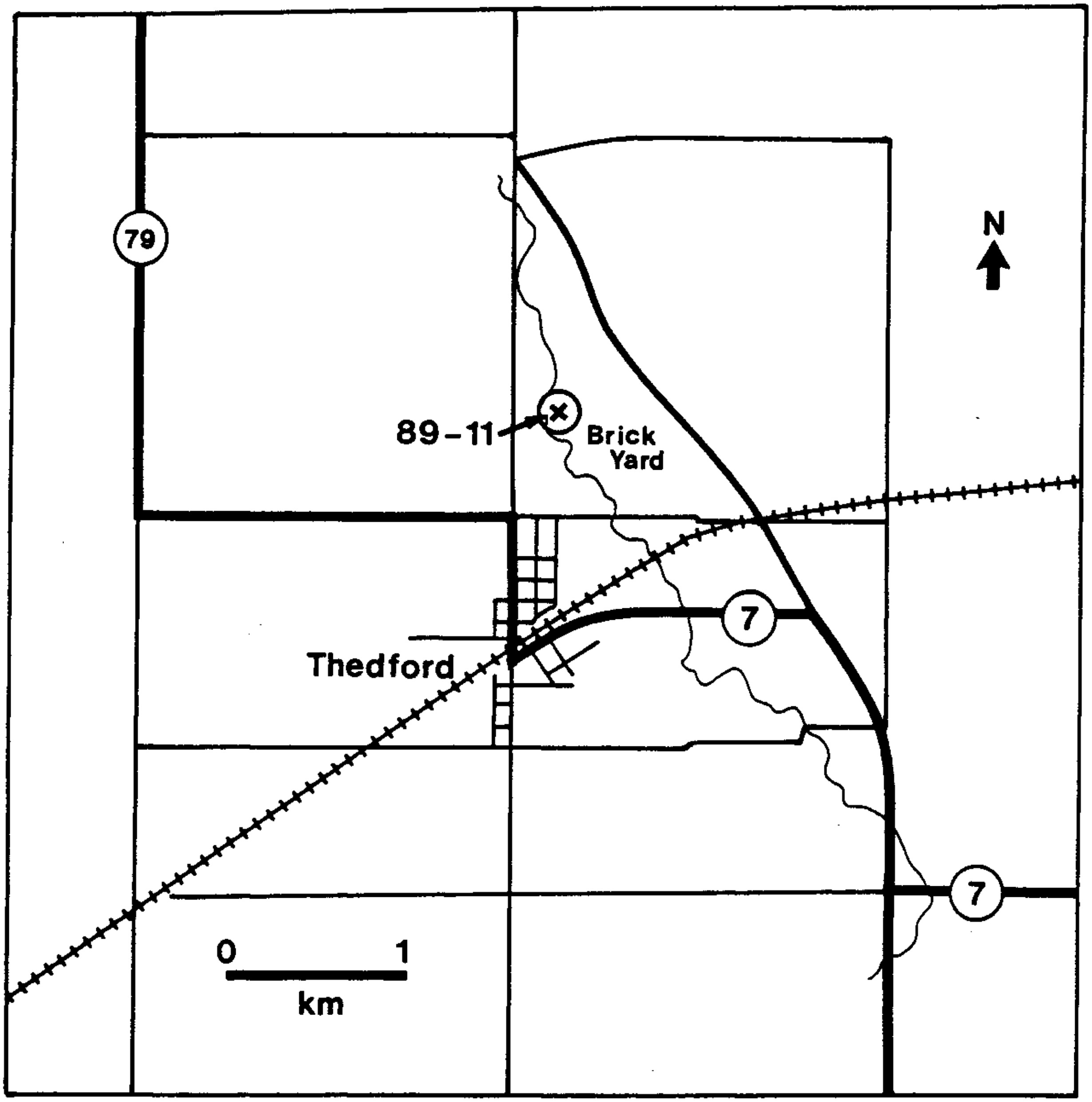
UTM Grid Zone:	17T	
Grid Reference:	4 781 032 m	Northing
	652 613 m	Easting

Figure 21. Location map and grid reference for the Niagara-on-the-Lake (OGS-89-09) drill site, situated on Canada Brick Quarry property, Niagara County, Niagara-on-the-Lake Township, lot 133.



UTM Grid Zone:	17T		
Grid Reference:	4 826 565 m	Northing	
	602 355 m	Easting	

Figure 22. Location map and grid reference for the Streetsville (OGS-89-10) drill site, situated at the centre of the Canada Brick Britannia Quarry, Municipality of Peel, City of Mississauga, lot 6, concession V.



UTM Grid Zone: 17T

Grid Reference: 4 780 453 m Northing
430 532 m Easting

Figure 23. Location map and grid reference for teh Thedfrod (OGS-89-11) drill site, located on Alan Hawkins (previously G. Coultis) Quarry (floor of quarry) County of Lambton, Bosanquet Township, lot 23, concession III.

CONVERSION FACTORS FOR MEASUREMENTS IN ONTARIO GEOLOGICAL SURVEY PUBLICATIONS

Conversion from SI to Imperial			Conversion from Imperial to SI		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
		LENGTH			
1 mm	0.039 37	inches	1 inch	25.4	mm
1 cm	0.393 70	inches	1 inch	2.54	cm
l m	3.280 84	feet	1 foot	0.304 8	m
l m	0.049 709 7	chains	1 chain	20.116 8	m
1km	0.621 371	miles (statute)	1 mile (statute)	1.609 344	km
		AREA			
1 cm2	0.155 0	square inches	1 square inch	6.451 6	cm2
lm2	10.763 9	square feet	1 square foot	0.092 903 04	m2
lkm2	0.386 10	square miles	1 square mile	2.589 988	km2
lha	2.471 054	acres	1 acre	0.404 685 6	ha
		VOLUME			
1 cm3	0.061 02	cubic inches	1 cubic inch	16.387 064	cm3
1 m3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m3
1 m3	1.308 0	cubic yards	1 cubic yard	0.764 555	m3
		CAPACITY			
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L .	0.219 969	gallons	1 gallon	4.546 090	L
		MASS			
lg	0.035 273 96	ounces (avdp)	1 ounce (avdp)	28.349 523	g
lg	0.032 150 75	ounces (troy)	1 ounce (troy)	31.103 476 8	g
1kg	2.204 62	pounds (avdp)	1 pound (avdp)	0.453 592 37	kg
1kg	0.001 102 3	tons (short)	1 ton (short)	907.184 74	kg
1 t	1.102 311	tons (short)	1 ton (short)	0.907 184 74	t
1kg	0.000 984 21	tons (long)	1 ton (long)	1016.046 908 8	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	1.016 046 908 8	t
		CONCENTRATION			
lg/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	gA
lg/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	Multiplied by	
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note: Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.

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