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ASPECTS OF CHAMPLAIN SEA SEDIMENTATION ASSOCIATED WITH GLACIAL RIDGES IN THE SOUTH OTTAWA REGION

by

Mark Hayward

Submitted to the School of Graduate Studies in Partial
Fulfilment of the Master of Arts Degree in Geography.

University of Ottawa
Ottawa, March, 1979

ABSTRACT

During the summer of 1978 the stratigraphy of Champlain Sea sediments exposed in sand and gravel pits south of Ottawa was drawn up in detail. The lithology, sedimentary structures and fossils present were recorded. These data provide the foundation for a reconstruction of marine sedimentation along the sand and gravel ridges of the south Ottawa region. A major marine facies can be recognized, comprising materials deposited in topographic lows along the ridges. These hollows are believed to be due to in many cases the melting of ice buried by subaqueous outwash sediments. The facies is called the "hollow-fill facies". Processes responsible for its deposition include debris flows and small turbidity currents due to slope instability, and straightforward wave-washing of the higher parts of ridges. As a concomitant of the diversity of processes, the hollow-fill facies comprises a variety of materials: diamictons (pebbly muds), gravels, sands and lutites.

RESUME

Au cours de l'été 1978, nous avons étudié en détail la stratigraphie des sédiments de la Mer de Champlain exposés dans des gravières au Sud d'Ottawa en nous attachant particulièrement à la lithologie, aux structures sédimentaires et aux fossiles. Ces données ont permis la reconstitution de la sédimentation marine le long des crêtes de sable et gravier. Le faciès marin principal est constitué par le matériel déposé dans des dépressions affectant ces crêtes. Nous pensons que ces cuvettes résultent dans la plupart des cas de la fonte de culots de glace enfouis sous des sédiments d'épandage sous-aquatique, d'où le nom de "faciès de remplissage de cuvette" suggéré pour ce faciès. Des coulées de matériel, de petits courants de turbidité résultant de l'instabilité des pentes, ainsi que le délavage par l'action des vagues de la partie supérieure des crêtes sont les agents responsables de sa mise en place. Du fait de la variété des processus, la nature des sédiments est aussi très changeante: diamictons (boues caillouteuses), graviers, sables et lutites.

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ACKNOWLEDGMENTS

I express gratitude to my thesis supervisor, Dr. Hugh M. French, for his continual advice, interest, encouragement and patience at all stages of the project. Thanks are due to Dr. Peter Worsley (Department of Geography, University of Reading) and Dr. Owen A. Dixon (Department of Geology, University of Ottawa) for their advice at the stage of the project's inception. I am also grateful to Rick Cheel (M.Sc. Candidate) for helpful discussions and criticism, and for companionship and transport on a number of occasions during the fieldwork.

Financial support during the period July, 1977 to April, 1979 was provided variously by a Department of Geography Assistantship, a summer teaching assignment, and research funds held by H.M. French.

Finally, I thank Mrs. C. Sabourin for the excellent typing, and the Communications Centre in the University of Ottawa for expertly handling the reduction of the sections.

The abstract was translated by Daniel Lagarec.

"There are no answers", he said with mystifying glibness.
"I'm looking for water".

(Paul Theroux: <u>The Great Railway Bazaar</u>)

CHAPTER 1

INTRODUCTION

Here is no water but only rock
(T.S. Eliot: The Waste Land)

"Champlain Sea" is the established name for the arm of the Atlantic Ocean present in the Ottawa - St. Lawrence lowlands after about 12,800 ^{14}C years B.P. The period of marine submergence was less than three thousand years in the Ottawa region, but the deposits associated with the sea are an important element of the surficial geology, while shoreline processes have etched finer details on the landscape.

This study emphasizes the marine sedimentary facies which are associated with several glacial ridges to the south of Ottawa.

(1) Aims and methods

The primary aim of this thesis is to determine the environment of deposition of Champlain Sea sediments exposed in a number of pits to the south of Ottawa (Figure 1). The ultimate goal is to present a number of facies models which generalize the data from the exposures, which are presented as drawn sections. A secondary objective is to put the various sites into their local setting by means of landform maps derived from the interpretation of air photographs, or a consideration of issues arising from surficial geology mapping and literature.

Fundamental to the thesis, therefore, is the notion that sections are data-banks of information on paleoenvironments. Schwarzacher (1975, p. 3) has likened the process of environmental reconstruction

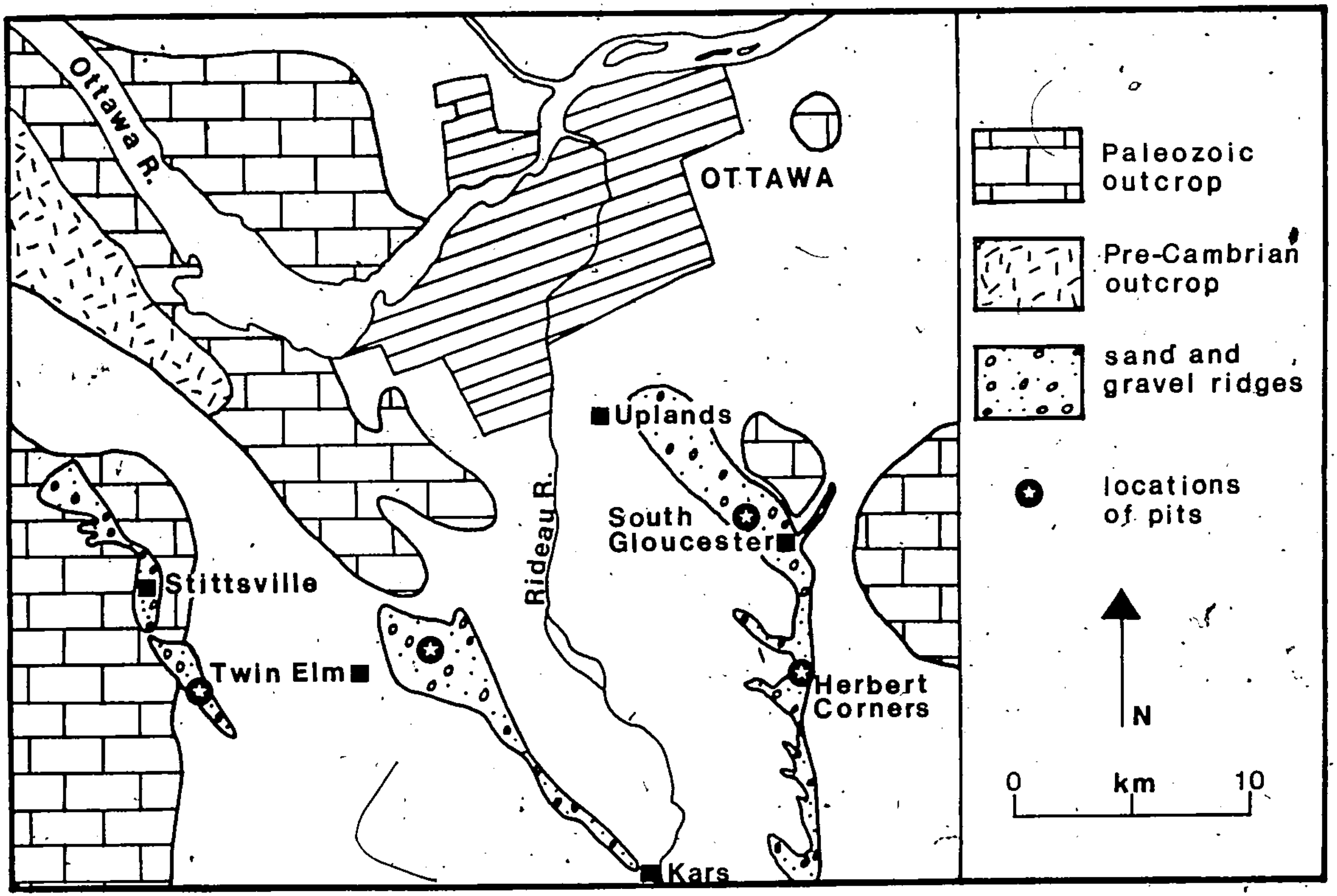

FIGURE 1: Map showing pit locations and the glacial ridges of the south Ottawa region. Source: Richard _et al_. (1977).

to the transmission of a message, in terms of information theory:

MESSAGE → ENCODING → TRANSMISSION → RECEPTION → DECODING

ENVIRONMENT → SEDIMENTARY PROCESSES → STRATIGRAPHIC SECTION → OBSERVATION → INTERPRETATION

A concomitant of this is the loss of information which the original message suffers owing to shortcomings in the system and extraneous "white noise" which, in terms of stratigraphy, may be post-depositional disturbance (e.g. the effects of tree roots), convergence of processes, or other variability.

Stratigraphic data will be of major importance to the present study, but the problem will not be to relate sequences, rather to develop low-order facies models similar to the illustrations of Hessland (1946) (Figure 2) and Terasmae (1965) (Figure 3).

The initial step in assembling evidence for an attempt at forensic paleogeomorphology is to gather stratigraphic data. This data may be classified as follows, with respect to one formation or one bed (Selley (1970)):

(a) geometry
(b) lithology
(c) sedimentary structures
(d) paleocurrents
(e) fossils

Stratigraphic relationships are also important, and in this case it is necessary to determine whether the boundaries are sharp and possibly unconformable, and whether there is offlap or onlap (Krumbein and Sloss (1963, p. 53 etc.)).

Most sections provide only a two-dimensional view of a body of sediment. However, the deposits which comprise the major element in

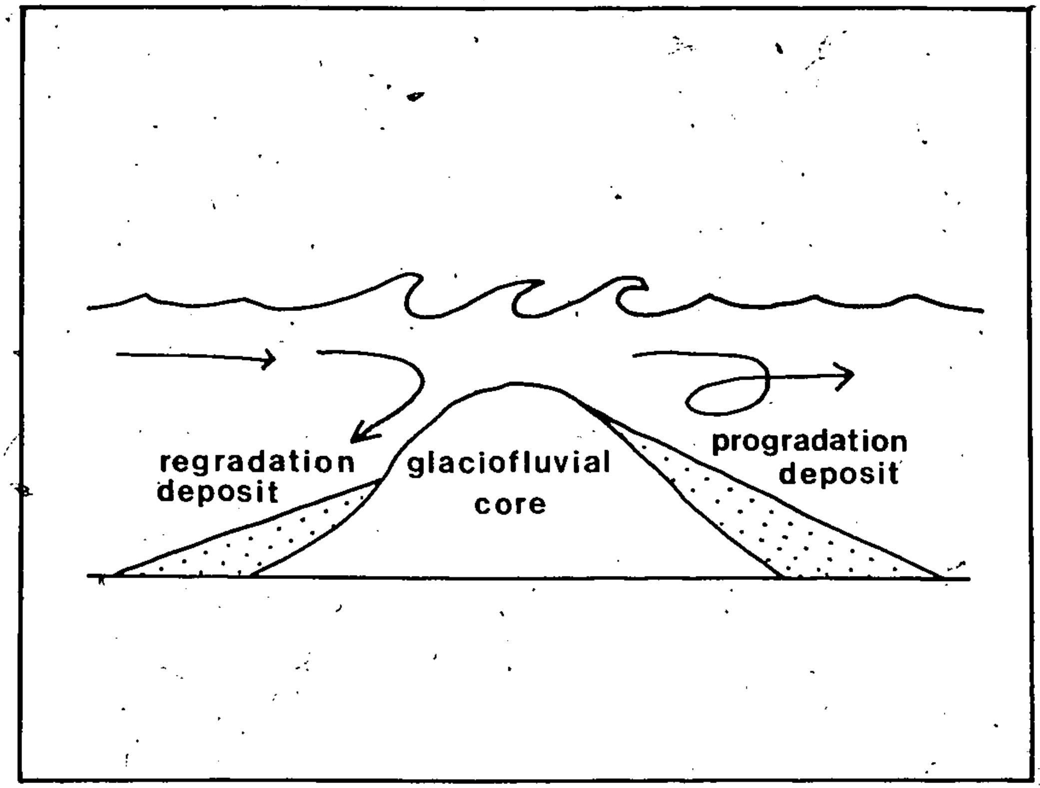

FIGURE 2: Wave-washed deposits flanking a ridge. (After Hessland (1946)).

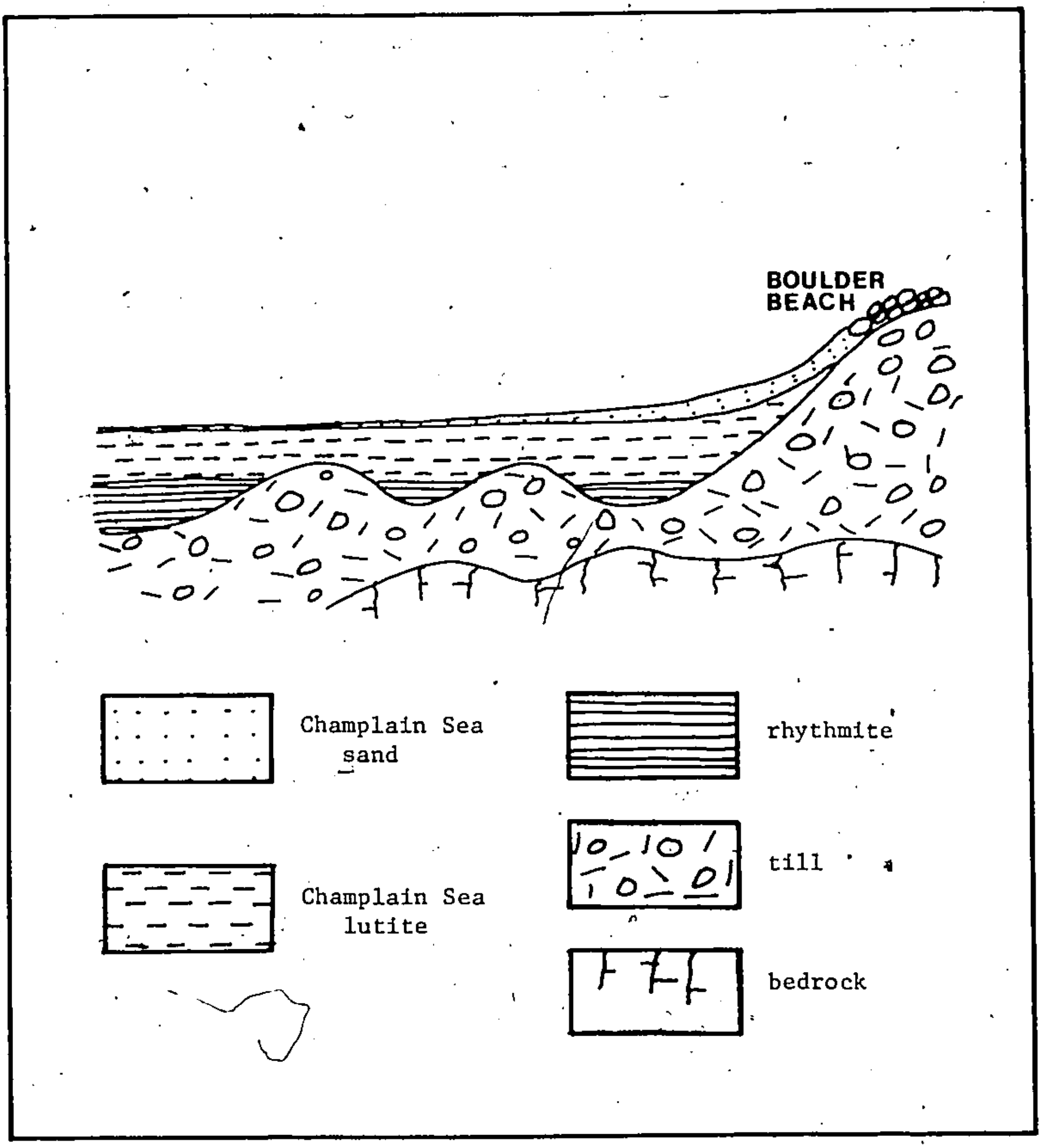

FIGURE 3: Champlain Sea facies in the Cornwall area. (After Terasmae (1965)).

the present study do not possess the characteristic geometry of littoral and sub-littoral deposits, which are usually linear and wedge-shaped.

Lithology can be documented in various ways, the most important aspects being texture, grain size and shape, fabric and petrology. The first is frequently illustrated by particle size distribution curves. Grain-size analyses are not included in the thesis because of the rudaceous or diamictaceous nature of much of the sediment which leads to problems of sampling and analysis, and also the dubious value of presenting numerous grain-size plots.

Just as particle size analyses can be carried out ad nauseam, so can investigations into the shape and roundness of clasts and sand grains be pursued without any significant gain in information. Moreover, it is unlikely in the case of Champlain Sea sediments that much rounding of particles occurred. Certainly, the sand fraction is unlikely to have undergone much rounding in the marine environment. For example, in their study of Champlain Sea sediments in the Oka Hills region near Montreal, Hillaire-Marcel et al. (1974) found that morphoscopic analysis of sand grains in the manner of Cailleux and Tricart (1963) indicated no change from the "non-usé" state to "émoussé luisant". Electron microscopy might well yield valuable results, but it is beyond the scope of the present study. As a result, no data of that nature were collected for the present study, although it might be thought of as a typically geographical approach (e.g. Briggs (1977)). Similarly, fabric and petrology are not treated in this study.

Sedimentary structures and paleocurrents are related subjects of investigation because the former are frequently used to ascertain the latter. At one locality small-scale cross-stratification was particularly well developed, and a number of measurements were taken in order to obtain the paleocurrent direction.

The fifth component of the stratigraphic data-bank is the paleontological evidence. The fauna may be used for paleoecological purposes, and, in some cases, remains may be used in order to determine paleocurrent vectors. The first role involves numerous difficulties (see pp. 14 to 21), and the matter of the orientation of organic remains in water is an unresolved problem (e.g. see Boucot et al. (1958); Nagle (1967); Brenchley and Newall (1970)).

The occurrence and preservation of macrofaunal species was noted during fieldwork. In one case where the orientation of barnacle fragments was particularly striking, their orientations were measured.

The most important aspect of the investigation, greater than the sum of all the previous parts, was the drawing of sections in their entirety, a practice which seems to have been all too little used.

During the early summer of 1978, following reconnaissance in the field, seven pits in four geographic areas were chosen for study (Figure 1). The sections displayed a considerable array of marine sediments. In order to form a horizontal frame of reference for the drawing of the section, a base line was set up close to the face and marked off in five-metre intervals. After drawing the profile of the top of the section and inserting a datum determined by hand-level, the units were drawn in, starting with the major stratigraphic divisions. When the boundaries of the units had been inserted, the lithology and faunal content of each unit were noted.

The elevation of the pit at the datum was determined, for most sections, by an altimeter with reference to a nearby benchmark.

The sections furnished a substantial body of data which gives a picture of the exposures at the time of record (various dates between June and August, 1978).

In order to provide a regional geomorphological context to the study of the sections, maps have been prepared for the areas surrounding the pits. Attention was focussed, during the preparation of these maps, upon those features due to marine processes. The maps were derived from the interpretation of air photographs, and published information.

(2) Champlain Sea sediments and shorelines

The extent and distribution of marine sediments in the Ottawa - St. Lawrence lowlands has become reasonably well known (Figure 4) as various areas are mapped by the Geological Survey of Canada and others. As yet, however, the literature on the geomorphology associated with the deposits is not extensive, and published sources perhaps do not give an adequate impression of the variety of marine sediments which is to be found.

A recent Geological Survey memoir dealing with the surficial geology of the Ottawa region has yet to appear; at present there are only the preliminary notes of Gadd (1961, 1962), the brief summary in Baird (1968), a surficial geology map (Richard _et al_. (1977)) and a number of maps on Open File (e.g. Richard (1976a and b)) for reference.

A brief consideration of the pre-marine features is in order because they form the major topographic elements which influenced marine

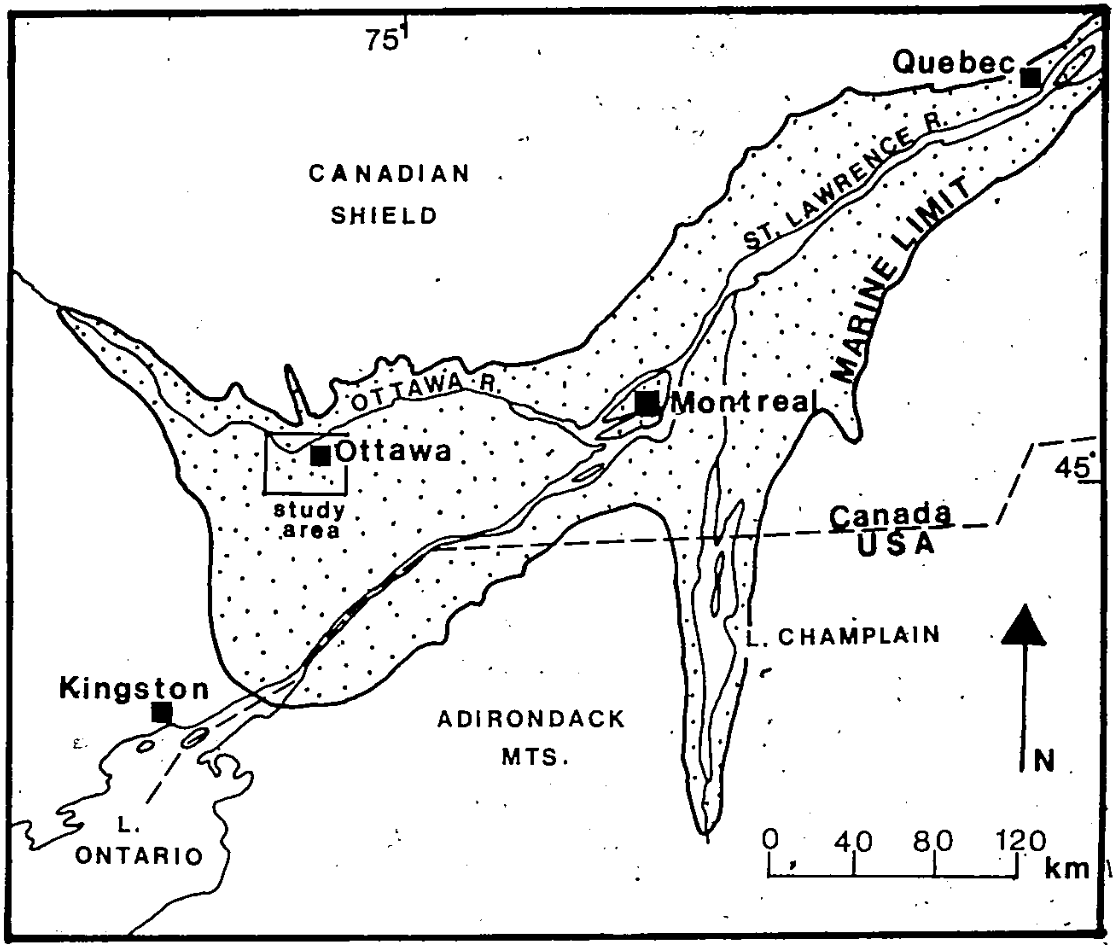

FIGURE 4: Map showing the approximate maximum extent of the Champlain Sea. (After Elson (1969b)).

sedimentation, and were themselves affected by the waves and currents of the Champlain Sea.

Outcrops of Paleozoic rock are important in the western part of the region shown in Figure 1. Elsewhere, fault blocks form isolated areas of more elevated terrain, as at South Gloucester. In the west the ground rises above 150 m in places, but east of the Rideau River all terrain is below that elevation.

In places the bedrock is mantled by a veneer of angular gravel which has been derived directly from it and reworked into beach ridges, as near South Gloucester (Figure 5). Boulder beaches occur locally (Figure 6A).

Glacial till, not buried by later sediments, forms an important unit at the surface, and has been drumlinized in places. The drumlin forms are subdued, however (Figure 6B), owing to partial burial by Champlain Sea clay and a degree of wave-washing. The latter aspect appears to be less important than in the Cornwall area, where Terasmae (1965) found striking examples of the effects of wave-washing. Gadd (1971) also has drawn attention to the occurrence of wave-washed forms in the central St. Lawrence lowlands.

The question of remanié forms due to wave erosion is, of necessity, brought up with respect to glaciofluvial landforms, because of the possible confusion of unreworked glaciofluvial sediments with materials redeposited by the Champlain Sea. A complete spectrum of reworking is possible.

In the Ottawa region the effects of wave action on glaciofluvial sediments appear to have been important, and must have led to considerable

FIGURE 5: Beach ridges on the limestone plateau near South Gloucester.
(From air photograph A23217-130).

FIGURE 6A: Boulder beach near French Hill approximately 25 km east-northeast of Ottawa (Grid Reference 672362).

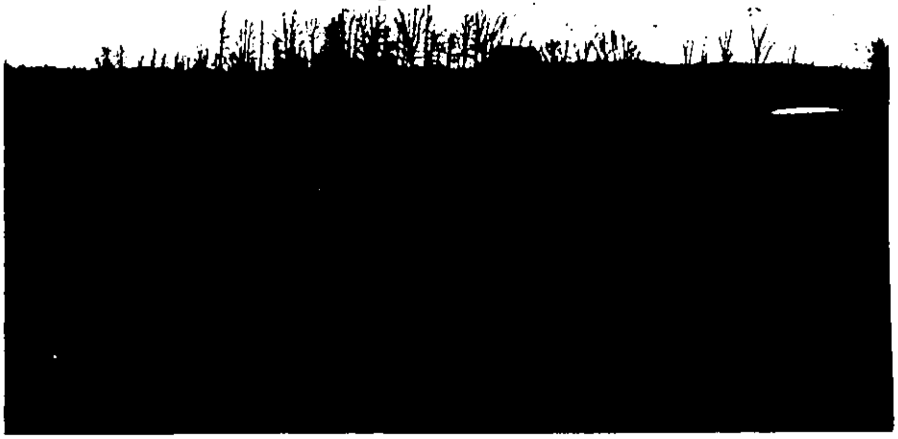

FIGURE 6B: Drumlin terrain near Manotick.

problems in surficial mapping. Examination of the legend employed in the 1:50,000 Open File maps (Richard (1976)) reveals the provisions made for the varying degrees of reworking. Evidence from sections gives a valuable perspective on this problem, although it can lead to slightly unfair criticisms of mapping designations.

It should be pointed out that the use of the word "glaciofluvial" may be inappropriate in many instances in the Ottawa region owing to the Wisconsinan ice having retreated in water. The sedimentological implications of this idea have been examined by Rust and Romanelli (1975) and Rust (1977). Gadd (1978) has disputed these claims, but Rust (1978) has replied to the criticisms. Informal field observations indicate that the areal extent of "subaqueous outwash", as defined and diagnosed by Rust, might be important.

Given that the retreat of the ice front was in water, one might also infer that marine and subaqueous outwash facies were to some extent isochronous. Gadd (1971) noted evidence from sediments in the central St. Lawrence lowlands which suggested the proximity of the ice front during marine sedimentation. In the Ottawa region the relations of ice and sea are less well known, despite a considerable number of radiocarbon dates. The fact that the equivalent of the St. Narcisse moraine probably lies on the Shield to the north of Ottawa means that this valuable stratigraphic marker of further east is absent in this part of the former basin of the Champlain Sea.

The admission of glacial influence in the Champlain Sea sediments of the Ottawa region does not appear to have been made. Rather, it appears that the formerly extensive exposures at Uplands, which showed a transition from glaciofluvial to varved to marine sediments (e.g. Romanelli (1970)), have been regarded as an unofficial type section for the glacial-to-marine transition in the area. This state of affairs will prevail until data on other sections are disseminated. One certainly should not rely on the descriptions of Champlain Sea sediments from other areas to clarify the picture for the Ottawa region.

We now turn to a consideration of beach ridges formed by the Champlain Sea. Noteworthy examples of wave-fashioned ridges have been cited by Johnston (1916) and Goldthwait (1933), and a more general description is given by Karrow (1961). The first noted with some enthusiasm the well developed series of ridges on Rigaud mountain, some 50 km from Montreal; Goldthwait mentioned other examples from the Collines d'Oka and Covey Hill. Except for a sequence of ridges near Kingsmere, north of Ottawa, examples of beach ridges in the Ottawa region are less impressive, although mapped extensively by the Geological Survey of Canada (Richard (1976)). In addition, Harrison (1977) has argued for more detailed study of the 'coastal geomorphology' of the Ottawa region.

Gadd (1971) has attempted a genetic interpretation of the coastal forms mapped in the Bécancour area, Québec, where some interesting configurations, similar to the "chevron" ridges observed on Foley Island in the eastern Arctic by King (1969), were found.

(3) Champlain Sea paleoecology

Although paléoecology is not a major element of the thesis, a review of the more recent work on Champlain Sea paleoecology is in order because such studies, where reliable, provide environmental data which complement those obtained from sedimentological and stratigraphic work.

Table 1 summarizes the findings of a number of studies. Superficially it would seem that the results of the investigations of bivalves are comparable in terms of detail with those obtained from microfossils (Foraminifera and Ostracoda). However, to arrive at estimates of temperature and salinity such as those quoted by Elson (1969a) (Table 1) a fairly circuitous path of reasoning must be taken. The studies by Cronin (1976a, b and 1977a, b), in which ostracode and/or foraminiferal species and assemblages were identified and related to modern analogs, demonstrate the value of microfauna in paleoecological work.

Cronin (1976b) collected Foraminifera, which are more abundant than Ostracodes, from a site 0.8 km northeast of Kars (Figure 1). The total assemblage possessed "a striking similarity to the arctic Foraminifera of today", and Cronin suggests related water temperatures of -1 to +8°C. Fillon and Hunt (1974) had earlier ventured that bottom water temperatures were less than 3°C for the first one - to two thousand years of marine presence in the Champlain Valley, New York.

The evidence of cold waters and a surprisingly late (10 900 ± 100 ^{14}C a B.P. - GSC 2312) radiocarbon date have led Cronin to suggest a lingering glacial presence in the western part of the Champlain Sea. Further evidence for such a phenomenon lies in Richard's (1975) notion of a late re-advance, although much more evidence is required before this can be admitted into the regional chronology.

TABLE 1

ATTEMPTS TO ELUCIDATE CHAMPLAIN SEA PALEOECOLOGY

WORKER	CRITERIA USED	CONCLUSIONS
Elson (1959, 1969a)	Molluscs: species, sizes	Colder earlier *Hiatella arctica* phase: salinity 26‰, temperature 2-3°C. Warmer later *Mya arenaria* phase: salinity 20-6‰, temperature > 5°C.
Wagner (1970)	Mollusc sizes	"boreal" improving to "more temperate", salinities lowest in remoter parts.
Romanelli (1976) (1)	Growth curves of molluscs	Trend to later stages of salinity 26-34‰, temperature 4-15°C. Salinities fell at end.
Fillon and Hunt (1974) (2)	Foraminifera: identification of species and assemblages	Bottom temperatures less than 3°C for first 1-2000 yr. Salinity declined from 30-33‰.
Cronin (1976a,b, 1977a,b) (3)	Foraminifera and Ostracoda: identification of species and assemblages	"Frigid" transitional phase with fluctuating salanities, *Hiatella* phase (after Elson) temp. rarely > 12°C sal. 18-35‰, *Mya* phase (after Elson) temp. 20-22°C (max.) sal. 3-18‰. Arctic bottom water in W. (glacial influence) Gulf Stream influx in E?

1. Gatineau Valley and Ottawa.
2. Champlain Valley, N.Y.
3. Champlain Valley and S. Québec for temperature and salinity.

Whereas foraminiferal assemblages probably reflect salinity (Cronin (1977b, p. 111)), individual ostracodes can be used to infer changing environmental conditions of salinity and temperature. Cronin (1977a and b) has established by this means a threefold biostratigraphic division of Champlain Sea sediments which applies to southern Québec and the Champlain Valley. The characteristics of the three phases have been summarized in Table 1. The two later phases seem to correspond to those proposed by Elson (1969a), on the basis of the occurrence of the molluscs Hiatella arctica and Mya arenaria.

Cronin's studies represent the most valuable contribution to date to Champlain Sea paleoecology.

Temperature and salinity estimates obtainable from bivalves (based upon associations, size frequencies and growth rates) have a lower resolving power than microfaunal data. Although this might be due to inherent biological factors, and it must be remembered that the Champlain Sea molluscan fauna is largely eurythermal and euryhaline, an equally plausible explanation is our underdeveloped understanding of the paleoecological significance of behavioral and biological traits. This point has been made by Craig and Hallam (1963) and Hallam (1967), but the work of Panella and MacClintock (1968), Stanley (1970), Farrow (1972) and Trewin (1973), inter alia, has remedied the situation to a large extent.

The macrofossils which are mentioned in this study are illustrated in Figure 7, and Table 2 lists those macrofossils found during field work, together with the abbreviations and symbols used in the sections in chapters 2, 3 and 4.

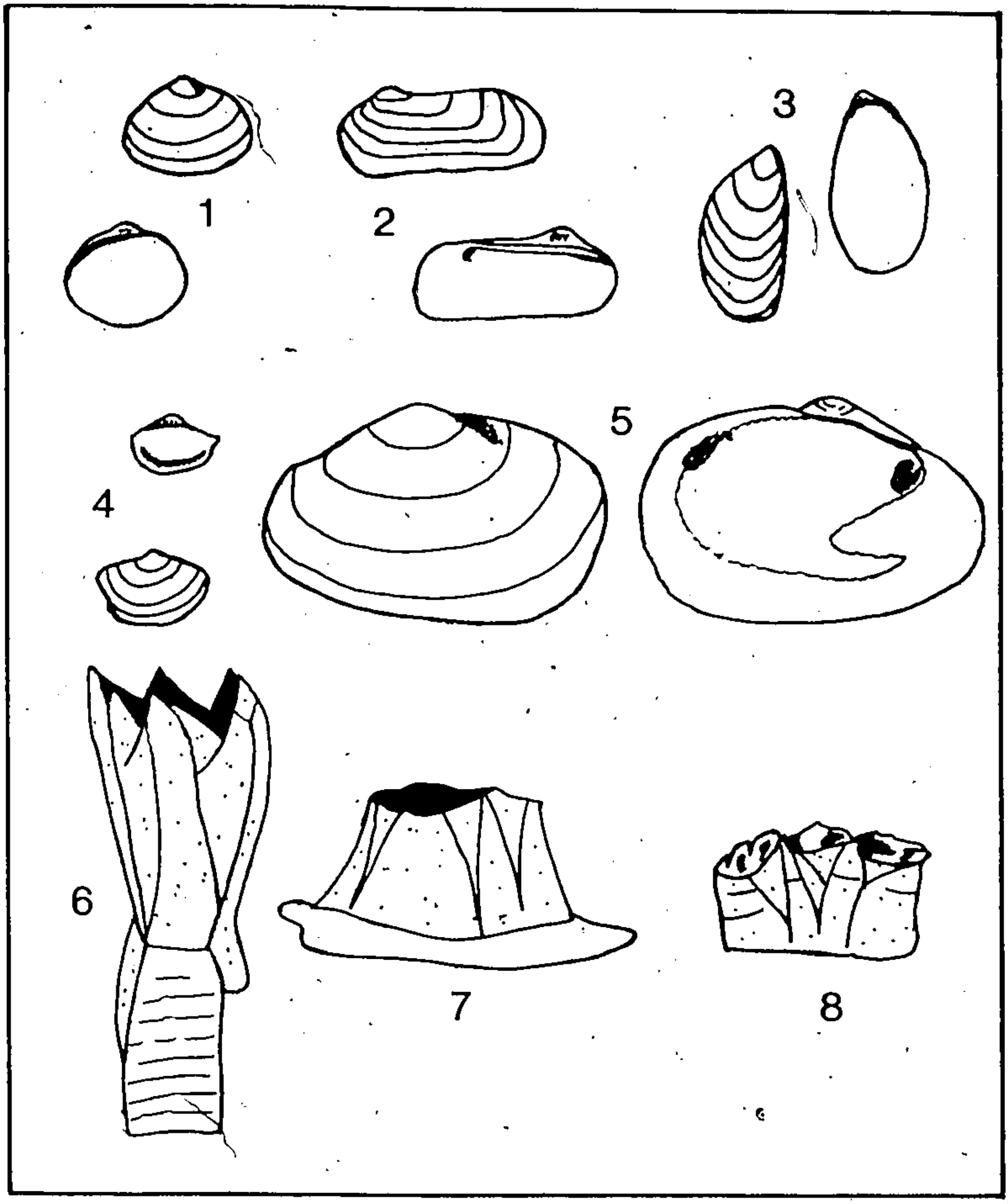

FIGURE 7: Sketches of common Champlain Sea fossils
Interior and exterior views of pelecypods:

1. Macoma balthica
2. Hiatella arctica
3. Mytilus edulis
4. Portlandia arctica
5. Mya arenaria

Barnacles: 6. Balanus hameri (narrow base)
7. Balanus hameri (wide base)
8. Balanus crenatus

(After Wagner (1970)).

(A) STATE OF PRESERVATION

☆	pelecypod(s) in life position
✪	pelecypods in various states of preservation
●	single valves and fragments of pelecypods
▲	barnacle(s) intact or in life position
✓	barnacle fragments

(B) FOSSIL NAMES

Ha	*Hiatella arctica*
Mb	*Macoma balthica*
Pa	*Portlandia arctica*
Bh	*Balanus hameri*
Bc	*Balanus crenatus*
Bs	*Balanus* (sp.)

TABLE 2: Symbols used in the sections in chapters 2, 3 and 4 and list of macrofossils found in the sediments.

Wagner (1970) employed shell length as a measure of the salinity of the Champlain Sea (low salinities being associated with stunting). However, Romanelli (1976) has rightly pointed out how desirable is the greater refinement obtained when growth rates are calculated from the length of the shell divided by the number of growth rings. This technique has also been employed in a study of two fossil assemblages from the "Laflamme Sea" (Elson (1969b)), by Hardy (1970). As a technique it has some potential, but it suffers from a lack of data from modern populations for comparison. Both Hardy and Romanelli use the same three studies of modern populations (Segerstråle (1960), Lammens (1967) and Lavoie et al. (1968)) for analogs, but these three studies do not come from a wide enough range of environmental conditions to serve in that role. Moreover, although temperature would seem to be the dominant control on growth rates (Lammens (1967)), the literature emphasizes the complexity of the controls on both size and growth rate (e.g. Nicol (1964) and Hallam (1965)).

At present the technique of growth rate analysis only enables the characterization of paleoenvironments in very broad terms, but is on a firmer foundation than the measurement of shell size in order to relate possible stunting to low salinities. There are numerous other causes of stunting in marine bivalves, including temperature, oxygen, turbidity, food supply and uptake, and wave action (Hallam (1965)).

Be that as it may, the work on molluscs has been an honest attempt to elucidate the paleoecology of the Champlain Sea. Elson's research (1969a) seems to have produced acceptable results, especially in the light of later work on the microfauna.

Romanelli (1976) attempted to make the work on bivalves more precise, and the precision of his results compares favorably with those of earlier studies. Accuracy is probably more important than precision in paleoecology, however, and it is doubtful whether the former has been improved. The paucity of growth rate data from modern populations remains a serious obstacle, and the writer would urge that no further studies in the manner of Hardy and Romanelli (op. cit.) be undertaken until that situation is resolved. In fact, the use of microfauna will probably render bivalves obsolete for the purposes of Quaternary marine paleoecology, at least where the former are abundant.

Finally, the recent geochemical work of Hillaire-Marcel (1977) should be noted. Such studies are a promising source of paleoenvironmental information. Even in the case of Hillaire-Marcel, however, one is faced with the problem of the ambiguity of macrofauna as indices, in this instance of water depth.

(4) Summary

In this study it is intended to add to the knowledge of Champlain Sea sedimentary environments, and to generalize the data derived from exposures into a number of facies models. Although the methods used will be largely those of stratigraphy, the thrust will be geomorphological, for rather than attempting to establish sequences, the object is to arrive at some understanding of Champlain Sea sedimentation.

One can foresee a continued interest in the problems of the Champlain Sea, each approach complementing the other in the completion of what is still a very patchy picture. It is hoped that the stratigraphic-geomorphic approach will be seen to be valuable and pursued in the future.

CHAPTER 2

MARINE SEDIMENTATION ON THE RIDGES AT STITTSVILLE AND TWIN ELM

> The subject, he insisted, was still in its pre-scientific stage. A lot of observations without any explanatory hypothesis.
>
> (Aldous Huxley: After Many a Summer)

This chapter describes several sections which lie to the west of the Rideau River. One section is from the Stittsville ridge, and five are from near Twin Elm (see Figures 8 and 12).

(1) The Stittsville ridge

(a) Local setting

Figure 8 shows the terrain features and surficial geology, as interpreted from air photographs, in the area around the exposure. Figure 9 is one photograph of the stereo-pair used to construct Figure 8. Figure 10 is a diagrammatic cross-section from northeast to southwest across the Stittsville ridge near Mulligan's pit.

West of the ridge is a plateau formed of ice-scoured Ottawa limestone (Ordovician) which rises to approximately 150 m. On exposed parts of this upland, beach ridges were built by the receding Champlain Sea. The materials of the ridges comprise resorted fragments of the local bedrock and winnowed till. The western edge of the bedrock terrain is flanked by till.

Resting upon the limestone is the Stittsville ridge, a feature formed by the subaqueous deposition of glacial outwash (Rust (1977) and

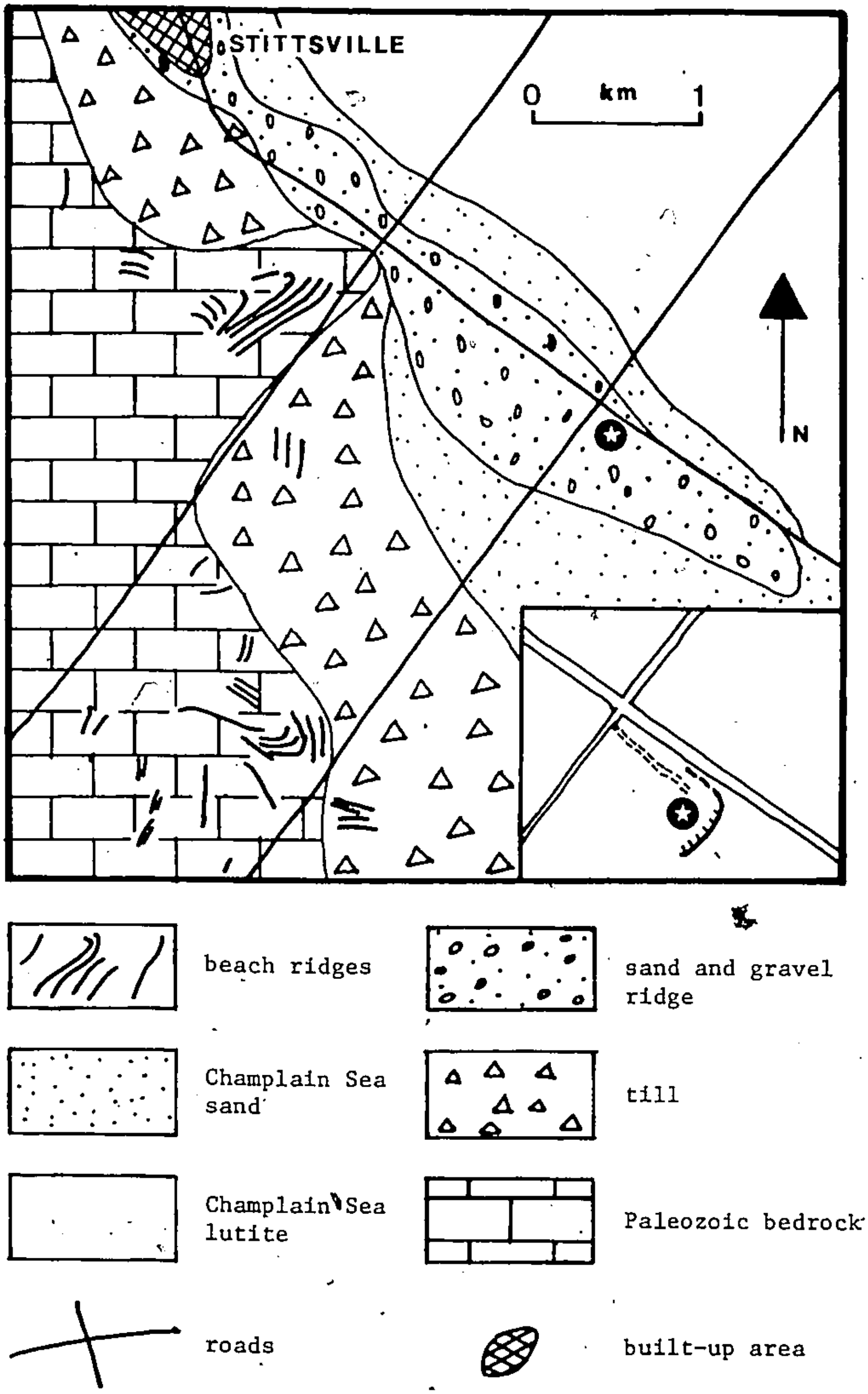

FIGURE 8: Map showing the surficial geology of the area around Mulligan's pit. Inset: location of pit. Source: air photographs A15596-1 and 2.

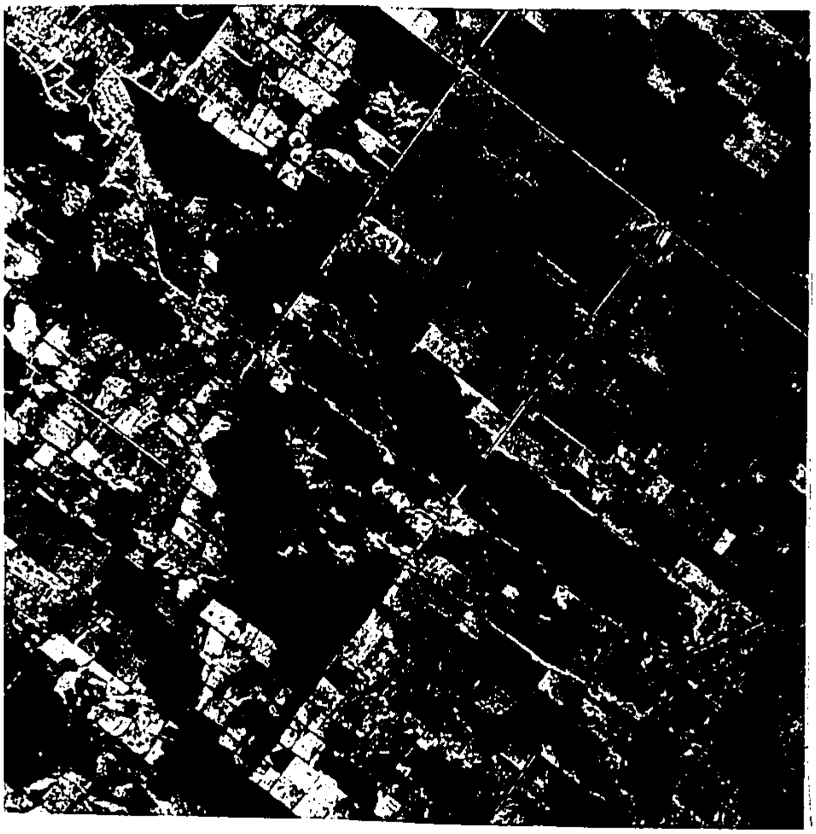

FIGURE 9: Air photograph of area around Mulligan's pit.
(Part of A15596-2).

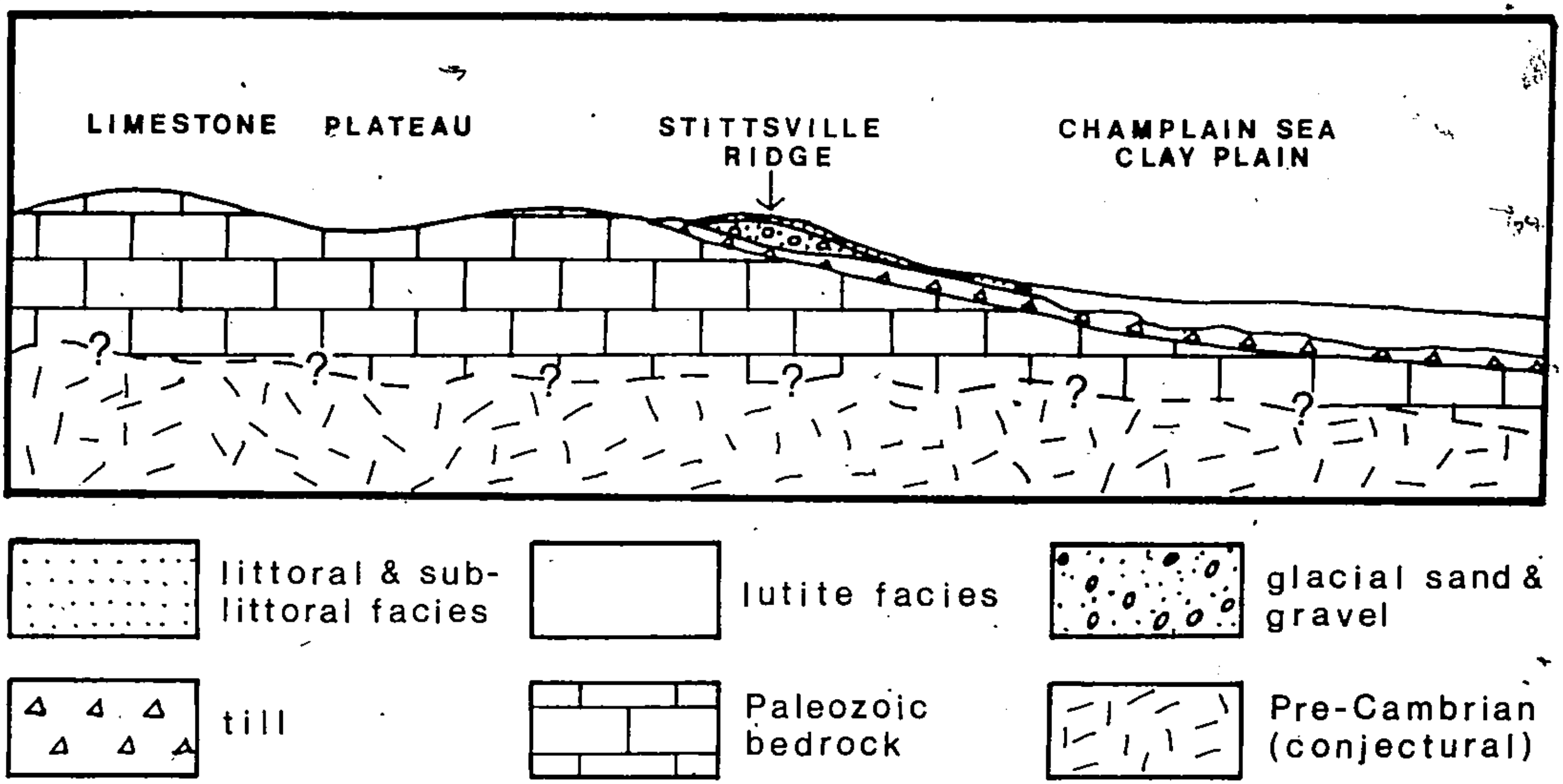

FIGURE 10: Diagrammatic geological section across the Stittsville ridge.
N.B. The details are only broad generalizations and subsurface relations are conjectural.

Cheel (in preparation)). The ridge has undergone degradation in the marine environment, and in places, especially to the northwest of Stittsville, the feature is truncated by a sandy gravel lag yielding a sparse marine fauna.

Flanking the ridge to the northeast is a plain underlain by the bottom facies sediments of the Champlain Sea.

(b) Mulligan's pit (298078) (Figure 11)

This pit is situated about 3.5 km southeast of Stittsville, west of the road from Stittsville to Richmond, i.e. near the southern end of the Stittsville ridge.

(i) description

A broad depression or channel filled with coarse sand and argillaceous material in the form of lenses and drapes is visible in the exposure. A wedge of sandy gravel, reminiscent of the lag deposits forming a cap to the glacial sediments elsewhere on the Stittsville ridge, also forms an important part of the fill. The sandy gravel in part interfingers with the sand-with-drapes, but after metre 18 it appears to overlie an unconformity, which is especially apparent near metre 40.

Also interfingering with the coarse sand and fines of the central part of the section is gravelly granular coarse sand with an apparent depositional slope of about 15 degrees.

All of the sediments in the channel or depression yield marine macrofossils. The sand-with-drapes contains single and paired valves of Hiatella arctica, Macoma balthica and Portlandia arctica. The granular coarse sand yields Hiatella arctica, in a well developed shell bed at the

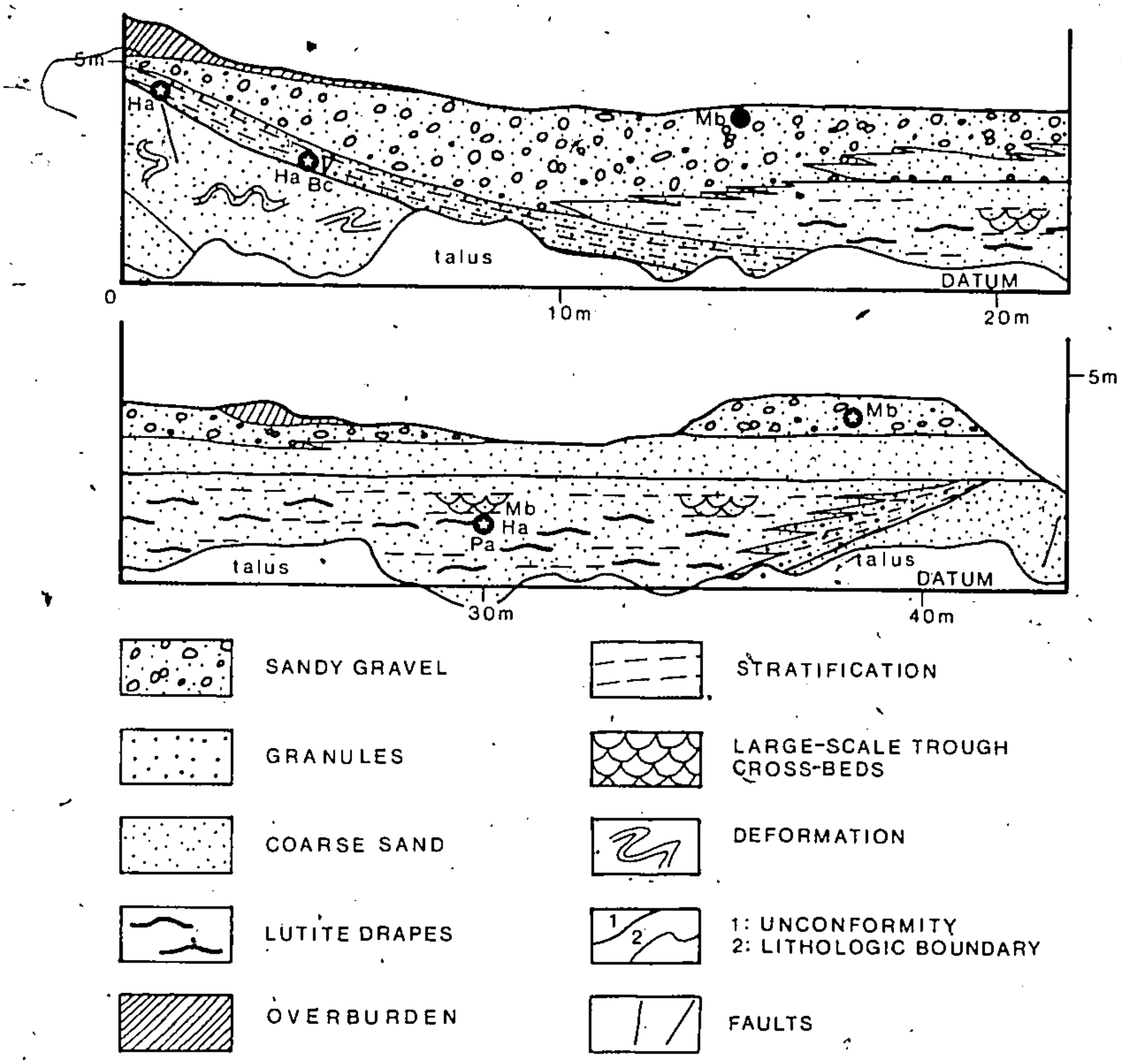

FIGURE 11: Section in Mulligan's pit, June, 1978. Datum: 104 m a.s.l. Orientation of exposure: 315°. Compiled from fieldwork. Fossil information as in Table 2.

base of the unit. The topmost sandy gravel contains <u>Macoma</u> <u>balthica</u> in various states of preservation.

The fossiliferous sediments are underlain by coarse and medium sand exhibiting faulting and deformation which is particularly noticeable beyond the drawn section (Cheel (in preparation)).

-----(ii) interpretation

Despite the channel-like form exposed in the section, there are several reasons for not adopting the explanation that the feature is a channel. Possibly most important is the faulted state of the unfossiliferous sediments, suggesting that melt-out of buried ice occurred some time after the sediments were deposited. Topographic lows and troughs are common on larger eskers, and the feature exposed in the pit may well be one of these.

Furthermore, the depositional slope of the granular coarse sand does not suggest a channel-fill type of deposit, but rather a traction-carpet sediment which has cascaded down the side of the depression. The interfingering of the granular coarse sand with the sediments in the centre of the section is not inconsistent with a channel interpretation, but other evidence is unfavorable to such an explanation.

For example, large-scale trough and planar cross-stratification in the centre of the section indicates paleocurrents approximately parallel to the face, i.e. across the trend of the possible channel. Moreover, the gradual transgression of the sandy gravels from the north-east (left on the section) suggests that the major energy supply for the process came from that quadrant. The interfingering of the granular coarse sand near metre 40 indicates inputs of sediment from the opposite direction, probably at different times to those from the northeast. However, the ultimate extension of the gravel unit across the feature suggests that the gradual infilling of the depression as wave-base approached was accomplished predominantly from a northeasterly direction.

The drape structures resemble lenticular bedding (Reineck and Singh (1973)), but a tidal explanation for these sediments is not favored, for the same reason that the channel notion may be discarded: The accumulation of extensive tidal or channel sediments without a coarsening upward in the sand-with-drapes is inconsistent with the marine regression that was taking place. Instead, the drapes, although preserved beds or laminae of argillaceous material, may be reconciled with a model involving minor mass flows into the hollow transporting debris swept from the sides. Thus, the fines accumulated in quiet water between storm events, which, by means of waves and wind-generated currents, eroded high-standing parts of the Stittsville ridge. Submarine currents eroded parts of the argillaceous beds and created bedforms characteristic of the upper part of the lower flow regime (planar and large-scale trough cross-stratification) in the sand. The presence of some gravel in the drapes may be attributed to ice-rafting.

In summary, a sequence of events for the exposed sediments may be outlined as follows:

(1) deformation of the unfossiliferous sands (which are subaqueous outwash — Cheel (in preparation));

(2) deposition of the sand-with-drapes, granular coarse sand and sandy gravel (all in part contemporaneous),

(3) continued deposition of the sandy gravel, and production of the unconformity, and

(4) reworking of the gravel in a beach environment.

(2) The Twin Elm ridge

(a) Local setting

South and east of the Jock River is a glacial feature which runs in a southeasterly direction towards Kars (Figure 12). The origin of the ridge has not been investigated, but a variant of the subaqueous outwash model is possible. Since the maximum elevation of the ridge is only 110 to 120 m, it probably came under wave attack fairly late in the period of marine submergence.

The ridge has been extensively wave-washed and the original form modified. Figure 12 portrays the inferred surfaces of erosional and depositional modification of the terrain. The highest surface was the earliest to be trimmed by the waves, and is characterized by a lag gravel similar to that at Stittsville. Intermediate wave-washed surfaces in places separate the highest bevel from the flanks of the ridge and from lower surfaces. Beach ridges occur on all of the above surfaces. Lower down the ridge is a depositional terrain unit formed of sand assigned to the Champlain Sea sub-littoral facies by Richard et al. (1977). It passes into the plain which is underlain by the fine-grained bottom facies of the Champlain Sea. The sediments of the ridge appear to have been redeposited primarily towards the west and south.

(b) Trail Road pit, near Twin Elm (394091) (Figures 13-23)

This section documents several exposures from extensive workings along Trail Road in Nepean Township (now City of Nepean), opposite the

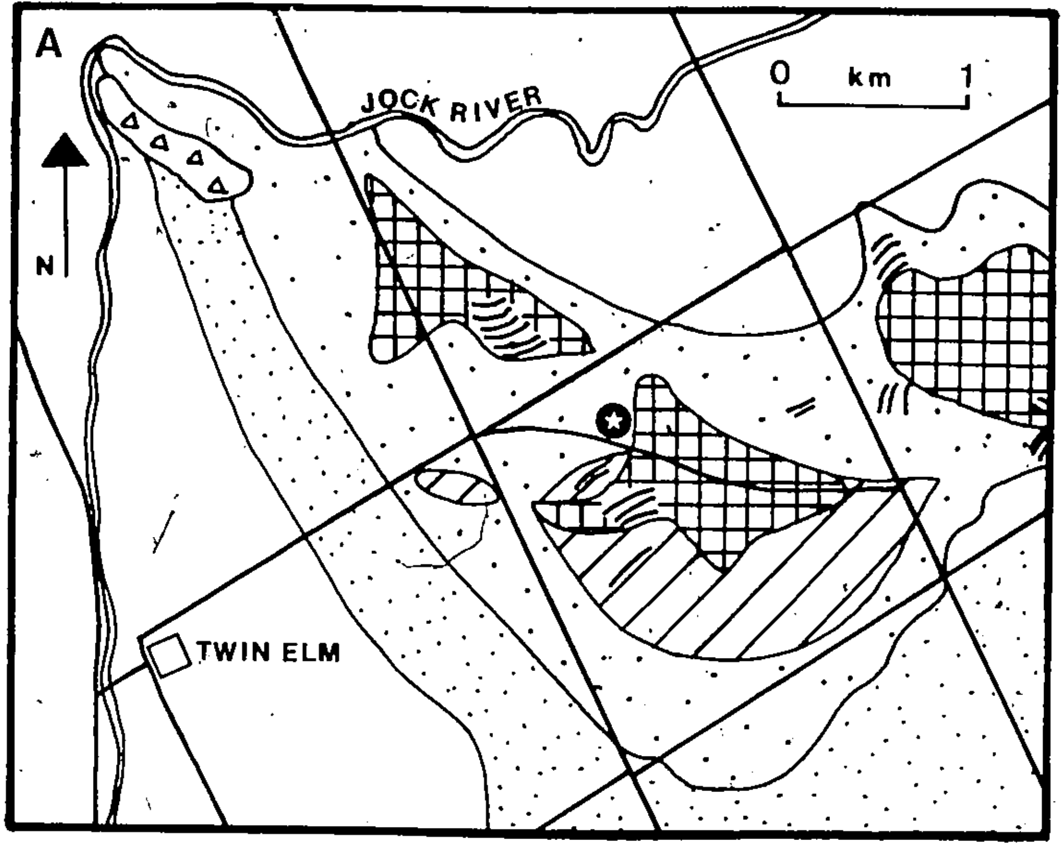

FIGURE 12A: Map of inferred wave-washing surfaces on the Twin Elm ridge. Source: air photographs A15596-3 to 5.

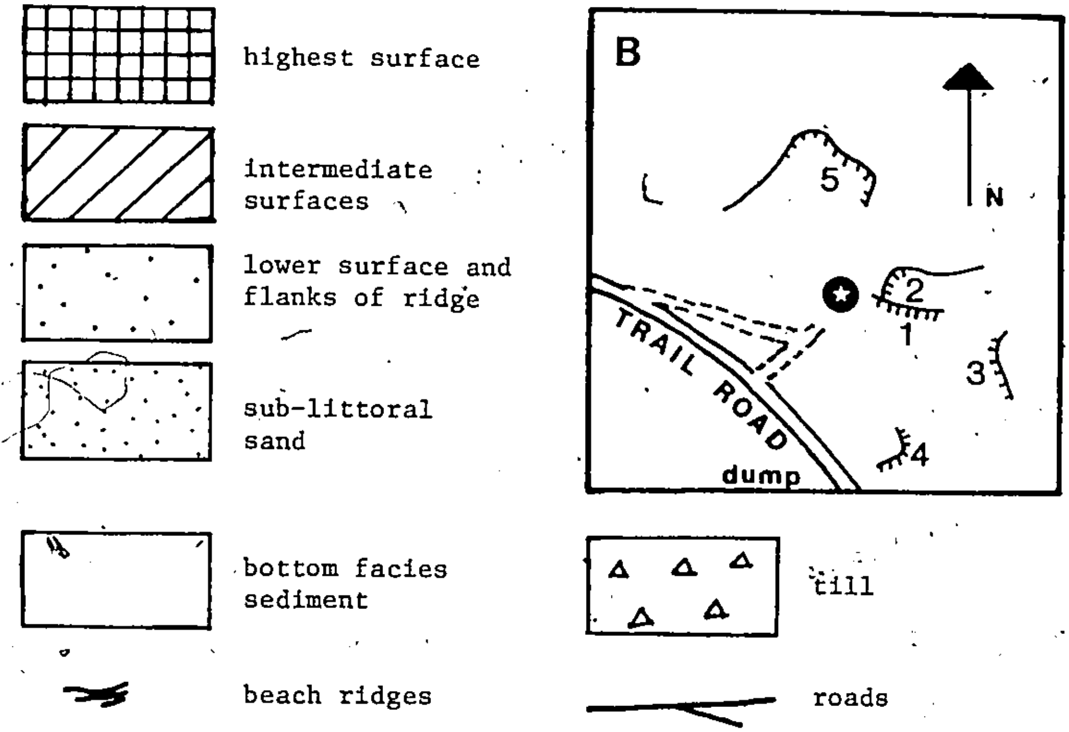

FIGURE 12B: Sketch map of the exposures.

municipal dump. Figure 12B gives the approximate locations of the sections studied in July, 1978. Each exposure will be described and interpreted separately.

Section 1 (Figure 13)

-----(1.i) description

Three major stratigraphic divisions are recognized in this section. The lowest comprises an unfossiliferous, poorly sorted sediment, here termed a diamicton. This deposit contains several large, striated boulders and some poorly defined silt lenses. Toward the base of the exposure are crudely stratified sand and gravel.

This unfossiliferous material is flanked and overlain by a variety of sediments containing a marine fauna, comprising the second major stratigraphic division. Among these materials is a deformed diamicton similar to the unfossiliferous one previously described. This contains shell fragments, but none found were large enough to be identified. Overlying the fossiliferous diamicton is an argillaceous unit, chiefly silt, but with clay at the base, and a number of large stones. The most noteworthy aspect of this unit is that pelecypod and cirriped shells abound in various states of preservation, the species present being Hiatella arctica, Balanus hameri and Balanus crenatus. Although most barnacles are in a fragmented state, a few were found attached to pebbles. Articulated valves of Hiatella are common, but many of the valves are single and convex-upward, especially to the left of the unfossiliferous unit. Between 2 and 13 m is a fossiliferous unit, less than 0.5 m thick, of alternating sand and granules with argillaceous lenses. In one locality unpaired Hiatella valves and separate Balanus sp. plates were

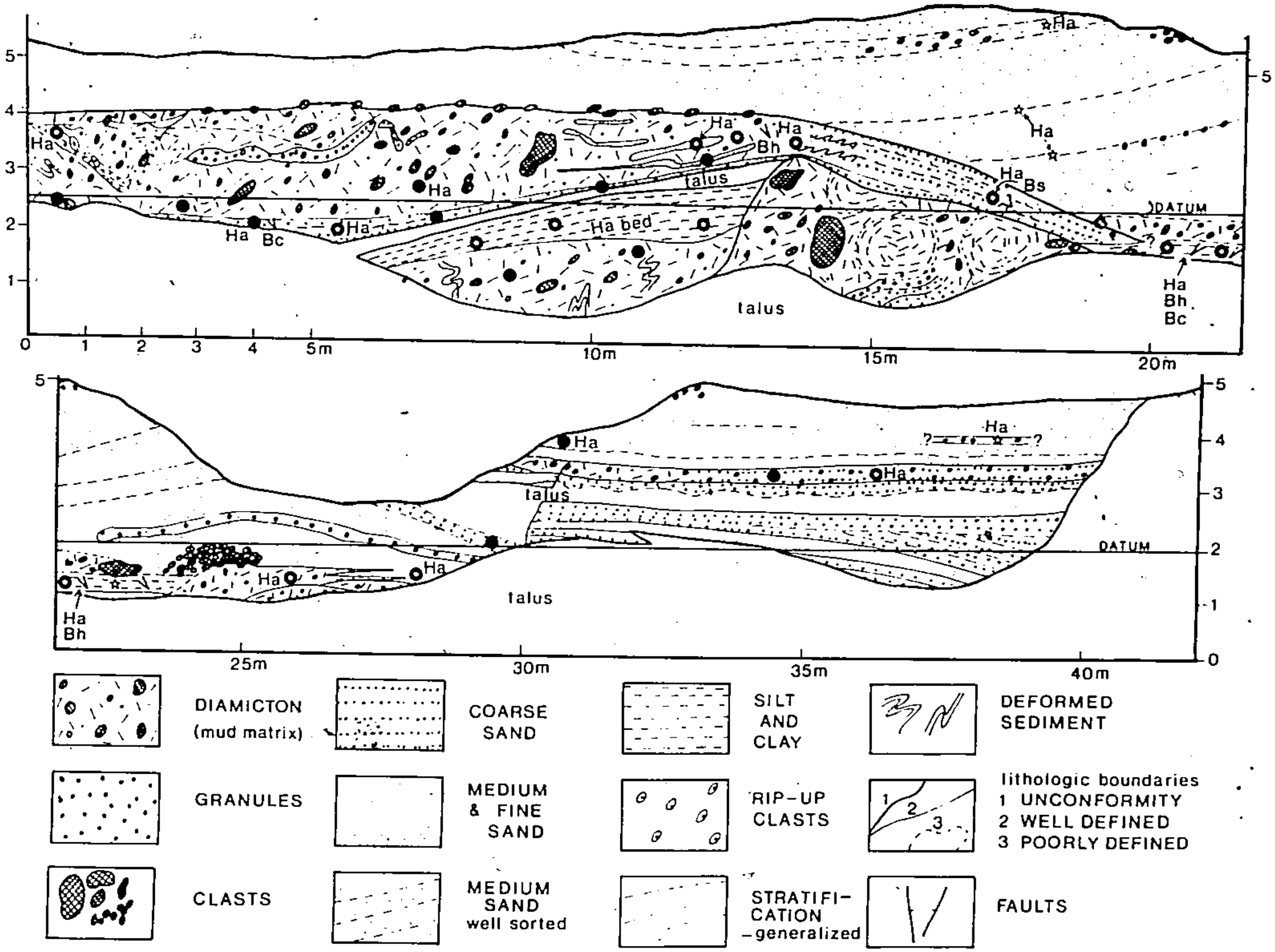

FIGURE 13: Section 1 in Trail Road pit at Twin Elm, July, 1978. Datum: 102 m a.s.l. Orientation of exposure: 200°. Compiled from fieldwork. Fossil information as in Table 2.

found, but within 2 m of this locality the characteristic fauna is articulated valves of Hiatella arctica. Most of the unit, however, is characterized by single, convex-upward valves of Hiatella.

From 19 m to 23 m the fossiliferous silt is overlain by a minor diamicton.

Above the sediments so far described is a diamicton diversified with lenses of sand, and passing, between 13 m and 20 m, into alternating beds of granular coarse sand and medium sand. Shell fragments and a few paired valves are present in the diamicton, and they were identified as being of Hiatella arctica.

The diversity of materials in this fossiliferous diamicton is illustrated in Figure 13. Near metre 1 is a distinct sub-unit of poorly sorted material containing coarse sand with rip-up clasts.

The sand lenses present in the upper fossiliferous diamicton have been deformed, and contain convex-upward valves of Hiatella arctica. This fossil is commonly articulated in the alternating coarse and medium sands, occurring with fragments of Balanus crenatus.

Thus far two of the major divisions have been described: the fossiliferous and unfossiliferous diamictons. The third division is separated from the two earlier ones by an unconformity with a gravel lag. The bulk of this unit comprises clean, well sorted medium sand largely obscured by its own talus. Prominent shell beds enable the stratification to be picked out. These beds contain articulated valves of Hiatella arctica.

Between 30 m and 40 m a greater diversity of sediments is present in the highest stratigraphic division: beneath the medium sands, coarser sediments contain Hiatella arctica in various states of preservation, and the depositional slope decreases upward in the section.

-----(1.ii) interpretation

The unfossiliferous diamicton represents a topographic high in the glacial deposits. The diamictons containing fossils are believed to be marine, but the "glacial" sediments may well have been deposited in a subaqueous environment as well i.e. represent a subaqueous flow till. Although a readvance of the ice would have incorporated marine shells into its sediments, invoking such an event is unnecessary. The presence of stratified materials within the fossiliferous diamictons leads one to consider two interpretations: the sediments may either be a flow till deposited in a submarine environment and colonized by or overriding a fauna which was able to live close to an ice front, or a redeposited sediment, possibly a debris flow. Armstrong and Brown (1954), Easterbrook (1963), Boulton (1968), Evenson et al. (1977) and May (1977) are examples of valuable discussions of similar materials and paleoenvironments.

Other possible interpretations for the fossiliferous diamictons are deposition from icebergs, or from an ice shelf. In the former case there is no call for the fauna to have been able to inhabit waters close to an ice front, but one cannot envision large icebergs because the sea was probably shallow here. Ovenshine (1970) has described ice rafting processes from Glacier Bay, Alaska, noting that three major mechanisms supplied sediment to the bottom:

(1) tilting, fragmentation and overturning of the bergs,

(2) mudflows and slumping, and

(3) meltwater rivulets on the icebergs.

Ovenshine, on the basis of his observations, has suggested that clusters of stones should be one diagnostic characteristic of ice-rafted deposits. In this context it is noteworthy that at metre 25 a group of cobbles was recorded. The possibility that the diamictons are deposits laid down by ice shelves (see, for example, Carey and Ahmad (1960) and Reading and Walker (1966)) should not be discounted entirely, but it is believed that the maximum extent and depth of the Champlain Sea were on too small a scale to support ice shelves.

The interpretation favored for the fossiliferous diamictons is one involving debris flows from the unstable slopes on the glacial terrain (the instability being due to the melt-out of buried ice and the undercompacted nature of the sediment), and a contribution from ice-rafting. If deposition occurred in proximity to the ice front, one could refer to the diamictons as flow tills.

The occurrence of stones in the fossiliferous silt which occurred between the two fossiliferous diamictons is corroborative evidence for ice-rafting. The dropstones provided suitable places for attachment by barnacles. However, barnacles can attach themselves to the discarded plates of their predecessors, as was observed in this case.

Pulsatory current activity is reflected in the arenaceous unit overlying the lower diamicton, periods of slack current being represented by silts which were subsequently partially eroded. This type of alternation may be indicative of storm events and calm periods.

A second phase of diamicton deposition followed those sands, and it appears that the environment was too turbid for the establishment of pelecypod communities, because only derived valves and fragments were found. Phases of quieter conditions saw the deposition of sand on which small communities did develop.

Ice melt was probably the cause of the small, basin-shaped feature at metre 1, sediments having filled a small hollow left by a melted block of ice. The rip-up clasts indicate the tearing up, by strong water movement, of a bed of cohesive, fine-grained sediment.

The period of diamicton deposition was terminated when slopes on the glacial sediments attained stability. By the time that had occurred, wave-base had probably fallen considerably. Tractive currents would have produced the unconformity which separates the earlier marine sediments from the overlying sands. The section from metre 30 to the end exhibits coarse sand with lenses of silt, and this indicates the gradual filling of a hollow by a variable supply of material. In a sub-littoral environment such pulses are likely to be due to an alternation of storm and calm conditions.

The apparent arching of the stratification near metre 25 is due to either the presence of a second rise in the pre-marine topography, or to melt-out of ice on either side of the 'anticline'.

Section 2 (Figure 14)

(2.1) description

This section adjoins the previous one, and offers a different perspective on the stratigraphy.

As with the section already described, the separation of the early fossiliferous from the unfossiliferous sediments ~~is~~ difficult on account of their sedimentologic similarity and poorly defined boundaries.

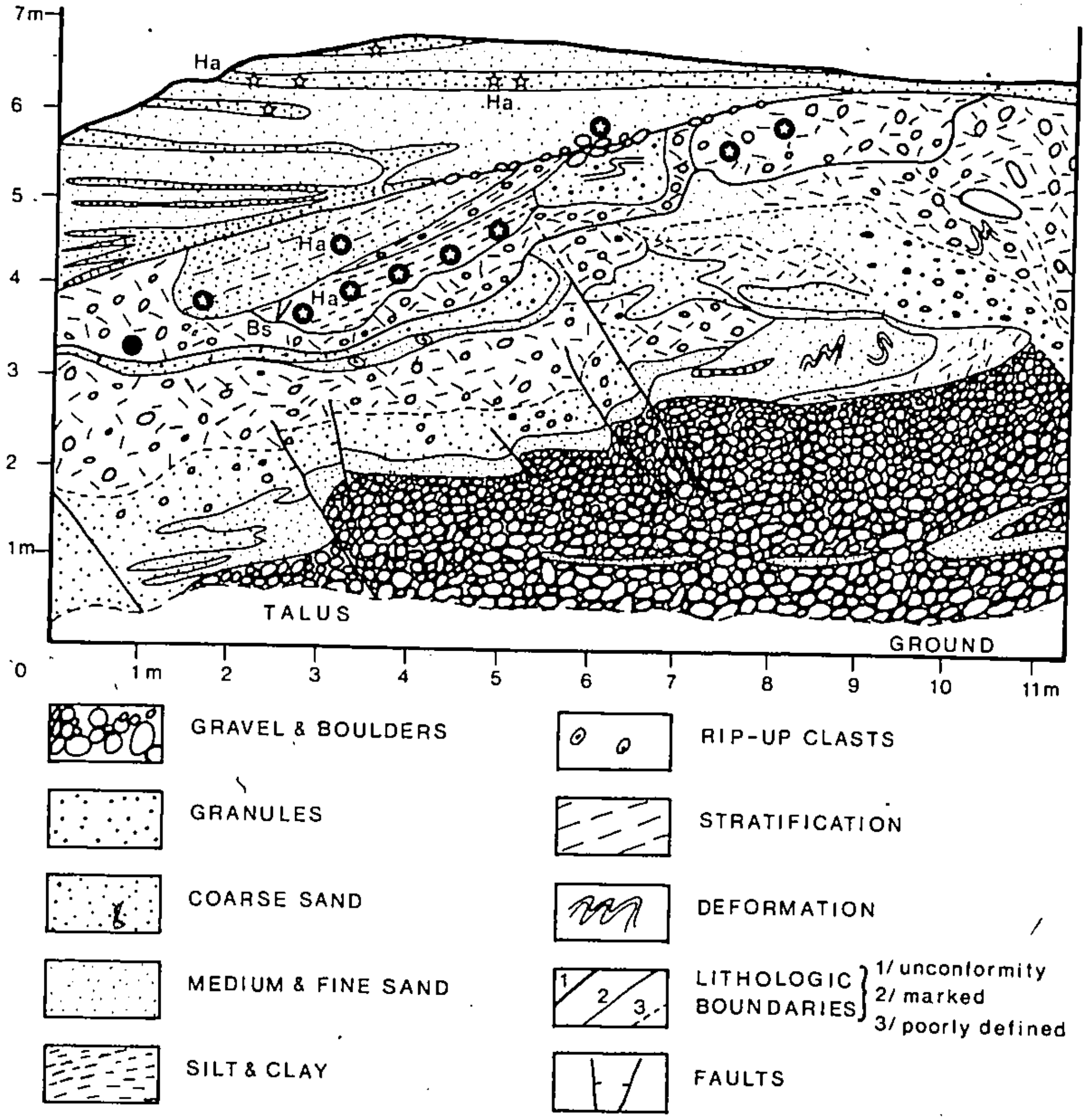

FIGURE 14: Section 2 in Trail Road pit at Twin Elm, July, 1978. Orientation of exposure: 260°. Compiled from fieldwork. Fossil information as in Table 2.

However, the same major stratigraphic divisions could be observed.

The lowest of the three divisions comprises faulted, fining upward, clast-supported gravel, and a deformed sequence of other sediments which had been affected by the same faults as the gravel.

The second division includes a fossiliferous diamicton, much thinner than in section 1, and a silty shell bed overlain by a fossiliferous bed of stratified sand. The last could be related to the unit of alternating coarse and medium sand in the section previously described. Hiatella arctica and Balanus hameri are present in the sand and in the silt.

As in section 1, the earlier fossiliferous deposits are truncated by an erosion surface with a lag. The deposit above, comprising the third major stratigraphic division, is mainly medium sand, with prominent shell beds of Hiatella arctica appearing near the top. It is likely that a higher, gravelly unit had been planed off prior to excavation.

-----(2.ii) interpretation

This section shows the similarity between the unfossiliferous deposits and the early fossiliferous sediments overlying them. That similarity suggests that the first fauna colonized a sea-bottom which had been derived locally, largely by slumping off the ridge. Although the writer does not favor a readvance of the ice, the ice front need not have been far removed from the locality. Proximity of the ice is consistent with the findings of Cronin (1976b) and accords with observations of Lewis et al. (1977, pp. 503-504).

The sediments display a history similar to that exposed in section 1. However, in this section the exposure is closer to the margin of the infilled hollow, therefore the pre-marine deposits are more visible and the marine sequence thinner.

Section 3 (Figure 15)

This section is about 100 m southeast of the two exposures described above.

-----(3.i) description

Two major divisions are visible in this section. The first is unfossiliferous, and characterized by an abundance of argillaceous material. A large, faulted body of silt is overlain by a diamicton. From 0 to 10 metres the latter is overlain by laterally variable, unstratified coarse sand, and deformed coarse sand.

Eroded into the above sediments, and comprising the second major division, is a basin-shaped feature filled with horizontally stratified medium sand. As in sections 1 and 2, a prominent bed of articulated Hiatella valves is present (Figure 16).

Although most of the surface has been stripped, a sandy gravel similar to that occurring at Stittsville overlies the above sediments. Remnants of this highest unit are visible and contain articulated and single valves of Macoma balthica.

-----(3.i) interpretation

The extensive silts may be a distal facies of esker fan or subaqueous outwash, whereas the diamicton is open to a wider range of interpretations. The latter was probably deposited in a submarine environment prior to the establishment of any macrofaunal communities,

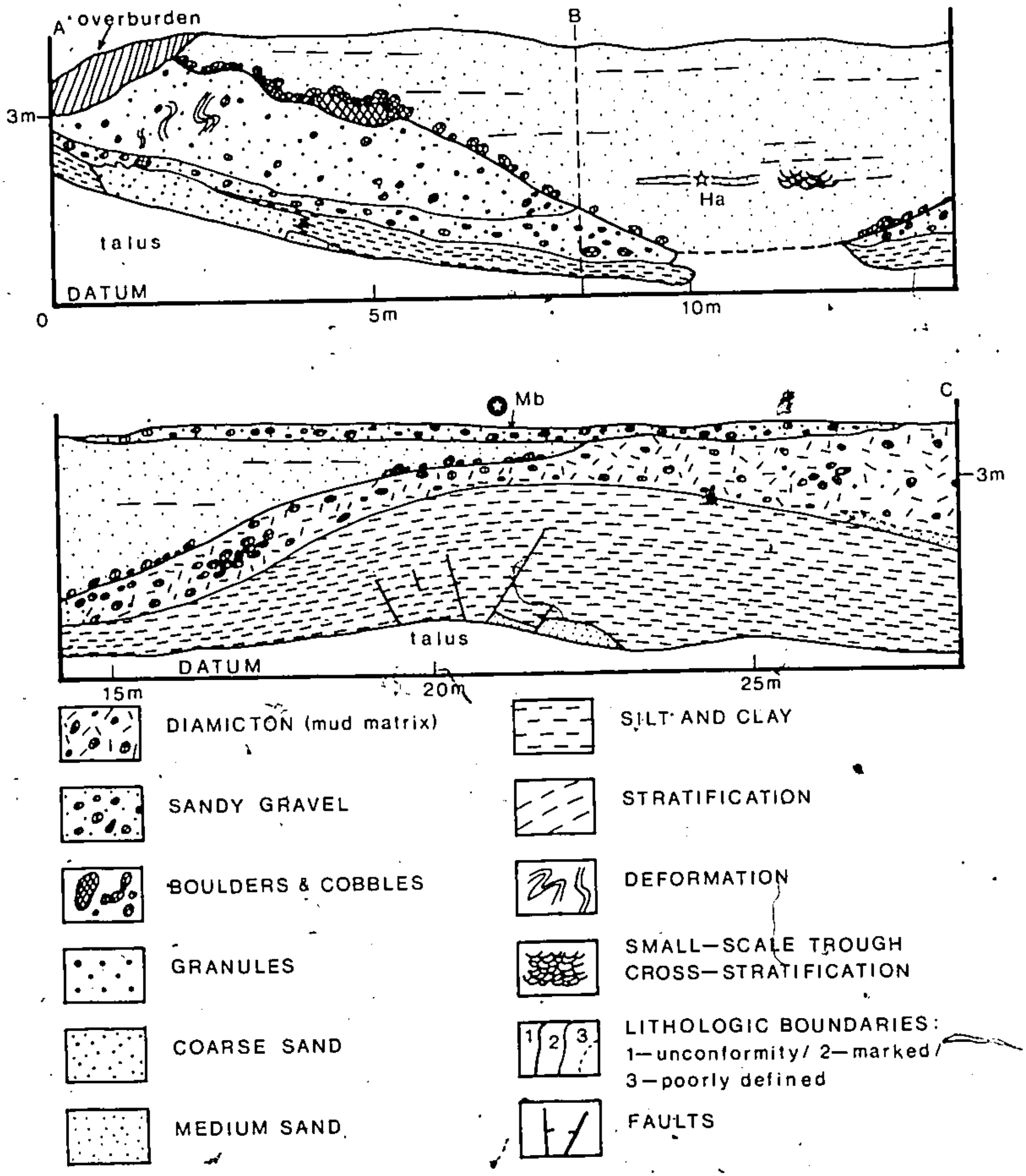

FIGURE 15: Section 3 in Trail Road pit at Twin Elm, July, 1978. Datum: elevation not ascertained. Orientation of exposure: A-B 310°; B-C 255°. Compiled from fieldwork. Fossil information as in Table 2.

FIGURE 16: Articulated valves of Hiatella arctica in medium sand of section 3 at Twin Elm.

by the same mechanisms discussed in section 1. Of these, ice-rafting in association with the slumping of ablation till is thought to be responsible, and may also have formed the coarse sands.

The feature filled with medium sand may represent a channel cut and filled beneath normal wave-base; alternatively, and the exposure was not three-dimensional, it may be simply a long, trough-like hollow.

The highest unit comprises the local equivalent of the Stittsville "lag", and is interpreted as a beach and nearshore deposit. It is separated from the underlying deposits by an unconformity and, in distinction to the medium sands with a biocoenose of Hiatella arctica, yields specimens of Macoma balthica. According to Cronin (1977b), Macoma balthica was the species most able to survive the 'rigorous littoral environment' of the Champlain Sea.

Section 4 (Figure 17)

-----(4.i) description

This section is situated some 150 m south of section 1.

The lowest unit exposed is an unfossiliferous, silty fine sand with deformed stratification and a few small faults. Overlying this is a grey lutite, less than 0.5 m thick, with some fossil fragments, its lower part affected by the faults which cut the earlier unit. The next in sequence is a richly fossiliferous bed of silt, the predominant fossil being Hiatella arctica, mostly in the form of articulated valves. A few fragmented specimens of Balanus crenatus were also found during fieldwork. In the longer part of the section shown, this bed is considerably less fossiliferous.

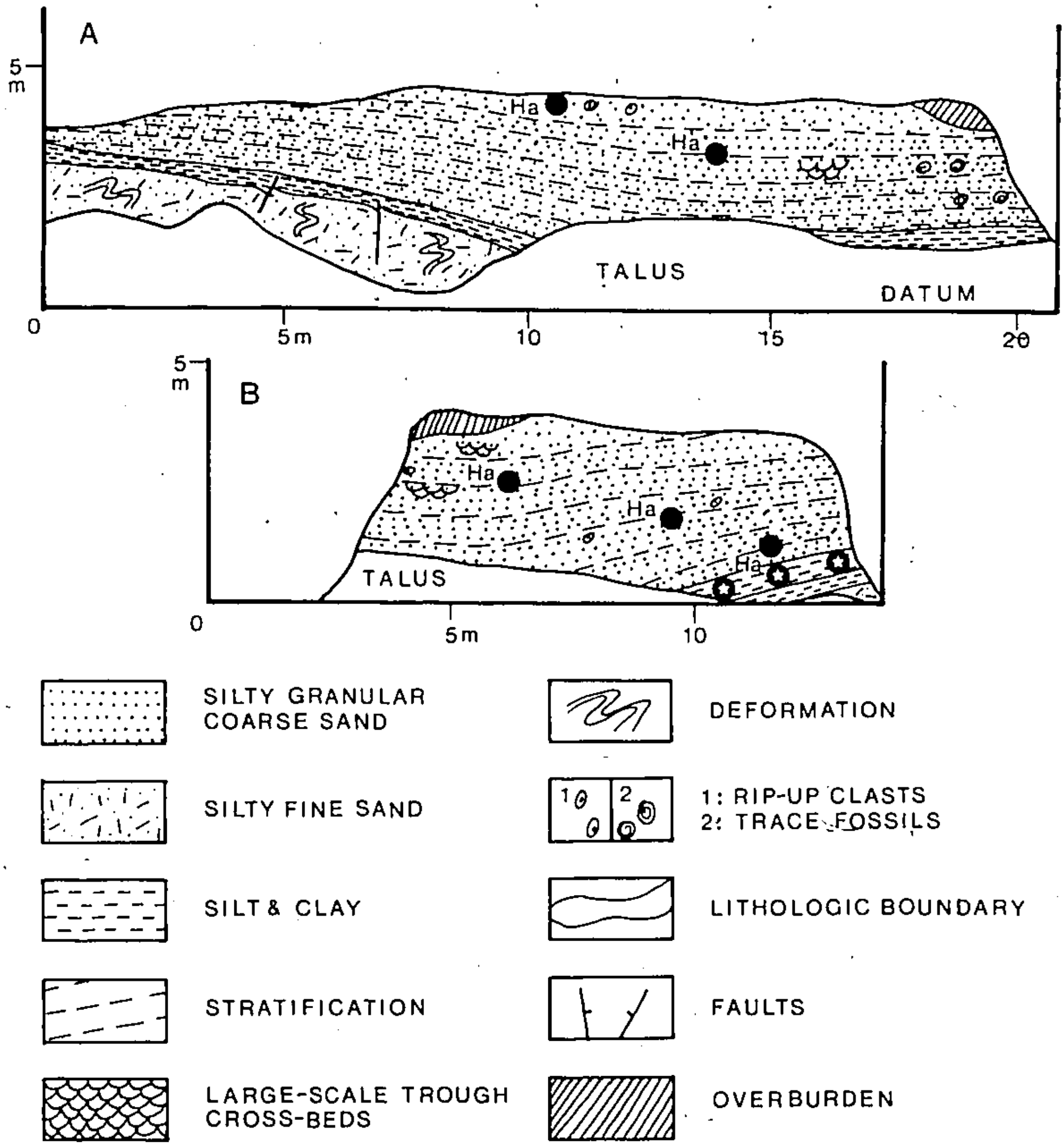

FIGURE 17: Section 4 in Trail Road pit at Twin Elm, July, 1978. Datum: elevation not ascertained. Orientation of exposure: Part A 235°; Part B 145°. Compiled from fieldwork. Fossil information as in Table 2.

The rest of the section comprises 1.75 to 2.50 m of silty granular coarse sand with convex-upward valves of Hiatella arctica, alternating with lenses of medium sand and silt (Figure 18). Trough cross-stratification is present in the medium sand, especially in the shorter segment of the section.

-----(4.ii) interpretation

The nature of the stratification clearly indicates the filling of a depression on the glacial topography. At first, deep-water lutites were deposited, but the greater part of the sediments is of coarser texture.

The Hiatella arctica assemblage in the silt probably represents a pioneer community more or less in life position, whereas the shells in the coarser sediments suggest reworking by currents because of their convex-upward orientation and their occurrence as single valves. The alternation of size grades in the arenaceous sediments may be indicative of an alternation of storm events with periods of more placid water.

The estimation of water depth, even in very general terms, is difficult in the case of this small hollow. The sands are thought to have been deposited below wave-base, but this means that the environment of deposition could have been anywhere from the sub-littoral to the deep-water zone.

Good evidence is present, however, for current activity, in the form of trough cross-stratification, oriented shells and rip-up clasts.

Section 5 (Figures 19, 20)

All of the sections 1 to 4 show the contact between the marine and pre-marine deposits. Section 5, situated approximately 100 m

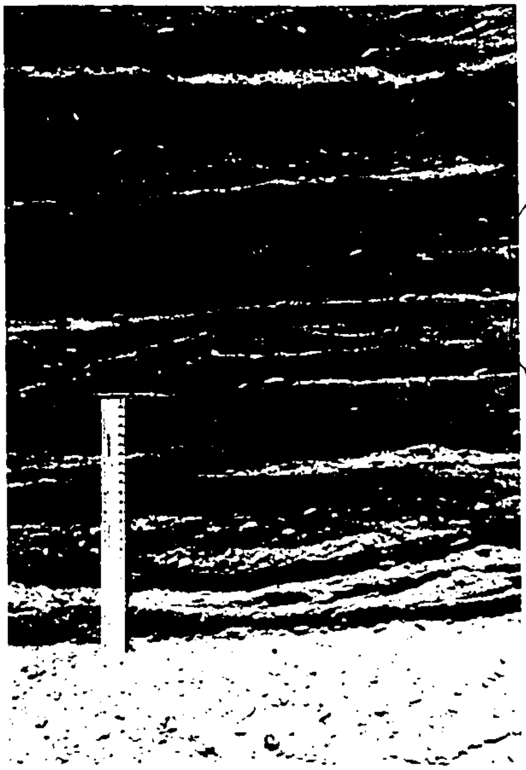

FIGURE 18: Silty granular coarse sand alternating with medium sand in section 4 at Twin Elm.

Note the convex-upward valves of Hiatella arctica in the medium sand.

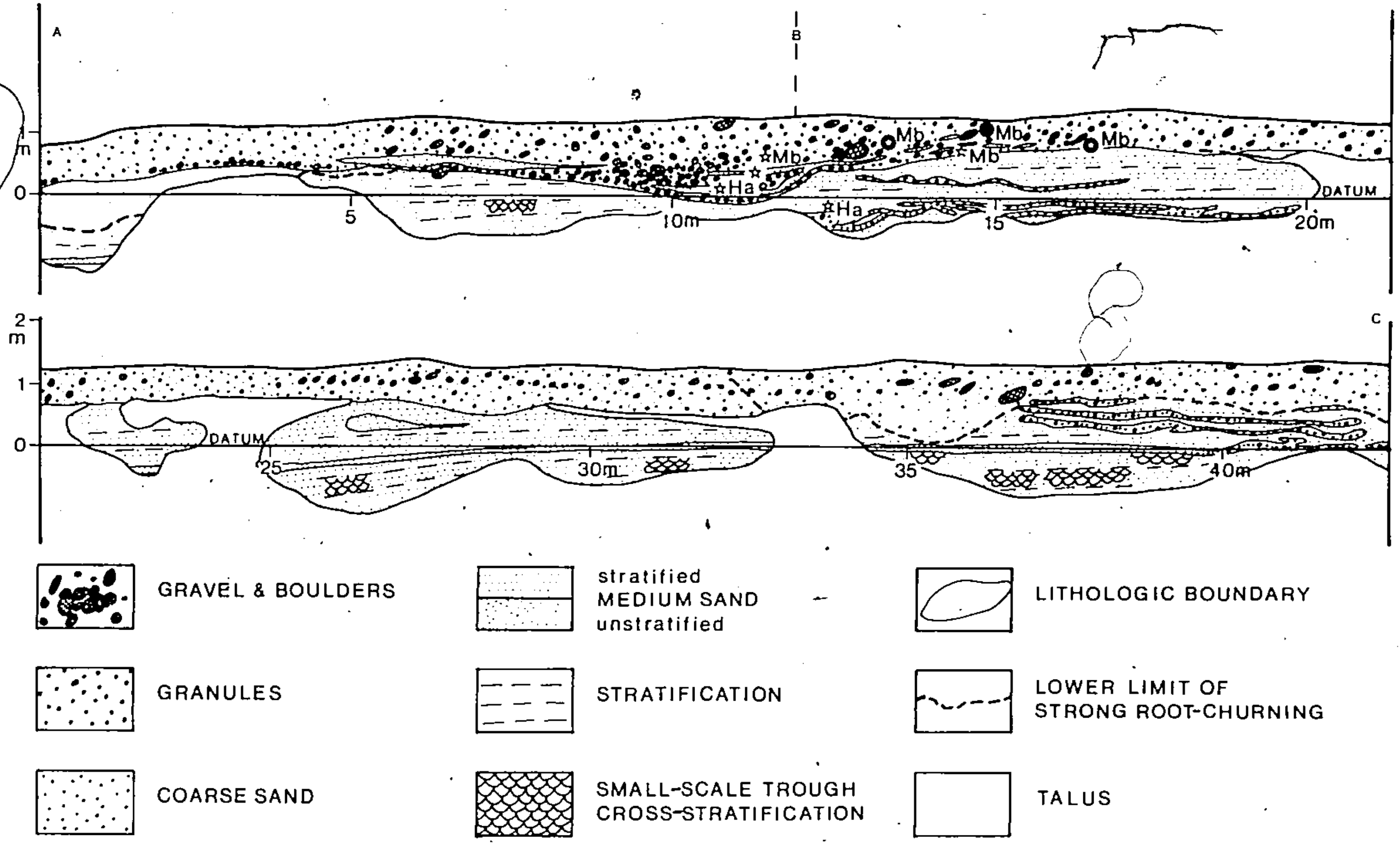

FIGURE 19: Section 5 in Trail Road pit at Twin Elm, July, 1978. Datum: 102.5 m a.s.l. Orientation of exposure: A-B 125°; B-C 235°. Compiled from fieldwork. Fossil information as in Table 2.

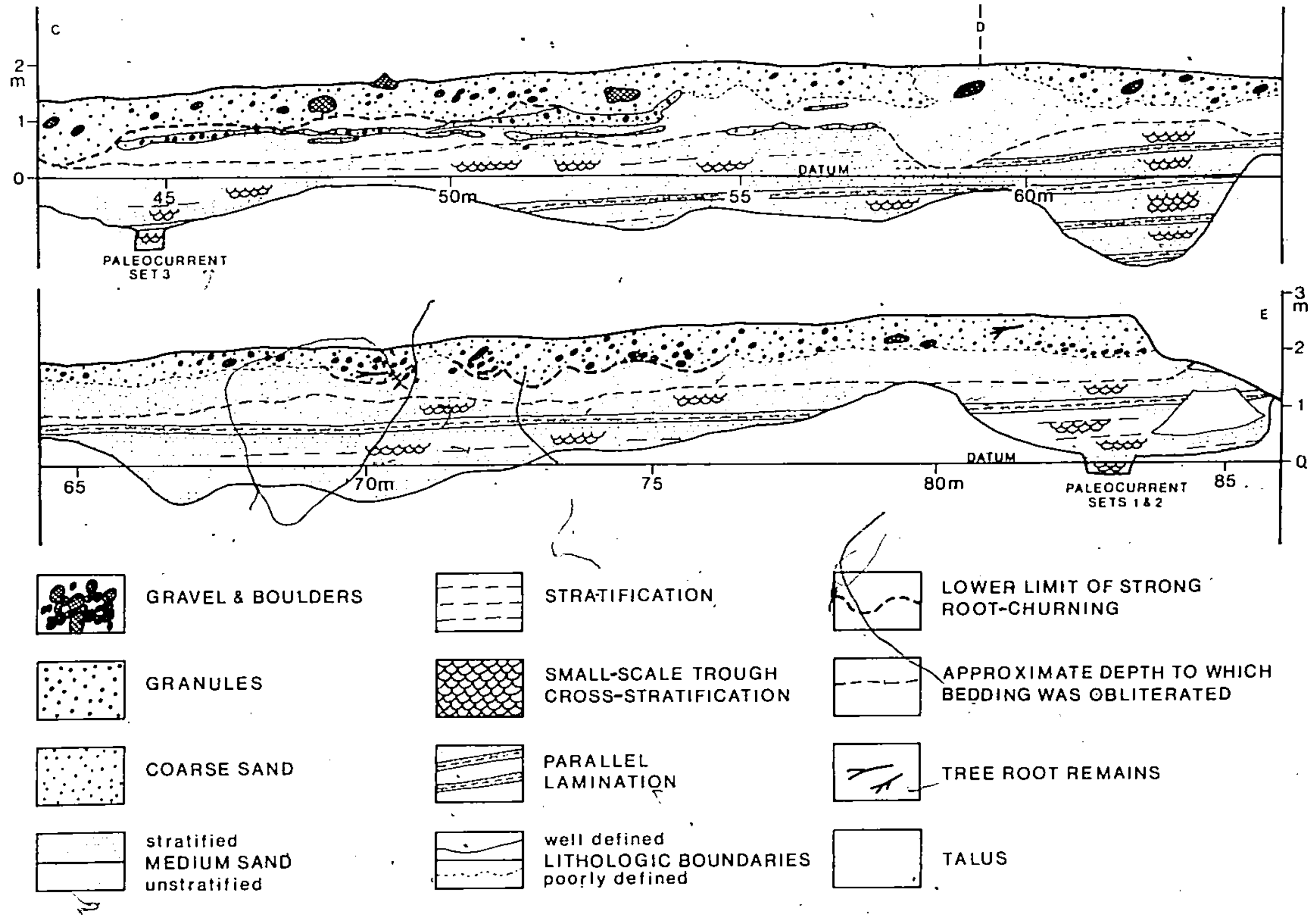

FIGURE 20: Section 5 in Trail Road pit at Twin Elm, July, 1978 (continued). Datum: 102.5 m a.s.l. Orientation of exposure: C-D 220°; D-E 310°. Compiled from fieldwork. Fossil information as in Table 2.

northwest of section 1, does not, but it displays a different type of marine deposit to those previously described.

-----(5.i) description

The section as drawn shows less exposure than was visible in May, 1978, when beds with a higher silt content and containing a few valves of Hiatella arctica were visible near metre 55. In November, 1978, a bed yielding paired valves of Hiatella arctica was observed low in the section near metre 40. These occurrences confirm that the entire sequence in the section is marine.

Despite its length, the section displays simple stratigraphy and sediments. The bulk of it comprises extensive fine to medium sands with small-scale trough cross-stratification. Between metres 10 and 15 these sediments contain a life assemblage of Hiatella arctica (Figure 21B).

Four sets of paleocurrent measurements were taken from the sands. Sets 1 and 2 were from the same location (near metre 83), but set 1 is stratigraphically above set 2. The two diagrams (Figure 22), constructed from measurements of small-scale trough cross-stratification, show a definite mode toward the northwest.

A third set of paleocurrent measurements (Figure 23) was taken near metre 45. These data give a very strong mode toward the northwest.

Set 4 (Figure 23) was obtained outside the drawn section and the vector displays a more northerly trend. Only twenty-five measurements were taken, because of the difficulty of finding suitable examples.

Overlying the cross-stratified sand are coarser sediments which contain a variable proportion of gravel. This unit has been extensively

FIGURE 21A: Life assemblage of Macoma balthica in section 5 at Twin Elm.

FIGURE 21B: Life assemblage of Hiatella arctica in section 5 at Twin Elm.

A is stratigraphically above B. Note the contrasting sediments of the two assemblages: gravelly sand for Macoma, cross-bedded fine sand for Hiatella.

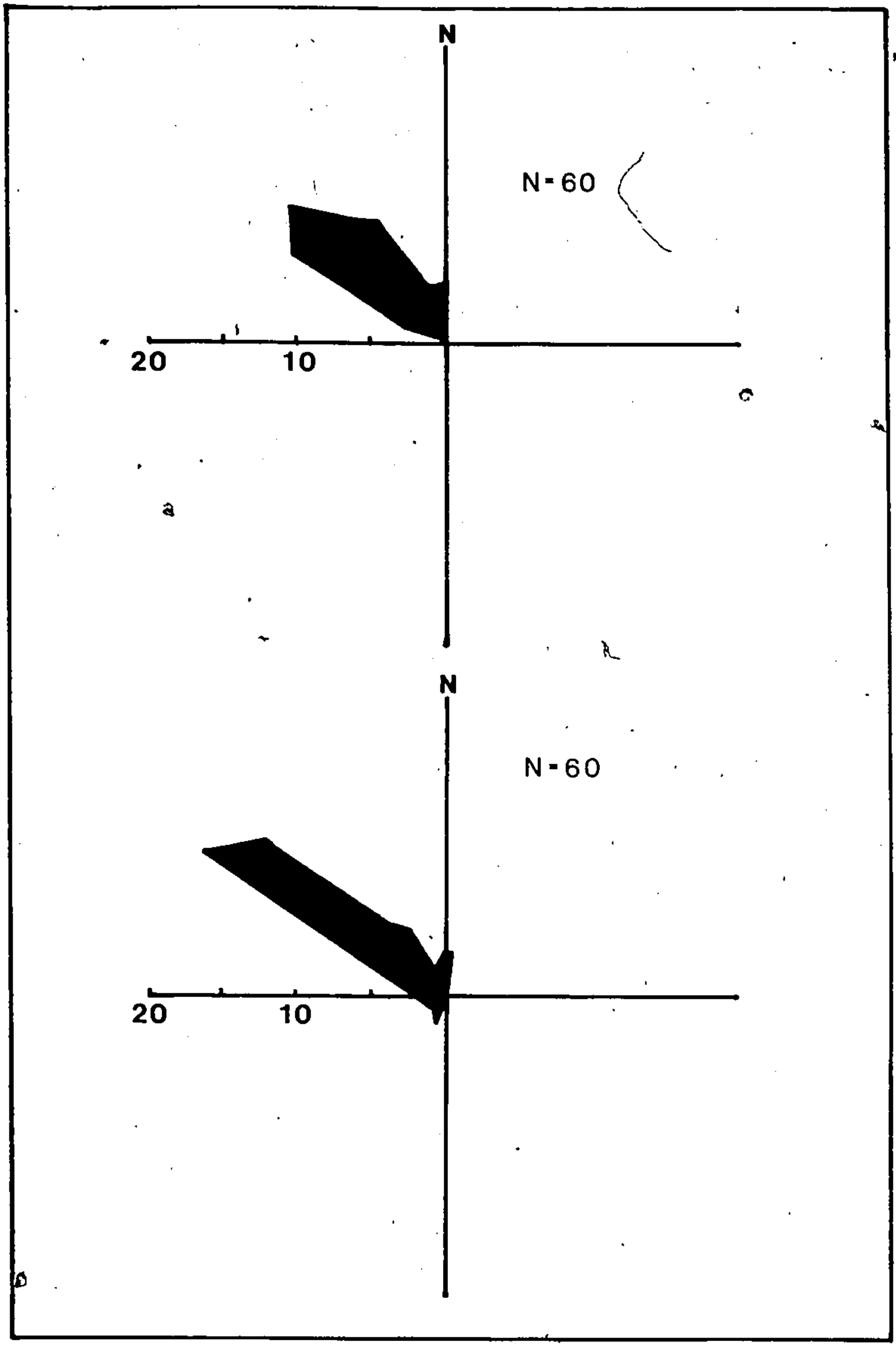

FIGURE 22: Polar coordinate plots of paleocurrent data from Twin Elm - sets 1 and 2.

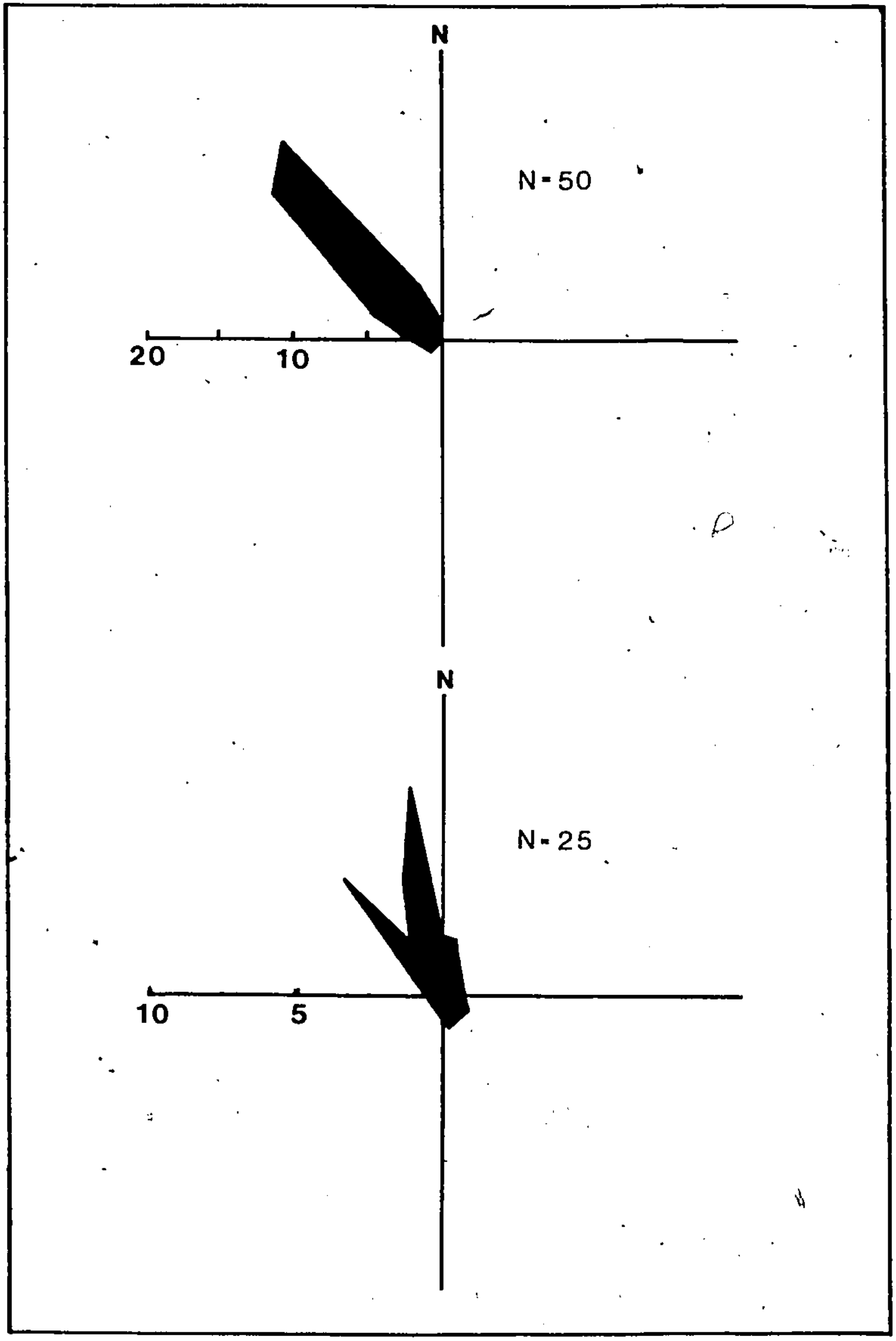

FIGURE 23: Polar coordinate plots of paleocurrent data from Twin Elm - sets 3 and 4.

disturbed by tree roots, as have the sands in part. The importance of that process is discussed in the Appendix.

The gravelly sand unit is not abundantly fossiliferous, but at metre 11, where the unit is more distinctly gravelly, paired valves of Macoma balthica were found in life position (Figure 21A).

-----(5.ii) interpretation

It is noteworthy that the marine sediments form a minor ridge at this point. The section from metre 5 to metre 60 is a dip section through the ridge, whereas from metre 60 to the end it is a strike section.

The paleocurrent measurements indicate a northwestward direction which is parallel to the long axis of the glacial ridge. Longshore currents are therefore suggested, and the sands which are extensively exposed in this section are thought to be part of the sub-littoral facies of the Champlain Sea.

Owing to the disturbance of the topmost unit, no interpretation is offered beyond that it probably represents a littoral deposit, as suggested by its coarser texture and the presence of Macoma balthica, which characterizes the gravelly littoral sediments elsewhere.

The important lateral relationship between the sediments in sections 1 and 5 could not be examined, but it is thought that the sediments in section 5 are stratigraphically above, although topographically below, those in section 1-----as would be expected in an offlap sequence.

(3) Summary

The exposures at Twin Elm and Stittsville furnished examples of important marine deposits. Several cases were observed of marine sediments filling depressions on the pre-marine deposits, and this type of sedimentation appears to have been of considerable local significance. Longshore transport of sand was in evidence in one exposure at Twin Elm.

CHAPTER 3

MARINE SEDIMENTATION ON THE RIDGE AT SOUTH GLOUCESTER

> The sand here looks like metal, it feels
> there like fur...
>
> (Louis MacNeice: 'Littoral')

This chapter discusses the stratigraphy exposed in two pits along the glacial ridge at South Gloucester, about 15 km south-southeast of Ottawa.

(1) The South Gloucester ridge

(a) Local setting

Figure 24 shows the surficial deposits and landforms in the area surrounding the two pits which are discussed, and Figure 25 is a geologic sketch cross-section northeast-southwest across the same area.

The South Gloucester ridge (referred to by other writers as the Bowesville moraine), rests on the dolomite escarpment which rises to about 130 m above sea-level. The ridge trends northwest-southeast and has been extensively quarried. No systematic study of the whole ridge has been undertaken. However, Rust (1977) has described large channels filled with massive sand from exposures neighboring those to be described, and has assigned the deposits to the subaqueous outwash facies.

The effects of the Champlain Sea in the area are numerous. For example, beach ridges (Figure 5) composed of little-worn fragments of the local bedrock, can be identified. Beach ridges also occur on the South Gloucester ridge itself. They appear to fall into two categories:

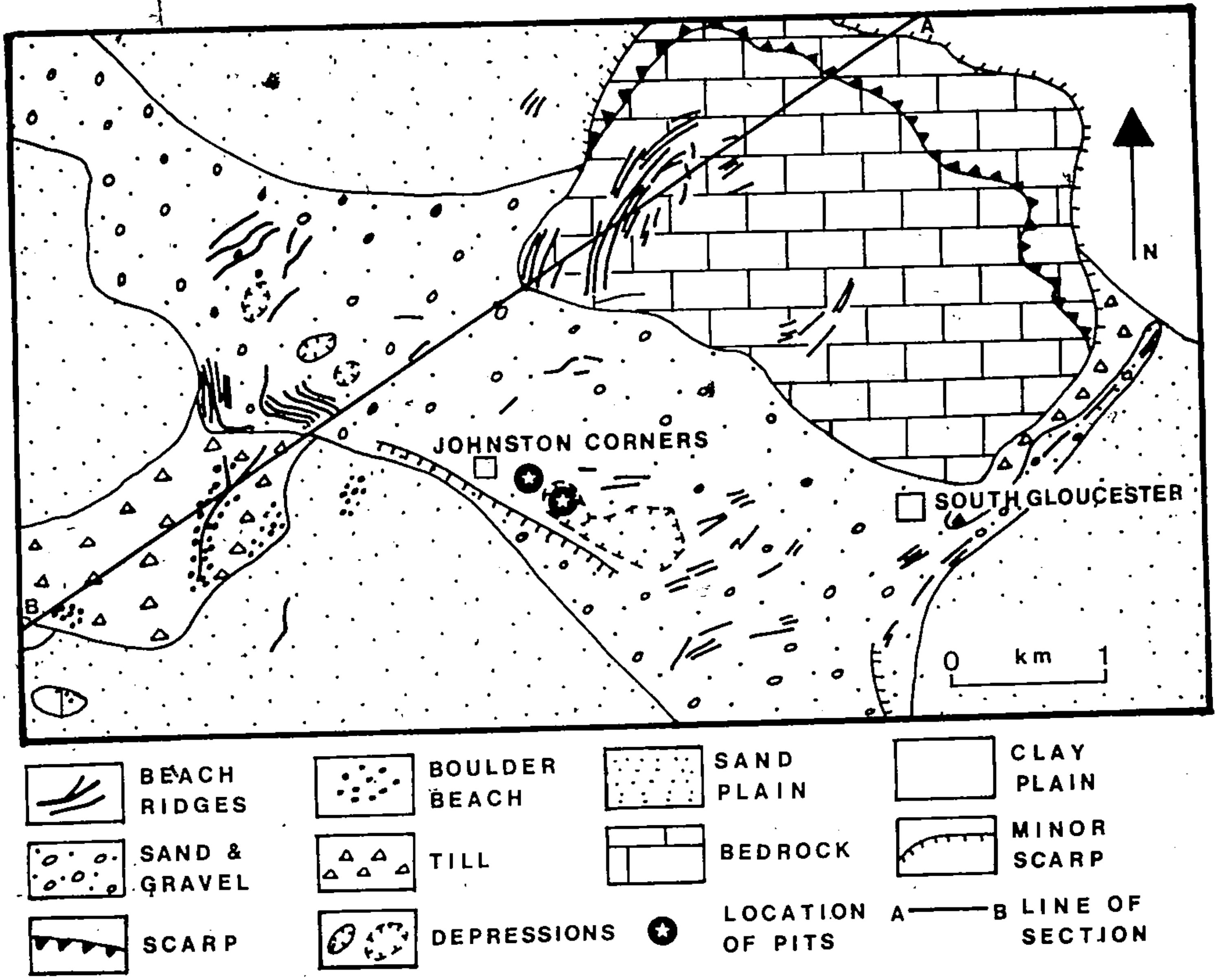

FIGURE 24: Map showing surficial deposits and land forms of the South Gloucester - Johnston Corners area.
Source: air photographs A15596 - 13 to 15.

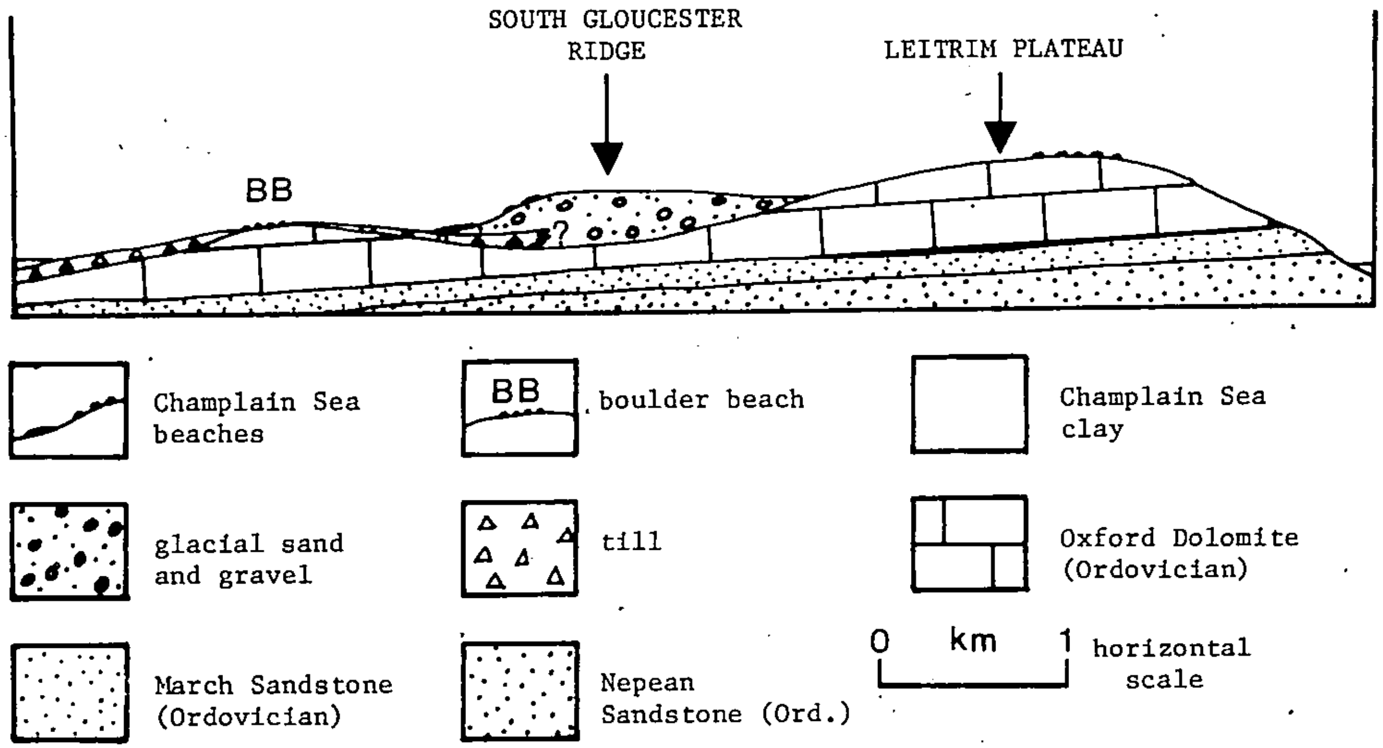

FIGURE 25: Geological sketch-section across Figure 24. (After Coleman and Henoch (1966)).

(a) possible former migratory bars on the planed summit of the ridge, and (b) staircases of ridges on the steep southwest-facing slope of the ridge, descending to an important beach (now largely obliterated by excavations) where the ridge meets the plain on deeper water sediments, at about 106 m above sea-level.

The surface of the spread of till has been wave-washed in the southwestern part of the area, and a fossil boulder beach is present as evidence for the process.

The higher ground is bounded by a plain, underlain by sand where the South Gloucester ridge probably supplied copious sediment to the Champlain Sea, and by lutite where the plain abuts onto the Ordovician escarpment.

(b) Dibblee's pits, near Johnston Corners

Two major sections are described from adjoining pits owned by Dibblee and Company in Gloucester Township. The first pit is reached by means of the main gate, 0.5 km northeast of Johnston Corners, on Rideau Road, or by a track branching off Albion Road, 0.4 km southeast of Johnston Corners. The second section can be reached via the first, or by means of an ungated track 0.8 km southeast of the crossroads.

Section 1 (Figure 26)

-----(1.i) description

Three major stratigraphic divisions can be recognized in this section—on the basis of texture, stratification and fauna. The lowest comprises faulted and deformed unfossiliferous sediments of variable texture. From 1 m to 10 m steeply dipping arenaceous materials are

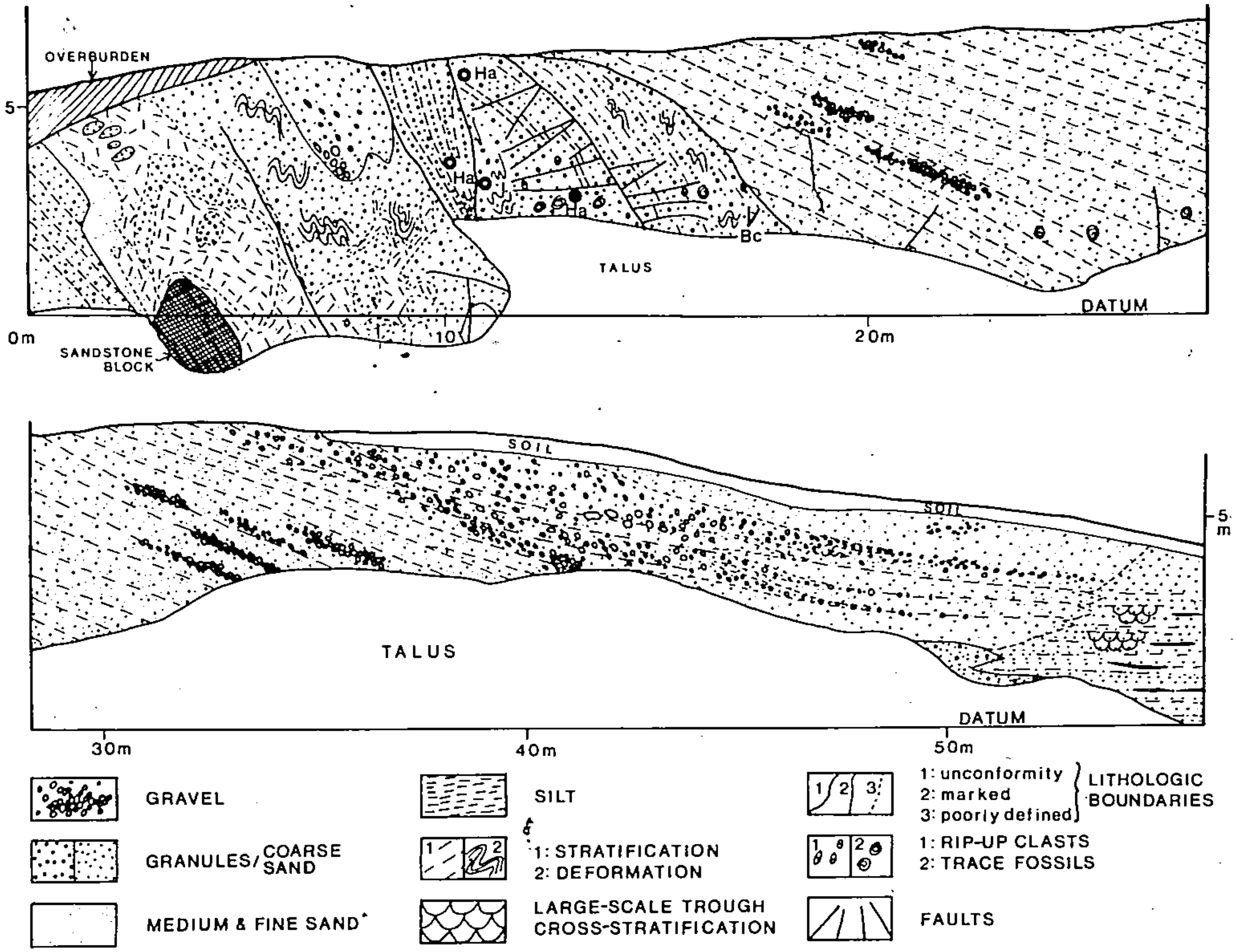

FIGURE 26: Section 1 at South Gloucester, August, 1978. Datum: 111.5 m a.s.l. Orientation of exposure: 327°. Compiled from fieldwork. Fossil information as in Table 2.

overlain my much-deformed silt, silty fine sand and granular coarse sand. Included within these sediments is a large sandstone block.

The sediments in the second stratigraphic division are fossiliferous. Articulated valves of Hiatella arctica are present in the lowest unit, a granular coarse sand with an apparent dip of about 65 degrees. Next in sequence is a bed of normally graded medium and coarse sand which also possesses a steep apparent dip. The graded sands are deformed, and cut by a number of low-angle faults with dips of between 24 and 42 degrees. Hiatella arctica valves, many of which are articulated, are present at the base of this bed, and single valves occur throughout the unit.

A less deformed unit of similar materials overlies these sediments, but is cut by a different set of faults. Some fragments of Balanus crenatus were collected, and mud balls and bioturbation structures are present.

The third major stratigraphic division is markedly less faulted, undeformed, and possesses stratification with an apparent dip of 23 degrees and a true dip of 27 degrees. This dip becomes gentler after metre 30 and eventually becomes horizontal. The sediments are medium to coarse sand, stratified on a scale of 30 to 100 mm, with a variable proportion of gravel. Primary structures are few where the depositional slope is steep. However, after metre 50, where coarse sand with interbedded medium sand and lenses of lutite occur, large-scale trough cross-stratification is present.

Throughout the third stratigraphic division only occasional shell fragments were found, but structures suggestive of trace fossils are discussed below.

-----(1.ii) interpretation

The three stratigraphic divisions are assigned to the following facies: subaqueous outwash, "early marine", and "later marine".

Characteristic of the pre-marine deposits at South Gloucester are large channels filled with massive sand, and occasionally dish structures. The unfossiliferous sediments exposed in this section, which are faulted and deformed, probably belong to the same subaqueous outwash facies.

The dip of the early marine sediments is too steep to be a depositional slope. Moreover, the low angle of the faults (and, indeed, the chaotic nature of the outwash sediments) suggest glaciotectonic influence. However, an explanation with simpler paleogeographic implications than a readvance of the ice is one which attributes the over-steepening to collapse due to the melt-out of buried ice.

Deposition of the early marine sediments probably resulted from the wave-washing which attacked the higher parts of the South Gloucester ridge at that time. A build-up of wave-washed sediment on the sub-marine slope of the ridge may have occurred from time to time, leading to the periodic generation of small-scale turbidity currents which resulted in the normal grading noted in the sands.

The glaciomarine and early marine sediments themselves probably provided a steep slope against which later marine deposits were built out as quasi-foreset beds. In essence, this represents a variant of the hollow-fill type of sedimentation noted at Stittsville and Twin Elm.

A second reason for not favoring an ice readvance is the occurrence of structures interpreted as trace fossils in the prograded sands. These structures, more numerous in the "early marine" deposits, are identified as the trace fossil, Ophiomorpha. Figure 27 illustrates a number of these fossils. It is noteworthy that the characteristic environment of Ophiomorpha, the burrow cast of a brine shrimp, is, according to Frey (1975), 'shallow sub-tidal below daily wave-base, but not below the base of storm waves'. According to Frey, this trace fossil may also extend out to quieter waters offshore, and is characteristic of relatively low to moderate energy environments. That description accords well with the conditions envisaged for the deposition of the marine sediments exposed in this section.

Toward the distal end of the prograded sands the depositional slope declines, and the large-scale trough cross-stratification signifies flows in the upper part of the lower flow regime in deeper water. The increasing stoniness in the same direction probably reflects the lowering wave-base and an influx of coarser sediment. Some of the gravel in the proximal part of the prograded sands may be ice-rafted in origin.

Section 2 (Figure 28)

-----(2.i) description

The same three stratigraphic divisions that occur in the neighboring exposure are present in this section. First, unfossiliferous, deformed sediments appear on both flanks. Second, overlying the silty, unfossiliferous sediments is steeply dipping silty granular coarse sand with single and articulated valves of Hiatella arctica, and broken and occasionally intact specimens of Balanus crenatus. The disposition of the beds is unusual in that they dip steeply in opposite directions. Numerous

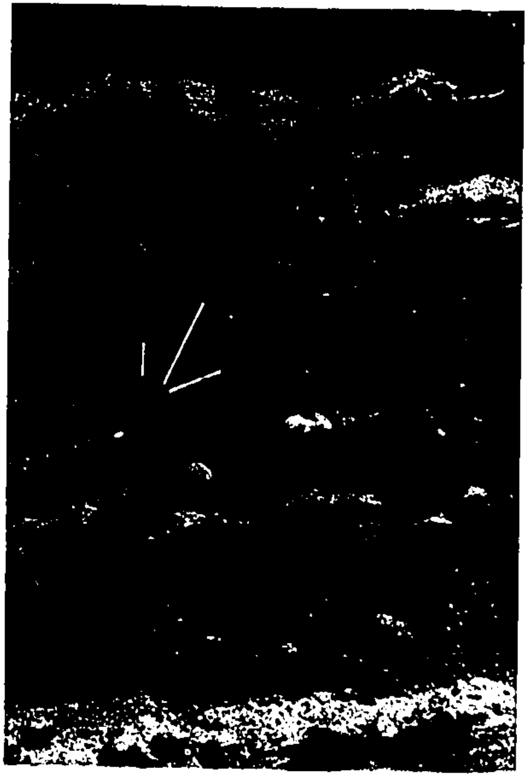

FIGURE 27: *Ophiomorpha* (near lens cap) and rip-up clast (lower, centre) exposed in section 2 at South Gloucester.

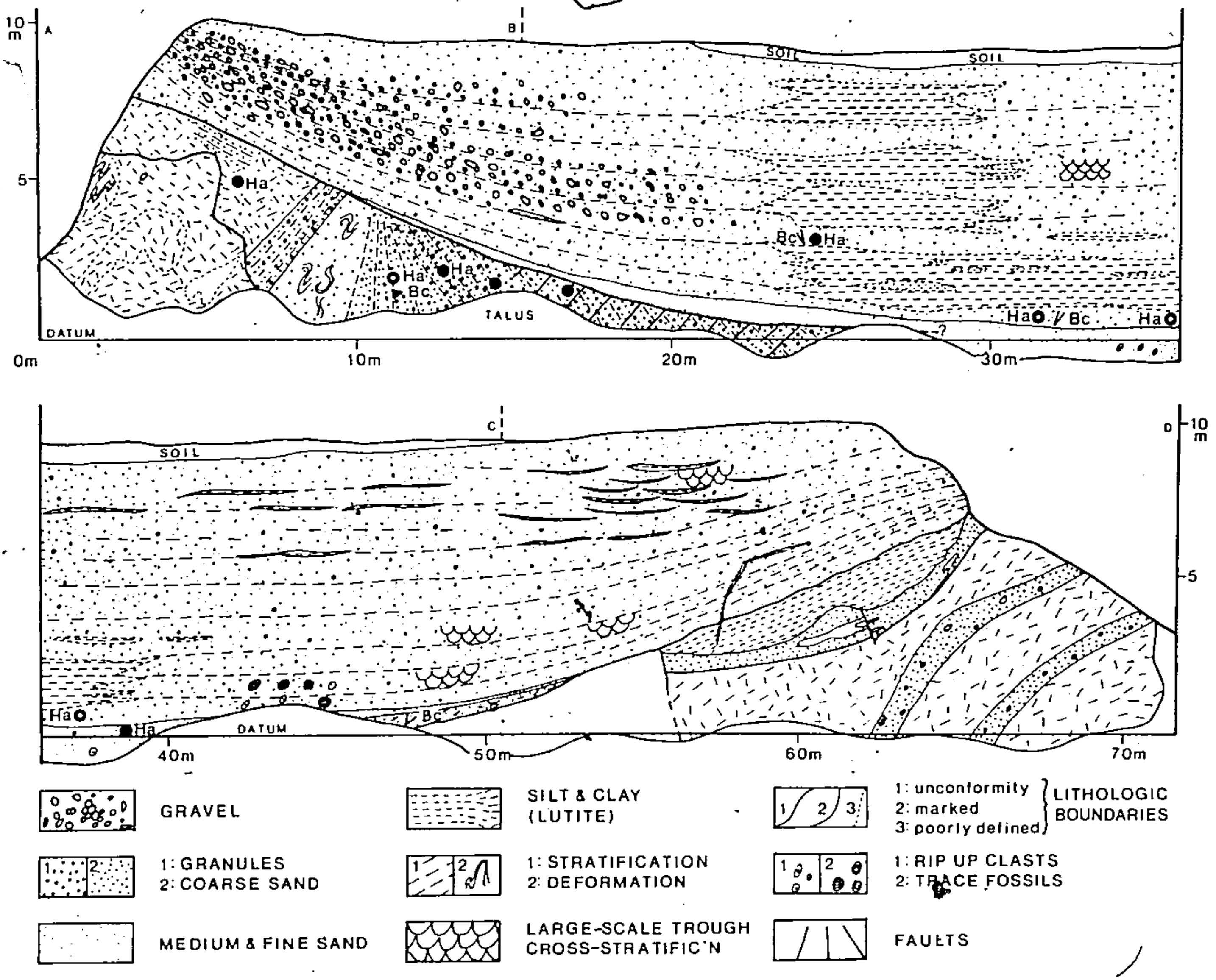

FIGURE 28: Section 2 at South Gloucester, July, 1978. Datum: 109 m a.s.l. Orientation of exposure: A-B 257°; B-C 314°; C-D 340°. Compiled from fieldwork and photographs. Fossil information as in Table 2.

small faults are also present. From 57 m to 65 m deformed sand is overlain by deformed silt and clay.

The third stratigraphic division is separated from the two lower ones by a marked unconformity. The first unit in this sequence of younger fossiliferous sediments is a thin bed of well-sorted medium sand which increases in thickness toward the middle of the section and appears to become an almost structureless, massive medium sand containing occasional lutite clasts.

The greater part of the exposure comprises coarse and medium sand with gravel and granules. The sand is frequently normally graded, and stratified on a scale of 30 to 100 mm, and therefore similar to the fossiliferous sediments in section 1. Unlike the materials in that section, however, there is a high lutite content in places, mainly in the form of laminae at the top of the graded sand beds. Weathering gives the impression that thick lenses of lutite exist. On Figure 28 this effect is used in order to generalize those parts of the exposure where argillaceous laminae are important.

Large-scale trough cross-stratification is present in parts of the section. The structures indicate flow approximately parallel to the section. Other structures in the sand are lutite clasts and trace fossils, the latter of the genus <u>Ophiomorpha</u> (Figure 27).

-----(2.ii) interpretation

As in section 1, one may refer to three major sedimentary facies: subaqueous outwash, "early marine", and "later marine". The first is specifically identified because of the presence of large channels filled with massive sand in the continuation of the section.

The section exposes a large depression or channel-shaped feature. This is believed to be a hollow produced by the melting of a large block of ice which was buried by subaqueous outwash sediments. The early stages of marine sedimentation, which produced the second major stratigraphic division, were contemporaneous with the melt-out of the buried ice, for the massive disruption and faulting of the earlier marine deposits suggest readjustment and slope instability at that time.

Despite the severe disruption of the deposits, the stratification is well preserved, and even the often-fragmented Balanus crenatus was found intact. This implies that the collapse resulting from the melt-out process took place slowly.

The early marine sediments reflect a copious supply of debris which did not undergo much sorting. The presence of articulated valves and complete barnacles indicates that faunal communities developed on these materials.

Although the faulting in the early marine sediments is attributed to the melt-out of buried ice, it is also likely that settlement of the sediments on the moderate paleoslope of the subaqueous outwash deposits, prior to later deposition, contributed in some degree to the faulting. The deformation in the argillaceous marine sediments between metres 55 and 65 are likely to be due to that cause. The presence of the lutites is evidence that some "normal" deep-water marine sedimentation did occur here.

Whereas the steep slope on the subaqueous outwash and earlier marine sediments in the previous section (Figure 26) allowed subsequent marine deposition to be prograded quite steeply outwards in the lee of the ridge, the absence of such a steep slope, and the presence of a closely constraining opposite flank, led to a different type of stratification in section 2. The divergence of bedding into the hollow is thought to be characteristic of a type of marine sedimentation which might be referred to as "hollow-fill".

The filling of the depression was probably accomplished by the sweeping of debris into deeper water at the time when wave-base was not far above the level of the ridge. Storm events followed by periods of calmer water may be reflected in the alternation of coarser with finer sediments.

Deposition was possibly from minor density currents during both the early and later phases of marine sedimentation: the grading in the sand is possible evidence of this. The massive sands with lutite clasts suggest deposition from another form of sediment gravity flow, the grain flow, but this process remains to be observed (Middleton and Hampton (1976)).

The presence of the unconformity between the "early" and "later" phases of marine sedimentation both here and in section 1 implies a depositional hiatus, but incomplete exposure of the hollow prevents a detailed explanation for the apparent cessation of sedimentation.

The occurrence of Ophiomorpha in the later marine sediments invokes the same comment as for section 1: it suggests that the sediments were laid down in a moderate to relatively low energy environment below daily wave-base.

In summary, the South Gloucester exposures, especially section 2, are the most impressive examples of hollow-fill stratigraphy observed during field investigations in the entire Ottawa area.

CHAPTER 4

MARINE SEDIMENTATION ON THE RIDGE AT HERBERT CORNERS

> The beach lines of Glen Roy have been called river terraces and moraine terraces. The cliffs of the Downs of England have been ascribed to shore waves. Glacial moraines in New Zealand have been interpreted as shore terraces. Beach ridges in our own country have been described as glacial moraines, and fault terraces as well as river terraces have been mistaken for shore-marks.
>
> (Grove Karl Gilbert (1890))

(1) Introduction

(a) Local setting (Figure 29)

A ridge of sand and gravel which runs southward from Greely to near Osgoode is a relatively broad and gentle feature which rises some 10 to 15 m above the surrounding terrain. To the east occurs undulating terrain of limestone bedrock and drumlinized glacial till, with depressions infilled with organic deposits on the former and Champlain Sea lutite on the latter. To the west of the Herbert Corners ridge is a second area of drumlinized till.

(b) Ideas concerning the history of the ridge

In their inventory of southern Ontario eskers, Chapman and Putnam (1966, pp. 82-85) refer to the ridge as an esker which has been so severely wave-washed that its original form is barely recognizable. The ridge was mapped therefore as a "sand plain". Examination of air photographs reveals that the original morphology of the ridge is visible in only a few places, as for example where it is breached by the Middle

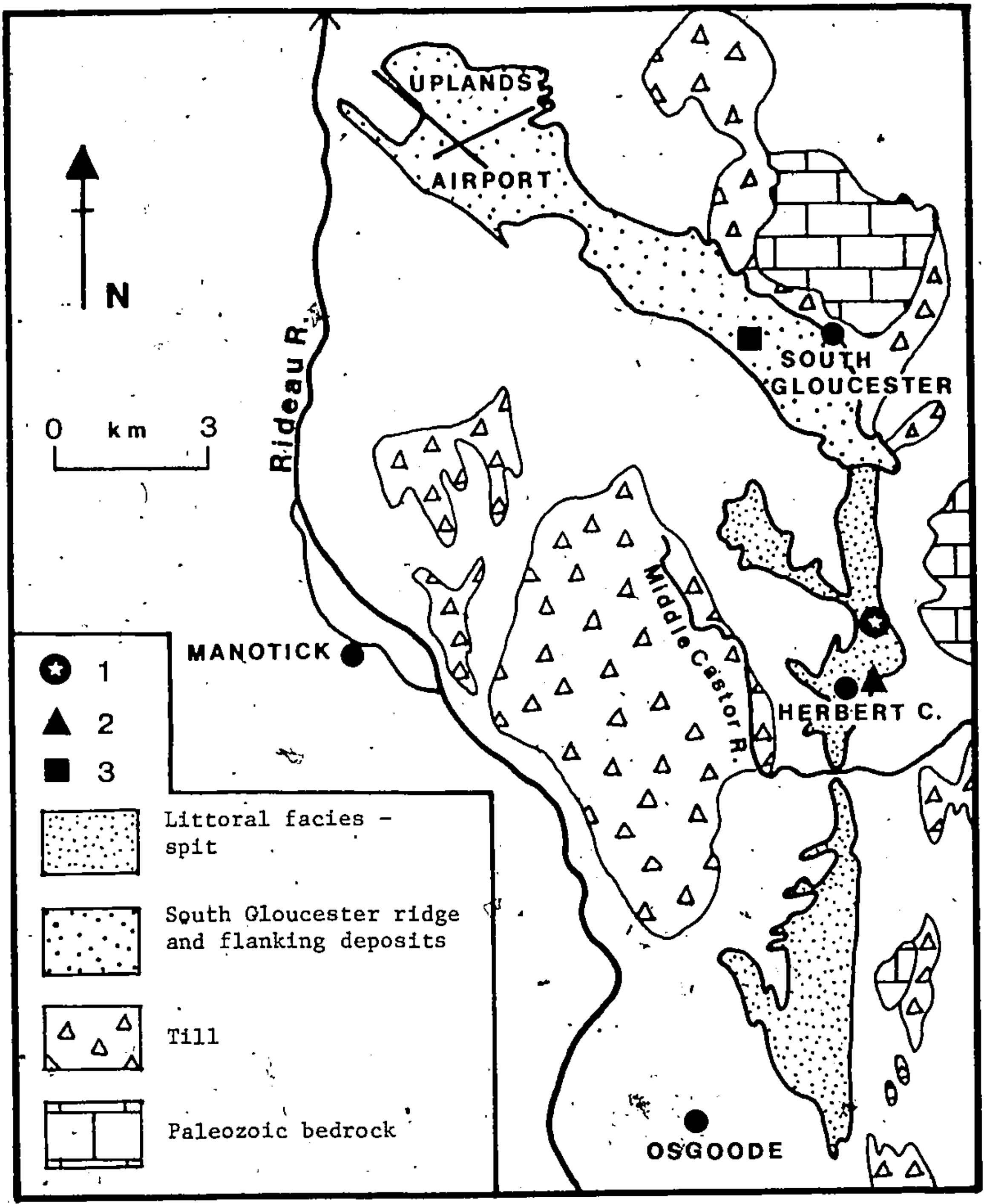

FIGURE 29: Map showing the location of the Herbert Corners sections in relation to the spit and South Gloucester ridge. (After Richard _et al_. (1977) and Harrison (1977)).

1: Pyper's pits; 2: Tierney's pit; 3: Dibblee's pits.

Castor River, 1.2 km south of Herbert Corners.

Rust and Romanelli (1975) and Rust (1977) have suggested that the sand and gravel ridges south of Ottawa, including the one under discussion, were deposited from melt-water outflows into a subaqueous environment. Richard (1976, 1977), however, maps the entire ridge as 'Champlain Sea: littoral facies', thereby making its relationship to the other ridges unclear. It is noteworthy that Richard's mapping of the ridges displays a possible spectrum of wave-reworking, from the Stittsville ridge, mapped entirely as "glaciofluvial deposits", through the South Gloucester and Twin Elm - Kars ridges, with a higher mapped proportion of littoral deposits, to the Herbert Corners ridge, where the main body of the ridge has been assigned to the littoral facies of the Champlain Sea (Figure 30). Richard notes that the surface of "glaciofluvial" sediments has been reworked in places, although presumably not enough to warrant mapping as a marine unit.

Harrison (1977) cites Richard's mapping as evidence that the ridge from Greely to Osgoode is a former recurved spit dating from the latter stages of the Champlain Sea. He interprets the Herbert Corners ridge as being marine in origin, built by sediment transported by currents resulting from the refraction of waves off the southeast end of the South Gloucester ridge ("Bowesville moraine"). This would be consistent, ignoring factors discussed later, with the presence of a considerable stretch (perhaps 150 km) of open water to the northeast in Champlain Sea times. It is likely that Harrison's criticism of paleocurrent information (1977, p. 59) is an attempt at an <u>ex postfacto</u> justification for the spit concept, which was deduced probably on purely morphological grounds (witness the form of the ridge on Figure 29 or 30).

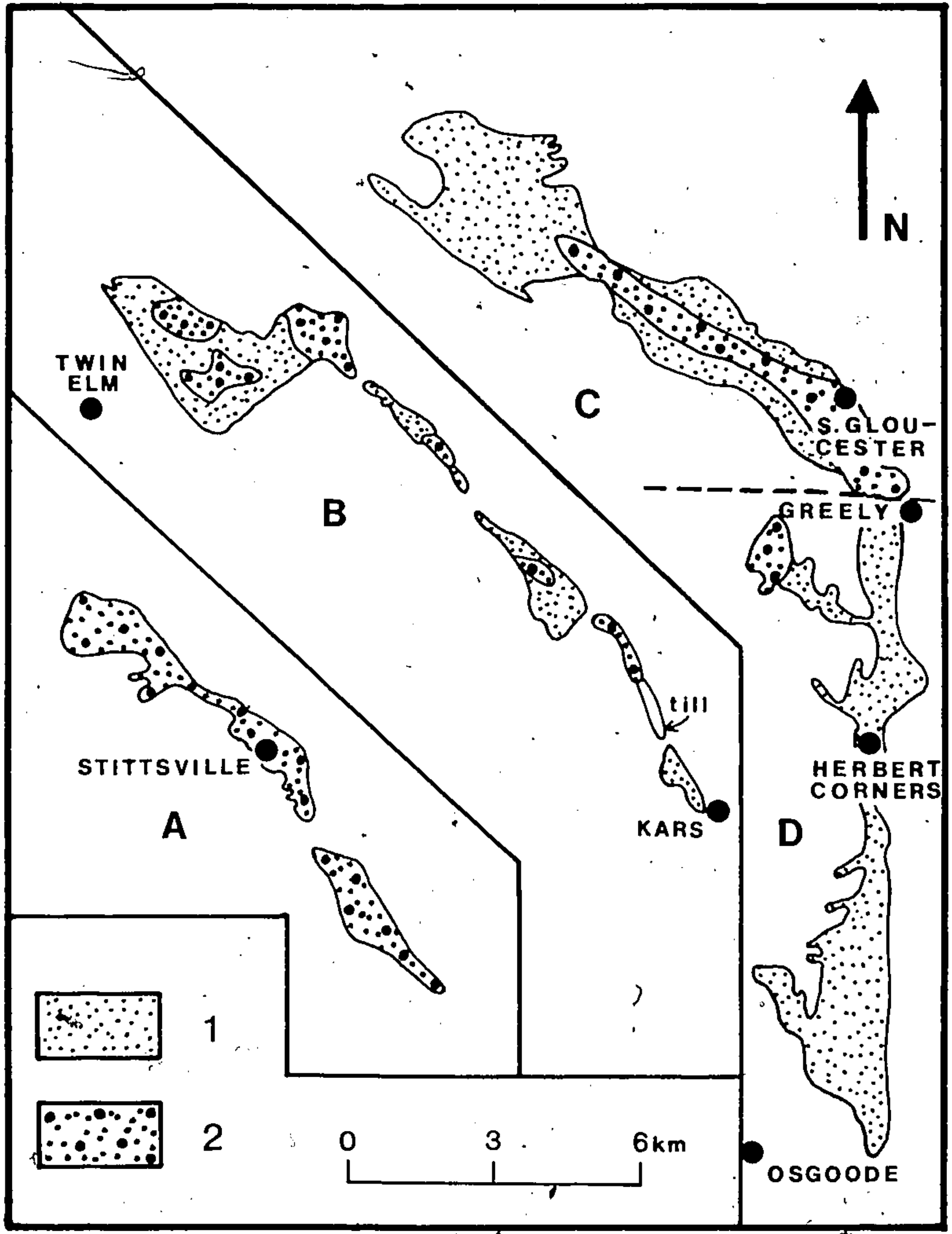

FIGURE 30: Maps of the glacial ridges south of Ottawa, showing degrees of wave-washing according to the mapping of Richard (1977). 1: "Littoral facies"; 2: "Glaciofluvial deposits".

A - Stittsville ridge
B - Twin Elm - Kars ridge
C - South Gloucester ridge
D - Herbert Corners ridge

(c) The spit hypothesis

During field investigations in 1978, the hypothesis that the Herbert Corners ridge represents a former spit was investigated. There are several lines of evidence which might be used to test this hypothesis:

(a) geometry and lithology of the body of sediment,

(b) its lithology,

(c) sedimentary structures present,

(d) paleocurrent pattern,

(e) faunal evidence, and

(f) the stratigraphic sequence.

These are briefly considered in turn.

Surprisingly for a geologist, Harrison places emphasis on the (geo)morphology of the ridge, not least its barbed appearance suggestive of a recurved spit. Morphology is the lowest order of evidence which may be used, and it plays a minor role in accepted stratigraphic procedure, hence the opposition to "morphostratigraphic units" (Richmond (1962)). A consideration of the geometry of the body of sediment is more sophisticated, but would encounter the problem of convergence: the geometry of eskers and spits is similar - both are roughly half-cylinder forms.

Lithology is not likely to be a discriminative parameter in the present case either, since the spit is probably derived from glacial sediment.

Syn-depositional sedimentary structures, which can be produced at a sediment - fluid interface in many environments, are of limited value alone (Selley (1970, p. 11)), until used to infer paleocurrent directions.

In the present context, one would expect the patterns to be broadly similar in the cases of glaciofluvial/subaqueous outwash sediment and spit deposits, possibly with greater variability in the former. Both would have entailed sediment transport from the north.

The larger scale features of stratification and depositional slope might be more helpful, but the anatomy of marine accumulation forms has been little studied. Fossil forms hold the greatest promise for study, as Gilbert (1890) was able to show for Lake Bonneville (Figure 31B). In experimental work, McKee and Sterrett (1961) examine the structure of simulated longshore bars under different hydrodynamic and sedimentary regimes, and their work indicates the complexity of response in the stratification. As yet, however, although the literature on the structure of coastal depositional forms is expanding (e.g. Greenwood and Davidson-Arnott (1976)), there is little which enables one to test the spit hypothesis on the basis of internal structure.

One might expect the spit sediments to be characterized by a marine littoral and sub-littoral fauna, but the presence of such a fauna must, of course, be considered in the light of other evidence.

An important aspect to be noted is the stratigraphic sequence, bearing in mind that the inferred spit would have been constructed in a regressive sea. On a very fundamental level, one would not expect spit sediments to be overlain by deeper-water deposits. Longshore currents would have superimposed coarser materials on the finer sediments of the offshore zone. To illustrate this, Figure 31A is an attempt to portray the sedimentary facies associated with a spit which developed in a regressive marine environment. The position of the spit is arbitrary,

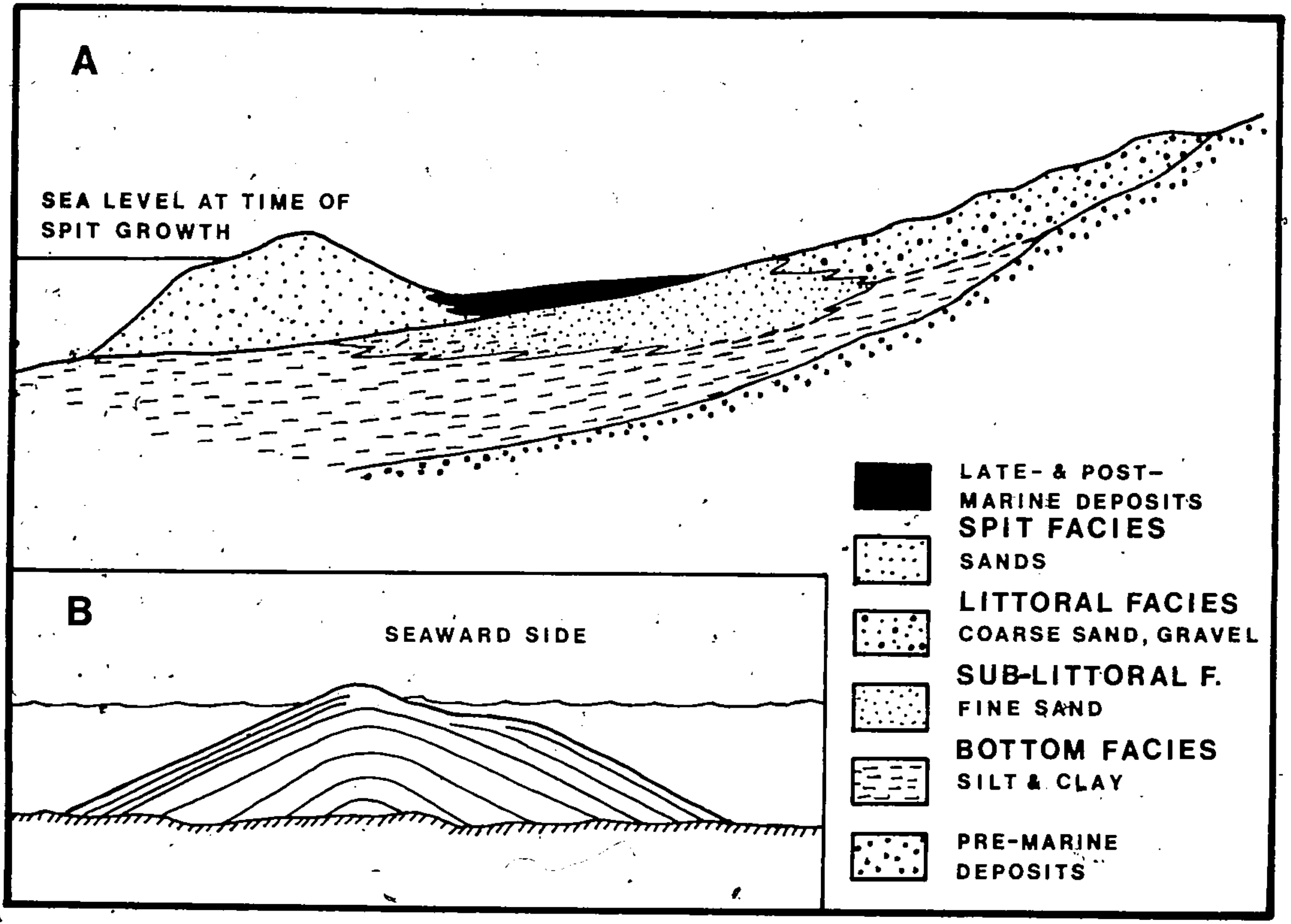

FIGURE 31A: Sedimentary facies and spit developed in a regressive marine environment. (Adapted from Curray et al. (1969)).

31B: The internal structure of a linear embankment. (From Gilbert (1890)).

and it is not intended to be a model for the one envisaged by Harrison.

(2) Exposures near Herbert Corners

A number of exposures in the vicinity of Herbert Corners provide an insight into the origin of the ridge.

(a) Tierney's pit (553070) (Figure 32)

-----(i) description

Three major stratigraphic divisions can be recognized in the exposure on the basis of sedimentology and fauna.

The lowest division comprises a unit of unfossiliferous silty fine sand with minor faulting and deformation. Planar cross-beds indicate flow from a northerly direction.

Overlying those sediments are fossiliferous materials of a similar nature, exhibiting a strong depositional slope (apparent dip 28 degrees, true dip 35 degrees). Since the true dip coincides with the angle of repose of the sand, the face is much obscured by talus. Balanus hameri is present, and some specimens are well preserved. This unit of silty sand becomes coarser toward the top, where it displays stratification in the form of a microdelta.

The third stratigraphic division comprises a unit of silty granular coarse sand disposed in a gentle basin form, with bedding on a scale of a few centimetres. Its relationship to the silty fine sand is obscured by talus. Single valves of Hiatella arctica, convex-upward, and separate plates of Balanus hameri with a preferred orientation (Figure 33), characterize the upper part of this deposit. Lower in the same unit are numerous specimens of Balanus hameri in excellent condition. There is

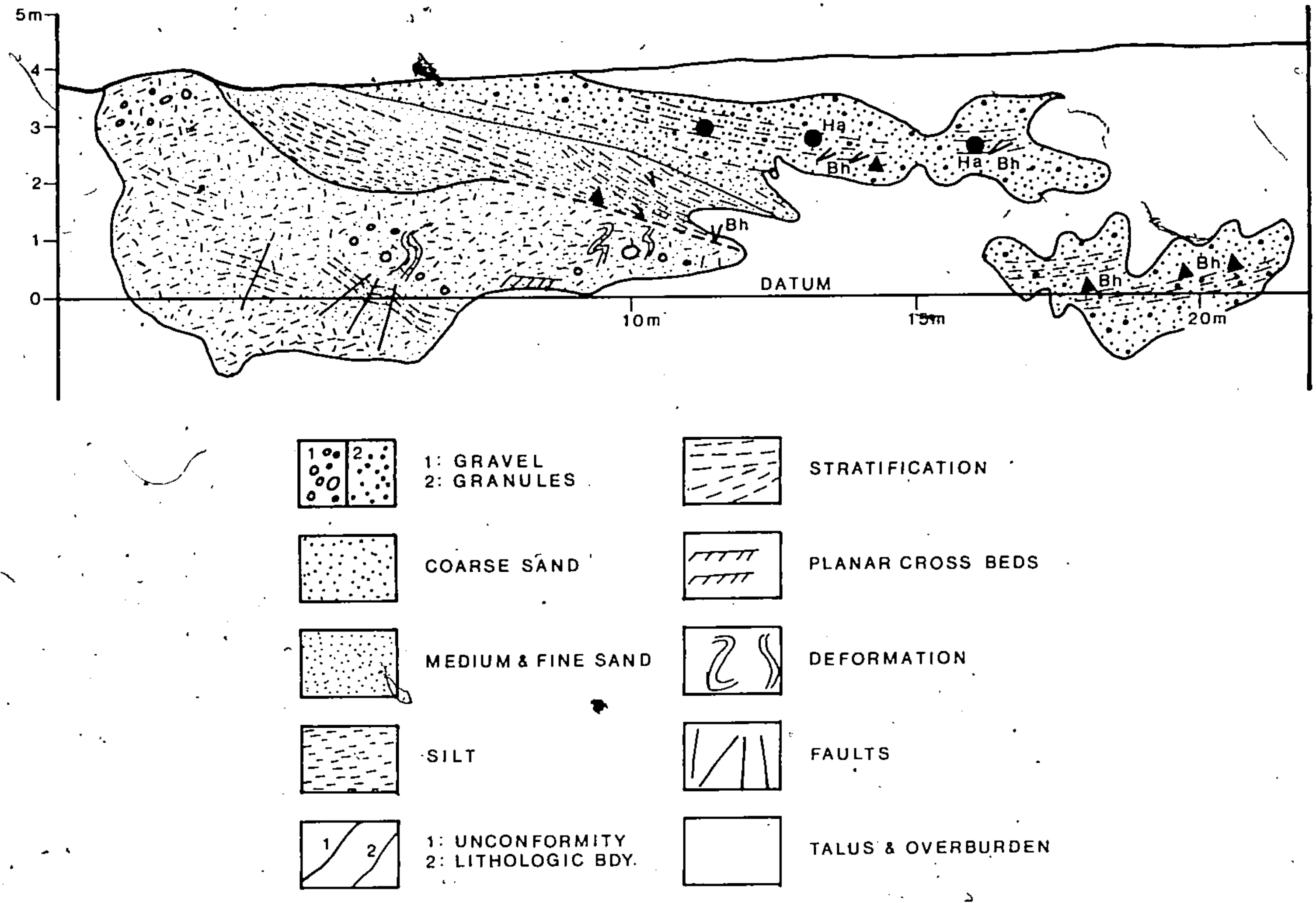

FIGURE 32: Section in Tierney's pit, July, 1978. Datum: 88 m a.s.l. Orientation of exposure: 80°. Compiled from fieldwork. Fossil information as in Table 2.

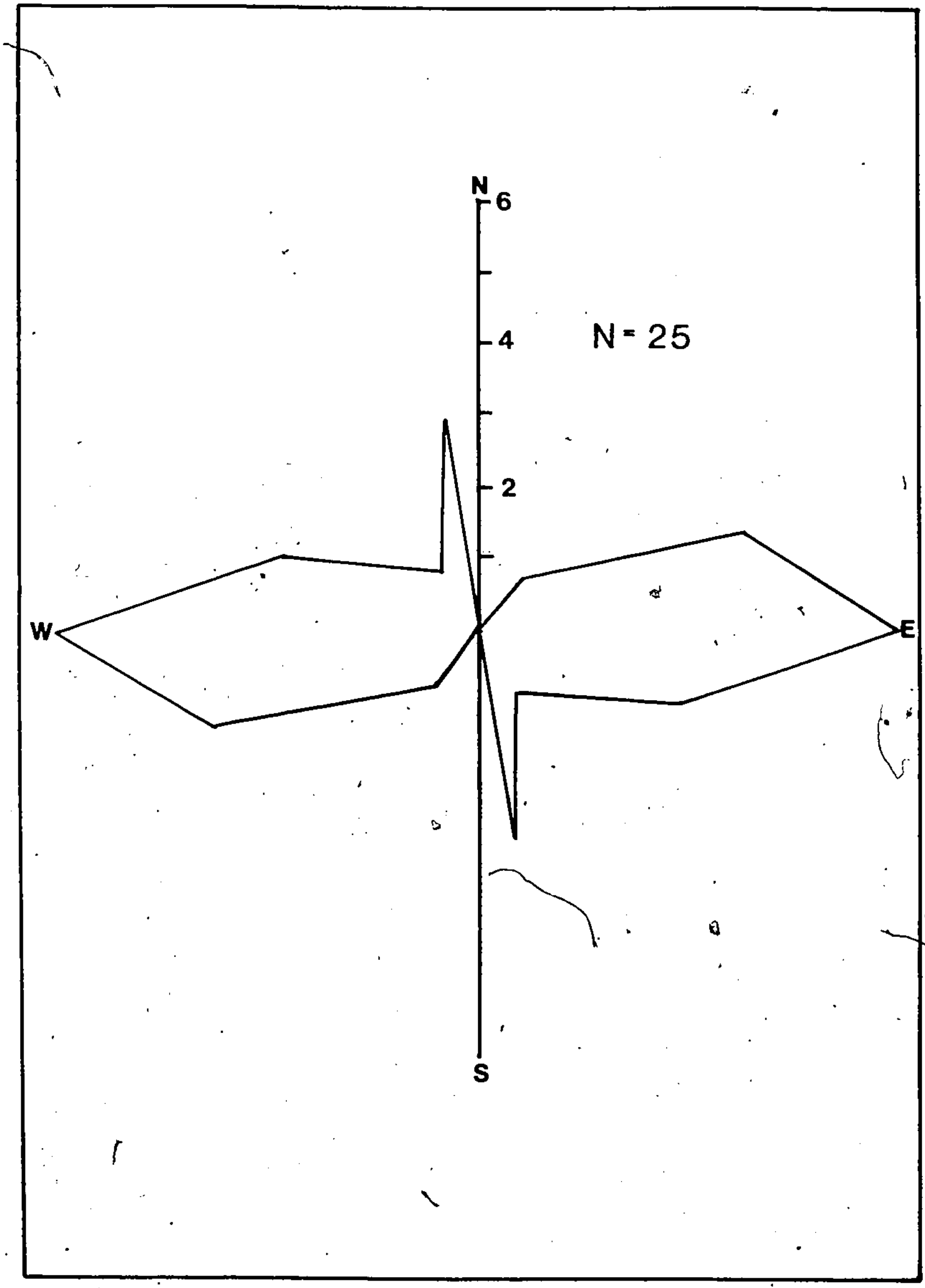

FIGURE 33: Orientation rose of <u>Balanus hameri</u> fragments, Tierney's pit, Herbert Corners.

also evidence of attachment to discarded plates of the barnacles.

-----(ii) interpretation

The unfossiliferous, faulted and deformed sands were laid down probably in close association with ice. A large pit, owned by Osgoode Sand and Gravel Ltd. and situated 0.2 km northeast of Tierney's pit, displays characteristics which correspond well with Rust's (1977) criteria for the recognition of subaqueous outwash. It is believed therefore that the lowest unit in the present section is part of the same facies.

The lower marine unit, also a silty fine sand, was probably derived locally from subaqueous outwash sediment and deposited in a kettle hole. The microdelta bedding indicates an inflow of sediment from the opposite direction to that from which the unfossiliferous sediments were transported, and provides an interesting elaboration on the hollow-filling process. It is proposed that the fossiliferous silty fine sand represents the local equivalent of the "early marine" deposits observed elsewhere.

Later hollow-filling (and the stratification suggests that process) was by coarser materials, reflecting either a different source of debris, or a lowering of wave-base, or both.

The microdelta indicates unidirectional filling of the hollow, and so does the disposition of the barnacle fragments recorded in Figure 33. However, without observations of the orientation of <u>Balanus hameri</u> plates in running water, it is difficult to state how they respond. Although well streamlined, a separate plate has a thickening at the basal end, which probably affects its hydrodynamic behavior. By analog with clast-and-matrix situations one would expect the plates to be aligned across the direction of current flow. These conditions hint at continued northward transport during the period of hollow-filling.

In summary, no evidence was seen to support Harrison's idea that the Herbert Corners ridge is a spit. Instead, the section at Tierney's pit furnishes yet another example of hollow-filling. This conclusion is supported by the evidence from two further exposures about 1 km north.

(b) Pyper's pit (west of road) (559086) (Figure 34)

-----(i) description

In this pit unfossiliferous sand is overlain by grey lutite (Figure 34). The latter yields no macrofossils. At the base, about 25 cm of lutite are overlain by 75 cm of medium sand alternating with lutite. Succeeding units are: a mainly massive lutite, a banded lutite with a thin bed of medium sand at the base, and a mainly massive lutite, the three comprising a sequence about 2 m thick. At the base of the lutite sequence a cobble of Pre-Cambrian gneiss was found.

-----(ii) interpretation

Although the lutites yield no macrofauna, the sediments are interpreted as marine. The section is thought to display an example of hollow-filling by bottom-facies fine sediments. The alternation of medium sand with lutite at the base of the hollow-fill possibly reflects pulses of coarser sediment supplied by a nearby ice front.

-----(iii) other evidence

A small exposure elsewhere in the pit reveals an argillaceous rhythmite cut by a number of faults which extend upward from the

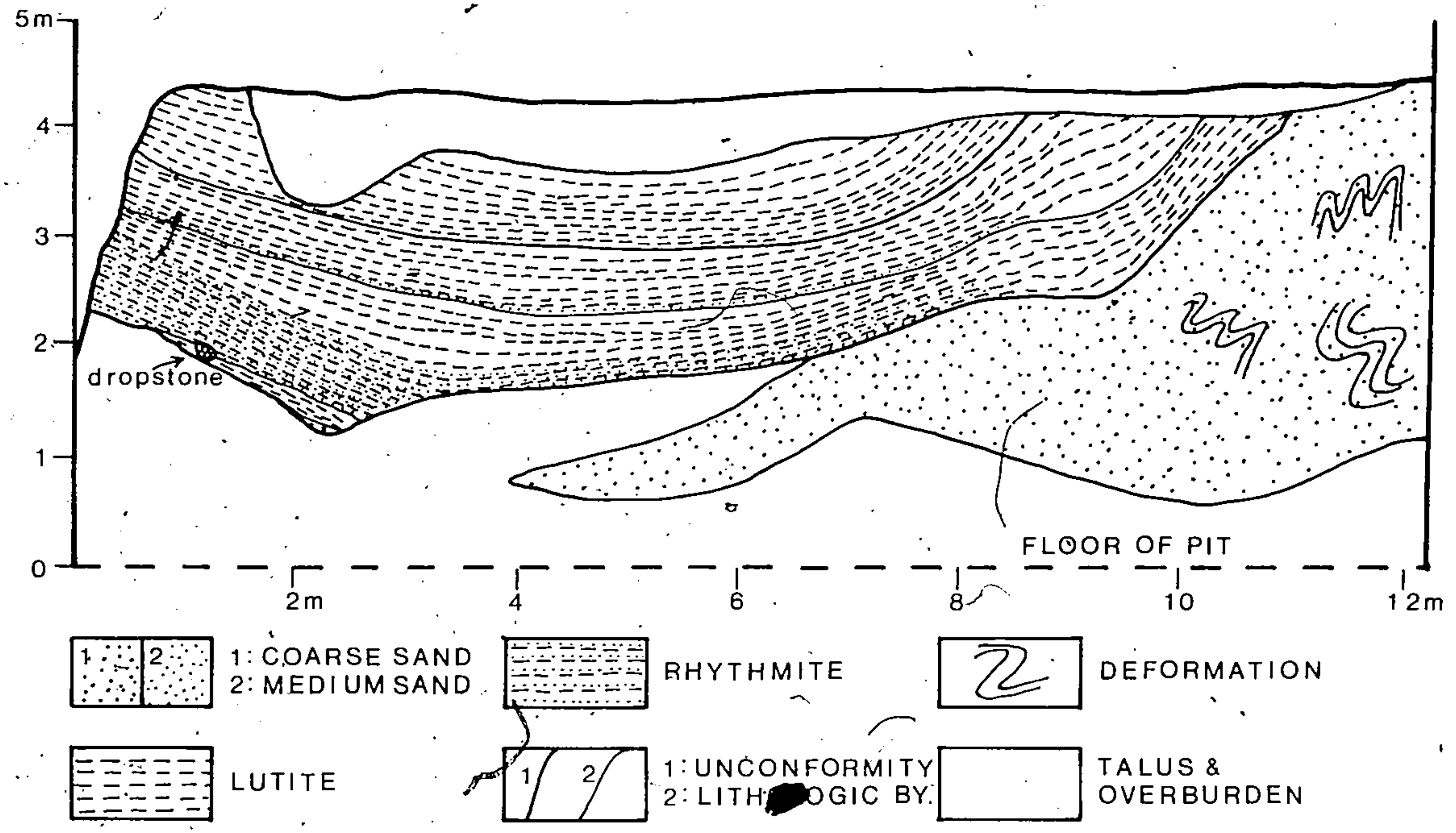

FIGURE 34: Section in Pyper's pit (west), July, 1978. Floor of pit 89 m a.s.l. at exposure. Orientation of exposure: 215°. Compiled from fieldwork.

underlying sands (Figure 35). This evidence indicates a lingering presence of buried ice while the earliest deep-water sediments accumulated. The varve-like nature of the earliest lutites is indicative of a pulsed sedimentation, again suggesting the proximity of the ice front, or influxes of coarser sediment from the sides of the hollow.

At a further exposure in this pit, another small, lutite-filled hollow was observed in the unfossiliferous sands. This massively bedded medium sand is similar to that occurring in the subaqueous outwash facies exposed in the large pit about 1 km away, referred to above (p. 80). Such stratification is not likely to be present in a spit. Furthermore, the sand is overlain by argillaceous sediments, and both the sand and the lutite are affected by faults. This evidence suggests that the relief of the ridge is due to the presence of an important eskerine/subaqueous outwash deposit, the irregular surface of which has been smoothed by marine sedimentation and wave action.

(c) Pyper's pit (east of road) (560088) (Figures 36 to 38)

A large exposure in this pit reveals extensive marine sediments which are important to a discussion of the spit hypothesis.

-----(i) description

Although the stratigraphy is basically simple, this section poses the greatest problems of interpretation.

Two stratigraphic divisions are visible. The first is rather poorly exposed and indurated by mineralization from groundwater. It comprises mainly medium and coarse sand with infrequent and dislocated specimens of Balanus hameri.

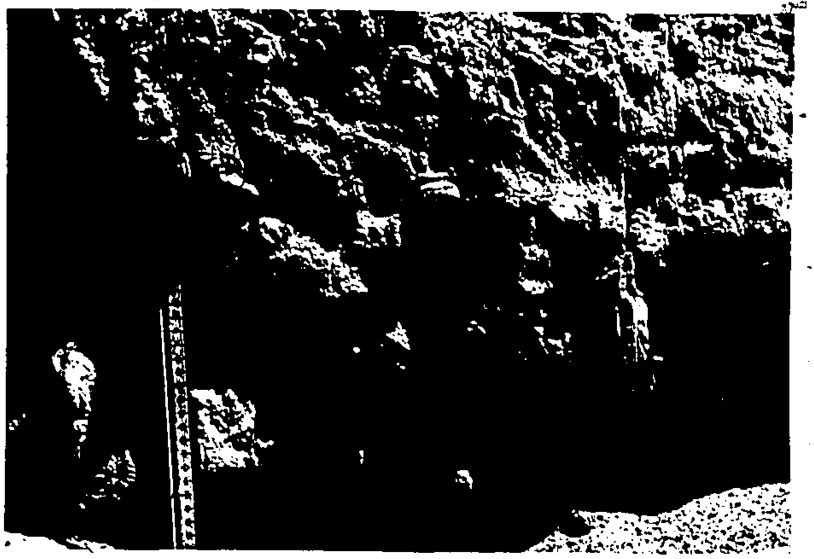

FIGURE 35: Faulted rhythmite (early marine bottom sediment). Pyper's pit (west of road), Herbert Corners.

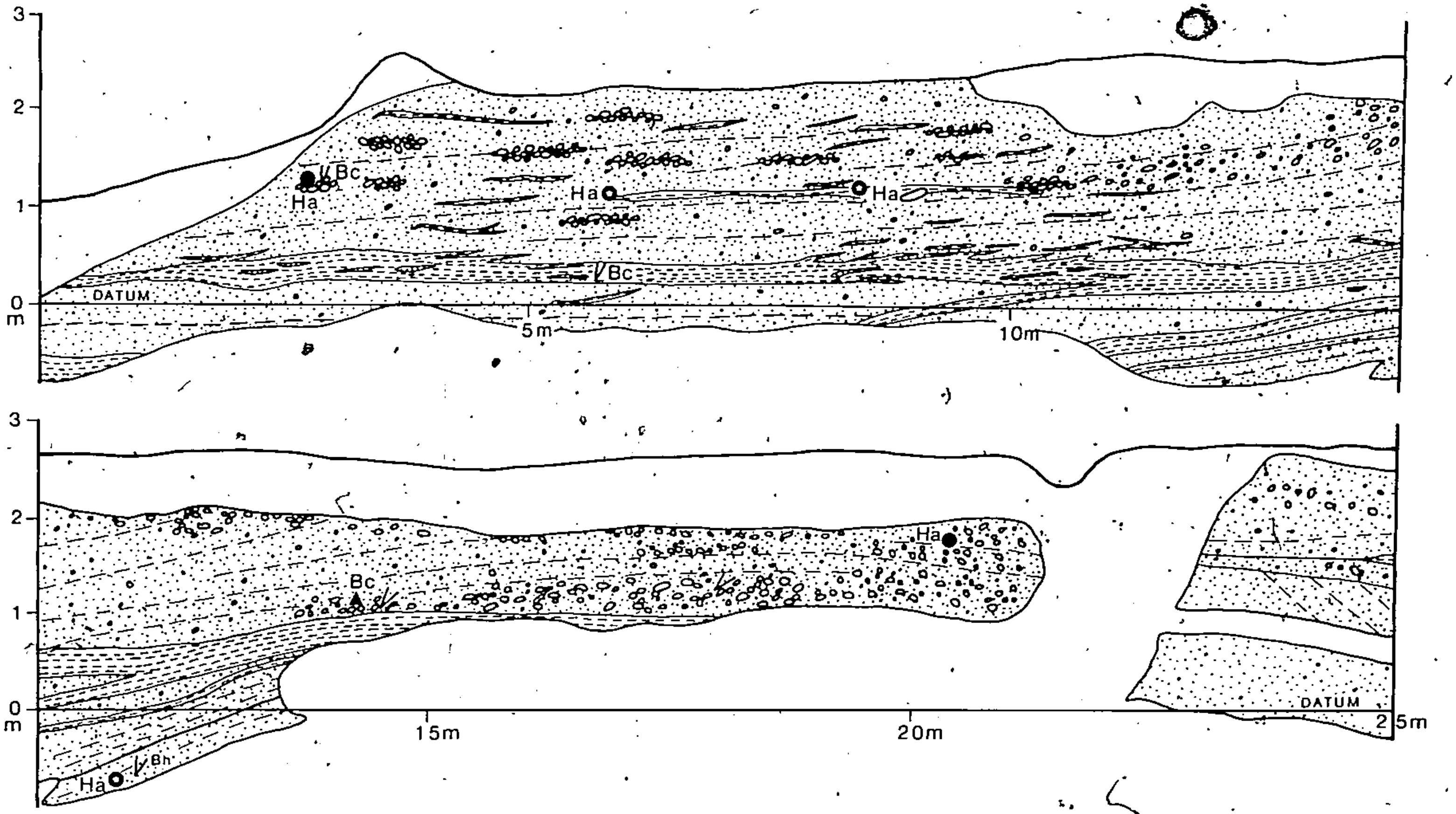

FIGURE 36: Section in Pyper's pit (east), July, 1978. Datum: 92 m a.s.l. Orientation of exposure: 88°. Compiled from fieldwork. For legend see Figure 38. Fossil information as in Table 2.

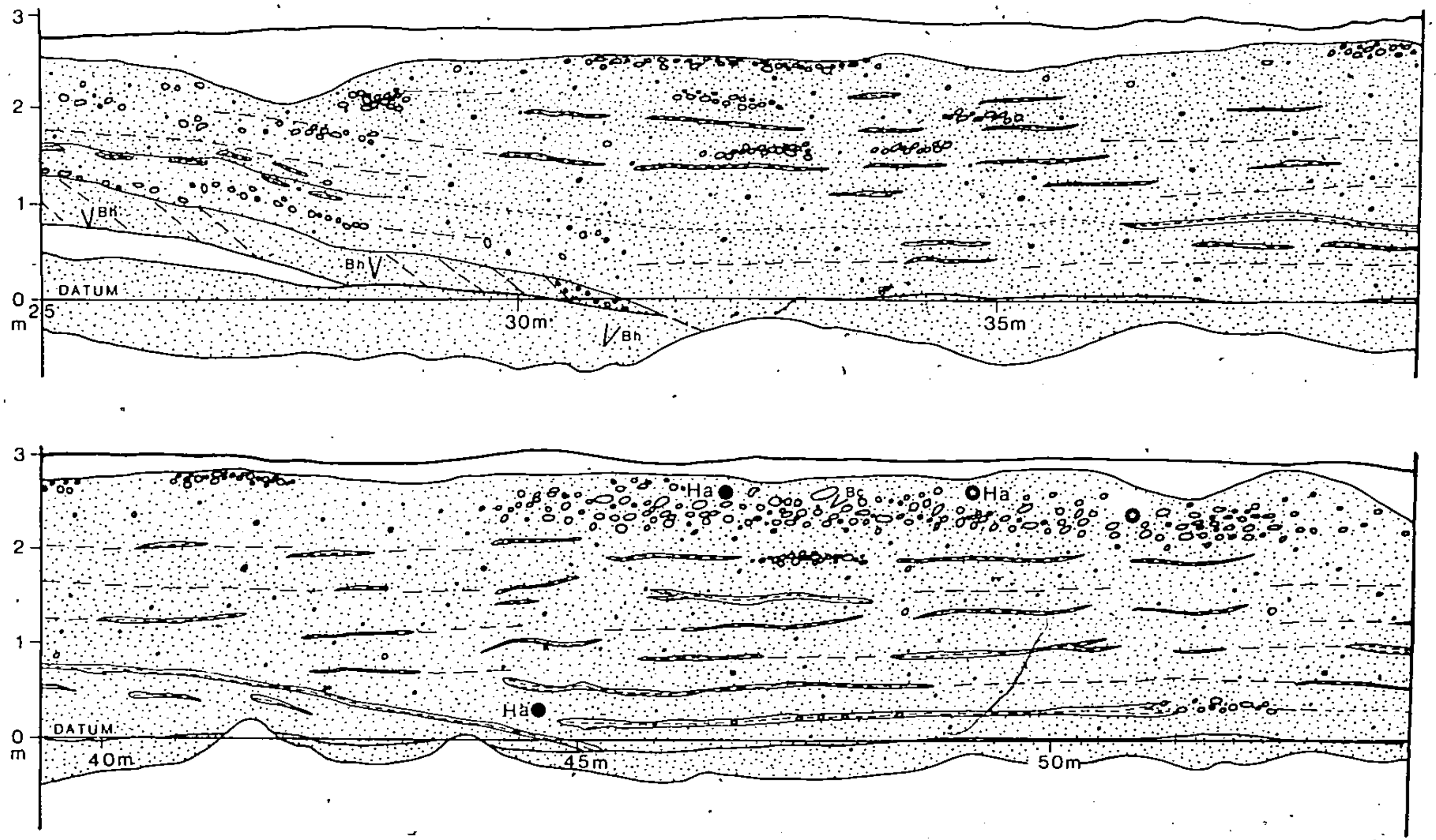

FIGURE 37: Section in Pyper's pit (east), July, 1978 (continued). Datum: 92 m a.s.l. Orientation of exposure: 88°. Compiled from fieldwork. For legend see Figure 38. Fossil information as in Table 2.

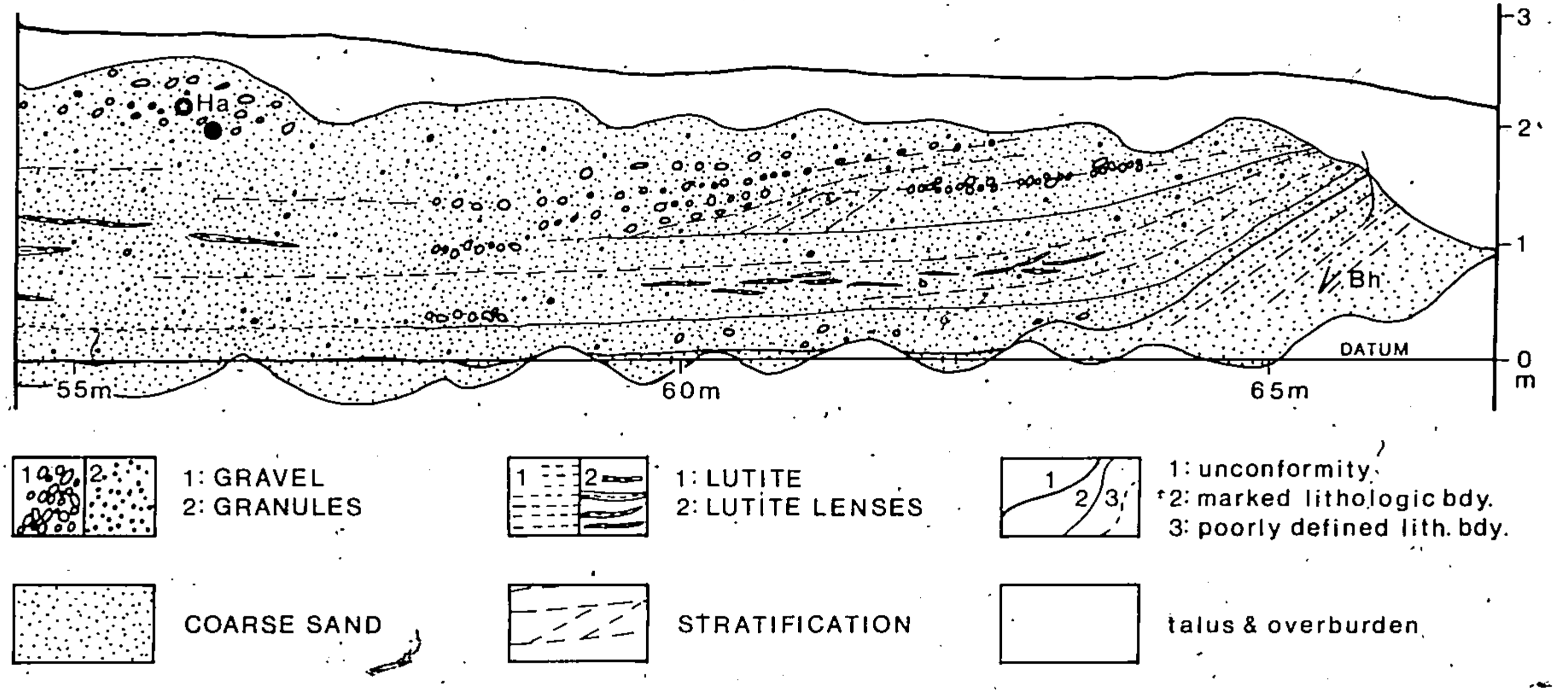

FIGURE 38: Section in Pyper's pit (east), July, 1978 (conclusion). Datum: 92 m a.s.l. Orientation of exposure: 88°. Compiled from fieldwork. Fossil information as in Table 2.

The other major stratigraphic division appears to overlie an eroded surface on the older sediments. It comprises an extensive accumulation of granular coarse sand of variable stoniness with a number of beds and lenses of silt. Fossils are rare, but in the gravelly material some complete specimens of Balanus crenatus, including some still attached to pebbles, are present. Articulated and single valves of Hiatella arctica are also present in the stonier sediments.

At metre 65 the granular sands are seen to diverge over a rise in the surface of the earlier deposits.

-----(ii) interpretation

The notion that two phases of marine sedimentation are in evidence is nowhere better seen than between 60 and 65 m, where the later deposits have the divergent stratification which appears to be characteristic of hollow-fill sediments. At this point the later sediments unconformably overlie the earlier. In this case the margin of the hollow is formed by a slope on the remanié surface of the earlier marine deposits. Implicit, therefore, is the notion that the sediments of the earlier phase of marine deposition were partially eroded in a marine environment, and it is supposed that this erosion reflects the encroachment of wave-base upon the former sea-bottom. The extensive granular sands are therefore interpreted as littoral and sub-littoral, an inference supported by the coarsening of texture toward the top, especially noticeable between 45 and 55 m.

A corollary of that interpretation is the possibility that the later marine sediments are intertidal, possessing as they do intercalated lenses and beds of argillaceous sediment similar to lenticular bedding (e.g. Reineck and Singh (1973)). However, stronger, independent evidence for tidal activity in the Champlain Sea is required before such an inference can be on firm ground. Moreover, if the sediments are tidal in origin one might expect a characteristic fauna, for example Mytilus edulis.

Finally, the local physiography should be borne in mind in the case of this relatively low-lying pit (elevation about 90 m). To the east is an area of bedrock which would have formed an extensive shoal at the close of the period of marine submergence. As well as reducing wave action on the Herbert Corners ridge and affecting faunal colonization by creating a lagoon complex of low salinity, the presence of such a feature is a further barrier to the acceptance of Harrison's claim that the Herbert Corners ridge is a spit.

(3) Conclusions

The exposures near Herbert Corners furnish adequate evidence to assess whether or not there is substance in the spit hypothesis.

The bedrock outcrop at South Gloucester must have provided a substantial bulwark for the South Gloucester ridge against the waves which attacked it from the northeast. Similarly, the outcrop of bedrock and the till terrain to the east of the Herbert Corners ridge make a marine accumulation form as envisaged in the hypothesis extremely unlikely.

The pits examined in the summer of 1978 all expose variants of the hollow-fill model. The marine sediments comprise only a small proportion of the ridge, and the extensive exposures in the Osgoode Sand

and Gravel pit reveal a substantial core of subaqueous outwash sediment. The small exposures recorded here of unfossiliferous, deformed and faulted sand may be related to the latter facies. The stratigraphic and sedimentologic evidence,admittedly patchy, offers no remission from the negative conclusions, which were reached on morphological grounds, regarding the spit hypothesis.

Finally, the problem of morphological evidence will be reiterated. Harrison employed Richard's map as primary data, an error which field investigations would have quickly revealed. The larger "barbs" on the "spit" are probably branches of the same esker/subaqueous outwash system, a large and important feature which can be traced from beyond Uplands to Kemptville, a distance of some 45 km. Such a feature is commensurate with the scale of the Wisconsinan ice sheet, unlike the supposed spit in the context of the Champlain Sea.

CHAPTER 5

SYNTHESIS

> Yes, and there was our critique of Darwin's
> Theory of Evolution, and an essay on the nature
> of gravity, which concluded that gravity had
> surely been a variable in ancient times.
>
> (Kurt Vonnegut: Slapstick)

(1) Introduction

In chapters 2, 3 and 4 a number of sections are presented, described and interpreted. The present aim is to collate and develop the ideas put forward in these chapters, and to compare, where possible, the sediments with analogous deposits elsewhere. In order to summarize the data from the sections, several facies models are presented.

The ensuing discussion is framed in terms of the facies which have been recognized, namely: glaciomarine, comprising sands and diamictons; sub-littoral and littoral sands and gravels; and hollow-fill, including diamictons, lutites, sands and gravels. Of particular concern is the last.

(2) Glaciomarine facies

Although the pre-marine sediments lie largely outside the scope of this study, they warrant brief consideration because they form the parent material of the marine deposits and, deformed, play the role of host depressions for the hollow-fill facies.

The papers of Rust and Romanelli (1975) and Rust (1977) prompt reconsideration of the origin of several sand and gravel ridges in the

Ottawa region. Revisions of interpretation, as is always the case in Quaternary studies, are partly bound up with increases in exposure, but the admission of so basic a tenet as glacial retreat in a body of water is itself a sharp spur to the revision of paleoenvironmental models.

The importance of these ridges to marine sedimentation lay in their role as sediment sources and sediment traps. Numerous authors describe the topographic diversity of glacial (<u>sensu lato</u>) ridges, this variety of terrain being either syn- or post-depositional. For example, Price (1973) documents a number of examples of the effects of the melt-out of buried ice in modern proglacial environments, and Shaw (1972) describes enclosed depressions in Shropshire, England, underlain by tilted and faulted strata. There is no doubt that the delayed melt of buried ice can play a significant geomorphic role. Figures 39 and 40 show steeply-dipping strata in the pit near Twin Elm. The near-verticality is probably the result of the collapse following the melt-out of dead ice.

Whether the unfossiliferous sands in several of the pits were engorged subglacially or subaqueously is not particularly important to the discussion, but the diamictons observed in the pit near Twin Elm (pp. 33-44) require comment because they are interpreted as having been laid down in water.

At Twin Elm the unfossiliferous diamictons were observed in several places in the pit, including some small exposures of non-marine sediments which were not drawn up.

There are several possible origins for the unfossiliferous diamictons. It is thought unlikely that they are lodgement tills.

FIGURE 39: Steeply dipping boulder gravel at Twin Elm, near section 3.

Note the almost vertical disposition of the boulder bed, which appears to overlie a massive silt. Pack is 45 cm high.

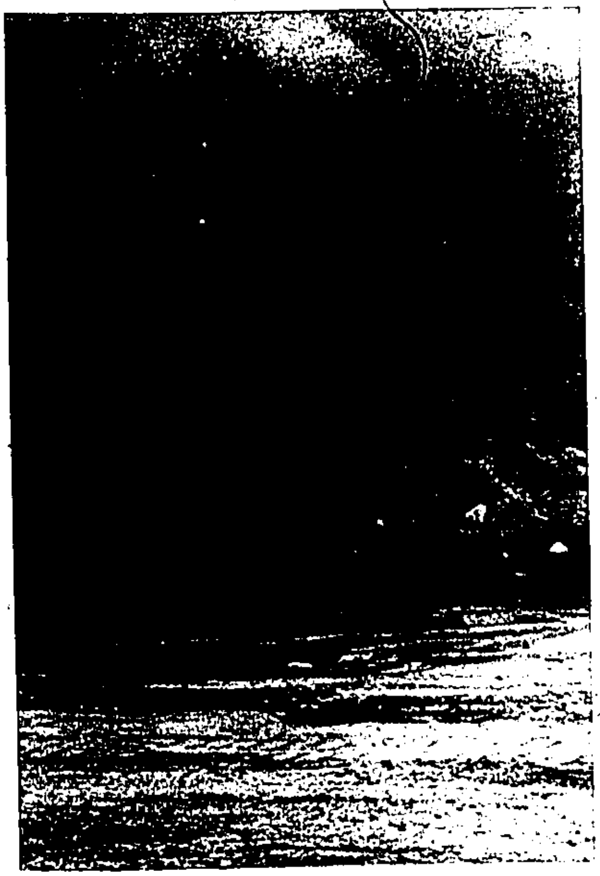

FIGURE 40: Deformed early marine bottom sediment at Twin Elm close to location of Figure 39.

The units are identified as follows:

A - Deformed massive silt (subaqueous outwash?)
B - Massive lutite
C - Lutite
D - Lutite

The pack is 45 cm high.

Armstrong and Brown (1954) and Easterbrook (1963) examined pebbly mudstones in exposures on the west coast of North America (British Columbia and Washington State respectively). Easterbrook interprets them as marine tills and found that they had higher void ratios and lower bulk densities than lodgement till, and that interstratified bedded sediments were also present. The occurrence of marine fossils was the most important evidence.

Armstrong and Brown (op. cit.) consider several hypotheses for the origin of the pebbly mudstones which they investigated--ice-rafting, deposition from ice shelves, and submarine slopewash processes--and conclude that the last were the most probable mechanisms.

Laminated diamictons described as "subaquatic flow tills" have been described from sections along Lake Erie by Evenson et al. (1977) and from Victoria, B.C., by Hicock and Dreimanis (1978). In other recent work, May (1977) describes lacustrine tills which he divides into two types: "lacustrotills" and "water-laid tills". The first "involves some form of subaqueous debris flow", and the second, dumping at a submerged snout, settling out in shallow water, or minor readvances. Naturally, similar processes would operate in a marine environment. The unfossiliferous diamictons at Twin Elm were insignificant when compared to the thicknesses of glaciomarine sediments found elsewhere (the more so when set against the enormous sequence described by Plafker and Addicott (1976)). In spite of this, it is believed that they may be interpreted as marine flow till which forms a sedimentary association with subaqueous outwash.

Stratigraphically above the glaciomarine facies is the hollow-fill facies, but this may be discussed more effectively later.

(3) Sub-littoral and littoral facies

The purpose of this section is to consider deposits which have not been assigned to the hollow-fill facies. Such sediments were particularly important at Twin Elm and Herbert Corners.

A broad picture of Champlain Sea currents will be achieved only after widespread paleocurrent data have been collected. Such an undertaking would not be formidable: Narayan (1963) gives an example of Cretaceous marine paleogeographical reconstruction for the Lower Greensand of southeast England and northern France. The water body concerned there was of similar size to the Champlain Sea.

Longshore currents were suggested as having been the transporting agents for the fine sands in section 5 at Twin Elm. The same mechanism was posited as being the cause of the approximately ridge-parallel cross-bedding observed in pits at Uplands (Figure 1) by Romanelli (1970). At Twin Elm, the difference between the height of the ridge and the elevation of the cross-bedded sands was about 10 metres at maximum, which indicates a water depth of less than that figure during the deposition of the sands.

The clean medium sands which occur above the unconformity in sections 1, 2 and 3 at Twin Elm were interpreted as sub-littoral, but they were deposited earlier in the offlap sequence than the sands in section 5. The vigorous scouring implied by the unconformity, and the possible channel in section 3, may have been a concomitant of the gradual lowering of sea-level.

The section east of the road near Herbert Corners (Figures 36 to 38) exposed sediments of coarser texture than those interpreted as sub-littoral at Twin Elm. The reasons for interpreting them as sub-littoral were: (1) the occurrence of earlier, eroded marine deposits beneath, and (2) the presence of coarser sediments above. At the same time, however, the divergent stratification over the rises in the earlier marine sediments was noted, and in another section (not presented) one flank of what may be another hollow was observed. More important was evidence pertaining to the interpretation of Harrison (1977) that the ridge from South Gloucester to Herbert Corners (Figure 20) is a Champlain Sea spit. According to this writer's interpretation, such evidence was found to be wanting. Although the sediments of the ridge had been much reworked by wave and possibly current action, it owed its essential form to a core of outwash deposits.

Coarser, littoral sediments formed the highest unit in Pyper's pit east of the road near Herbert Corners, and similar instances were observed at Mulligan's pit (Figure 11) and Twin Elm (Figures 13 to 20). Removal of the topmost units by operators must have destroyed evidence of the littoral facies in some cases. The sandy gravels of the Stittsville ridge frequently were seen to overlie an unconformity on the sub-aqueous outwash, and this marked erosion surface probably represents an important plane of wave-bevelling. Only a few remnants of a sediment similar to the Stittsville lag were preserved at the Twin Elm location, but the lag's characteristic fauna, <u>Macoma balthica</u>, was present. In section 5 at Twin Elm the analogous unit was considerably less stony, and rather featureless. It is thought that in this case the sediments had been affected by tree root growth (see Appendix).

In summary, the sediments of the littoral and sub-littoral facies, as represented on the recent surficial geology map (Richard et al. (1977)), are considerably less important than had been imagined prior to field investigation. The field work suggests that the hollow-fill facies, which is scarcely mapable, is the more important along the ridges.

(4) Hollow-fill facies

(a) Introduction

This environment is discussed in terms of the sediments which comprise it, each sediment type being considered with respect to its mode of deposition.

It is surprising that hollow-fill type deposits have not been noted previously in Champlain Sea sediments. Most sand workings are along ridges, where marine modification of the glacial topography was important. Gadd (1971, p. 61) cursorily notes offshore sediments occurring as "thin layers and pockets in depressions among the knolls and ridges of the Drummondville moraine", but that description gives no indication of the frequent large size of the hollows which have been filled, nor of the importance of the marine deposits within them. Until present field investigations in the Ottawa region, recorded here, revealed the significance of hollow-filling, descriptions of wave-washed terrain were restricted to those by Karrow (1961), Terasmae (1965) and Gadd (1971). The writer imagined these to be representative of the importance of marine reworking of glacial sediments anywhere in the region of former inundation.

In the Ottawa region the hollows have been filled with diverse materials: diamictons, lutites, sands and gravels. These are discussed in turn.

(b) Fossiliferous diamictons

The unfossiliferous diamictons are interpreted as glaciomarine flow tills. The fossiliferous diamictons are thought to have been derived largely from their unfossiliferous counterparts by debris flow processes on slopes subject to instability due to the melt-out of buried ice. Such events could have taken place a considerable period after the ice-front had receded from the locality, owing to the longevity of the buried ice. The dispersed clasts in the diamictons are characteristic of debris flows (as well as tills) (Middleton and Hampton (1976)). The interbedded sands indicate deposition in an environment where currents also transported sediment, between episodes of debris flow.

The fossiliferous diamictons, as exposed, do not form an important part of the hollow-fill facies from the point of view of the quantity of sediment involved, but they represent one of several mechanisms which transported materials into the hollows.

(c) Sands and gravels

The sands and gravels which form the most important component of the hollow-fill facies are likely to have been transported by several mechanisms. Fundamental distinctions between the types of processes thought to have operated are: (1) wave action or no wave action (depth of wave-base); and (2) current-induced sediment movement or slope instability-induced sediment movement. It should also be recognized that more than one process probably would have been active at any one time.

The discussion will proceed from a consideration of slope instability, to current action, thence to wave action, concluding with an overall assessment of the roles of these processes in the development of the hollow-fill facies.

Aspects of slope instability have already been discussed in relation to the fossiliferous diamictons at Twin Elm. The particularly poorly sorted nature of those sediments seems amenable to the debris flow interpretation. It is possible that slope instability-induced sediment gravity flows were responsible for the silty granular coarse sand which characterizes some of the "early marine" infillings, especially in the two pits between Johnston Corners and South Gloucester. In both of these sections the early silty granular coarse sand was seen to be much affected by faults. The instability due to melt-out of buried ice and/or foundering on steep slopes may well have been the initiators of flows of debris of a poorly sorted nature into the depressions.

Morganstern (1967) has described how slumping and failure on slopes can lead to the generation of turbidity currents. The turbidity current process is part of a continuum of sediment gravity flows which also includes the debris flows discussed above (Middleton and Hampton (1976)). It seems reasonable to suggest, therefore, that minor turbidity current events could have resulted from slope instability. A further factor contributing to instability would have been rapid deposition of sediment. Where this occurred, the underconsolidated nature of the sediments would increase the probability of slope failure or movement of debris.

It is thought that sediment movement analogous to the flows of debris on sandy talus slopes, readily observable in any pit, might be a fair model of some of the hollow-fill sedimentation which took place.

Current action, or the effects thereof, would be difficult to distinguish from the results of slope instability where the two were operative; indeed, shear stresses on sediments, induced by currents, might lower the threshold of instability on slopes, thus enabling failure to occur. At the same time, while one might expect currents to have produced at least a modicum of sorting, short distances of transport into hollows might only have been sufficient to produce a sediment which one might describe as a "silty granular coarse sand". Rip-up clasts, which were noted in that type of sediment at Twin Elm and South Gloucester, are suggestive of appreciable water movement (if current action is inferred), which may have eroded argillaceous sediments laid down in quieter water. The fines, in the case of the silty granular coarse sand, may have been transported as either discrete or flocculated particles, later to infiltrate the sands as a matrix. The rip-up clasts would have been transported, as rolls or slabs of cohesive material, in the traction load.

The occurrence of rip-up clasts and other relict or transported lutites (e.g. the drapes at Mulligan's pit) returns one to the matter of sediment gravity flows. In the South Gloucester sections some graded bedding was noted, but one need not expect this particular characteristic (1) to be evidence for turbidity currents, or (2) conversely, the absence of it to negate the inference that small-scale density flows did occur. Deposition from such processes need not have produced all, or any, of the characteristics described (e.g. Stanley (1963)) from ancient turbidites. Without any sedimentological evidence, however, circumstantial evidence would have to be relied upon. In the case of the sediments interpreted as having been deposited from small-scale density flows in this study it is thought that there are sufficient sedimentological grounds for that interpretation (see chapter 2(1b) and chapter 3(1b). Suffice to say that small sediment gravity flow events probably played a major role in the sedimentary dynamics of the hollow-fill process, especially at Mulligan's pit and Dibblee's pits. It should be noted that the hollows exposed at those sites were the largest and deepest observed (about 45 m x 10 m at Mulligan's pit and approximately 65 m x 12 m at South Gloucester section 2), suggesting that reasonably diagnostic sedimentary structures were able to develop.

Current action without the complications of real or hypothesized sediment gravity flows was suggested for the section at Tierney's pit (Figure 32). That pit provided the illustration of a small hollow being filled at first by a sediment of very local provenance. A phase of unidirectional filling by a supply of current-transported debris is suggested by the inferred microdelta. The sands were deposited on reaching the slacker waters of the hollow.

More fundamental than any of the above is the question of the role which currents played in the Champlain Sea. Such a problem can lead to the search for modern analogs. Possible candidates for the role of analogs are Hudson Bay (see e.g. Pelletier (1968)) and the Baltic Sea (e.g. Winterhalter (1972)). An approach to the problem by means of such analogs is not favored, for these reasons: first, it should be noted that paleocurrents in hollow-fill sediments are likely to be of only local significance; and second temperature and salinity differences occasioned by the retreating ice-front, and the presence of emerging islands, complicate Champlain Sea paleo-oceanography. The writer sees no problem, however, in suggesting that currents were responsible for depositing some of the hollow-fill sediments; just how important was this role depends upon the contribution of the other factors.

Some currents are wave-generated, especially when the influence of shorelines comes into play. It is to a consideration of wave-washing as a source of hollow-fill sediment that we now turn.

Among the sections documented, no better illustration of the effects of wave-washing can be found, it is suggested, than the case of Mulligan's pit. In that section (Figure 11) the sandy gravels were seen to gradually extend across the hollow feature so that, ultimately, they came to overlie an erosion surface bevelled across the southwest rim of the depression. No currents, within reasonable limits, would have been capable of transporting such coarse debris; only when wave-base had lowered sufficiently could the gravels be set in motion. The presence of coarser materials (i.e. larger than 4 mm) in the South Gloucester sections was also ascribed partly to wave-washing. Blomquist (1969) provides one of the best examples of the effects of wave reworking of a glacial ridge. In other notable work, Rudmark (1975) shows the morphological effects on eskers of wave-washing processes, and Hessland (1946) describes the "accumulation forms" (terraces, deltas and cones) built by marine redistribution of glacial and glaciofluvial sediments. The morphological interpretations of Hessland differ markedly from earlier, stratigraphic ones by de Geer (1910) and Antevs (1928), although Hessland took full note of subsurface data.

The silty granular coarse sand at Twin Elm was noted above in the discussions of slope instability and currents. Similar sediments occur at Tierney's pit. These deposits might be profitably further discussed at this point, because, alternating with medium sands, they have been referred to as 'storm and calm' sediments. The variability of wave power and depth of wave-base with weather are factors which would obviously affect the texture of sediments being deposited in a hollow. During events of high wave amplitude (and thus deeper wave-base) sediments were stirred up and transported into hollows. Among the sediments would be argillaceous materials which settled out under calm conditions. During a period of "normal" weather, mild, wave-induced tractive currents of a particular competence would prevail, transporting medium sands into the hollows. In the case of the alternating sediments, therefore, it is thought that both wave- and current-related water movements transported sediments into the hollows. The effects of wave action would have extended to wave-base, and wave-induced water movement may have contributed to slope instability.

We can imagine, then, that the sands and gravels of the hollow-fill facies were deposited by a variety of interacting processes.

(d) Lutites

The word "lutites" is used here, as perhaps it should be for the so-called "Leda clay", to imply deposition in fairly deep water, and, more important, to avoid speaking of clays.

In the case of the finest sediments, current action implies non-deposition. In one pit, near Herbert Corners, lutite was seen to be filling a small hollow (Figure 34). This represents an instance where the water was placid enough for the fine sediments to settle out. Poor circulation entailed a ponding of cold, probably anoxic water which provided an environment unsuitable for faunal colonization.

(5) Conclusions on the hollow-fill facies

(a) Processes

Wave-washing, currents and slope instability, and the interactions between them, have been considered from the point of view of their possible role in supplying sediments to the hollows. In the case of the Stanley Corners section (Figure 11) and section 2 at South Gloucester (Figure 28) it is thought that small-scale turbidity current events were important contributors of sediment to the depressions. In order to initiate these events it was necessary that sediment supply was high, or, alternatively, that the slopes were unstable owing to the melting of buried ice. The latter mechanism is favored on account of its simplicity, requiring no further-removed process to supply a large quantity of sediment which, underconsolidated, would be prone to slumping. Possible agents to achieve a high supply of debris are especially active wave-washing, strong currents, and an outflow of sediment from a nearby ice-front. Of the three, the first may have been important in the case of the coarse sands in Mulligan's pit, for the sandy gravels at the top are ample testimony to the later direct action of wave-washing.

Wave-washing, it is thought, supplied the prograded sands exposed in Dibblee's pit (Figure 26). That deposit might be classified as a "progradation deposit" in the manner of Hessland (1946). The alternating sands in section 4 at Twin Elm, and similar sediments in Tierney's pit, were ascribed to the fluctuations in wave-base which would have accompanied changes in weather. The alternating sands are a distinctive deposit resulting from that process.

It is thought that the two major contributors of sediment to the hollow-fill facies were density flows induced by slope instability, and influxes of sediment, which occasionally may have been in the form of density flows, as a result of wave-washing of parts of the ridges which stood above the continually lowering wave-base. Currents normally associated with the marine environment are thought to have been of relatively minor importance owing to the size of the debris in many cases, and the very fact that the depressions were enclosed or partially enclosed.

(b) Facies models

By way of summary, five low-order facies models of the hollow-fill facies are presented (Figure 41). Each represents what is believed to be an important variant of hollow-fill sedimentation, irrespective of how many sections displayed characteristics of the model. As Sugden and John (1976, p. 8) remark, 'models are invariably inadequate and almost always wrong, but they are constructed as working hypotheses which can summarize elegantly a number of ideas.

In the models below the marine sediments are divided into three hypothetical phases: (1) "early hollow-fill"; (2) "later hollow-fill"; and (3) littoral and sub-littoral deposits. The first two correspond to the "early marine" and "later marine" stratigraphic divisions which are particularly in evidence at South Gloucester. The pre-marine deposits have been included as category 0. No temporal correlation is intended between the phases of marine sedimentation.

Model A - "diamicton type"

Twin Elm section 1 is the prototype for this model, and two phases of diamicton deposition are illustrated, the later one including

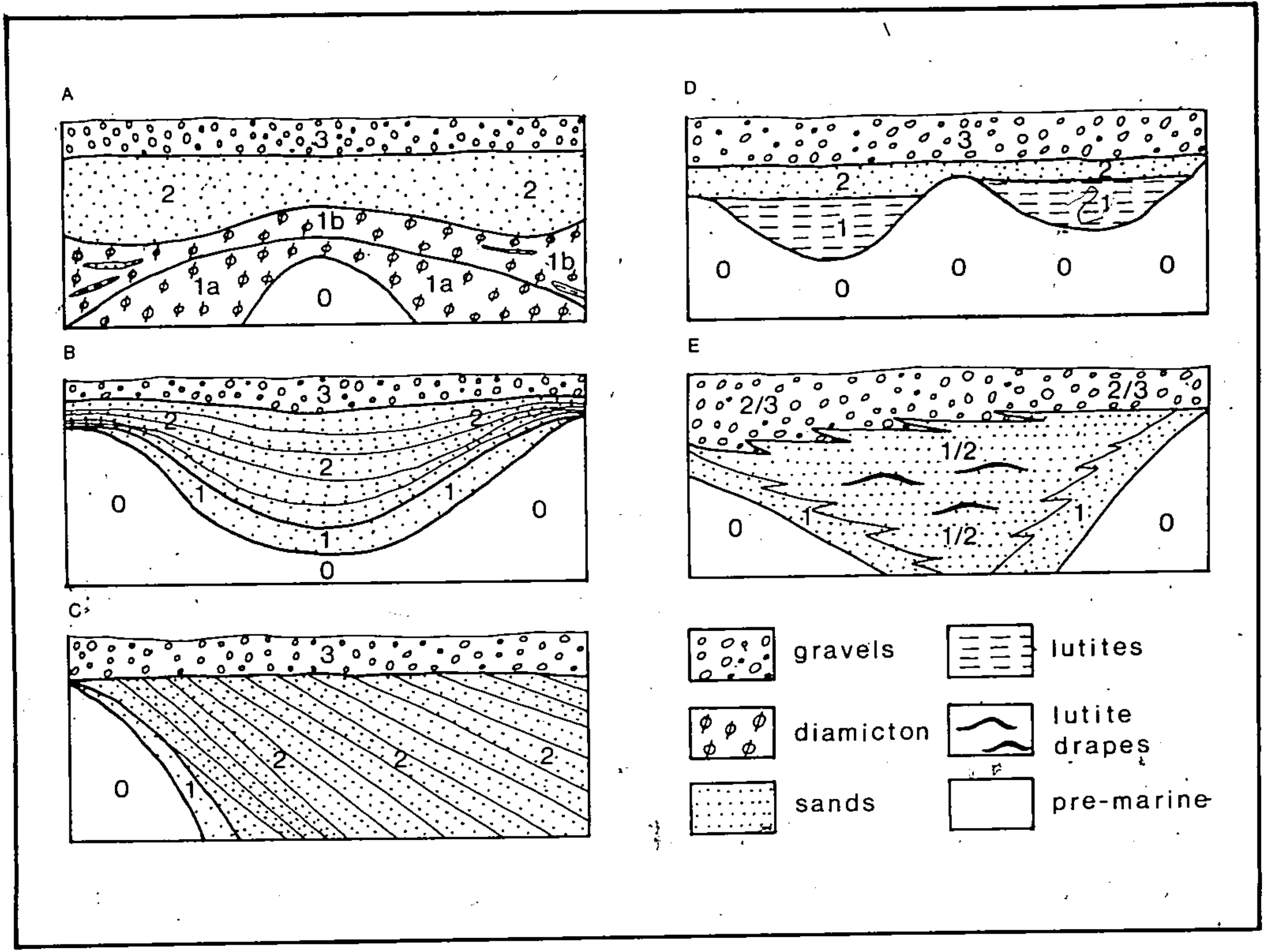

FIGURE 41: Facies models derived from the pit data. 0 - pre-marine deposits. 1 - "early hollow-fill". 2 - "later hollow-fill". 3 - littoral and sub-littoral deposits. See text for explanation.

interbedded stratified sediment. Another characteristic of that section, namely the completion of the hollow-filling by sands, is incorporated in the model.

Model B - "divergent stratification type"

Many variations of this model are possible, and South Gloucester section 2, Twin Elm section 4, and Tierney's pit are examples. The "early hollow-fill" sometimes underwent deformation before the deposition of the "later hollow-fill", the first having been deposited while wave-base was above the level of the ridge, the second after waves had commenced eroding the feature.

Model C - "foreset type"

In the case of a wide depression where sediments were built out in the lee of one flank of the hollow and sedimentation was not greatly influenced by the opposing flank, foreset bedding probably would have resulted. Section 1 at South Gloucester is evidence for this. The type of hollow-fill represented by this model is related to the "progradation deposits" of Hessland (1946) and to the wave-washed sediments observed by Blomquist (1969).

Model D - "lutite type"

Where a low energy environment enabled the settling out of fine sediment, a hollow-fill similar to that observed at Pyper's pit (west) (Figure 34) would have developed. A complete sequence would probably reveal a coarsening upward in the sediments, as Romanelli (1970) observed at Uplands.

Model E - "complex type"

In many schemes there is a 'catch-all' category, but this model is included for the principle it illustrates rather than its precise details. Contrasting with the impression of almost discreet stages of hollow-filling given by some sections, that at Mulligan's pit (Figure 11) suggests a continuous filling process. In this case, interfingering relationships are the rule, and the unconformity is readily attributable to the commencement of wave attrition on the ridge. Thus, in this model, the stratigraphy is quite complex, but the inferred processes show a simple evolutionary trend from those unrelated to wave action, through those where it played an indirect role, to deposits which owe their character (ignoring heredity) to wave action.

Along the sand and gravel ridges in the south Ottawa region, the processes operating in the Champlain Sea effected considerable reworking of sediment. Some materials were transported by longshore currents, but sediment was also deposited in numerous depressions left by the decay of dead ice. The facies models presented above summarize several types of "hollow-fill" which one might expect to observe in analogous situations elsewhere.

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APPENDIX

THE EFFECTS OF TREE ROOTS

In the higher parts of some sections the sediments appeared featureless and poorly sorted. Where a history of agricultural activities is apparent, such phenomena can be attributed to ploughing. In other instances, especially where deforestation is historically recent, the churning effects of the growth of tree roots and possibly falling trees can be diagnosed as the cause of the homogenization. Figures 42 to 45 illustrate examples of the effects of tree roots from the Twin Elm exposures. In Figures 19 and 20 the zones of root-churning have been mapped.

Figure 42 shows the truncated roots of a tree which was uprooted during excavations neighboring section 5, and Figure 43 illustrates part of the root system *in situ*. It is apparent that the deep root systems of deciduous trees (observed down to 4 m below the surface in a pit near Herbert Corners) can be a potent agent obliterating sedimentary structures. Figure 44 is a close-up of the zone affected by tree roots, and it illustrates the featureless nature of the sediments beneath the soil profile. In Figure 45A no tree roots are visible, but the topmost metre of sediment appears structureless. The last example (Figure 45B) portrays the undulatory nature of the top layer near metre 70 in section 5. Such corrugations are often associated with ploughing, but in this case the residue of a decomposed root is visible. In regions of Europe which were formerly affected by a peri-glacial climate, such features might be attributed to "frost-churning".

Judiciousness in interpretation, therefore, may often be required when the growth of tree roots has affected sections. Usually, an information loss will have resulted, unlike in dumping, where spurious units may be created.

FIGURE 42: Exposed root system of fallen tree near section 5 at Twin Elm.

Note the sediment enclosed in the root system. Notebook gives scale.

FIGURE 43: Part of tree root system *in situ* near section 5 at Twin Elm.

The sediments have been much altered by root growth and soil-forming processes. Notebook for scale.

FIGURE 44: Detail of upper part of root-churned layer near section 5 at Twin Elm.

The sediment is the gravelly sand described from section 5. The photograph illustrates the structureless and homogenized nature of the sediment and why no detailed interpretation was offered. Notebook is 21 cm long.

FIGURE 45A: Root-churned sand and gravelly sand in continuation of exposure shown in section 5 from Twin Elm. Notebook for scale.

FIGURE 45B: Root-churned zone near metre 70 in section 5, Twin Elm.

Note the undulating lower boundary of the gravelly sand. Dark material is decomposed root. Trowel gives scale.