THE DEPOSITIONAL ENVIRONMENT OF THE QUEENSTON FORMATION IN SOUTHERN ONTARIO

by

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I would like to thank my supervisor Dr. G. V. Middleton for the help in completing this thesis. I would also like to thank Canada Brick Ltd. and Brampton Brick Ltd. for allowing me access to their quarries.

ABSTRACT

The Queenston Formation has been interpreted as a non-marine deltaic deposit since the turn of the century because of its apparent lack of fossils, and evidence for subaerial exposure. The source of the sediment was interpreted to be an orogenic zone in New York or Pennsylvannia.

Features such as gypsum nodules and limy siltstones were interpreted as being secondary. However, petrographic studies have found that the siltstones contain marine fossils and some gypsum nodules have inclusions of halite. Moreover, the fine sand grains in the mudrock are not aeolian. Paleocurrents indicate that the source of the sediment transport was generally north-south not east-west. The siltstone and limestone interbeds are flat based, graded, and show no evidence for channeling. Some beds also contain large escape burrows.

It is proposed that the Queenston Formation was deposited as a supratidal; mudflat that was regularly flooded by the sea. The mud could have been transported by longshore drift from a river somewhere towards the north, as the paleocurrents in the Queenston mimic major tradewind patterns for the Late Ordovician.

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INTRODUCTION

The Queenstone Formation is the north-western extension of the taconian clastic wedge which originated from a south-eastern source area in New York State and Pennsylvannia during the Late Ordovician (Colton, 1970). In Southern Ontario, the Queenston is between 150 and 200 m thick (Guillet, 1967), and has a regional dip of 3 degrees south-southwest (Dyer, 1923). A typical Queenston section in Southern Ontario consists of massive red mudrock interbedded with limestone and calcareous siltstone. In New York State, the Queenston consists of sandy mudrock interbedded with channelized sandstone (Patchen, 1966). On Manitoulin Island, the Queenston Formation grades laterally into fossiliferous blue shales and limestones (Foerste, 1919).

The formation was named after the town of Queenston Ontario by A. W. Grabau in 1908, and placed in the Upper Ordovician (Richmond) system the same year. Grabau (1909) described the Queenston and Juniata Formations as non-marine or continental in origin due to extensive dessication cracks and an absence of fossils. Foerste (1916) described the Queenston as the estuarine representative of marine strata elsewhere known as the Richmond Formation. Subsequent work by Caley (1940), Guillet (1967) and others have supported a non-marine estuarine model for the Queenston in Southern Ontario, Because of its apparent lack of fossils.

The goals of the present study have been to determine the depositional environment of the Queenston Formation in Southern Ontario. To accomplish these goals, the Queenston was mapped at eight locations in South-Central Ontario (Figure 1). Studies of thin sections and mudrock grains were carried out in the laboratory.

STRATIGRAPHY

Introduction

The Queenston Formation was mapped at eight outcrops in South-Central Ontario (see Figure 1). Previously, the sections of the Queenston have been described by Guillet (1967) at various brick quarries throughout Southern Ontario.

The Queenston mudrocks are usually massive and exhibit a nodular texture (Guillet, 1967). However, in some zones of limited thickness (1 to 3 m) the mudrock can become intermixed with siltstone, producing laminated silty mudrock (see Canada Brick Bronte Creek outcrop). At the same outcrop, the mudrocks contain dessication cracks and are moderately bioturbated (M. J. Risk, personal communication). The mudrock becomes softer, and loses its consistency near the top of the formation. This phenomena seems to be related to a decreasing percentage of detrital quartz and feldspar towards the top of the formation (see mudrock chapter). The mudrock also contains black reduction spots. They are less than 1 cm in diameter, and speckly many mudrock horizons (see Photo). The reduction spots are surrounded by a spherical region of green mudrock that is commonly less than 3 cm in diameter.

The Queenston Formation consists of approximately 20-25% siltstone. The rest of the formation is red hematitic mudrock with some minor green mudrock and limestone near the base. The percent of siltone increases near the center of the formation (Canada Brick Bronte Creek outcrop) to approximately 40%, but decreases to less than 5% near the upper contact with the Silurian Whirlpool Sandstone (Milton outcrop). The siltstones also become softer near the top of the formation, giving them the erosional relief of green mudrocks. The siltstones can be laterally continuous or lenticular, and usually have smooth flat bases.

The internal structure of most siltstones from the bottom to the top of a layer consists of mudrock rip-up clasts, parallel lamination and occasionally symmetrical ripples or ripple cross-stratification. The rip-up clasts are usually flat, 1 to 3 cm in diameter and randomly oriented. Although smaller mudclasts can be found throughout the siltstone layers, the largest ones are confined to a 1 or 2 cm zone at the base of the layers. The zone of parallel lamination dominates the internal structure of most silt-stones, and is sometimes capped off by symmetrical ripples or ripple cross-stratification. The ripples usually have an amplitude and wavelength of 0.5 and 4 cm respectively. The crestlines are usually sinuous, and both the crests and troughs are well rounded. Wrinkle marks occur near the top of some siltstone beds, and fain dessication cracks are also common near the base.

Carbonates only occur in the lower and middle parts of the formation. Although it is not evident in the field, petrographic studies of the carbonates have shown them to contain oolites, pellets, algal aggragate grains, and an assortment of other fossils. many of the limestones show birdseye texture, and some contain the trace fossil Diplocraterion on their top surface. Some limestone beds in the Bronte Creek outcrop also contain vertical tubes 1.5 to 2.0 cm in diameter. Some of these tubes extend right through the limestone while others do not (see Photo 3). Most carbonates occur in zones of limited thickness, and are not dispersed throughout an entire outcrop. They can be laterally continuous or lenticular, but most of them have flat bases. The carbonates contain large rip-up clasts (1 to 4 cm near the base) then fine upwards to silty limestones.

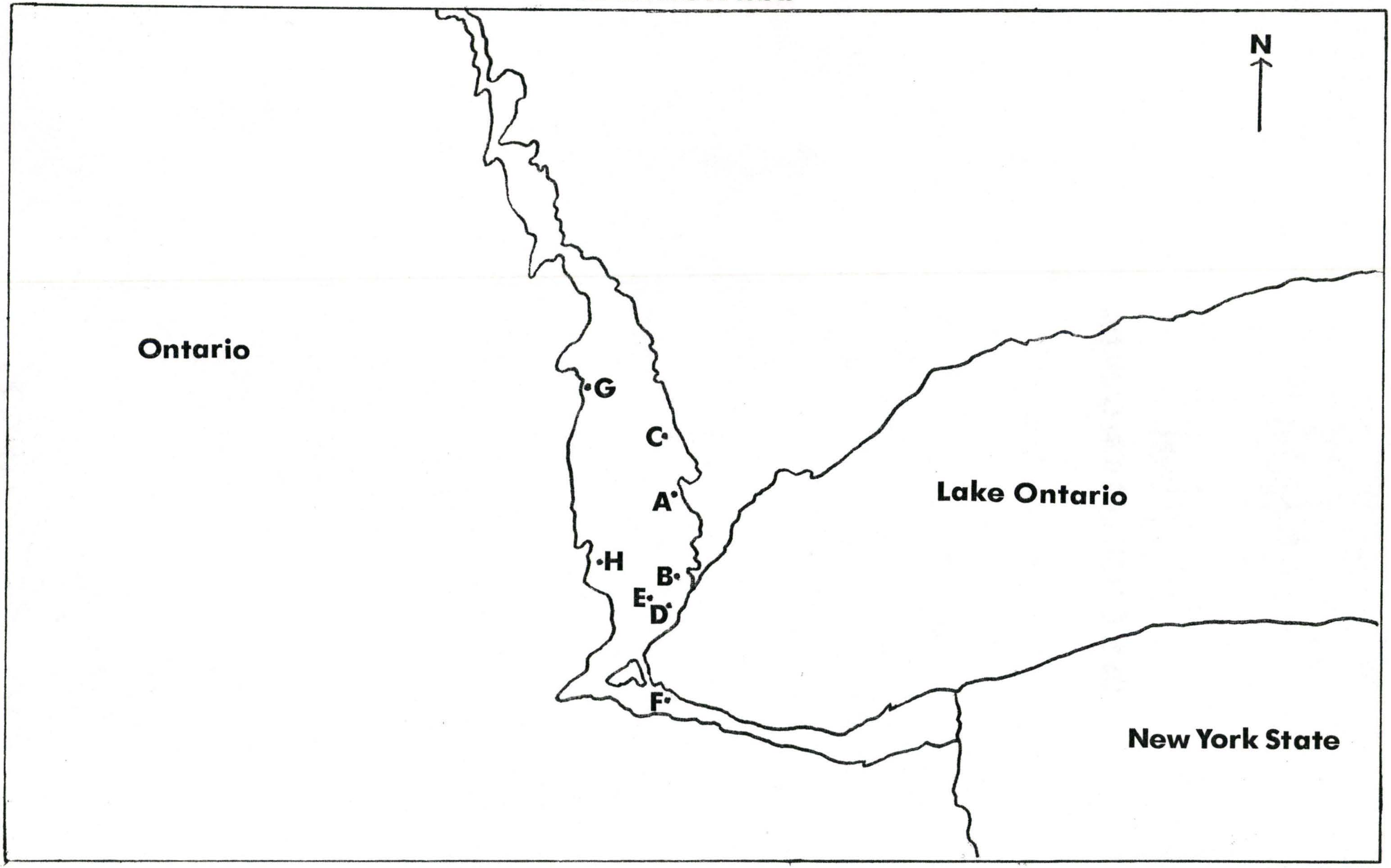
Evaporites occur throughout the entire formation, but show preference for limited stratigraphic horizones. Gypsum is quite common, and can be nodular, laminated or irregular-shaped inclusions. The nodular variety can be greater than 20 cm in diameter, and is sometimes associated with small amounts of halite.

Paleocurrents are variable, but the symmetrical ripples show an average crestline orientation of 119.3 degrees based on 22 measurements (Figure 2). The slight asymmetry of some symmetrical ripples, and a few cross stratifications seem to indicate that the direction of flow was generally from north to south. This, however, is only based on a few formation cannot be made.

These observations have been used to subdivide the Queenston into 3 distinct members: the Streetsville Member, the Bronte Creek Member and the Milton Member. The Streetsville Member is defined by the upper limit of oolitic limestones. The Bronte Creek Member is defined as the region of numerous siltstone interbeds near the middle of the formation. The Milton Member is the upper zone where mud-rocks are dominant.

Figure 1: Location map for the eight outcrops in South-central Ontario. Also shown is the outcrop of the Queenston Formation in Southern Ontario.

LOCATION MAP



0 10 20 30 40
km

A. C.B. Streetsville
B. 16 Mile Creek
C. Brampton Br.
D. Bronte Creek
E. C.B. Bronte Creek
F. Red Hill
G. Cheltenham
H. Milton

Figure 2: Approximate stratigraphic location of the eight outcrops. The Streetsville Member extends from the Streetsville to the Bronte Creek outcrop. The Bronte Creek Member includes a few 10's of meters near the center of the formation. The Milton Member includes the last 50 to 70 meters of the formation.

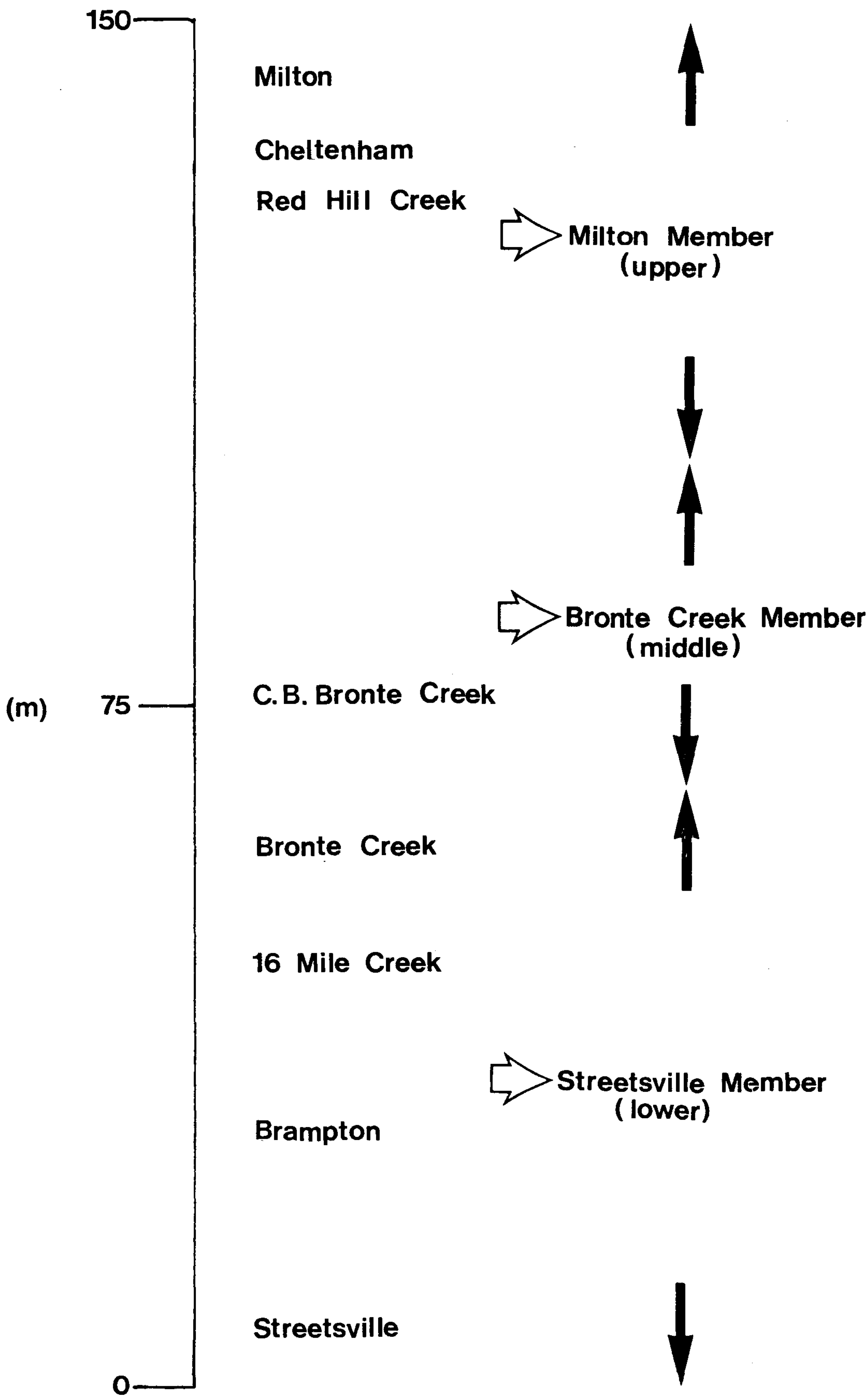
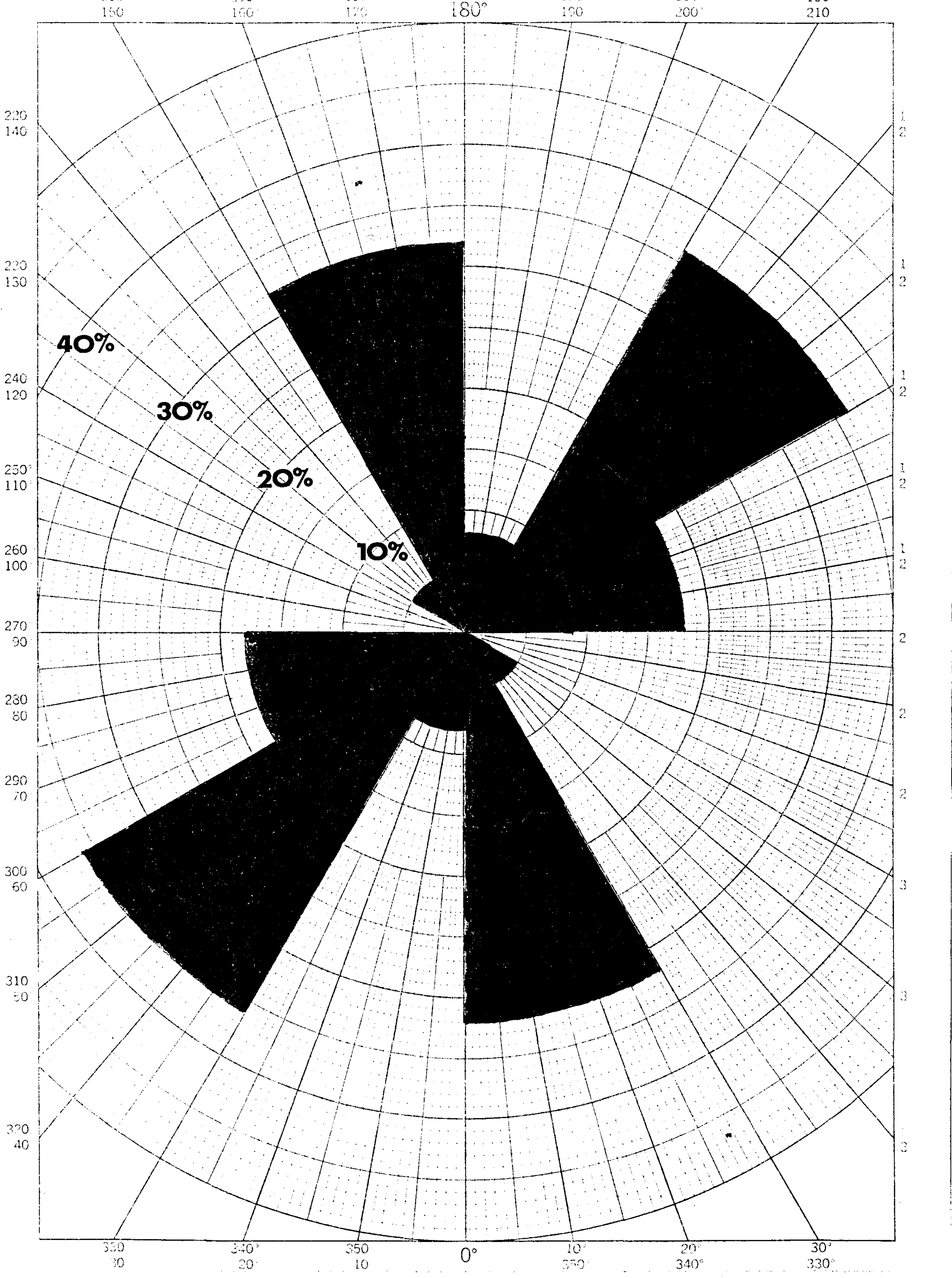

150
Milton
Cheltenham
Red Hill Creek
Milton Member (upper)
Bronte Creek Member (middle)
(m)
75
C.B. Bronte Creek
Bronte Creek
16 Mile Creek
Streetsville Member (lower)
Brampton
Streetsville
0

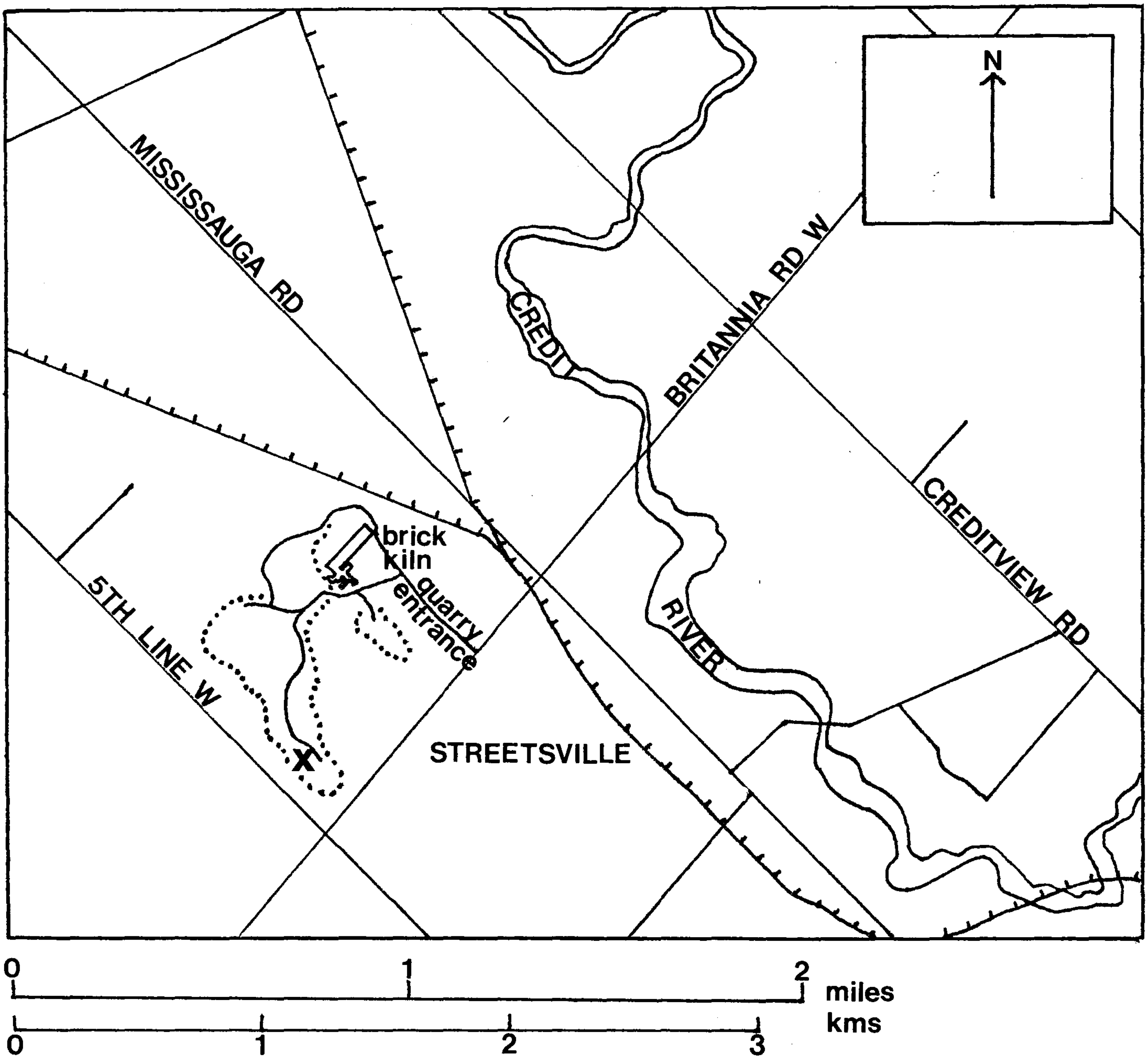
Figure 3: Rose diagram for the Queenston Formation paleocurrents.



40%
30%
20%
10%
180°
150
160
170
190
200
210
220
140
230
130
240
120
250
110
260
100
270
90
280
80
290
70
300
60
310
50
320
40
330
30
340°
20
350
10
0°
10°
350°
20°
340°
30°
330°

Figure 4: Location map for the Canada Brick Streetsville outcrop.

LOCATION MAP



LEGEND	
ROAD	
RAILWAY	
CREEK	
LOCATION OF OUTCROP	X
OUTCROP ORIENT.	SE FACE

Canada Brick Ltd. Streetville

This outcrop is located at the Canada Brick Ltd. quarry in Streetsville, Ontario. In this section, the lower contact of the Queenston Formation rests on a fossiliferous oolitic limestone that forms the stratigraphic top of the Dundas-Meaford Formation in the Streetsville area,

Visually, the contact is not abrupt but continuous, with both formations showing a regular interlayering of oolitic limestones and green calcareous siltstones in red hematitic mudrocks. But certain fossils which are visible in the mudrocks, siltstones and limestones of the uppermost Dundas-Meaford are absent from similar lithologies in the Queenston. Ostracods in the mudrocks, burrows and mottling in the siltstones and bryozoan colonies in the limestones all disappear quite abruptly with the transition upwards into Streetsville Queenston strata. However, the trace fossil Diplocraterion and fossil hash layers associated with distinct oolitic limestone zones do persist well upwards into the Queenston (see Bronte Creek outcrop).

The mudrocks of the Queenston comprise about 80% of the stratigraphic section at Streetsville. However, the thickest single layer of mudrocks in the Streetville section is less than 90 cm thick, indicating that the mudrock was continually interrupted by siltstones and limestones. The mudrocks contain very few macroscopic features to distinguish them from mudrocks in other parts of the formation. While the mudrocks in the upper Meaford showed some lamination, those in the Queenston at Streetsville and elsewhere are massive and unfossiliferous. There are some bleached green mudrocks above and below a large siltstone layer at the top of the outcrop. Similar green shales are found throughout the entire Queenston Formation and most are associated with siltstones. The mudrock rip-up clasts at the base of all the limestones and siltstones are both red and green. They are angular, randomly oriented and average no more than 2.5 cm in diameter.

The siltstones in the Queenston are typical of most siltstones throughout the Queenston Formation. They consist of a basal region full of angular mudclasts followed by a region of parallel lamination followed (usually) by a region of in-phase symmetrical ripples. In some instances the tops appear to have been eroded off of the siltstones so that the ripples do not occur. Siltstones account for 14% of the Streetsville stratigraphy, and occur at all horizons. Although they are a separate facies from the carbonates (limestones), they are not wholly distinct. In places they can grade upwards or downwards into the limestones, showing somewhat of a continuum between the two lithologies. The thickest silstone layer in the outcrop is 10 cm thick (near the 8.5 meter mark), and the thinnest is less than 1 cm. Most of these siltstones are laterally continuous in the quarry where they outcrop, but there is some minor lensing throughout the stratigraphic section.

The limestones in this outcrop account for only about 6% of the total stratigraphic section. They are oolitic and very hard, exhibiting mudrock rip-up clasts at the base and symmetrical wave ripples at the top. Like most carbonates in the Queenston, they occur in specific zones rather than dispersed throughout an outcrop. In the Streetsville, they occur only in the lower 5 meters of the section, and are only really concentrated in a 1 meter zone between the 2 and 4 meter markers. The limestones are generally lenticular, but a few are laterally continuous across the outcrop.

Sedimentary structures are quite common in various Streetsville lithologies. The mudrocks, however, do not show any macroscopic sedimentary structures. The ripples which occur at the top of some of the limestones and siltstones have rounded crests and troughs. They have an average crest-line orientation of 145.3 degrees with a standard deviation of 29.3 degrees based on eight samples from the bottom to the top of the formation. The average wavelength for the ripples is 4.2 cm, and the average amplitude is 0.5 cm. The ripple crestlines are straight and sinuous. Wrinkle marks occur near the top of some siltstone layers. Their crest to crest spacing was approximately 3 mm, and they had an average crestline orientation of 134 degrees based on two samples from the bottom of the formation. Faint dessication cracks also occur at the base of the siltstones and limestones, but they were not well developed. The mudrocks at the contact with the Meaford showed well developed dessication cracks, but these structures did not continue throughout the rest of the Queenston mudrocks.

Black reduction spots occur throughout the entire Streetsville outcrop. They are found in most siltstones and mudrocks, and show no preference for any horizon.

Photo 1: Symmetrical ripples from Canada Brick Streetsville outcrop.

Photo 2: Dessicated mudrocks at the Streetsville outcrop.

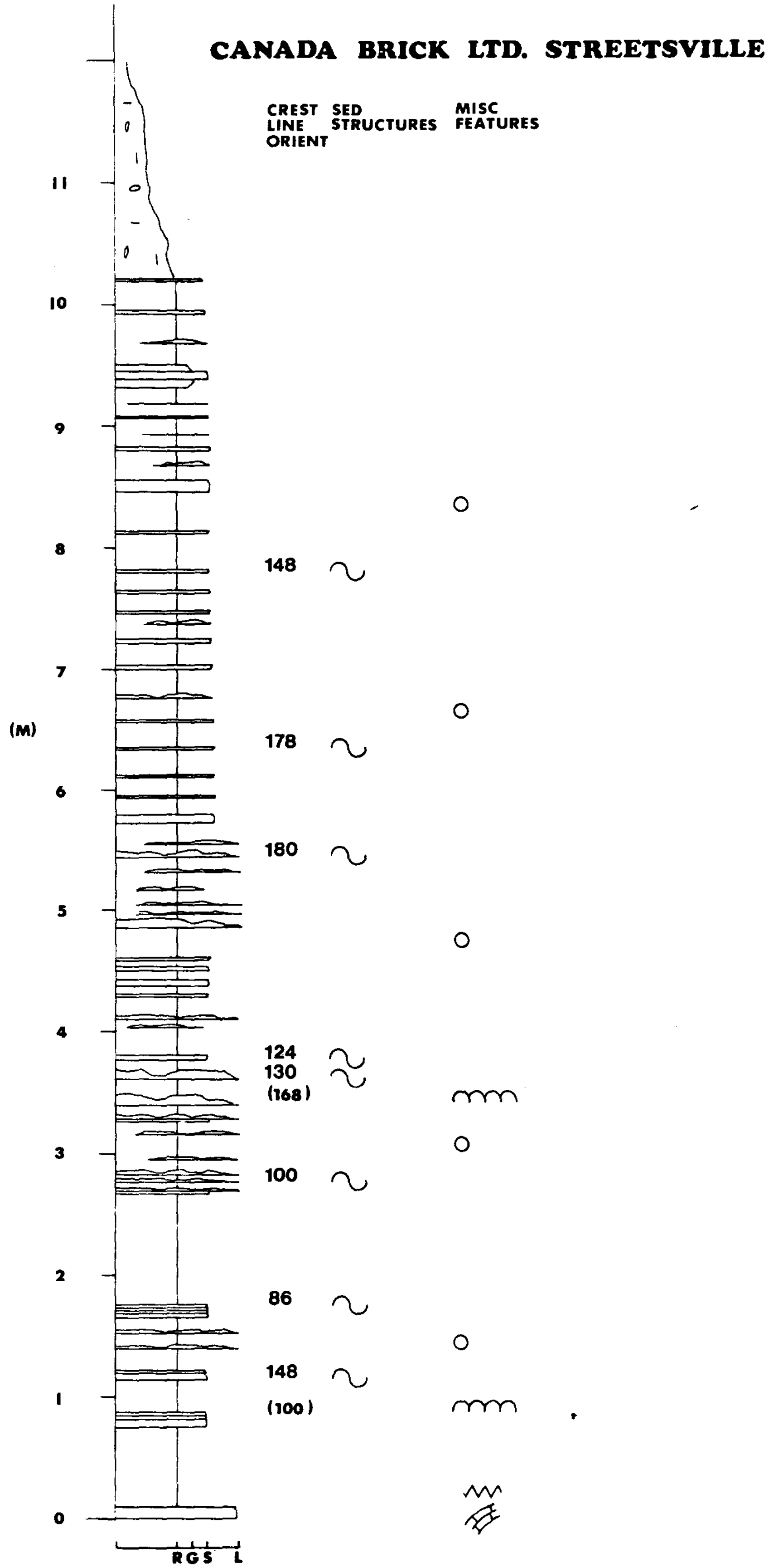
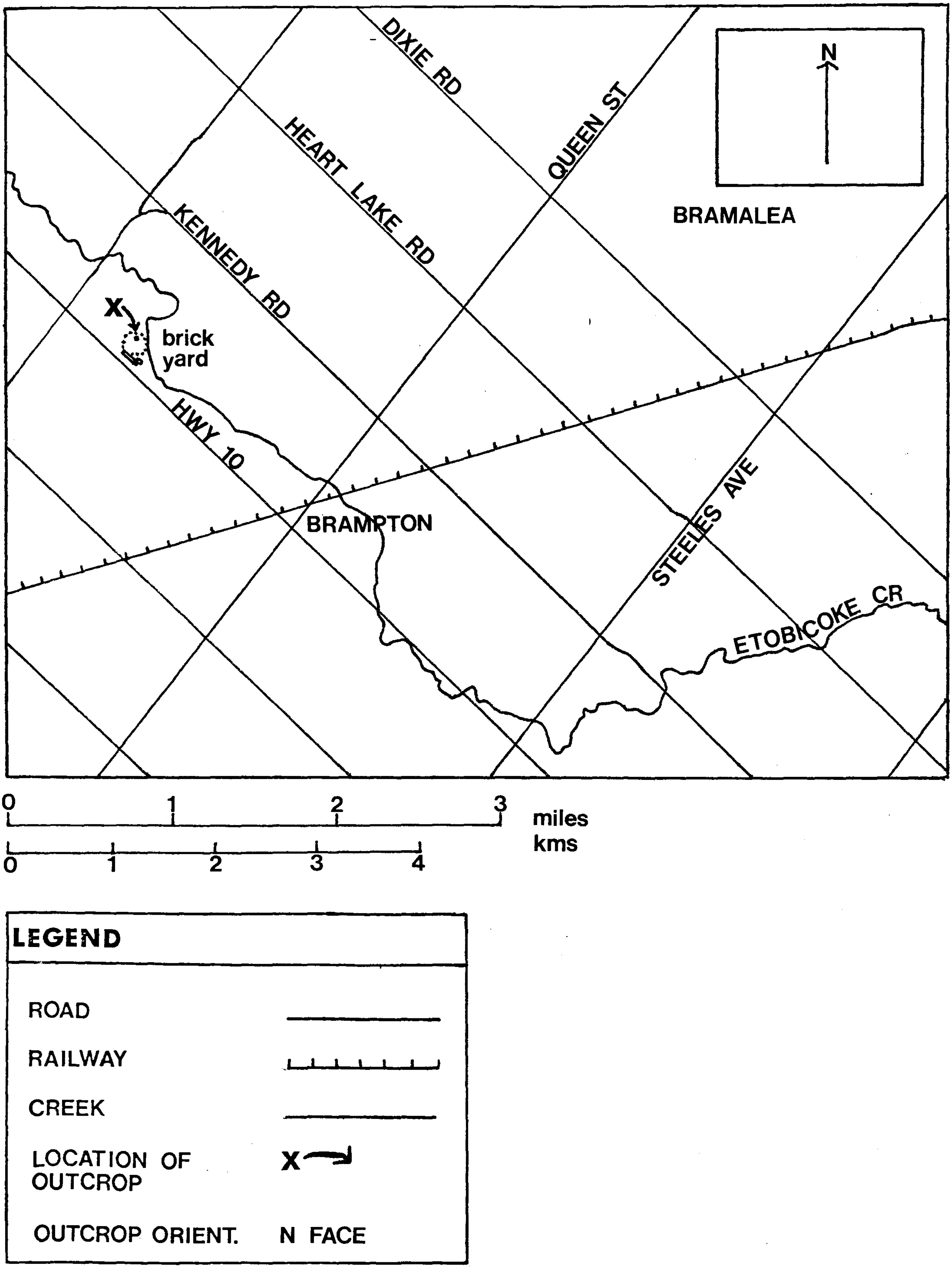

CANADA BRICK LTD. STREETSVILLE
CREST LINE ORIENT
SED STRUCTURES
MISC FEATURES
(M)
11
10
9
8
7
6
5
4
3
2
1
0
148
178
180
124
130
(168)
100
86
148
(100)
R G S L

Figure 6: Location map for the Brampton Brick Ltd. outcrop.

LOCATION MAP



Brampton Brick Ltd.

The Brampton Brick Ltd. section is located off Higway 10 in Brampton, Ontario. It is part of the lower Queenston and, along with the Cheltenham section, is several miles north of most other outcrops. The measured section is only the upper half of the north face, since the rest of the face was covered by debris and could not be measured.

Some of the siltstone layers in the Brampton section are much thicker than those observed in other parts of the Queenston. One layer at the 3 m marker is 25 cm thick and shows good parallel lamination throughout most of the layer. The siltstone at the very base of the section shows uni-directional flow structures with some cross-stratification. However, an accurate flow direction in this case was difficult to determine. There are also some zones of intensely intermixed silt and mudrock, similar to that observed in the Canada Brick Ltd. quarry at Bronte Creek. However, most of the siltstones not in these zones are flat based and laterally continuous. There are rip-up clasts at the base, but many layers lack good symmetrical ripples at the top.

The mudrocks at Brampton are generally massive and structureless except in the well mixed silt and mud zones. Here they are siltier, and show faint parallel laminations. There is also some bleached green shale around some siltstones, but this lithology is not abundant throughout the section.

The evaporites that occur at Brampton are limited to specific zones rather than dispersed throughout the section. Generally, gypsum nodules less than 15 cm in diameter are abundant in these zones. These zones are laterally continuous across the outcrop. There are also some thin gypsum layers that run parallel or sub-parallel to the local stratification. The gypsum layers are less than 3 mm thick, and the crystals are oriented perpendicular to bedding.

BRAMPTON BRICK LTD.

CREST LINE ORIENT | SED STRUCTURES | MISC FEATURES

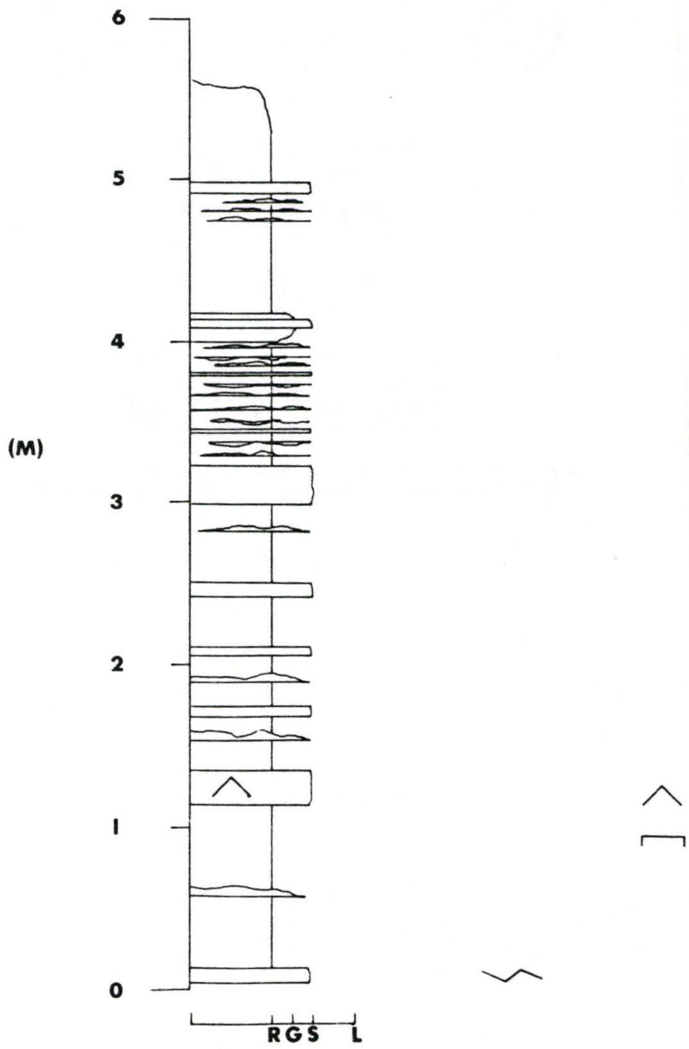
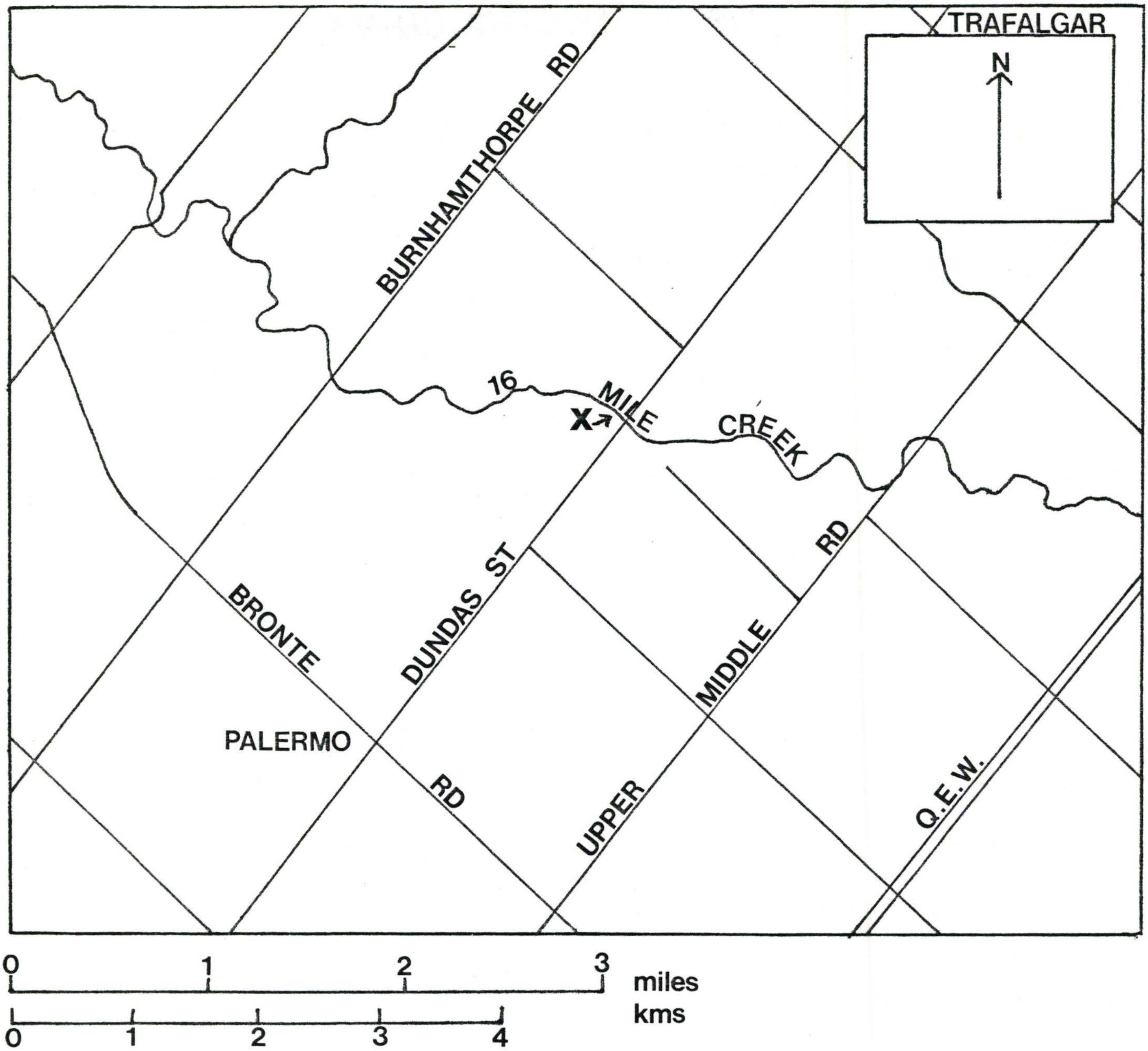


Figure 8: Location map for the Sixteen Mile Creek outcrop.

LOCATION MAP



LEGEND	
ROAD	———
RAILWAY	(railway symbol)
CREEK	———
LOCATION OF OUTCROP	X
OUTCROP ORIENT.	S FACE

Sixteen Mile Creek

The Sixteen Mile Creek section is located off Highway 5 in Halton County. It represents the upper part of the south wall on the banks of Sixteen Mile Creek. Stratigraphically, it is part of the lower Queenston along with the Bronte Creek, Brampton and Streetsville outcrops.

The siltstones at this outcrop are somewhat different than those in other parts of the formation. They are flat based and laminated, but individual layers also split easily along planes parallel to bedding. This produces beds which are composed of numerous thin layers. Most of these thin layers are no more than 3 cm thick. Some of these layers contain symmetrical ripples with larger wavelengths. The ripples with crestline orientation of 95 degrees have wavelengths of 12 cm. The ripples immediate above it have wavelengths of only 4 cm. The bases contain angular to sub-angular rip-up clasts.

The mudrocks in the Sixteen Mile Creek section are massive. However, there are zones of thinly bedded siltstones and mudrocks where the mudrocks shows faint lamination. The interlayered zone between the 1 and 2 m markers is an example of this.

The section is 25 to 30% siltstone with some green shale and the rest is mudrock. Although the siltstones occur throughout the section they seem to be more concentrated in some zones. Similarly, there are zones where the mudrock is uninterrupted for 1 meter of strata and other regions where it is interlayered every few centimeters.

SIXTEEN MILE CREEK

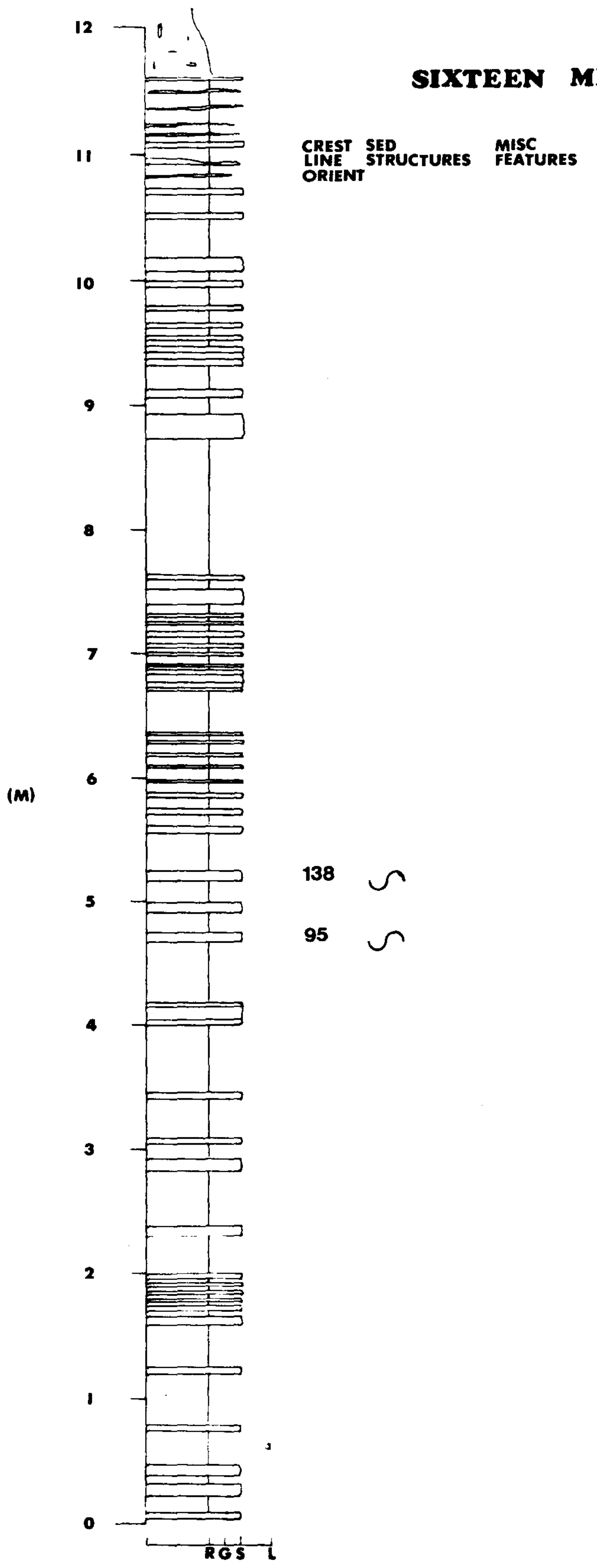
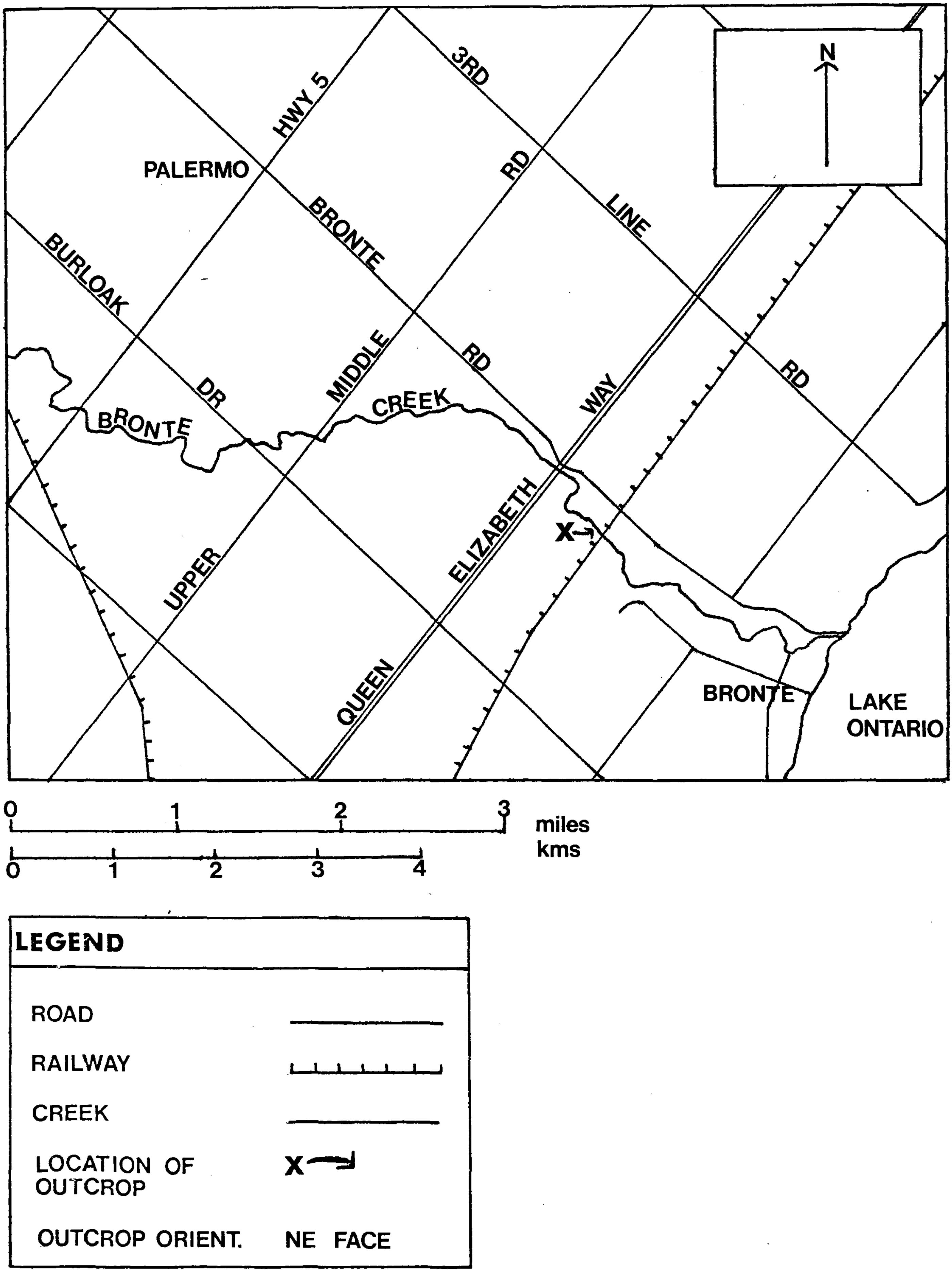


Figure 10: Location map for the Bronte Creek outcrop.

LOCATION MAP



Bronte Creek

The Bronte Creek outcrop is located in Halton County between the Queen Elizabeth Way and the town of Bronte. The Queenston strata exposed along Bronte Creek exhibits some of the most interesting lithology and palaeontology observed anywhere in the formation. Although the outcrops are extensive, only the bottom few meters are easily accessible for mapping.

The outcrop consists of interlayered siltstones, limestones and mudrocks. Although the limestones are confined to the first meter of this section, they also occur in narrow stratigraphic zones higher up in the Bronte Creek outcrop where they were not accessible for mapping. The siltstones occur throughout the entire section. Some are laterally continuous, and others are lenticular. The mudrocks are massive and lack macroscopic sedimentary structures.

The siltstones layers contain angular rip-up clasts at the base and grade upwards into parallel lamination. Symmetrical ripples or ripple cross-lamintion are present at the top of some siltstones, but in many cases they appear to have been eroded away. When symmetrical ripples occur, they usually have rounded crests and troughs and sinuous crestlines.

The limestones that outcrop at Bronte Creek show a wide variety of sedimentary features. They are oolitic and contain numerous sparry vugs (approximately 1 to 4 mm in diameter) that are vaguely concordant with bedding. These vugs weather out as black specks in the rock and are easily observable in outcrop. At the top of many of the limestone layers, along rippled surfaces, if the trace fossil Diplocraterion. It occurs in great abundance in these limestone zones along with some small ostracods. Although these fossils -- especially Diplocraterion -- are ubiquitous in the limestone zones, they are absent in siltstones immediately above them. Structurally, the limestones are similar to the siltstones. They contain numerous large angular rip-up clasts at their base, and ripple cross-lamination near the top. They also frequently contain symmetrical ripples at the top of the layers. The ripples have rounded crests and troughs and sinuous, Diplocraterion encrusted crestlines. There are also small rip-up clasts (less than 3 mm in diameter) that weather as small indentations in the surface of the limestones. Most limestone layers become siltier near the top. Moreover, the rip-up clasts decrease in size from the bottom to the top of a layer. They are dessication cracks at the top of some of the limestones, but like those in most Queenston siltstones and limestones they are not well developed.

The paleocurrents in this outcrop average 112 degrees with a standard deviation of 36 degrees based on 8 crestline orientations from the siltstones and limestones. In some cases, the ripples were slightly asymmetrical. This provided the information for the current directions given in the stratigraphic section. The current direction appears to be from the northeast to the southwest. Most of the ripples have wavelengths of 4 cm and amplitudes of 0.5 cm. The crestlines are sinuous, and the ripple crests and troughs are well rounded.

The macroscopic palaeontology of this Bronte Creek section, as mentioned previously, consists of the trace fossil Diplocraterion and small ostracods. There are also large escape burrows in some of the dessicated limestones (see Photo 3). Some go right through the beds while others do not. Other fossils also occur in both the siltstones and limestones, but they are only observable with petrographic techniques.

Although no evaporites occur in the Bronte Creek section, some of the silty limestones near the base of the section contain small (1 to 4 mm) cubic casts. These structures resemble casts of halite crystals that were dissolved away, and filled in by sediment.

BRONTE CREEK

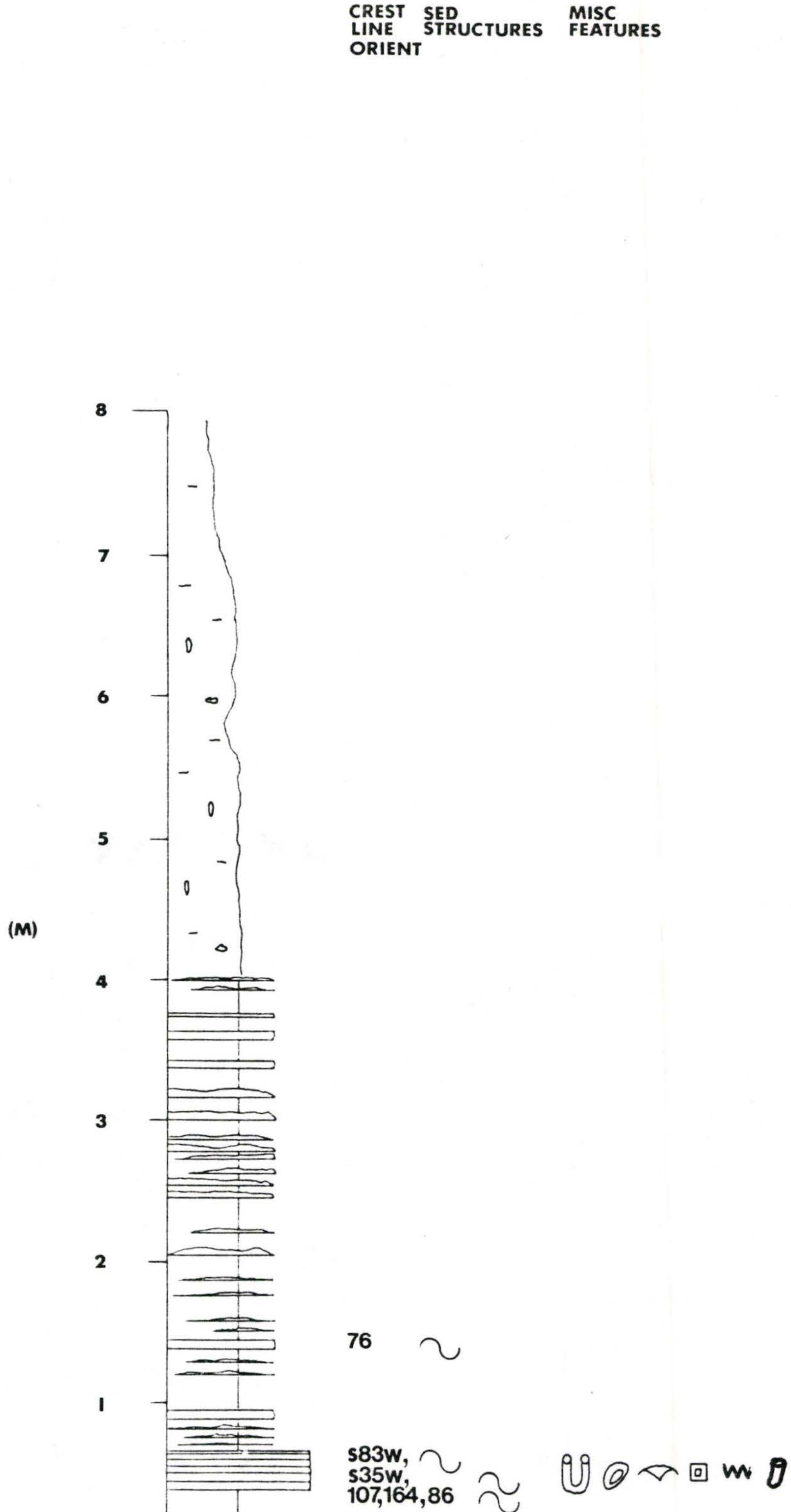


Photo 3: Large (1.5-2.0 cm) vertical tubes in dessicated limestone bed. The dessication cracks, and some of the tubes, extend right through the beds.

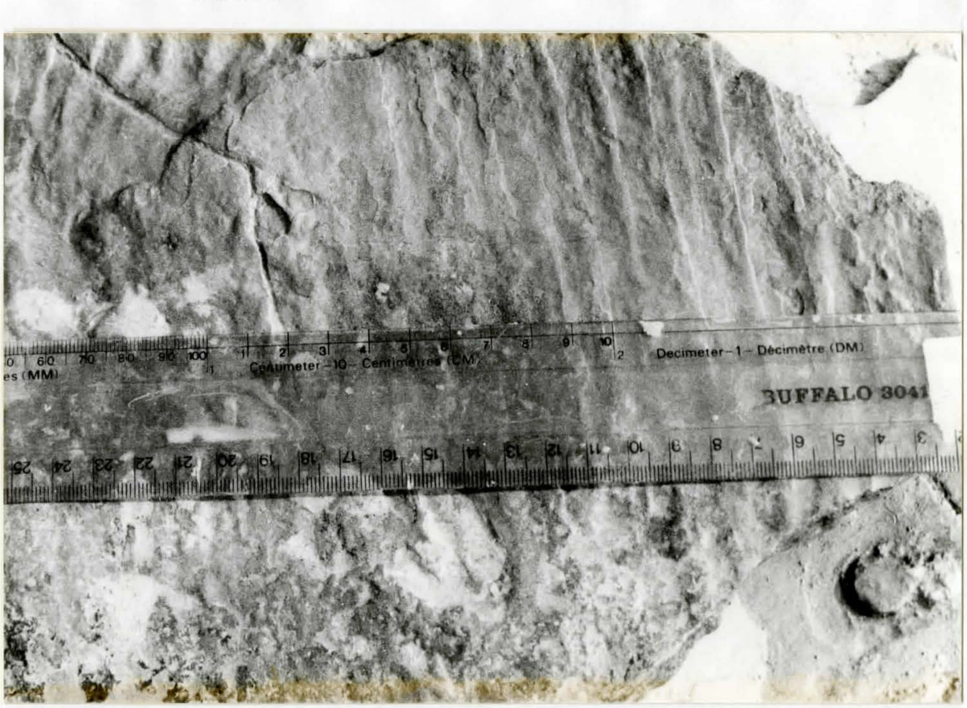
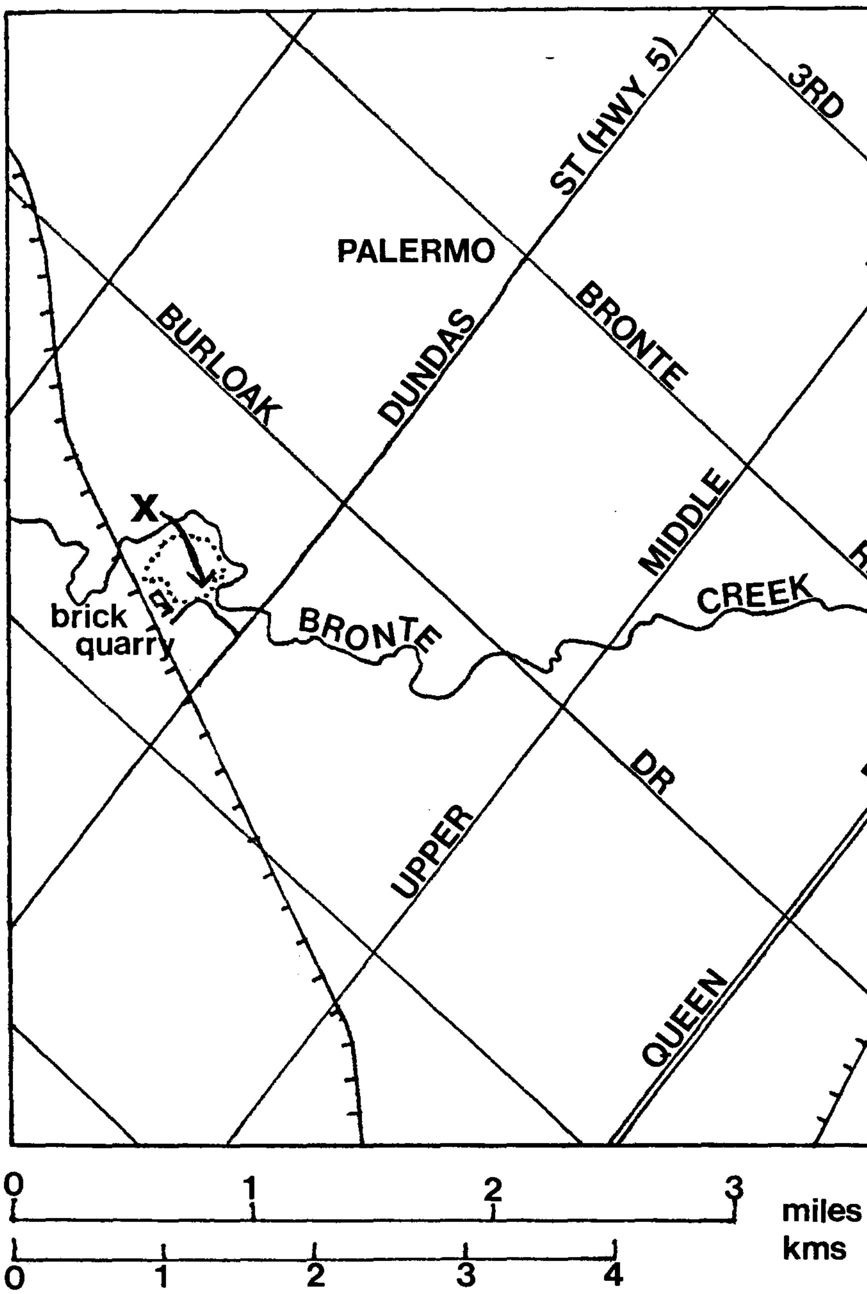


Photo 4: Micro-ripple structures from Bronte Creek. The amplitudes are on the order of 1 mm.

Figure 12: Location map for the Canad Brick Bronte Creek outcrop.

LOCATION MAP



LEGEND

ROAD	
RAILWAY	
CREEK	
LOCATION OF OUTCROP	X
OUTCROP ORIENT.	SE FACE

Canada Brick Ltd. Bronte Creek

The Canada Brick Ltd. quarry at Bronte Creek is located off Highway 5 in Halton County. It represents the stratigraphic center of the Queenston Formation and exhibits characteristics quite distinct from the upper and lower part of the Formation.

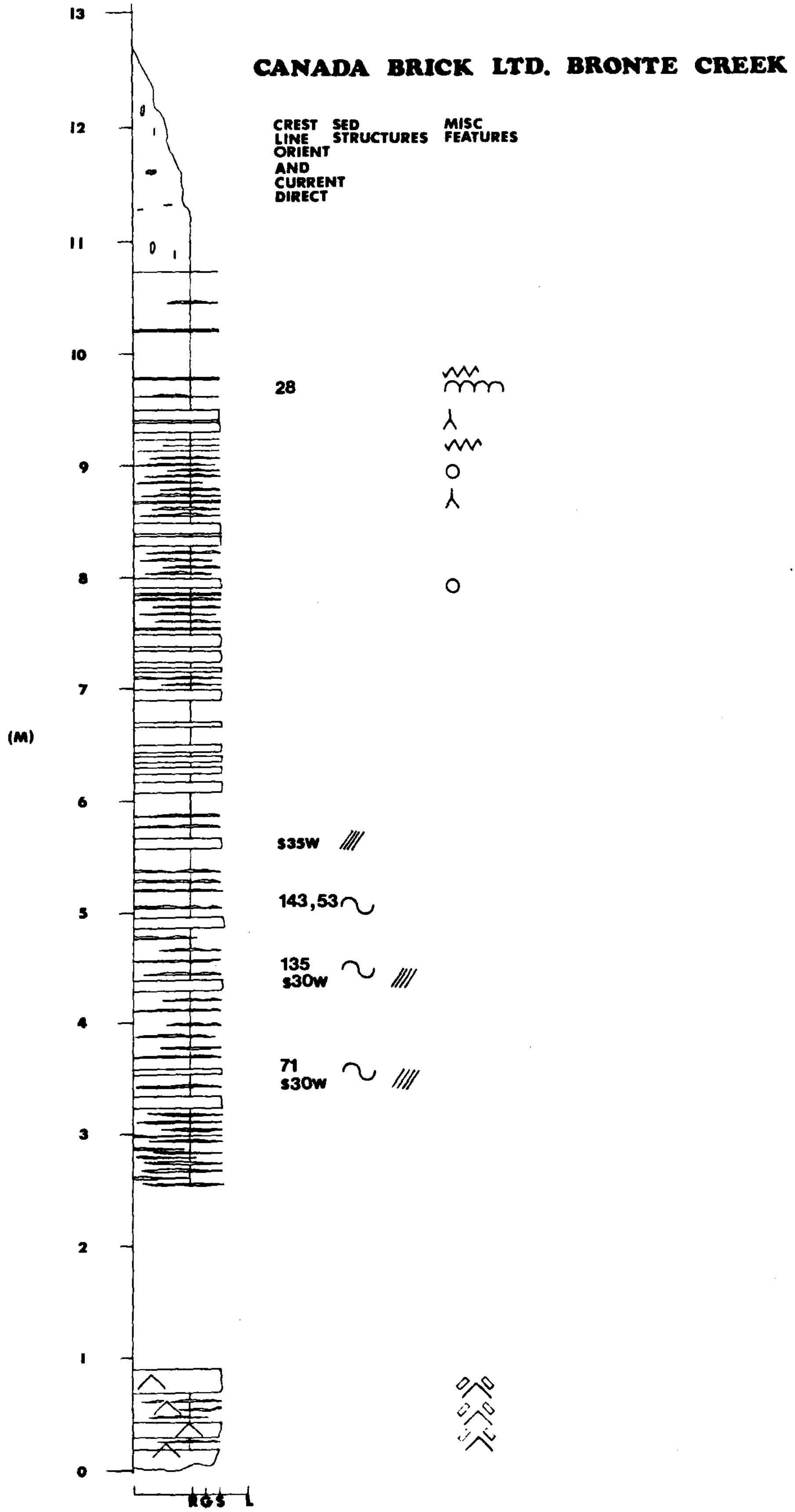
The most impressive characteristic of this outcrop is the percentage of siltstone interbeds. About 40% of this outcrop is siltstone and the other 60% is mudrock. In many cases, however, there is a large percentage of silt in the mudrocks and mud in the siltstones producing hybrid layers that are intermediates between the two lithologies. Therefore, there are many red siltstones and silty mudrocks throughout this outcrop. Most of the siltstone layers are lenticular. There are, however, some thicker siltstone layers that are laterally continuous, and can be traced for some distance across the south-east face. Their internal structures are similar to those of siltstones throughout the formation. However, the sequence of sedimentary structures in this outcrop from the base to top of a siltstone generally consists of rip-up clasts, parallel lamination, ripple cross-stratification then symmetrical ripples. Two sequences of alternating lamination/cross-stratification can occur in some siltstone layers with both laminated and cross-stratified layers being less than 2 cm thick. The rip-up clasts at the base of the siltstones are abundant and large. Some can be up to 15 cm in diameter, and most are quite angular.

The mudrocks of this outcrop show more variation than mudrocks in other parts of the formation. They contain a great deal of silt and show parallel laminations especially near the top of the section. There are also good dessication cracks in these mudrocks at the top of the section. The dessicated mudrocks also show considerable bioturbation (M. J. Risk, personal communication). Black reduction spots occur extensively throughout the mudrocks.

The gypsum-halite deposits that occur in the lower part of this section are the most extensive deposits observed in the Queenston. They consist of numerous gypsum nodules, thin gypsum layers and halite films. The halite does not occur as large euhedral masses, but as staining on the mudrocks and siltstones that contain the gypsum nodules. The nodules themselves can be up to 20 cm in diameter, and are found embedded in the mudrocks as well as the siltstones. Thin gypsum layers, 1 to 2 mm in thickness, also occur. They are either parallel or at a low angle to bedding, and their individual crystals are oriented perpendicular to the bedding surface.

The paleocurrents in the Canada Brick Ltd. Bronte Creek quarry are quite variable. One siltstone between the 2 and 3 m markers shows crestline orientations of 143 and 53 degrees in two symmetrical ripples planes located only

1.5 cm from each other. The average crestline orientation in this outcrop is 100.5 degrees based on four measurements from the quarry. The ripple crsstline geometry was straight to sinuous, and the ripple crests and troughs were well rounded. The average amplitude and wavelength were 0.4 cm and 4.2 cm respectively. The direction of current transport was not apparent from the symmetrical ripples, but three cross-stratified siltstones indicated current transport from about 31 degrees east of north to 31 degrees west of south.



CANADA BRICK LTD. BRONTE CREEK
CREST LINE ORIENT AND CURRENT DIRECT
SED STRUCTURES
MISC FEATURES
13
12
11
10
9
8
7
6
5
4
3
2
1
0
(M)
28
S35W
143,53
135
S30W
71
S30W
R G S
L

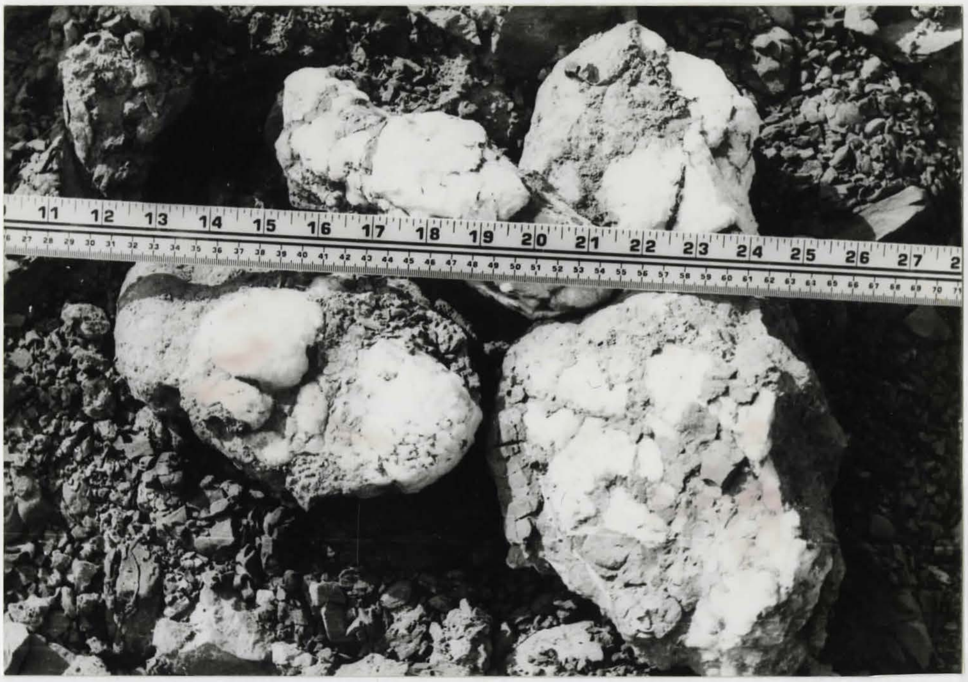


Photo 5: Gypsum nodules from the lower section.

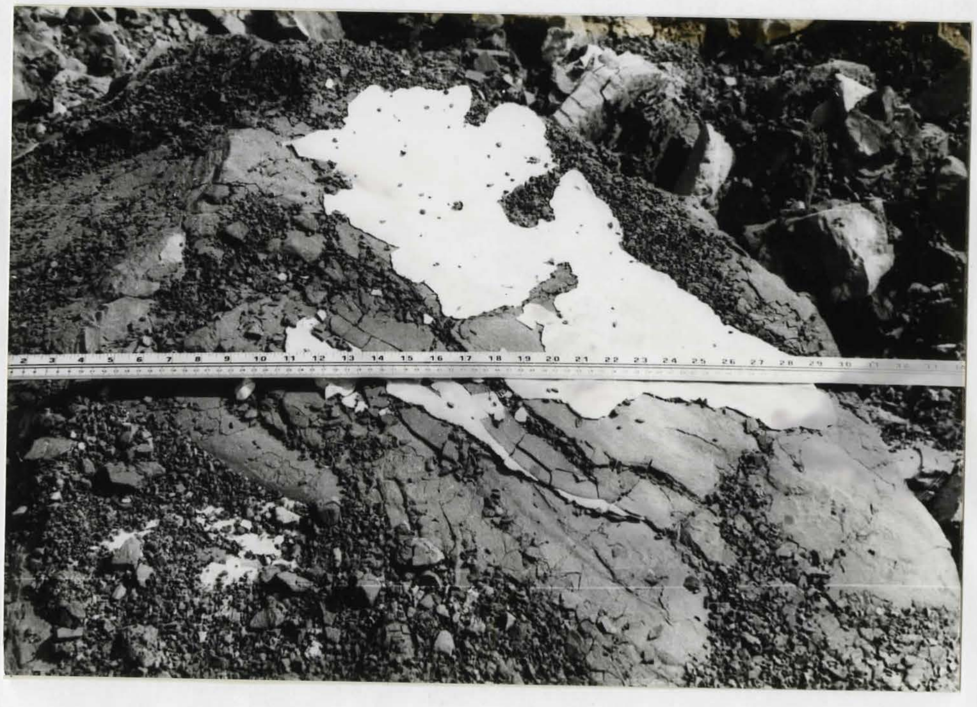


Photo 6: Laminar gypsum in joints within the mudrock.

Photo 7: Reduction spot with black nucleus from the upper part of the section.

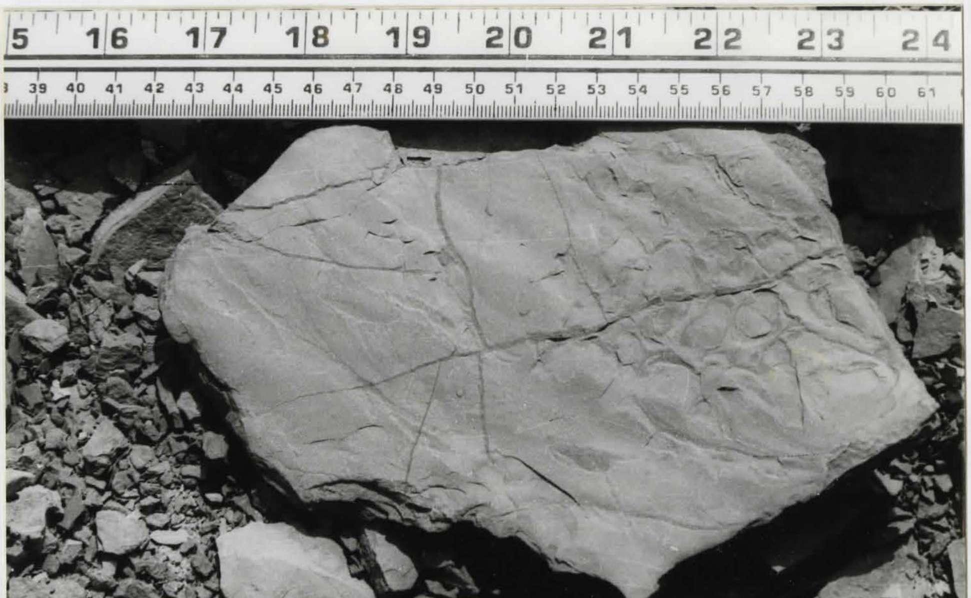
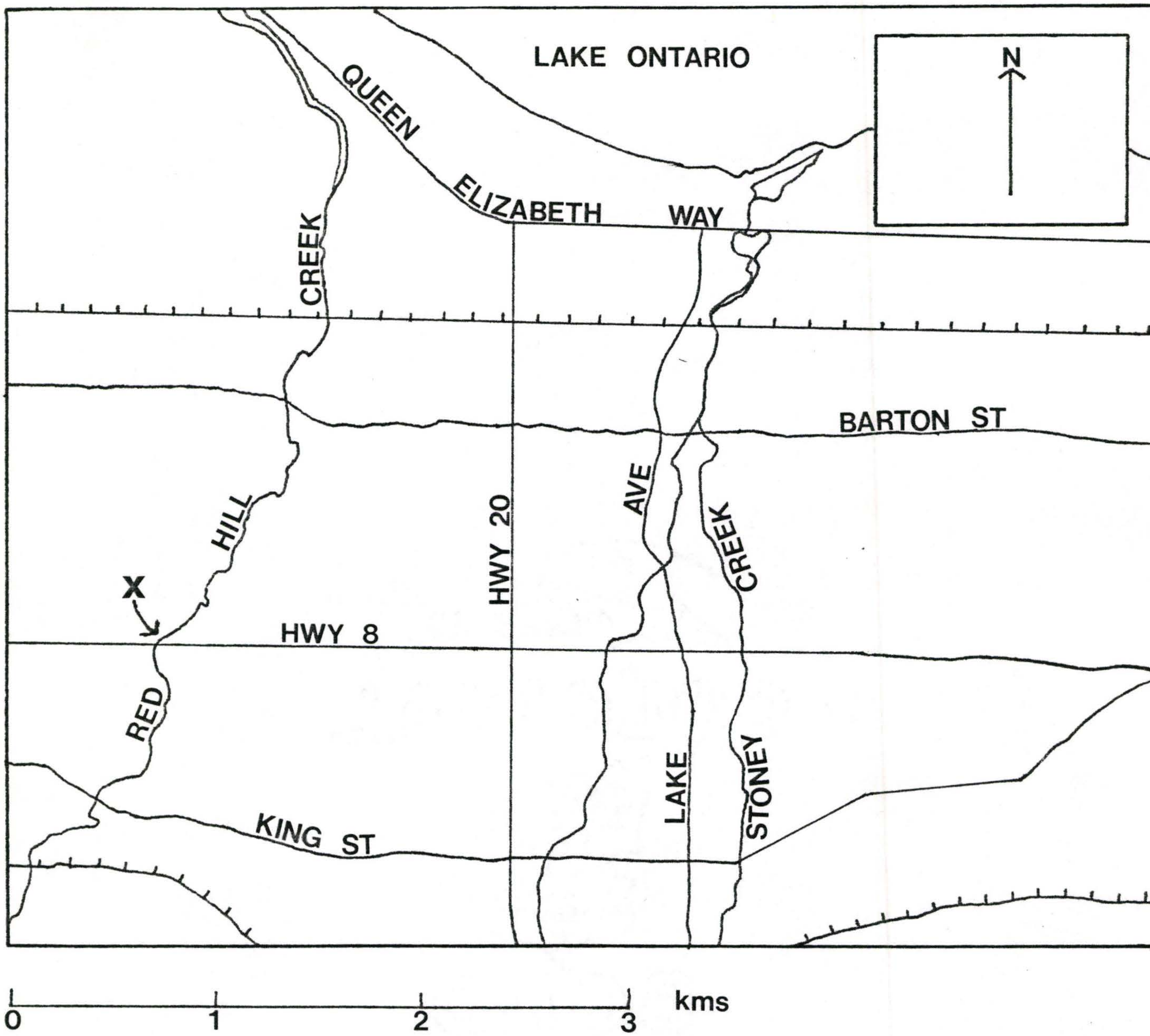


Photo 8: Dessicated mudrocks from the upper part of the section.

Photo 9: Rounded rip-up clasts at the base of a siltstone bed.

Figure 14: Location map for the Red Hill Creek outcrop.

LOCATION MAP



LEGEND	
ROAD	
RAILWAY	
CREEK	
LOCATION OF OUTCROP	X
OUTCROP ORIENT.	NW FACE

Red Hill Creek

The Red Hill Creek outcrop is located off Highway 8 in east Hamilton. Stratigraphically, it is part of the upper Queenston since it is located within 50 m of the contact between the Queenston and Lower Silurian Whirlpool Formation.

The siltstones in this outcrop are noticeably different from those in the lower or middle parts of the formation. Lensing is very rare, so practically all of the siltstones are laterally continuous. The siltstones are softer and shalier and begin to resemble green shales. There are very few good sedimentary structures such as ripples or cross-stratification. However, there are still angular 3 cm rip-up clasts near the base and extensive wrinkle marks in some of the siltstones. In fact, pseudo wrinkle marks (i.e. wrinkle marks that have not fully developed or have been partially eroded) completely dominate the internal structures of some siltstones. There are also faint round nodules similar to black reduction spots in the siltstones, but they are brown, not the ebony black colour of most Queenston reduction spots.

The mudrocks at Red Hill Creek are massive. They show none of the faint laminations observed in zones of intense siltstone lensing. Many mudrocks at the base of the section have gypsum inclusions. Some of these inclusions are layered gypsum with crystals perpendicular to bedding.

Others are amorphous oddly shaped inclusions, less than 3 cm in diameter, that speckle the outcrop along small fractures.

The gypsum deposits at this location are not well developed, but they show a variety of gypsum forms and occur extensively throughout the lower few meters. Most of the nodular gypsum is concentrated in one or two siltstone layers at the very base of the outcrop. The nodules are usually less than 3 cm in diameter, and form a laterally continuous horizon in these siltstones. Above the nodular deposits, in the red mudrocks, are two other forms. They are the thin layered gypsums described in previous outcrops, and small amorphous pink inclusions that seem to be located along fractures and indentations within the rock. The amorphous pink inclusions are very common and extend about four meters up from the base of the section.

The sedimentary structures in this outcrop, and the rest of the upper Queenston, are very limited. They can be adequately described as poorly cross stratified and poorly laminated shaly siltstones.

RED HILL CREEK

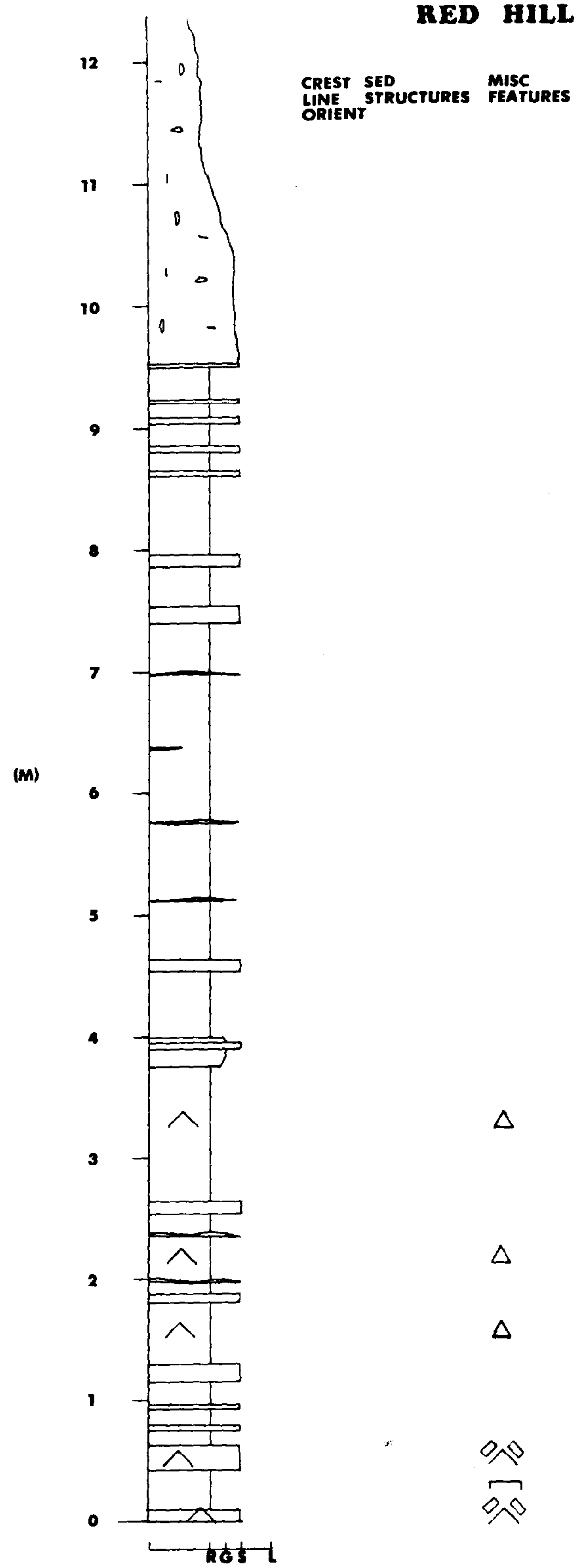
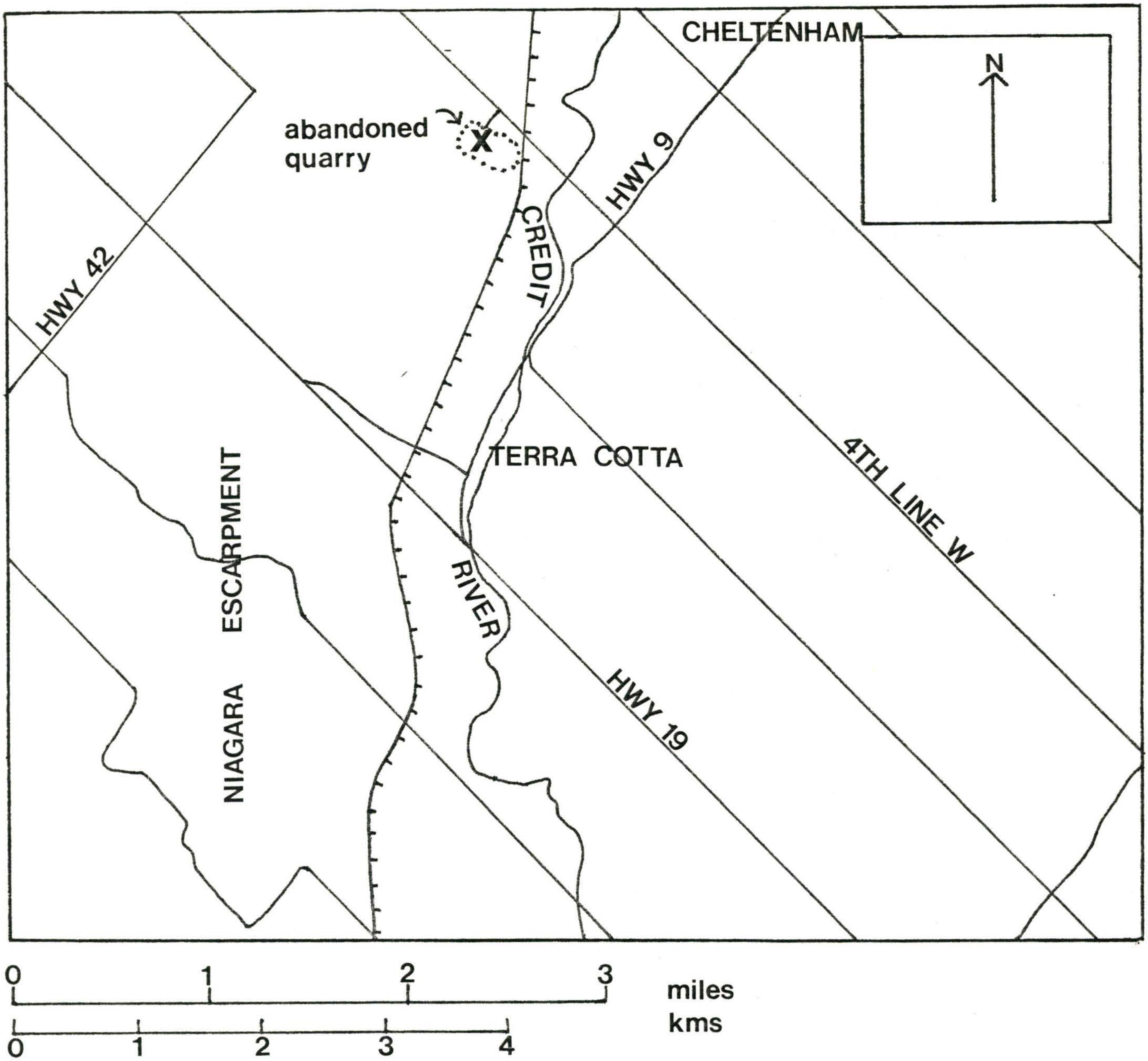


Figure 16: Location map for the Cheltenham quarry.

LOCATION MAP



LEGEND

ROAD

RAILWAY

CREEK

LOCATION OF OUTCROP

OUTCROP ORIENT. NW FACE

Cheltenham

The Cheltenham section is located in Peel County just outside the town of Cheltenham. It represents the upper Queenston in the same general stratigraphic level as Red Hill Creek and Milton. It is furthest north of any section that was mapped.

Like many upper Queenston sections, the Cheltenham section is rather non-descript. It consists of interlayered laterally continuous siltstones in massive red mudrocks. There is some green shale around the siltstone contacts, but it is generally a minor lithology. The siltstones are well laminated. They are also harder and greener than siltstones in the Red Hill Creek and Milton outcrops. The siltstones also contain an abundance of black reduction spots. They occur in varying sizes up to a centimeter in diameter and are more abundant than at any other outcrop. There are some symmetrical ripples at the top of a few layers, but good paleocurrent readings were not attainable. Like most siltstones, they contain angular to sub-angular mudrock rip-up clasts at their base.

The mudrocks are massive and show little lamination or other sedimentary structures. However, like the siltstones they contain many black reduction spots. These spots are present at all mudrock horizons, and show little preferred orientation.

In this section, siltstone comprises only about 15% of the total lithology. Although the siltstones occur throughout the whole section, they tend to be more concentrated at certain horizons (i.e. between the 2 and 3 or 6 and 7 m markers).

CHELTENHAM

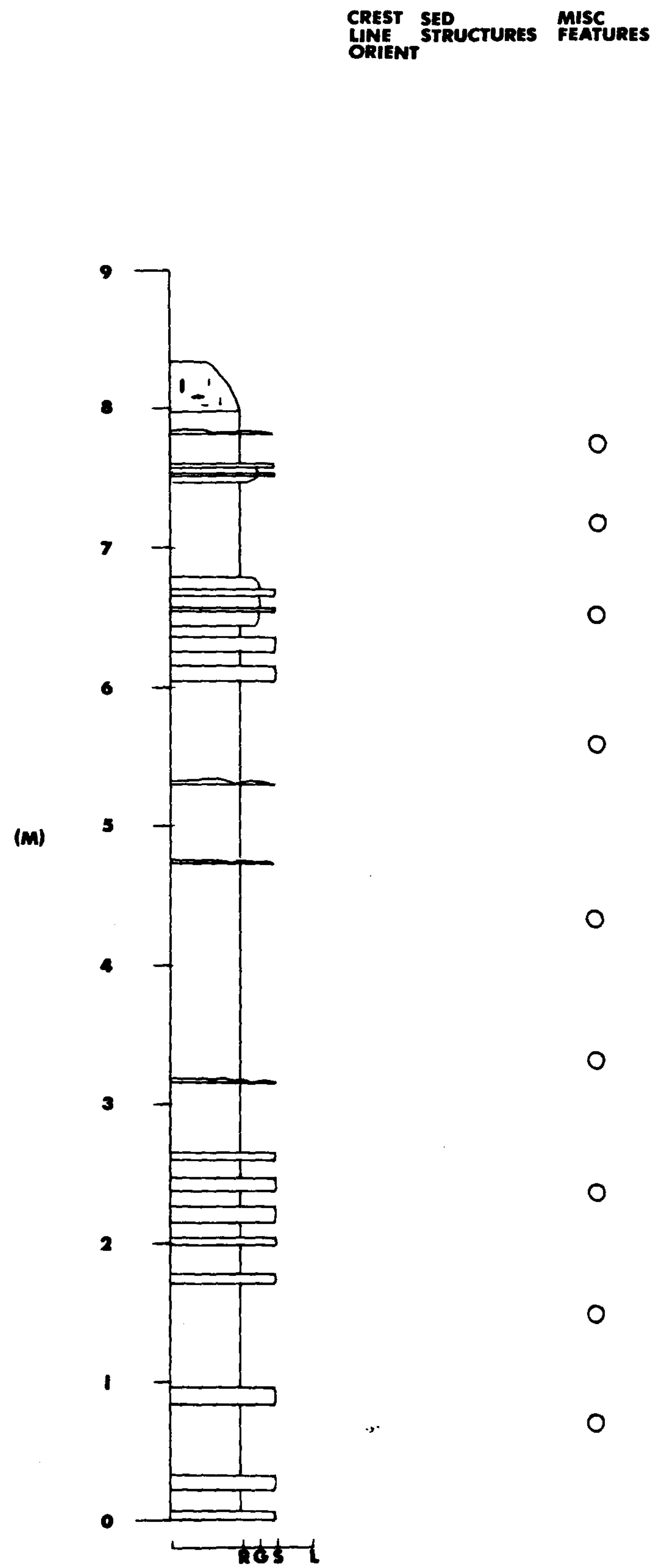
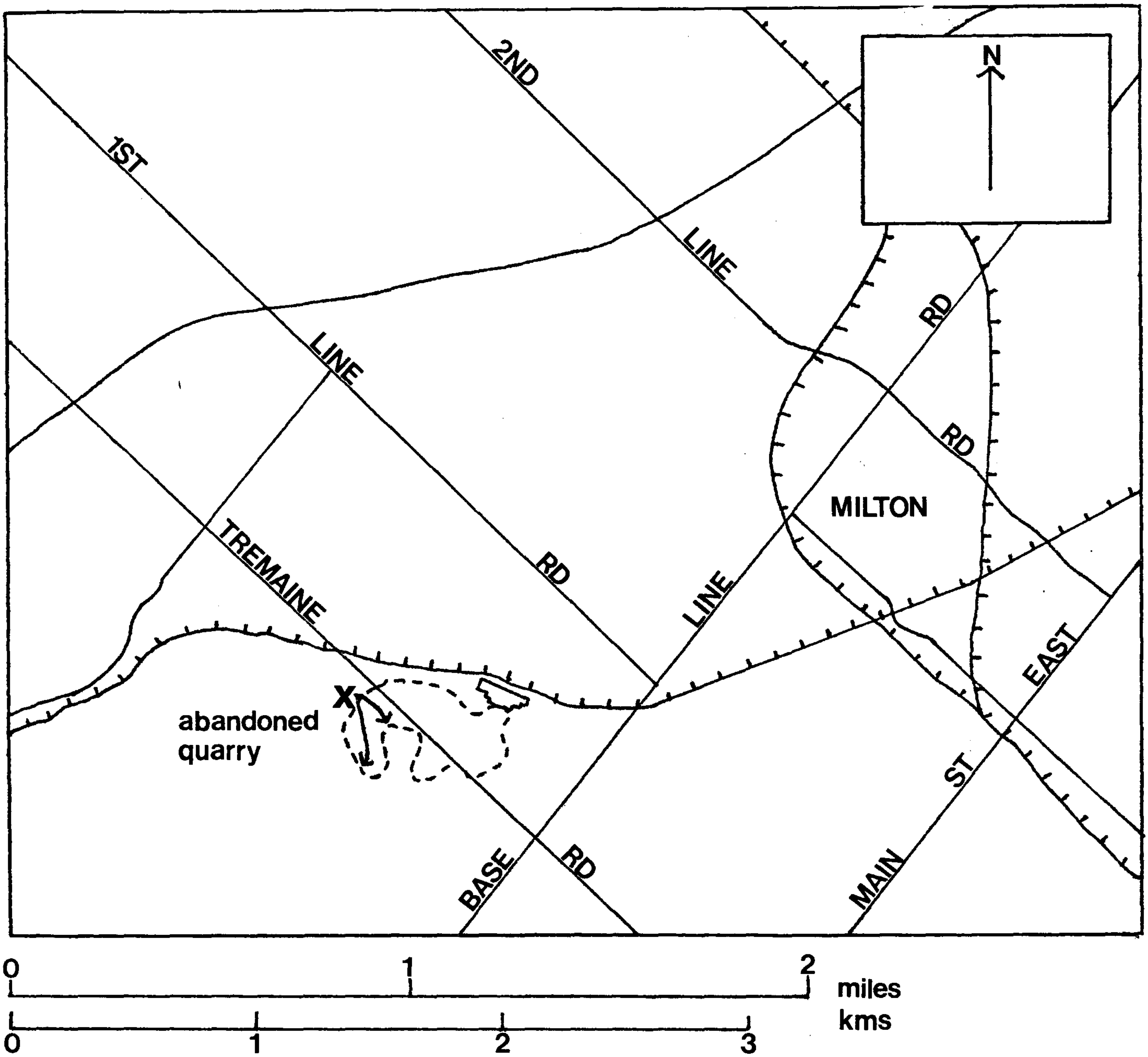

CREST LINE ORIENT
SED STRUCTURES
MISC FEATURES
9
8
7
6
5
(M)
4
3
2
1
0
R G S
L

Figure 18: Location map for the Milton quarry.

LOCATION MAP



LEGEND	
ROAD	———
RAILWAY	┴┴┴┴┴┴
CREEK	———
LOCATION OF OUTCROP	X→
OUTCROP ORIENT.	SW FACE

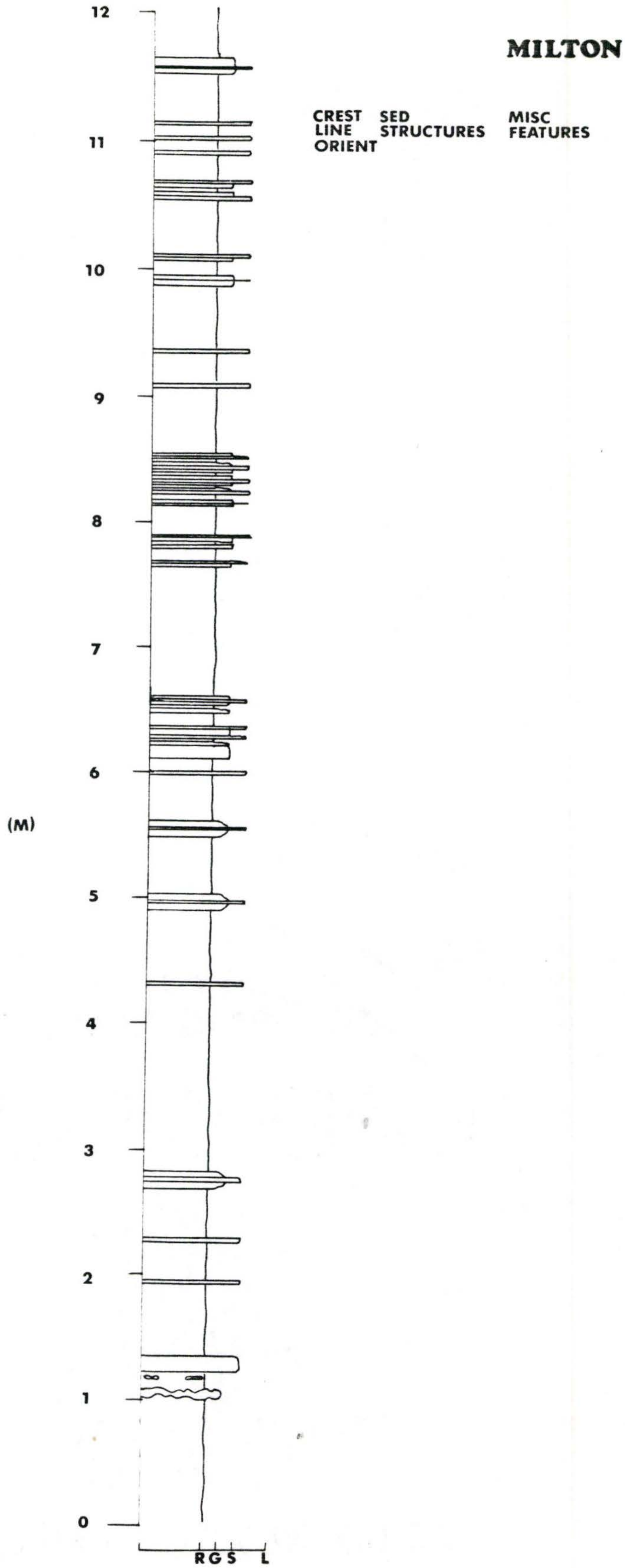
Milton

The Milton outcrop is located below the Niagara Escarpment just outside the town of Milton. It represents the stratigraphic top of the Queenston Formation, and is just below the contact between the Queenston Formation and the Silurian Whirlpool Sandstone.

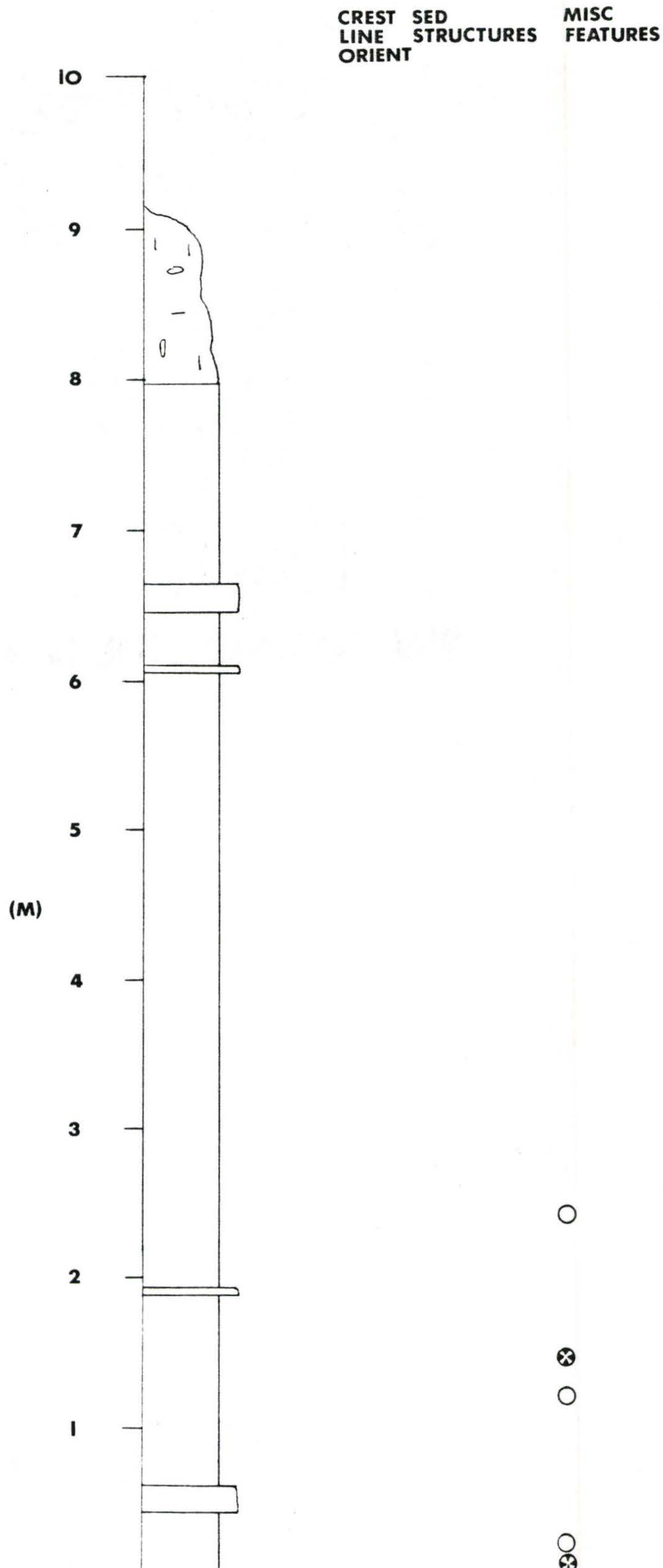
The siltstones at the Milton outcrop have lost much of their resistance to erosion, and are replaced by green shales. Virtually all of the layers are laterally continuous, but most lack good sedimentary structures. Although most layers have rip-up clasts at the base followed by parallel lamination, there are no symmetrical ripples at the top.

The mudrocks at Milton are massive. Some of the mudrocks in the upper section contain calcite geodes (0.5 to 2.5 cm in diameter), and black reduction spots. The mudrock is less silty than at the lower outcrops, and loses all its consistency when it becomes wet.

The upper section at Milton is almost totally dominated by red mudrock. This is true for all Queenston exposures that are only 7 to 10 m away from the base of the Whirlpool Sandstone.



MILTON
CREST LINE ORIENT
SED STRUCTURES
MISC FEATURES
(M)
0
1
2
3
4
5
6
7
8
9
10
11
12
R G S L


CREST LINE ORIENT
SED STRUCTURES
MISC FEATURES
10
9
8
7
6
5
(M)
4
3
2
1
0
R G S L

PETROLOGY

Detrital Grains in Mudrock

Bisulfate fusion of 25 mudrock samples from the Queenston Formation indicates that the percentage of detrital quartz and feldspar decreases towards the top of the Queenston Formation. Most of the basal sections consists of approximately 10% sand grains, but this number decreases to less than 2% near the upper contact with the Whirlpool Sandstone. This seems to coincide with a decrease in the percentage of siltstone interbeds towards the top of the formation (see Figure 20).

Fine sand grains extracted from the mudrock are sub-rounded and appear frosted (Photo 10). However, high resolution photographs of the outer surface show that the sand grains contain many V-shaped pits (Photo 11).

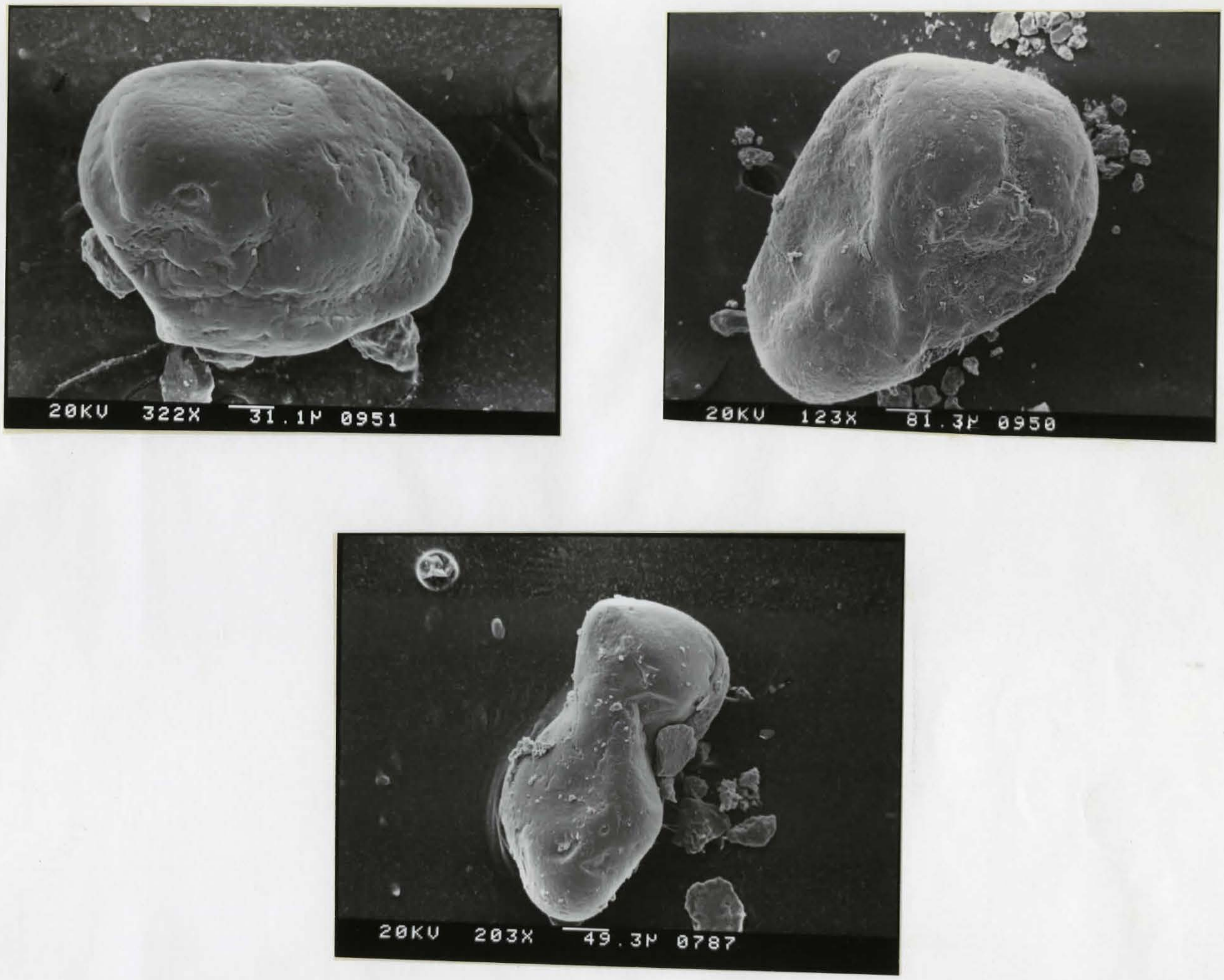


Photo 10: SEM photographs of fine sand grains from the Bronte Creek and Milton sections.

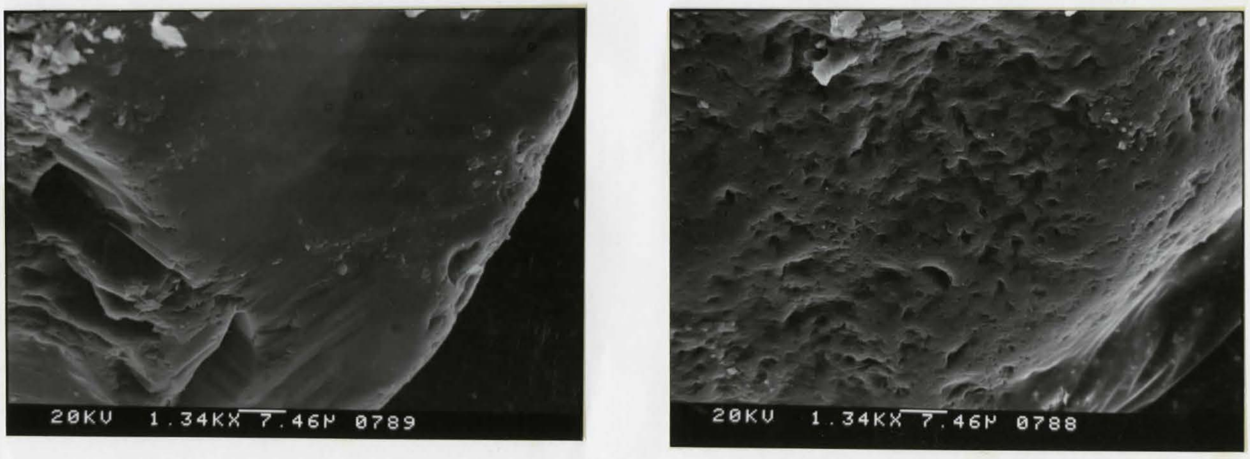
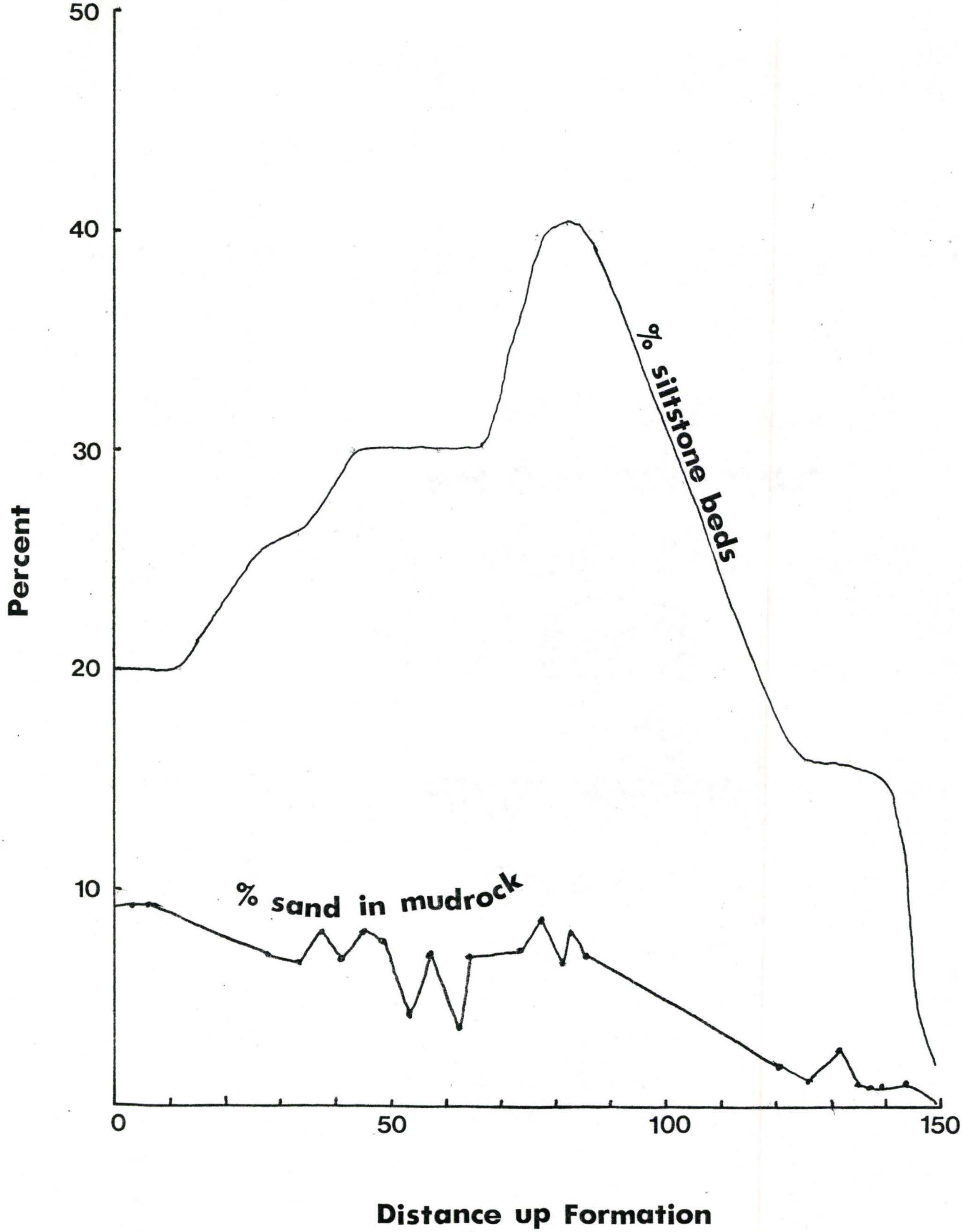


Photo 11: High resolution photographs of the outer surfaces of fine sand grains.

Figure 20. % Sand in mudrock and % siltstone beds as a function of distance up the formation.



50
40
30
20
10
Percent
% siltstone beds
% sand in mudrock
0
50
100
150
Distance up Formation

Petrography of the Siltstones

Although most siltstones in the Queenston exhibit no fossils in outcrop, all of the siltstones contain a considerable amount of fossil detritus. Petrographic studies of siltstones from the Bronte Creek, Canada Brick Ltd. Bronte Creek and Cheltenham sections all show fossil fragments of brachiopods (Photos 13 and 14). Moreover, they all contain altered remnants of oolites, pellets and other fossil fragments. Calcium carbonate comprises 40 to 70% of most siltstone layers.

The rusty weathering observed in some siltstones is caused by trace amounts of disseminated iron sulfides. This feature is more characteristic of silstones in the upper half of the Formation such as Canada Brick Bronte Creek, Milton and Cheltenham.

Photo 13: Canada Brick Bronte Creek siltstone.
Scale: 2 mm across long axis.

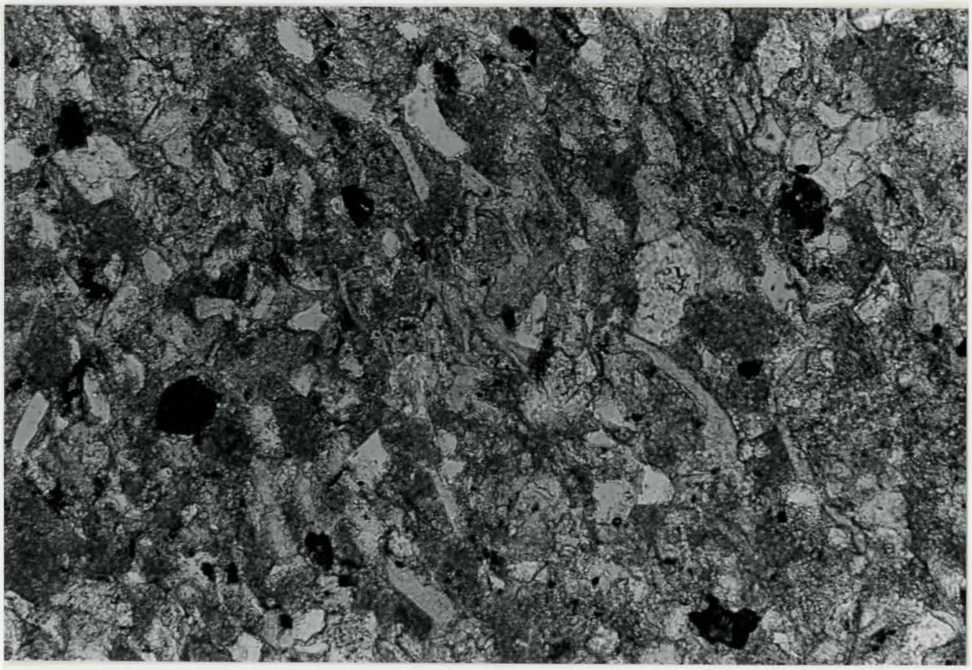


Photo 14: Cheltenham siltstone.
Scale: 2 mm across long axis.

Petrography of the Carbonates

Petrographic studies of carbonates from the Streetsville and Bronte Creek outcrops indicate that they are fossiliferous micro-oolitic limestones. They contain a great deal of oolites, pellets, brachiopods, ostracods, dasyldacean algae, bryozoans and algal aggregate grains (see Photos 15-20). The skeletal grains occur most abundantly in fossil hash zones within individual limestone layers, and do not represent in situ fossil assemblages. The shells are small (3 mm or less), and are well fragmented. In many limestones, ostracods weather out of the rock leaving small black carapaces visable at the surface. Most of the limestones are graded and capped off by a thin silty layer. In some of these silty layers -- especially at Bronte Creek -- there are symmetrical ripples full of the trace fossil Diplocretarian. This trace fossil only occurs in the limestone layers, and is therefore restricted to very limited stratigraphic horizons.

Birdseye textures occur extensively throughout the limestones especially at Bronte Creek. The birdseyes are 1 to 3 mm long, and are composed of sparry calcite. In outcrop, these calcite vugs weather out as black specks that are vaguely concordant with bedding. Similar textures can be observed in the limestones of the uppermost Dundas-Meaford Formation at the Canada Brick Streetsville outcrop.

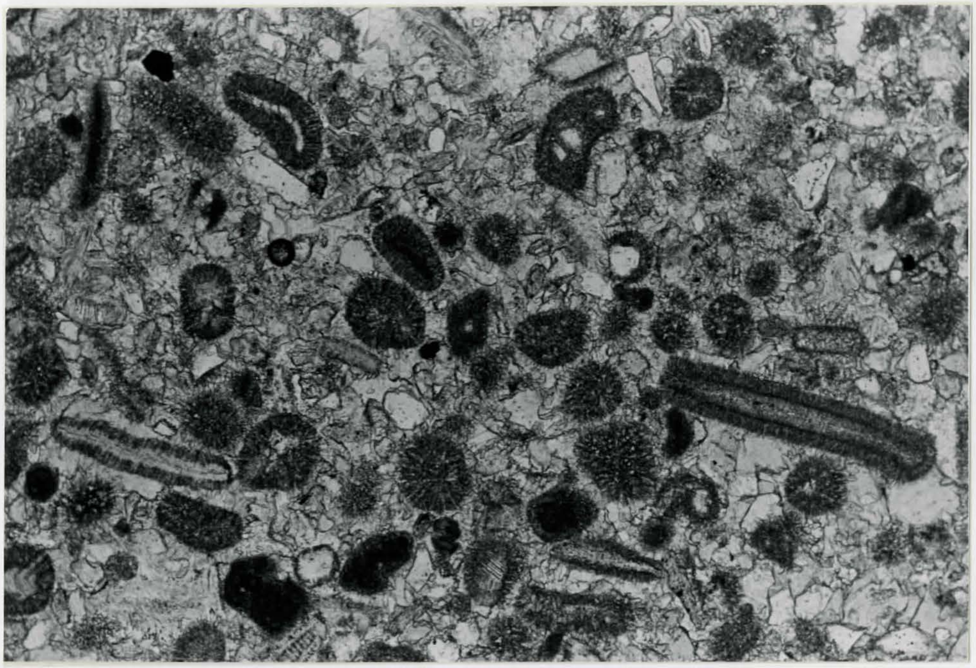


Photo 15: Bronte Creek limestone.
Scale: 2 mm across long axis.

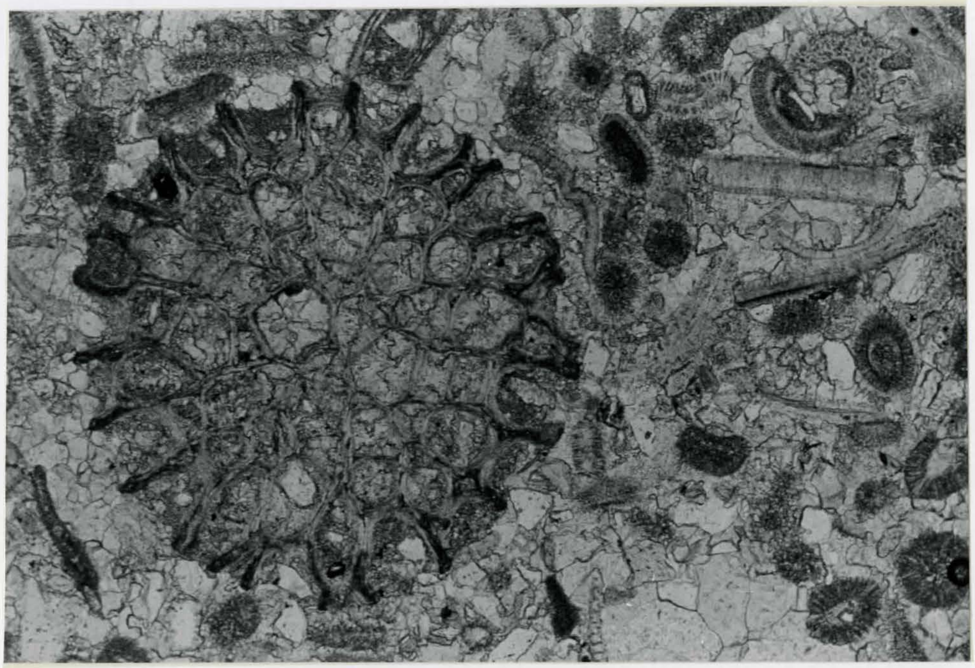


Photo 16: Large bryozoan fragment in Bronte Creek limestone. Scale: 2 mm across long axis.

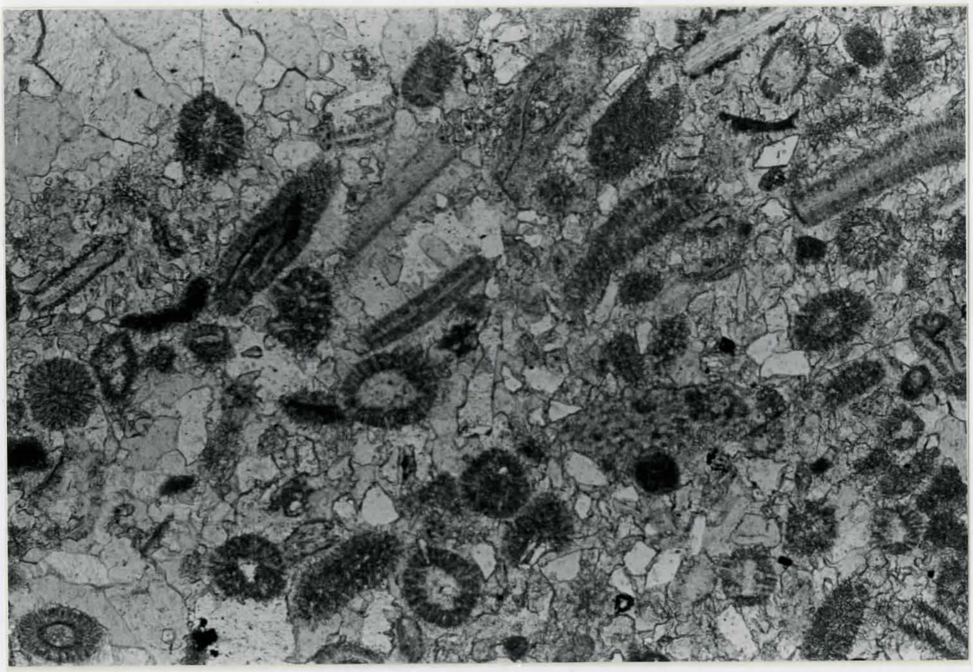


Photo 17: Bronte Creek limestone. Notice sparry vug at the top (Birdseye texture). Scale: 2 mm across long axis.

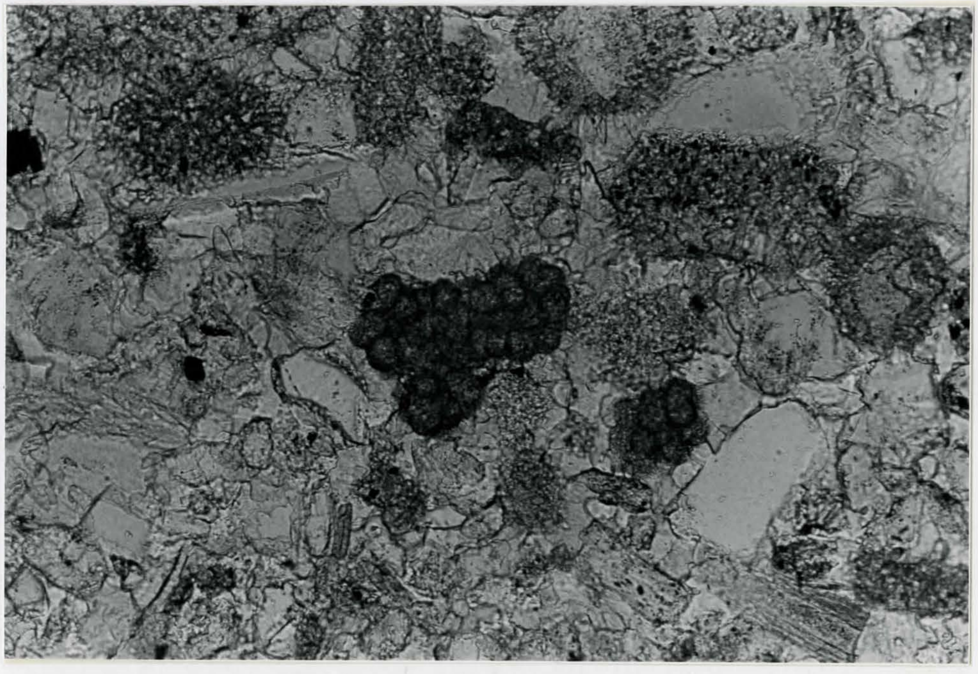


Photo 18: Aggregate grain in Bronte Creek limestone. Scale: .5 mm across long axis.

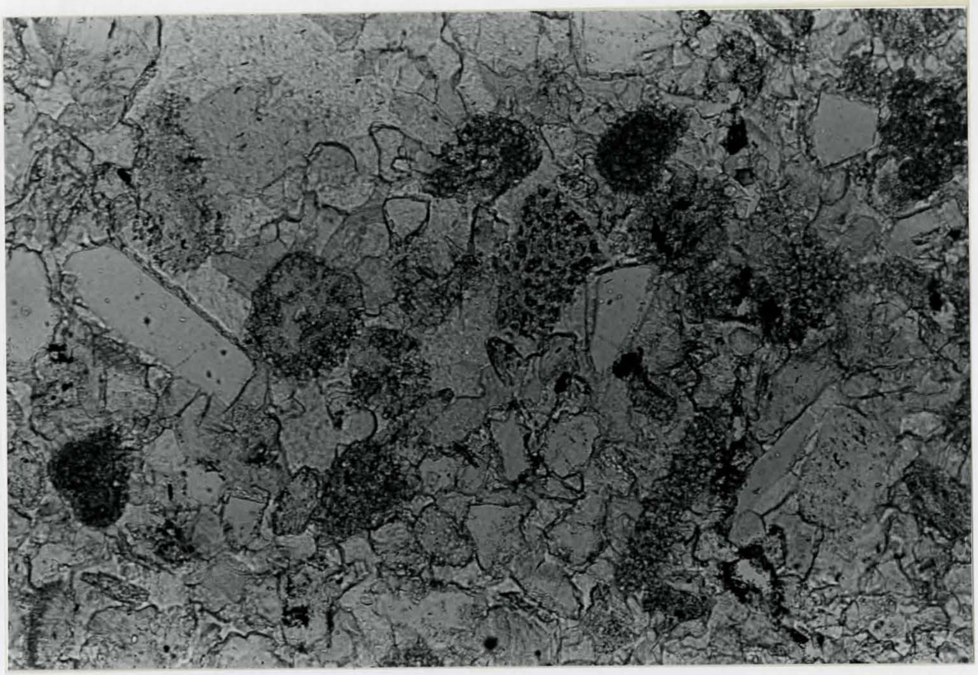


Photo 19: Dasyldacean algae (center).
Scale: .5 mm across long axis.

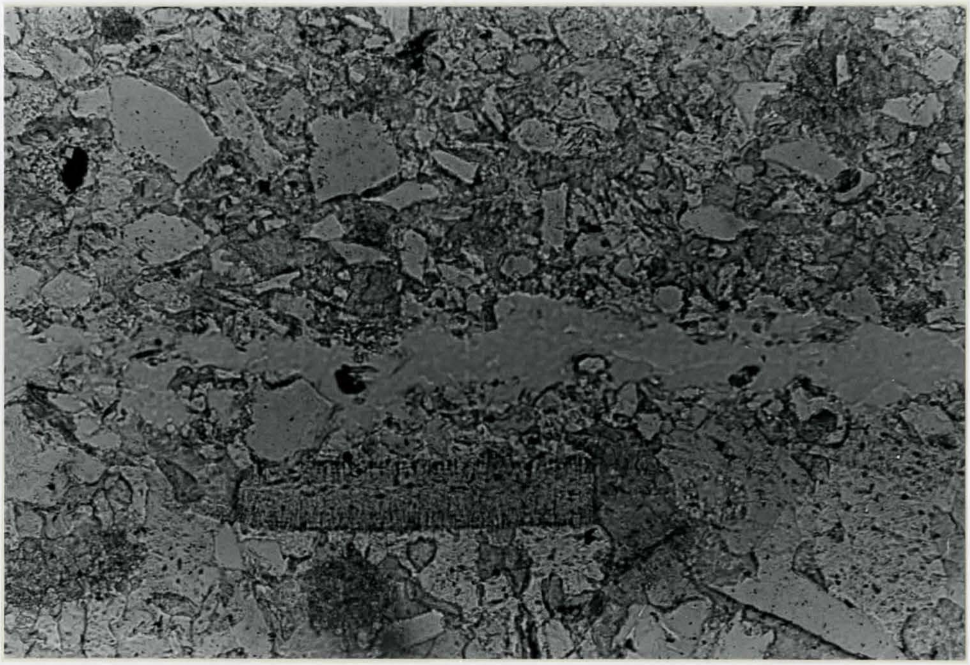


Photo 20: Burrows in Canada Brick Streetsville limestone. Scale: .5 mm across long axis.

Black Reduction Spots

Reduction spots occur extensively throughout the Queenston mudrocks. Qualitative chemical analysis has indicated that the major chemical constituents are no different from the surrounding mudrocks: Si, K, Al, Ca and Fe. Therefore, the cause of the reduction of ferric iron to ferrous iron surrounding the small black nucleus is probably the result of organic matter within the mudrocks (see Photo 7).

X-ray analysis of the black nucleus indicated the presence of poorly crystallized montomorillonite-illites (Dr. D. Grundy, personal communication). This would provide the medium for absorbing the organic matter, and keeping it from oxidizing over long periods of time. Thus argument is strengthened by the fact that there is vanadium at the core of the reduction spots. Vanadium, in low oxidation states, is frequently associated with reduction spots (Mykura, 1984).

CONCLUSIONS

The Queenston Formation has been described as a non-marine delta since the turn of the century. Gradau (1909) and Foerste (1916) both interpreted the Queenston Formation as being deposited sub-aerially due to its lack of fossils. Caley (1940) interpreted the Queenston as non-marine for the same reasons. He also interpreted the high calcium carbonate deposit of Queenston siltstones as being the result of carbonate rich groundwaters percolating through the formation. Guillet (1967) supported this view, and concluded that the gypsum nodules throughout the formation were secondary. Sweet et al. (1971) studied the conodont faunas of Middle and Late Ordovician rocks in Eastern North America, but reported no conodonts from the Queenston.

The siltstones in the Queenston contain 40 to 70% carbonate. Although Caley (1940) interpreted this carbonate as being secondary, petrographic studies have shown that they contain brachiopod and Dasyldacean algae fragments. These fossils, especially the Dasyldacean algea, are diagnostic of a marine environment (Flugel, 1982). It is also highly unlikely that the siltstones had 40 to 70% porosity after burial.

Some of the gypsum nodules in the Queenston Formation have inclusions of halite. This would be highly unlikely if the gypsum was secondary. Moreover, the evaporite horizons are laterally continuous, and limited to narrow stratigraphic horizons within the formation. This supports the proposal that the gypsum is a primary precipitate from sea water (Dean et al. 1978).

The detrital quartz grains within the mudrocks do not appear to be aeolian. They contain many V-shaped pits which are typical of subaqueous sand and silt quartz grains (Margolis and Krinsley, 1974). Blatt (1982) reports that alluvial fan mudrocks contain 27% aeolian sand grains. This is inconsistent with the Queenston where the total quartz and feldspar sand component decreases from 10 to less than 2% towards the top of the formation. This decrease mimics the decrease in siltstone towards the top of the formation, and could reflect a common depositional source for the mudrocks and siltstones (see Fig.). Detrital sand grains from Queenston mudrocks closely resemble beach sands (Rieneck and Singh, 1980).

There is no evidence of rivers or distributaries anywhere in the Queenston in Southern Ontario, although they have been reported from the Queenston in New York State (Patchen, 1966). All siltstone layers are thin, graded and have flat bases. Most siltstone layers are also laterally continuous, and can be traced along an outcrop.

The paleocurrents reflect a north-south transport mechanism, not the east-west model proposed for continental sedimentation. This could be due to paleowind directions, since the Late Ordovician trade winds blew from the north-east to the south-west. These trade winds would have travelled approximately parallel to the coast of the inferred taconian land mass (Dott and Batten, 1981) (see Figure 21). This could also explain the lack of channeling in the Queenston: perhaps all the mud was derived from a river to the north and transported by longshore currents towards the south-west (G. V. Middleton, personal communication).

Therefore, the depositional model must fit the following criteria:

1. Graded marine siltstone beds
2. No channels or distributaries
3. Massive mudrock
4. Periods of exposure or dessication
5. Restricted, occasionally, to allow the formation of evaporites
6. North to south paleocurrent directions
7. Mudrocks which contain beach not aeolian sands
8. Organic matter (reduction spots) in the mudrocks
9. Large vertical escape burrows in the dessicated Bronte Creek limestones.

Therefore, it is proposed that the Queenston Formation in Southern Ontario was deposited as a supratidal mudflat. This would account for the dessication cracks, wrinkle marks and evaporites. It would also account for the birdseye textures in the limestones, and low diversity of life in the formation, both of which are typical of estuarine or transitional environments (Flugel, 1982). However, a simple supratidal mudflat with a continental source to the south-east is not adequate, since the north-south paleo-currents, massive mudrocks, beach sand, large escape burrows and lack of channeling must be explained. For this reason, it is proposed that the mud was derived from a river (or rivers) to the north where the muds were flocculated and transported south-west by longshore currents to the depositional site (see Fig. 21). Regular flooding by the sea produced the calcereous marine siltstones.

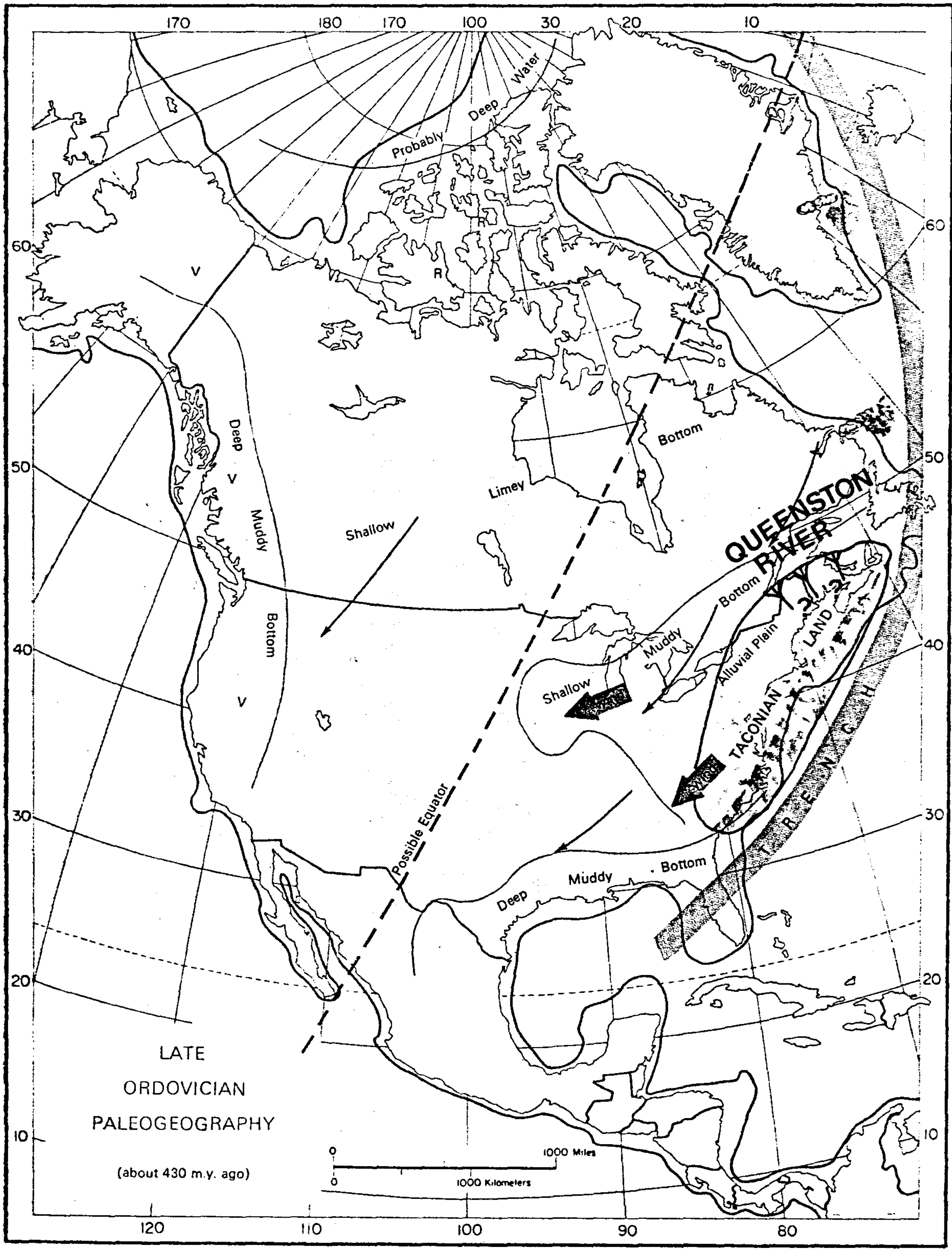


Figure 21: Paleowind directions in the Late Orovician from volcanic ash fragments (Dott and Batten, 1981).

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LEGEND

lithology

R G S L

- R Red Mudrock
- G Green Mudrock
- S Siltstone
- L Limestone

- Gypsum
- Halite

sedimentary structures

- Cross lamination
- Symmetric Ripples
- Unidirectional Structure

miscellaneous features

- Wrinkle Marks
- Dessication Cracks
- Black Nodules
- Gypsum Nodules
- Gypsum Inclusions
- Gypsum Layers
- Ostracods
- Diplocraterion
- Bioturbation
- Birdseye Texture
- Halite Staining
- Halite Casts
- Calcite Geodes
- Large Unidentified Escape Burrows