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LATE QUATERNARY MARINE GEOLOGY OF MAKKOVIK BAY, LABRADOR

CHARLES Q. BARRIE
DAVID J.W. PIPER

Canada

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LATE QUATERNARY MARINE GEOLOGY OF MAKKOVIK BAY, LABRADOR

Abstract

Makkovik Bay is a low relief, 35 km long, complex fiord on the central Labrador coast. It is a well stratified, partially mixed-type estuary during the summer, probably with moderate sea water exchange. The degree of stratification appears to be related to fluvial flux and tidal mixing and is attenuated by sills and mid-fiord constrictions. Low values of suspended sediment and high rates of sediment accumulation measured by sediment traps suggest that the contemporary environment is wave-dominated, resuspending marginal sediments with deposition in the deeper basins.

Three major surficial units are recognizable within Makkovik Bay as interpreted from 3.5 kHz acoustic analogue data: lower basin-fill, conformable cover and upper basin-fill units. The lower basin-fill unit underlies the conformable cover unit in the deeper, quieter basins and is thought to be composed of coarse proglacial delta sediments, probably deposited prior to 11 000 years B.P.

The conformable cover unit is acoustically well stratified and mantles the entire bay, outcropping along topographic highs and in the nearshore zone. Short cores and grab samples penetrate an upper zone of stiff, homogeneous, olive-grey clayey silt and a lower zone of alternating brownish-grey and olive-grey beds with thin basal silt laminae. The distribution of benthonic foraminifera suggests a high rate of sedimentation in an open bay environment.

The conformable cover unit is interpreted to have had runoff-dominated deposition from suspension occurring during the last major transgression terminating at approximately 10 000 years B.P. Glacial detritus was transported fluvially northwards along the Makkovik Brook and nearby valleys and distributed across Makkovik Bay within the upper fresher water layer of a well stratified two-layer type estuary. Rapid deposition occurred through the lower, more saline water layer.

The upper basin-fill unit is characterized by poor acoustic reflectivity and a ponded depositional style with a variable degree of onlap which is inversely related to wave energy. Two piston cores penetrate four major facies of the upper basin-fill unit that represent a transition from runoff-dominated to contemporary wave-dominated deposition during regression and a decreasing fluvial flux. The lithologies change upwards from alternating olive-grey and yellow-brown muds through grey-brown to dark greyish-olive muds. The sedimentation rate decreases upwards from approximately 0.3 to 0.07 cm/year. At the base of the upper basin-fill unit benthonic foraminifera indicate open bay conditions, but become progressively more estuarine upwards. The transition to wave-dominated deposition occurs earlier in the Approaches than the Outer Bay; it is controlled by runoff and the relative sea level.

An erosional unconformity occurs within the upper basin-fill unit, at approximately 6500 years B.P., during the Holocene hypsithermal, and may be related to increased storm wave action, or to renewed wave activity after a brief period of suspension dominated deposition.

Résumé

La baie de Makkovik est un fjord complexe, de 35 km de long à relief bas, situé sur la côte centrale du Labrador. C'est un estuaire bien stratifié, à brassage partiel en été, présentant probablement un échange modéré d'eau de mer. Le degré de stratification semble être associé au flux fluvial et au brassage dû à la marée; il est atténué par des seuils et des rétrécissements situés au milieu du fjord. La faible concentration des sédiments en suspension et la forte accumulation des sédiments, mesurées par les pièges à sédiments, font penser que l'environnement actuel est dominé par les vagues; celles-ci remettent en suspension les sédiments marginaux qui se déposent dans les bassins profonds.

D'après l'interprétation des données acoustiques analogiques en 3,5 kHz, on distingue trois principales unités superficielles dans la baie Makkovik: l'unité inférieure de remplissage des bassins, l'unité de couverture concordante et l'unité de remplissage supérieure. L'unité inférieure de remplissage est recouverte par l'unité de couverture concordante dans les bassins plus profonds, plus calmes et est probablement constituée de sédiments grossiers deltaïques proglaciaires, probablement déposés il y a plus de 11 000 ans B.P.

L'unité de la couverture concordante est bien stratifiée acoustiquement et recouvre toute la baie, affleurant le long des hauteurs topographiques et dans les zones proches des rivages. Des carottes courtes et des échantillons isolés ont été prélevés dans une zone de silt argileux, gris-olive, homogène, rigide et dans une zone inférieure constituée d'une alternance de bancs gris-olive et gris-brun et de fines intercalations de silt basal. La distribution de foraminifères benthoniques laisse penser qu'on est en présence d'un taux élevé de sédimentation dans un environnement de baie ouverte.

L'unité de couverture concordante serait constituée surtout de sédiments apportés par ruissellement au cours de la dernière grande transgression qui s'est terminée il y a 10 000 ans B.P. environ. Les alluvions glaciaires auraient été transportées vers le nord par des cours d'eau empruntant la vallée de la rivière Makkovik et les vallées environnantes et déposées dans la vallée de Makkovik formant la couche supérieure d'eau plus douce d'un estuaire constitué de deux couches bien stratifiées. Dans la couche inférieure, à eau plus salée, la sédimentation aurait été plus rapide.

L'unité supérieure de remplissage est caractérisée par une sédimentation d'eau plus calme dont la réflexibilité acoustique est pauvre, présentant un degré variable de transgression qui est inversement relié à l'énergie des vagues. Deux carottes prises par carottier à piston ont traversé quatre principaux faciès de l'unité supérieure de remplissage des bassins qui représente une transition de la sédimentation procédant du ruissellement à la sédimentation contemporaine due aux vagues pendant la régression et le flux fluvial décroissant. La lithologie change de bas en haut, d'une alternance de boues gris-olive et brun-jaune à des boues brun-gris passant à des boues olive grisâtre foncé. Le taux de sédimentation décroît vers le haut de 0,3 à 0,07 cm/année environ. À la base de l'unité supérieure de remplissage, les foraminifères benthoniques indiquent des conditions de baie ouverte, qui deviennent progressivement plus estuariennes vers le haut. La transition vers la sédimentation dominée par les vagues se produit plus tôt dans les abords que dans la baie extérieure; elle est contrôlée par le ruissellement et le niveau relatif de la mer.

Il y a 6 500 ans B.P. environ, au cours de l'hypsithermal de l'Holocène, il s'est produit une discordance d'érosion dans l'unité supérieure de remplissage des bassins, reliée peut-être à une action accrue des vagues de tempête ou à une activité renouvelée des vagues après une brève période d'une sédimentation due surtout aux matières en suspension.

INTRODUCTION

Location

Makkovik Bay is a low profile fiord located on the isostatically rising central Labrador coast at 55°10'N (Fig. 1). It is approximately 35 km long and about 2 km wide. The fiord consists of a number of basins separated by sills and constrictions. Maximum water depths increase seawards, reaching 70 m in the outer bay. The Approaches to the bay (Fig. 2) include a number of deep basins and islands.

Purpose and background

This study had two main purposes:

1. to produce a model of sedimentation of an inlet characterized by a relative fall in sea level.
2. to describe the nature of late deglaciation of the central Labrador coastline.

Sedimentary processes within glaciated coastal inlets have been studied in Nova Scotia (Stanley, 1968; Piper and Keen, 1976; Amos, 1978; Barnes and Piper, 1978) and Newfoundland (Slatt, 1974, 1975). Both areas are characterized by a relative rise in sea level with continual reworking and redistribution of glacial drift deposited during periods of lower sea level. In Labrador the glacio-isostatic rebound is continuing and has created a shoreline that has been emerging during the Holocene (e.g. Daly, 1902; Andrews, 1969). The inlet sediments of Labrador have not previously been studied in detail. In a reconnaissance survey of Makkovik Bay, Piper and Iuliucci (1978) delineated six sediment types derived primarily from marginally exposed marine sediments. They suggested that during deglaciation the sea level stood 35-40 m above present, with proglacial deltas having silt and clay bottomsets extending across the bay. Since then, the falling sea level has reworked the coarse clastics into a nearshore sandy prism and the fine portion into the basins with an intermediate zone of no net deposition. One of the objectives of the present study was to examine these processes in greater detail, both sedimentologically and oceanographically.

The glacial history of the Makkovik region is poorly known. Because of the bare, glacially polished hilltops surrounding Makkovik Bay, Ives (1958) proposed a relatively thick ice sheet extending well out onto the continental shelf. In contrast, Vilks and Mudie (1978) found open water foraminiferal assemblages and tundra pollen in shelf sediment cores off central Labrador, which suggest open water shelf conditions and at least the presence of some coastal refuges or nunataks as early as 21 000 years B.P.

Correlation of pollen lake stratigraphies to the north (Short and Nichols, 1977; Short, 1978) and south (Jordan, 1975) of Makkovik suggests that glacial retreat from the coast began as early as 10 300 years B.P. and ice disappeared from the interior by about 5000 years B.P. (Short, 1978). Pollen assemblages suggest that cold conditions continued after deglaciation until the hypsithermal climatic optimum between approximately 7000 and 4500 years B.P., followed again by a cooling period commencing at about 3000 years B.P. (Short, 1978; Mudie, 1980).

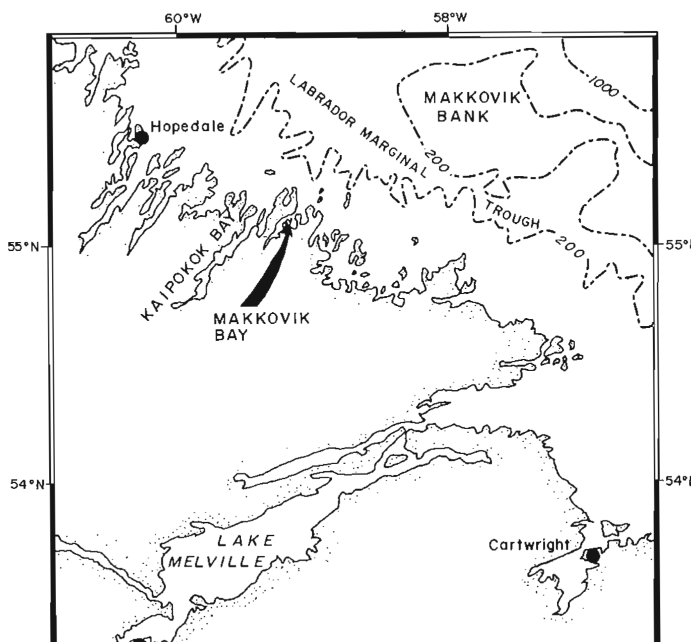


Figure 1. *Location map of Makkovik Bay.*

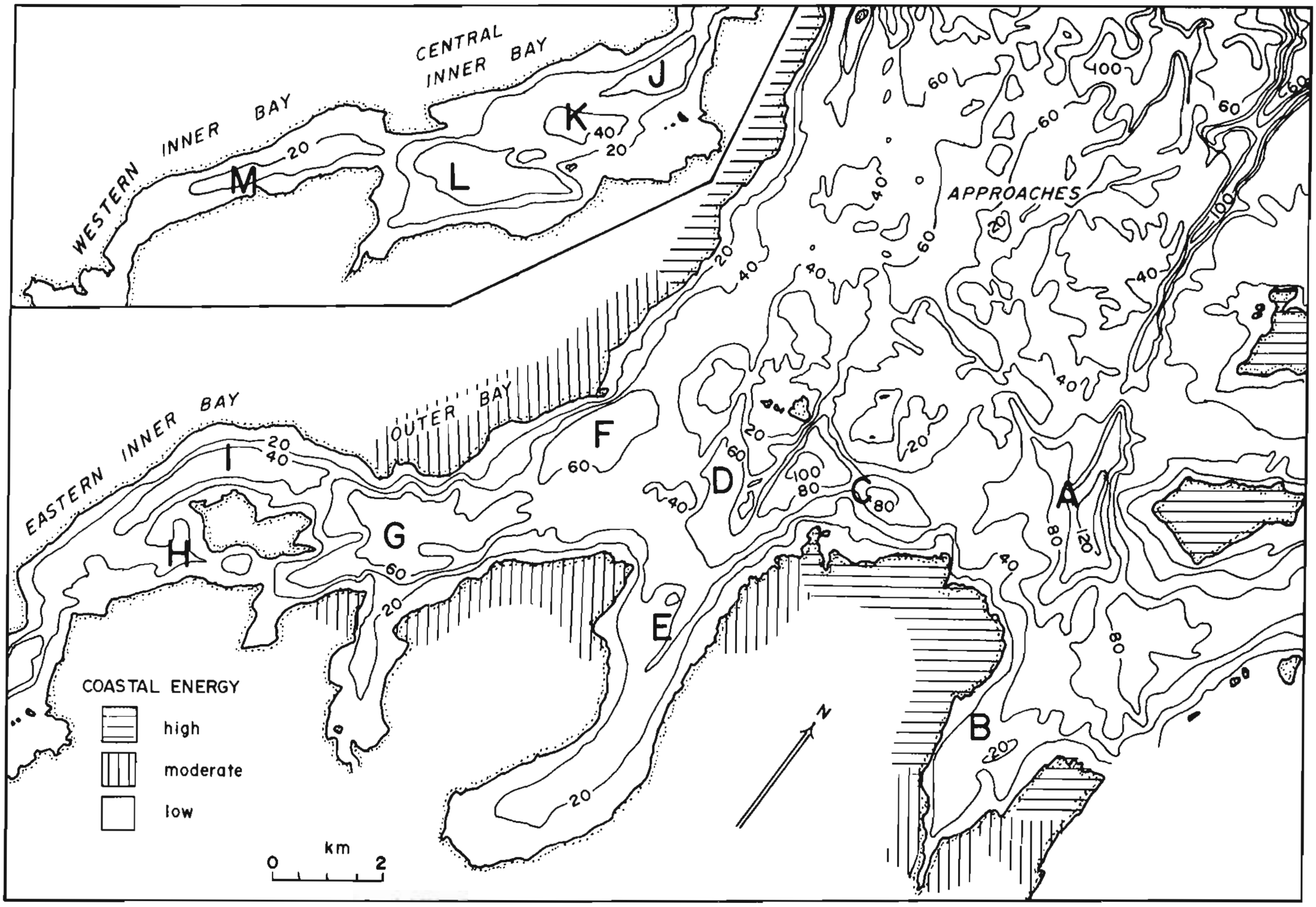


Figure 2. Bathymetry of Makkovik Bay. Contours at 20 m intervals based on Canadian Hydrographic Service field sheets. Shoreline energy based on height of wave wash zone from Rosen (1979a). Basins A-M refer to Figure 13.

Field methods

Approximately 285 km of 3.5 kHz seismic reflection profiles (Fig. 3), 13 temperature-salinity profiles, 6 suspended sediment samples and data from 4 sediment traps were collected from Makkovik Bay during August 1978, using a 35 foot fishing boat, the "Cathy Ford". Navigation was by sextant sights to landmarks. By allowing the boat to drift, wave noise was minimised in the 3.5 kHz profiles, and there was time to take closely spaced samples. However, drift rates and directions were not constant, and side echoes were enhanced by this technique. Observations were made on surficial land deposits during boat down-time. Two ten metre Benthos piston cores were collected in July 1978 on **CSS Hudson** cruise 78-020. A total of 149 short gravity cores and 313 grab samples were collected in 1977 (Piper and Iuliucci, 1978) and 1978.

Morphology and bathymetry

Makkovik Bay is divided into three morphologic regions: the Approaches, the Outer Bay, and the Inner Bay (Fig. 2). The outer limit of the Approaches is marked by a series of shoals and islands forming a sill with a least depth of about 30 m. The Approaches is an area of complex relief, with basins up to 130 m deep and extensive shoals. Most of the basins lie along three north-northeast trending lineaments, that continue southwards to define the embayments of Wild Bight, Ford's Bight and Makkovik Harbour (Fig. 3).

The Outer Bay, from Ikey's Point to Big Island, is about 5 km wide and the central basin is over 60 m deep. The Inner Bay has a much more irregular morphology, with constrictions less than 1 km wide at Grassy Point and Burntwood Point dividing it into an eastern, central and western part. The Inner Bay forms a number of basins, decreasing in depth from 50 m in the east to only 20 m in Western Inner Bay.

The Makkovik River enters the head of the Western Inner Bay. The only other sizeable river to discharge into the Bay, Makkovik Brook, enters at the head of Makkovik Harbour.

GEOLOGY OF SURROUNDING LAND AREAS

Geology

Bedrock geology has been summarized by Gandhi et al. (1969), who review previous work. The rocks comprise Archean and early Proterozoic gneisses, and early Proterozoic metasediments and intrusions.

Surficial sediments in the Makkovik area are thin and of limited extent. Small deposits of till are found in the protected valleys (e.g. King, 1963) but in most cases are overgrown by vegetation. Three sandy or gravelly deposits described by Piper and Iuliucci (1978) as raised outwash marine deltas were re-examined.

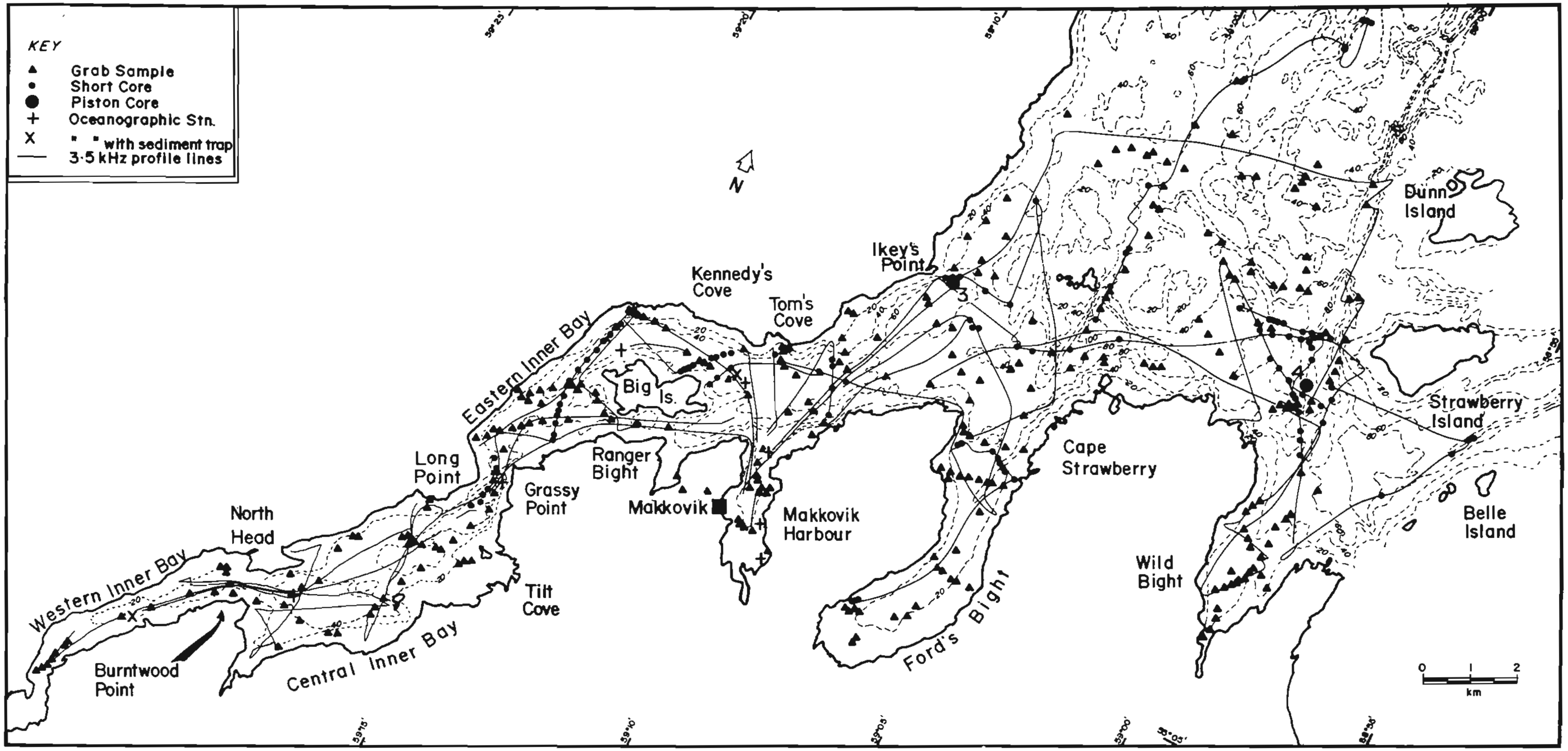


Figure 3. *Track chart and sample locations, Makkovik Bay.*

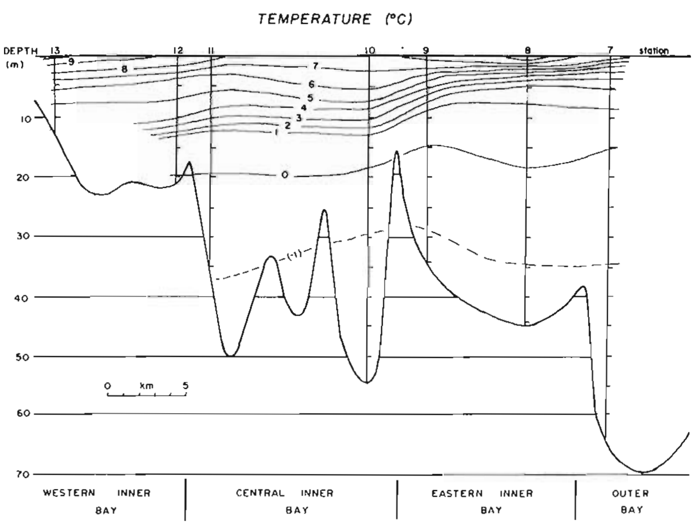
The Ranger Bight gravel pit is located just west of Makkovik settlement, 40 m above present sea level. Gravel and sandy gravel strata dip obliquely (15 degrees E) toward the hillside except on the west side of the pit where they level then dip slightly downbay (5 degrees W). The gravel deposit is unconformably overlain by a boulder layer overlain by well sorted, laminated sand. The gravelly strata and their highly variable dips suggest that the deposit is a kame delta, and not a marine delta. However, the unconformable veneer of well sorted laminated sand is probably a nearshore deposit, suggesting that the post glacial marine transgression reached at least 40 m above present sea level in Ranger Bight.

The Burntwood Point delta has sandy forsets dipping about 20 degrees downbay, cut by two marine terraces at approximately 10 and 20 m above present sea level.

The delta at the head of Makkovik Harbour is exposed on a downbay facing bluff. It consists of 6 m of sand dipping 25 degrees downbay overlying stiff grey clay (exposed on the foreshore). Gravelly sand and diamicton at the top of the bluff may be a solifluction deposit.

Coastal geomorphology

High energy shorelines (with a wave wash zone greater than 6 metres: Rosen, 1979a) face the Labrador Sea with bedrock cliffs up to 40 m high and only small isolated cobble beaches in embayments (Fig. 2). Moderate energy shorelines consist of rocky headlands, with cobble or sandy pocket beaches and occasional intertidal platforms, with a boulder barricade at the low tide level (Rosen, 1979b).



Low energy shorelines (wave wash zone of less than 2 metres) occur in the protected inner bays, and are characterized by narrow sandy beaches or fringe marshes and a nearly continuous intertidal platform. Streams debouch sandy, fan-shaped prisms over the platforms.

PHYSICAL OCEANOGRAPHY

General statement

There has been no previous work on the physical oceanography of Makkovik Bay, but some general characteristics of other Labrador fiords (Nutt, 1963; Nutt and Coachman, 1956) can be applied to the bay.

The coastline of Labrador experiences a maximum tidal range of about 2 m; a range of this magnitude was measured in Makkovik Harbour. Fiords are completely ice covered from November to late May. Mixing of fiord water with the Labrador current establishes isothermal (<1°C) and isohaline (32-33‰) conditions through the winter.

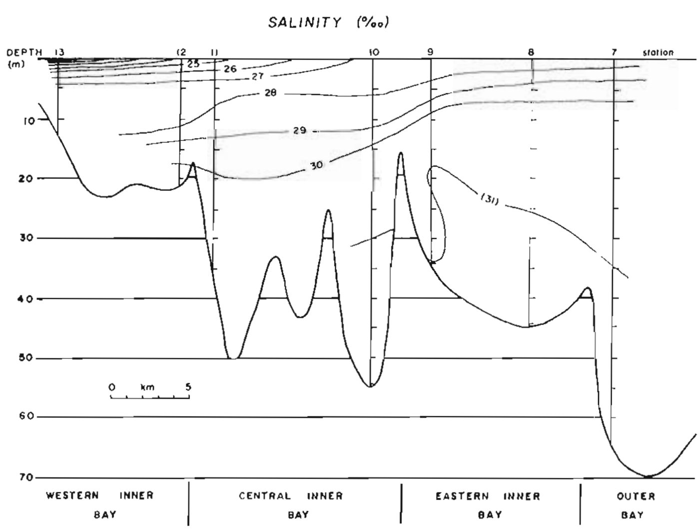
High runoff in the spring establishes a partially mixed, two-layer, stratified system composed of a warmer, fresh water veneer over a basal pocket of Arctic water. The degree of stratification is directly proportional to the volume of runoff which decreases throughout the summer, and to the restriction of water exchange with the Labrador current which is controlled by sill depth and channel width.

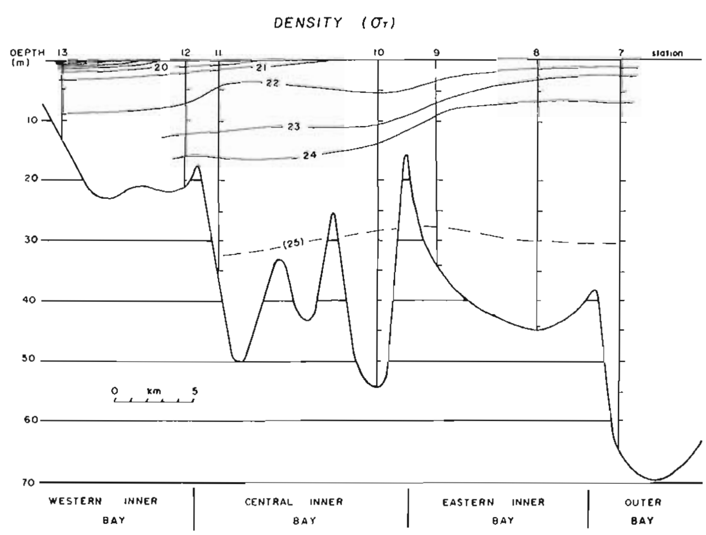
Physical oceanographic measurements

Temperature, conductivity and hence salinity were measured at 5 m depth intervals at seven stations (Fig. 3) from the Outer Bay to the Western Inner Bay on August 10, 1978, using a Beckman RS-5 sensor. There is a stable stratification throughout the bay (Fig. 4) with step-like gradients at constrictions. The profiles are very similar to those of Hebron Fiord, described by Nutt (1952) and Nutt and Coachman (1956), and therefore, similar oceanographic processes are suggested for Makkovik Bay.

Figure 4

Downbay profiles for August 10, 1978, during ebb tide, of temperature, salinity, and water density. Values in parentheses are estimates, since sensor will not measure negative temperatures.





The temperature-salinity distributions match those of dynamically active fiords in the sense that fresh water supply is sufficient to create an estuarine circulation flow above pockets of deeper, more stagnant water.

Maximum significant wave heights recorded seaward of Makkovik are 7.3 m with a 16 second periods (Rosen, 1979a). During August 1978 the largest waves in the Outer Bay were estimated visually to be 2 metres high while 0.5 m high waves were experienced in the Inner Bays. On calm days, a 1 m high, long period, swell was experienced in the Approaches and Outer Bay. These observations suggest that long period waves do enter the Approaches and Outer Bay, so that wave disturbance at the sea floor in water depths of many tens of metres is possible (Komar and Miller, 1974).

Suspended sediment and sediment traps

Six water samples were taken at a total of three stations during flood tide on August 10th, 1978, using 12 L Niskin Go Flow bottles, then pressure filtered using a maximum of 5 p.s.i. onto 4.7 cm Nucleopore polycarbonate membranes (Sundby, 1974). The dried membranes were weighed on an electomicrobalance in a dust free laboratory. Total analytical error is conservatively estimated at ±.08 mg/L. The results are plotted in profile in Figure 5.

Microscopic examination of the Western Inner Bay samples revealed primarily organic material, buff "flocs" and clay size material. The Outer Bay samples had dominant quartz and feldspar silt and minor floc material. The Central Inner Bay samples had an intermediate composition.

The highest concentration (8 mg/L) was taken in the shallow, well protected Western Inner Bay close to the mouth of Makkovik River, and is dominated by flocs. Near bottom suspended sediment concentration is lower in the Central Inner Bay than in the Outer Bay, the latter considerably more exposed to waves and swell capable of resuspending bottom sediments. The high suspended sediment concentration at 30 m depth in the central bay (Fig. 5) may also be due to resuspension and concentration along the upper edge of the salt wedge (e.g. Meade, 1972).

Twelve sediment traps were constructed from a 10.7 cm internal diameter, 60 cm long plastic pipe held vertically clamped to a taut, vertical mooring line (B. Hargrave, personal communication) and were suspended on two mooring lines, one in the Outer Bay and one in the Western Inner Bay, for a period of seventeen days. Each mooring had two sets of three traps, one set suspended 5 metres off the bottom and one set 10 metres below the thermocline. Because of the shallow depth in the Western Inner Bay, the upper trap was placed just above the base of the thermocline.

Immediately after retrieval, the upper two thirds of the trap water was decanted to remove the "suspended" sediments and the remaining sample was poisoned, bottled, and subsequently desiccated and weighed in the laboratory. The dried sediment was calculated as the number of grams of sediment that would pass through one square metre per day (Hargrave et al., 1976; Fig. 5).

The amount of sediment recovered in the Outer Bay trap extrapolates to a depositional rate of 1.7 m per thousand years, that in the Inner Bay to 0.5 m per thousand years. This relatively low rate of accumulation, compared with relatively high suspended sediment concentrations, suggests that wave resuspension of sediment is of importance in the bay.

ACOUSTIC STRATIGRAPHY

Analysis of acoustic profiles

The acoustic profiles were obtained with an ORE over-the-side boom mounted 3.5 kHz high resolution seismic reflection system. The thickest acoustic sequences occur in the basins, but most of the acoustic horizons cannot be traced directly from one basin to another. Individual basins must thus be interpreted before a synthesis can be made. Accordingly, thirteen representative basins were chosen (lettered A to M in an upbay direction in Fig. 2).

For each basin a line tracing was made of a representative 3.5 kHz acoustic profile. Except for obvious basement derived hyperboles, all major lines were traced regardless of their apparent origin. Sediment derived hyperbolic reflectors were also included although they may originate from suitably oriented small objects or side echos of nearby features. From these line tracings, a descriptive acoustic stratigraphic column was compiled and subdivided into acoustic facies on the basis of reflector characteristics and the depositional style of successive reflectors, and the character of individual reflectors such as the strength and continuity of the reflector.

Reflector strength is classified as weak, moderate, and strong, and is evaluated separately for each profile because of variation in instrument setting, water depth, and acoustic velocities of different sediment types. Therefore, in correlating two profiles, reflector intensity may be different but the relative strengths will be comparable. Reflector continuity may be either continuous or discontinuous.

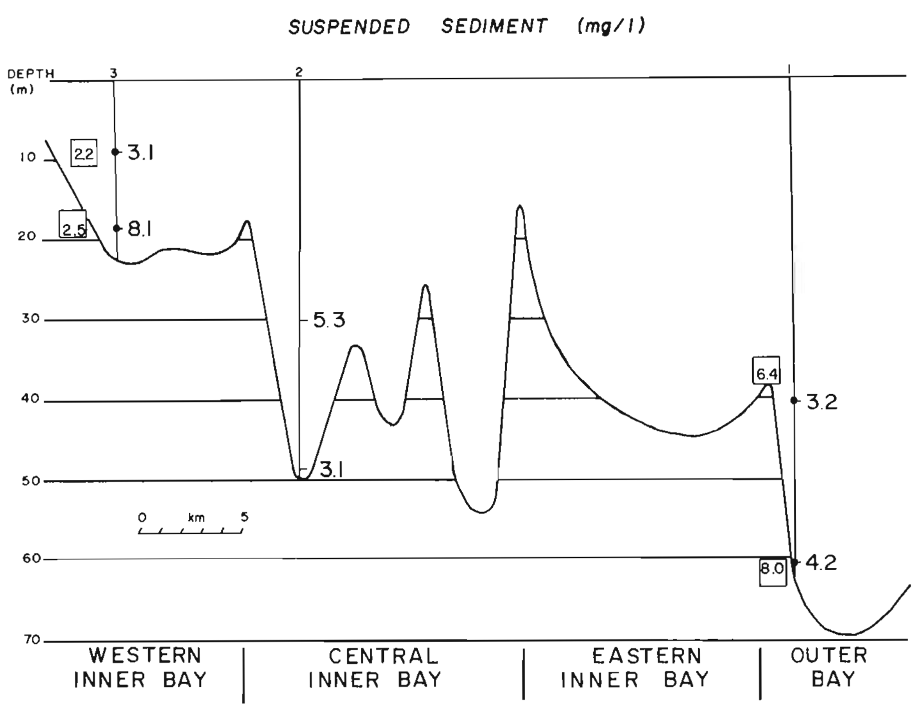


Figure 5

Concentration of suspended sediment in mg/L in August, 1978. Dots indicate sediment traps: numbers in boxes are trap accumulation rates in gm/m²/day.

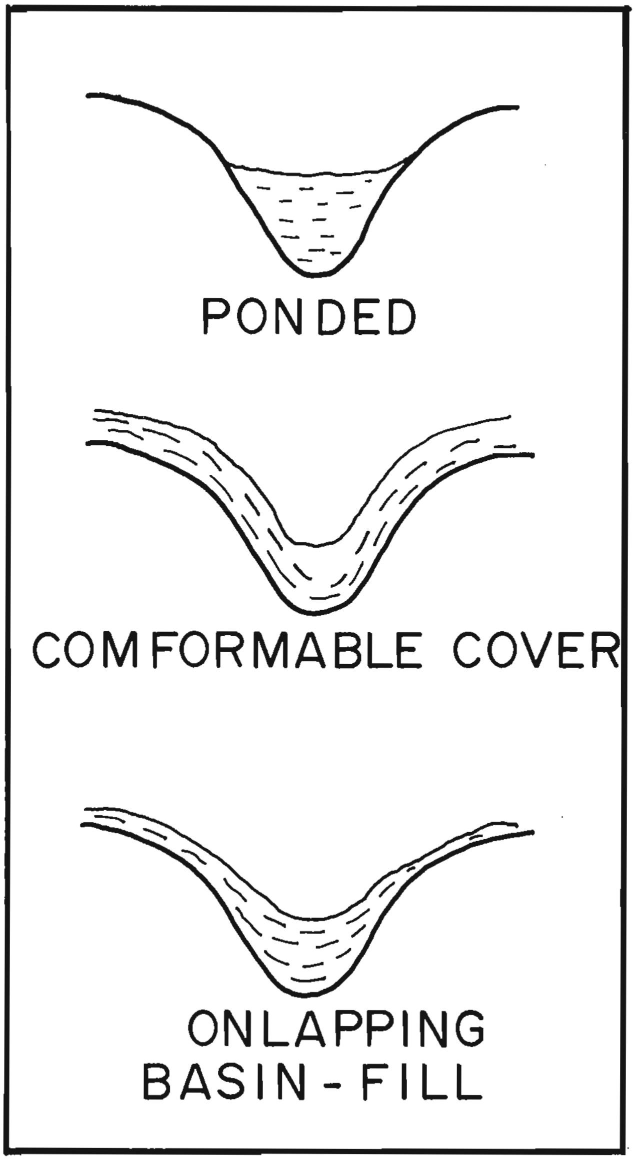


Figure 6. *The three depositional styles of acoustic reflector recognized from 3.5 kHz profiles.*

An erosional unconformity is based on evidence of truncated horizons, not just the likely representation of specific hyperbolic surfaces (Damuth and Hayes, 1977).

The strong, lowest, usually continuous reflection is considered to be acoustic basement. On the acoustic record it varies from a smooth solitary reflection to irregular tightly overlapping hyperbolae with widely varying vertex elevations.

Three styles of relationships between reflectors and the basin margin are distinguished (Fig. 6), and are referred to subsequently as depositional styles:

1. Ponded basin-fill consists of horizontally stratified reflectors indicating that the sediment is contained by the basin in a fluid-like manner.
2. Conformable cover reflectors may thin on the basin slopes but can be traced across sills into adjacent basins.
3. The onlapping basin fill type possesses the infill characteristics of the ponded forms plus the flank climbing habit of the conformable type. Reflectors may pinch out on the basin flank.

Depositional style is best assessed only from low gradient basin slopes, preferably on records collected at a low boat speed. The acoustic artefact of over steepening (side effect) of slopes (Van Overeem, 1978) can obscure the nature of the sediment on the basin margin, superimposing a ponded morphology on all types. No sediments appear to accumulate on very steep slopes.

Description of examples of basins

The detailed description of the stratigraphy of each basin has been presented elsewhere (Barrie, 1979, 1980). Only selected examples are given here. Basin F, located in the Outer Bay adjacent to Ikey's Point (Fig. 2, 3), shows many of the characteristic features of basin stratigraphy (Fig. 7). Five acoustic profiles were collected across the basin. Thicknesses described below assume V = 1500 m/sec, and refer to the type section illustrated in Figure 7.

The basal 4 metres have ponded to onlapping, very weak reflectors, distinguished as acoustic facies F1. It was not recognized in any of the other four profiles collected across the basin. The overlying acoustic facies F2 is 12 metres thick and has numerous strong, continuous reflectors that are generally conformable with the basement, although individual horizons do thin in shallow depths. The upper surface of this unit is eroded where it outcrops in water depths of almost 60 metres. It was eroded prior to the deposition of the overlying unit F3 at a depth of 95 metres at the base of the steep slope off Ikey's Point (a, Fig. 7).

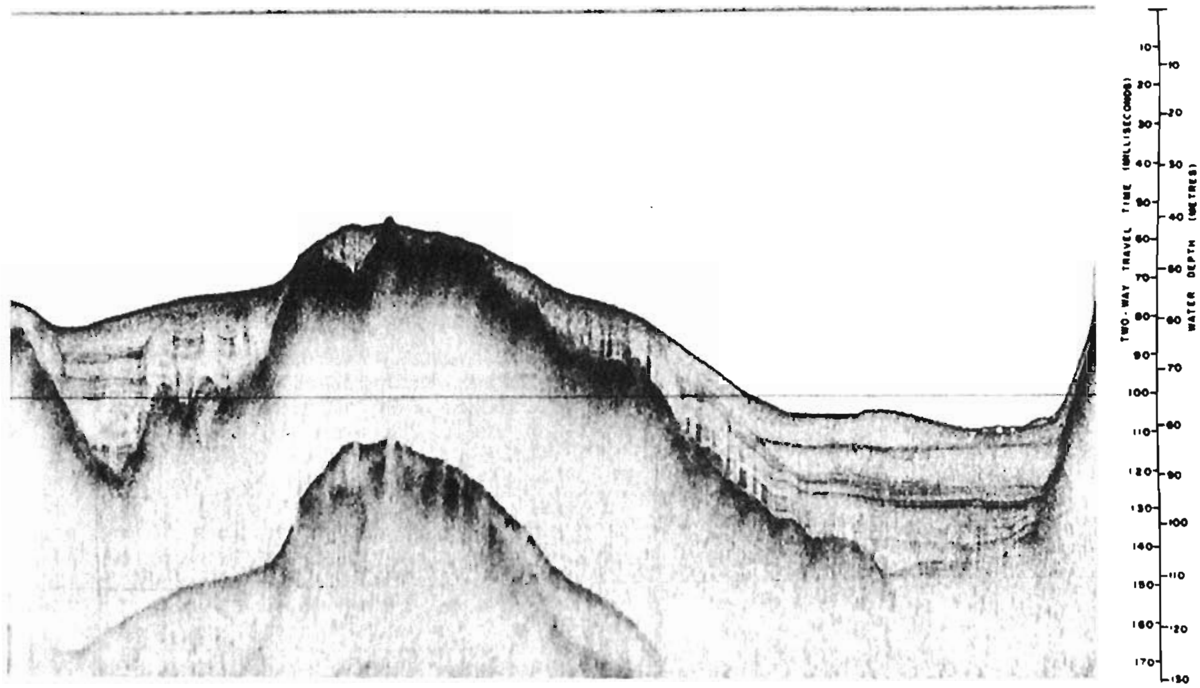
Acoustic facies F3 is 6 metres thick and is acoustically transparent with very weak reflectors. It has a ponded depositional style, although indistinct internal reflectors suggest conformable to onlap style. Faint reflectors appear to be truncated at the upper surface which is characterized by a strong reflector (b, Fig. 7).

F3 is overlain by 8 metres of acoustic facies F4 which is characterized by an onlapping basin-fill style. It has weak continuous reflectors and minor, moderate strength, discontinuous reflectors. Rapid thinning of F4 close to the steep slope in the west suggests a low net depositional zone, and possible truncations of reflectors (c, Fig. 7) may indicate actual erosion.

Basin A (Fig. 8) located between Strawberry Island and Cape Strawberry is typical of the Approaches. The lowest acoustic facies (A1) above basement is characterized by strong, continuous conformable reflectors. It is up to 24 metres thick and its upper surface is truncated by an erosional unconformity (a, Fig. 8). Unit A2 has a maximum thickness of approximately 12 metres and is characterized by weak, discontinuous evenly spaced reflectors. The style is intermediate, between conformable and onlapping basin-fill. A2 does not extend to the deepest part of the basin, and its upper surface is clearly erosional, although there is also some pinching out of reflectors.

Basin G, which is located down bay from Big Island, has the thickest sequence of sediments in the Bay (Fig. 9). The basal 10 metres comprise G1, with strong and moderate strength reflectors that are usually continuous. The lowermost 4 metres are partially obscured by basement derived, irregular hyperbolae. Acoustic facies G1 appears to be ponded at the base and slightly onlapped at the top. Acoustic facies G2 has primarily weak to moderate strength, discontinuous reflectors. It is approximately 13 metres thick and is ponded with slight onlapping tendencies. A few hyperbolic reflections with vertices of equal elevation occur in the upper parts of the unit (a, Fig. 9). Acoustic facies G3 is up to 13 metres thick and is conformable with the basement. The reflectors are continuous and are strong at the base of the unit, and decrease in strength upwards. The uppermost

BASIN F



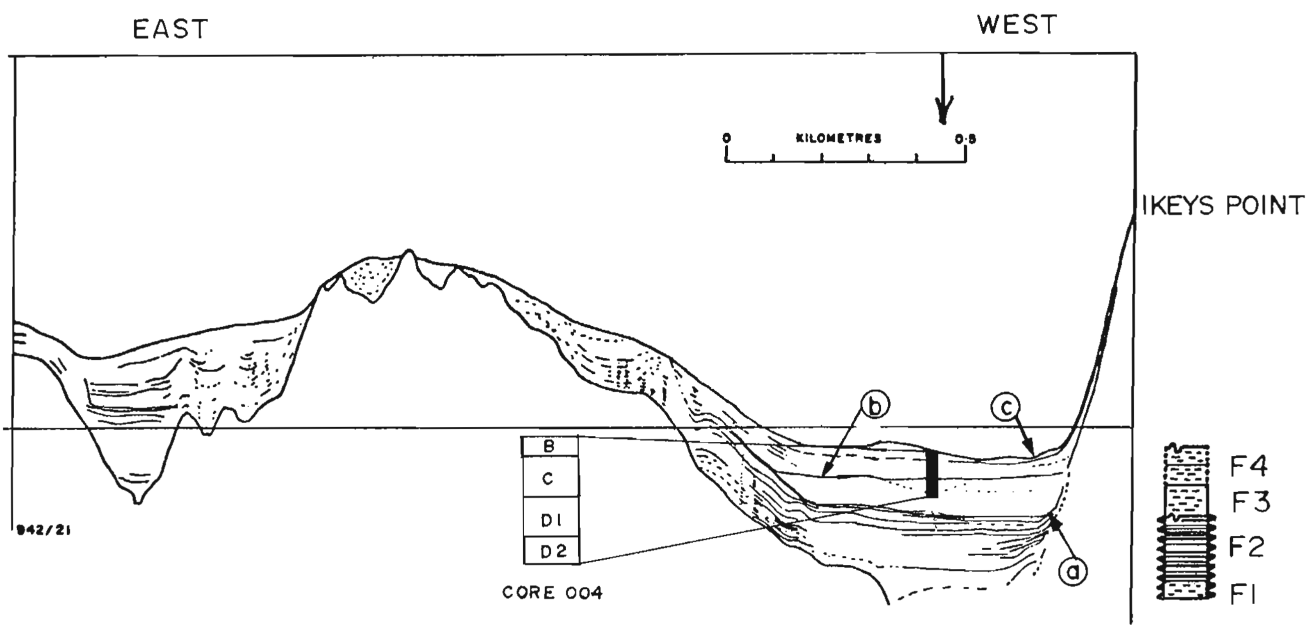


Figure 7. *Basin F: 3.5 kHz profile (top) and line tracing (bottom). Arrow indicates location of type acoustic section (right), showing acoustic facies F1-F4. Key to acoustic section symbols in Figure 13. Also shown is correlation with piston core 004. For explanation of a, b, c, see text.*

BASIN A

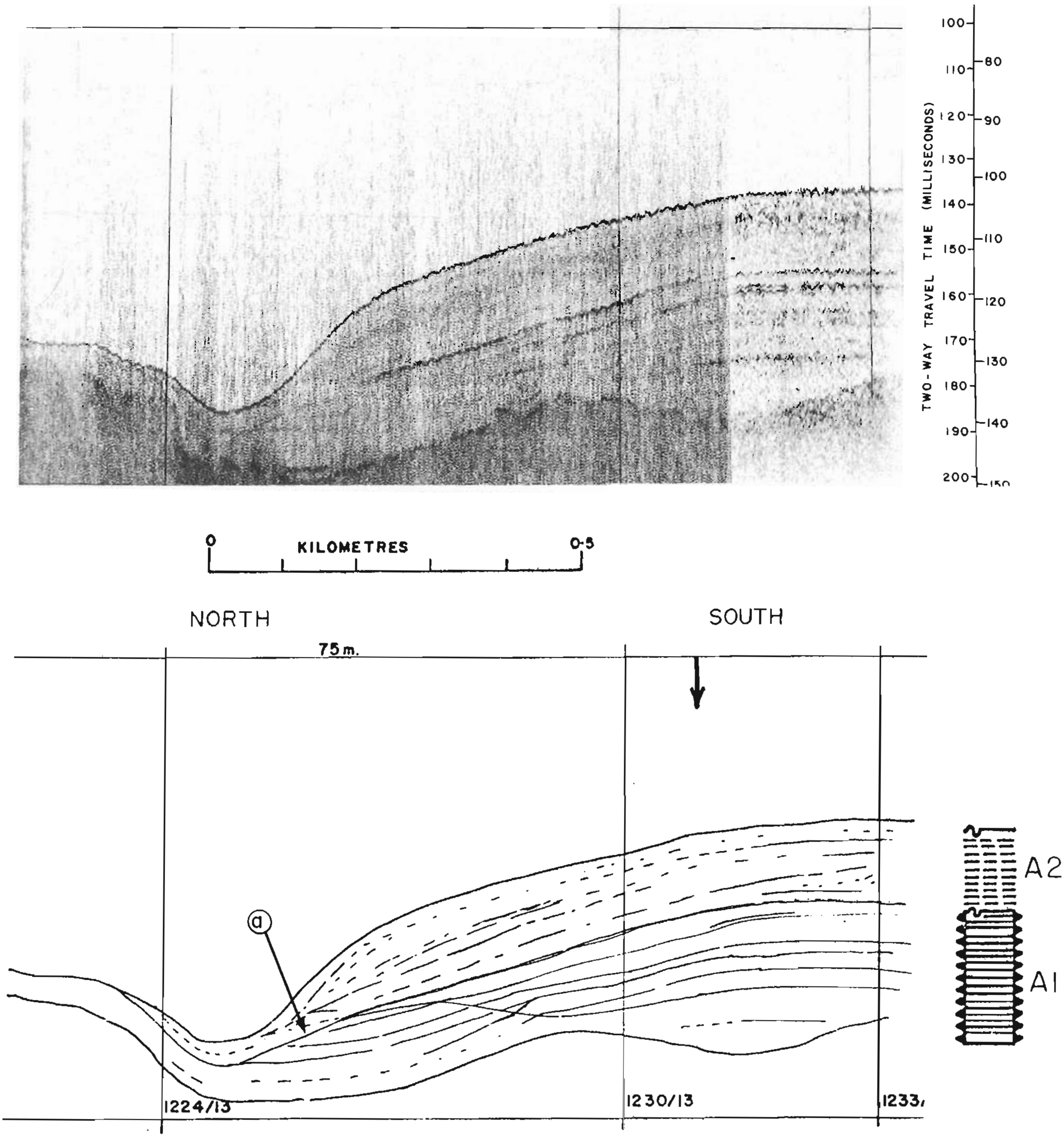


Figure 8. *3.5 kHz profile, line tracing and type acoustic section (right) for basin A. For explanation of a, see text.*

BASIN G

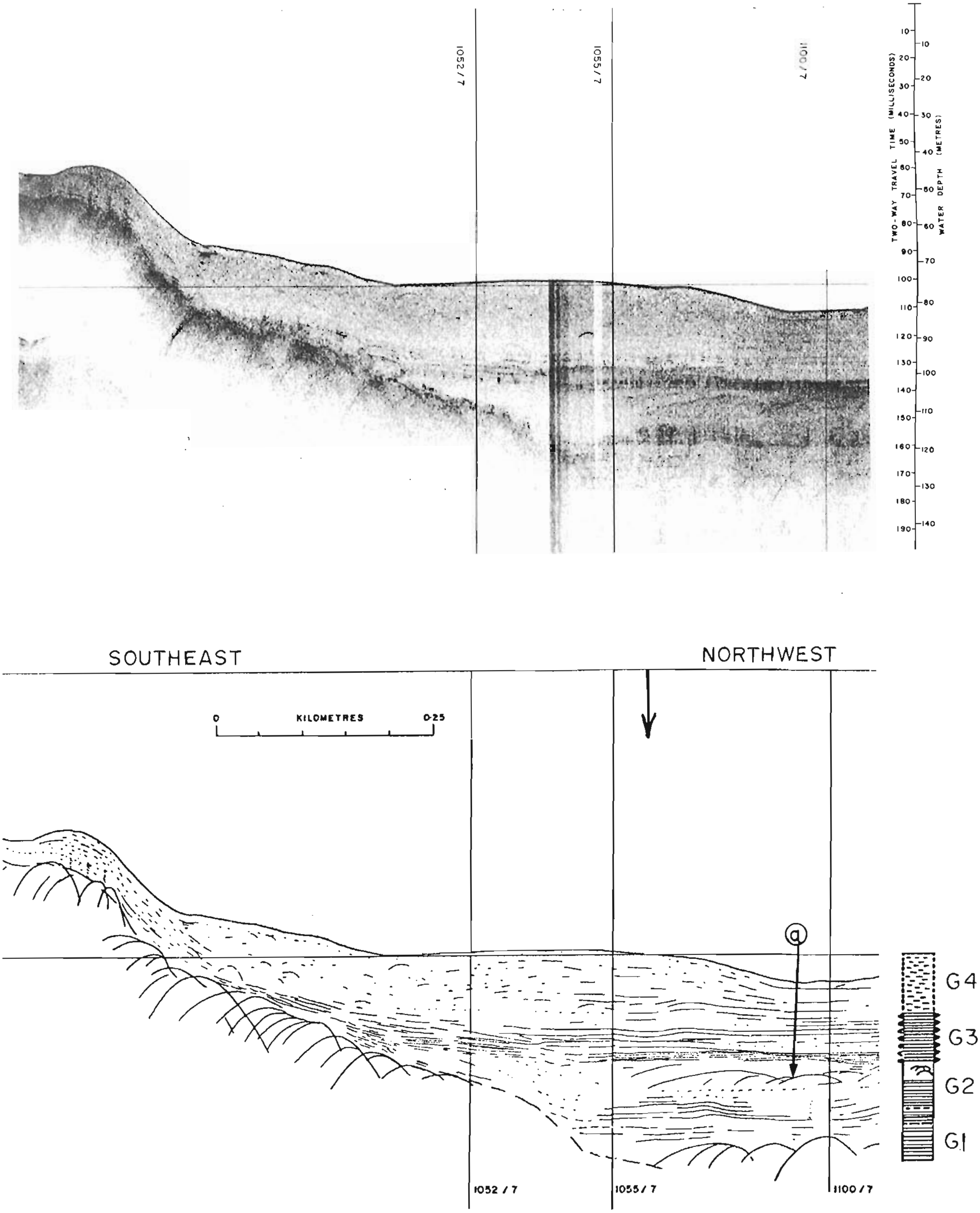


Figure 9. *3.5 kHz profile, line tracing and type acoustic section column for basin G. For explanation of a, see text.*

BASIN J

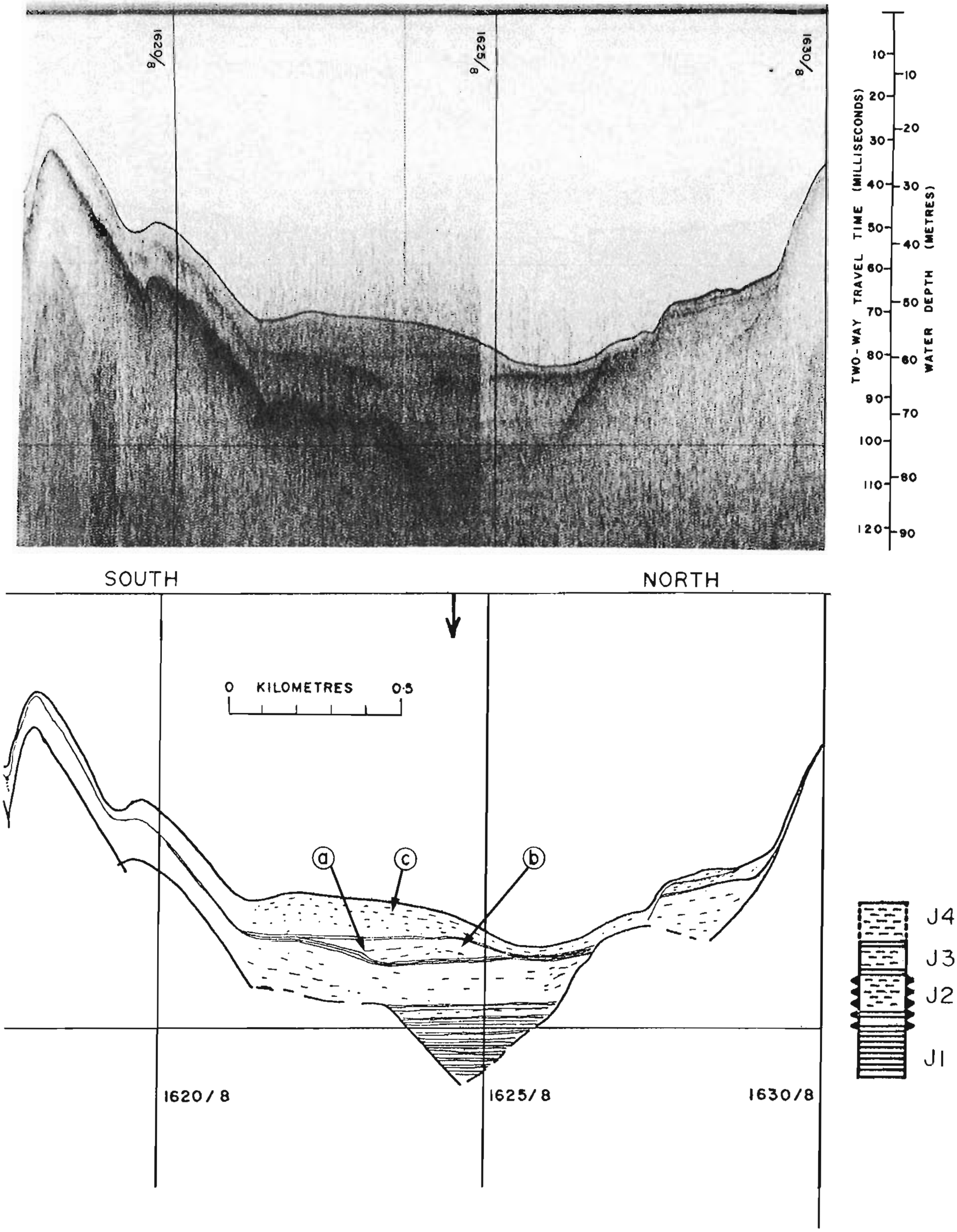


Figure 10. *3.5 kHz profile, line tracing and type acoustic section for basin J. For explanation of a, b, c, see text.*

BASIN L

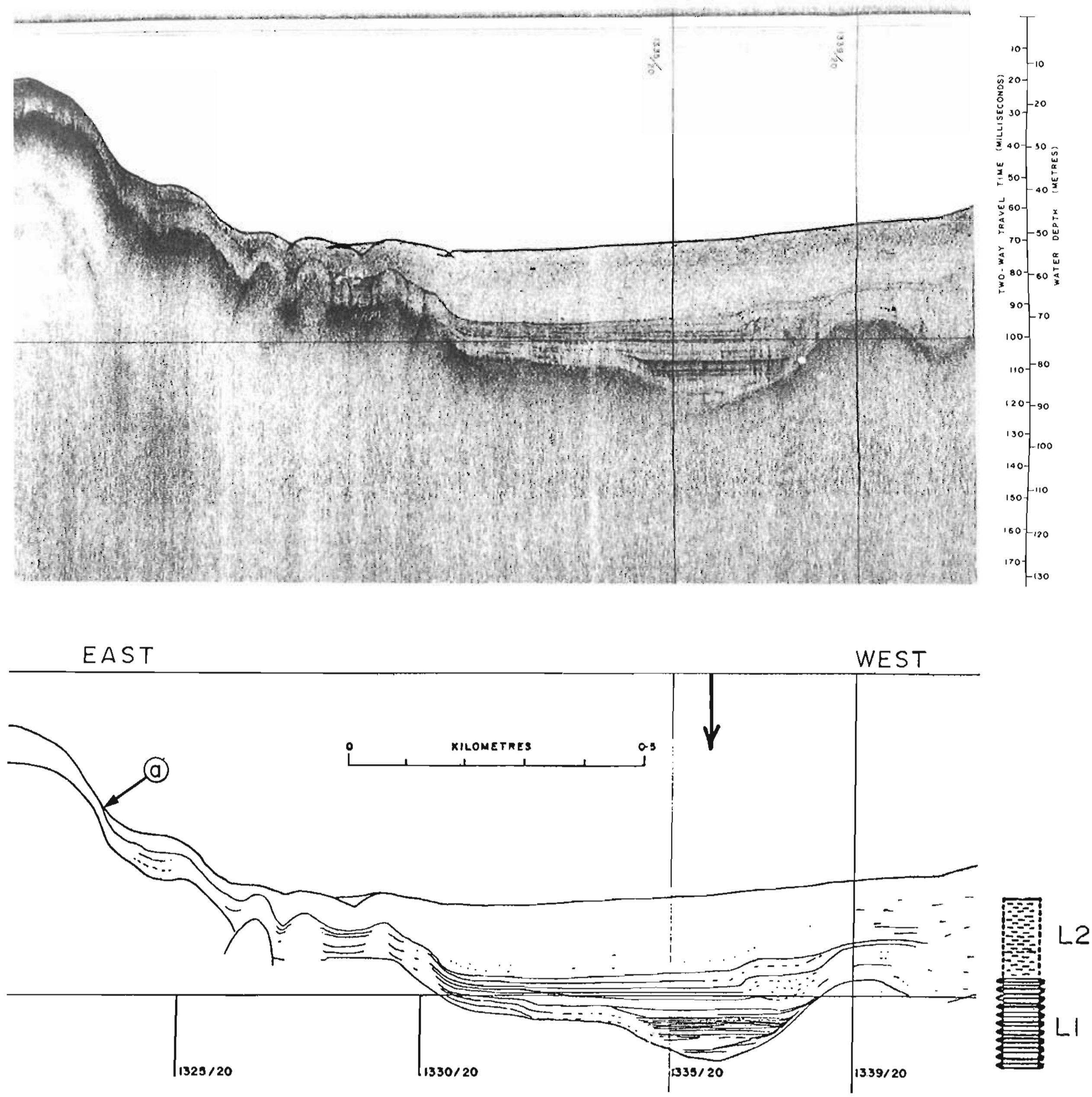


Figure 11. *3.5 kHz profile, line tracing and type acoustic section for basin L. For explanation of a, see text.*

acoustic facies, G4, has a maximum thickness of 16 metres and appears to have an onlapping basin-fill style. The reflectors are usually either weak and continuous or moderate and discontinuous.

Basin J is located just upbay of Grassy Point. The acoustic profile is noisy (Fig. 10). The basal 8 metres (J1) has strong continuous, ponded reflectors. Acoustic facies J2 is up to 9 metres in thickness and has weak to moderate, discontinuous, conformable reflectors. The upper reflector is very strong and continuous. Unit J3 is a 4 metre thick ponded wedge found only in the centre of the basin (a,b, Fig. 10) and has moderate noncontinuous reflectors. Although ponded on the upbay side (a), the individual reflectors pinch out rapidly downwards on the downbay side (b). The upper surface is a strong and continuous reflector that does not appear to be erosional. The uppermost 6 metres comprise J4 which is characterized by onlapping basin-fill strata with weak to moderate, noncontinuous reflectors. Unit J4 thins rapidly above b where J3 pinches out. There does not appear to be an unconformity at either interface but there may be an internal unconformity within J4 (c, Fig. 10).

Basin L (Fig. 11) is located east of Burntwood Point. The lower 20 metres comprise L1, characterized by strong and moderate continuous reflectors that are conformable

BASIN M

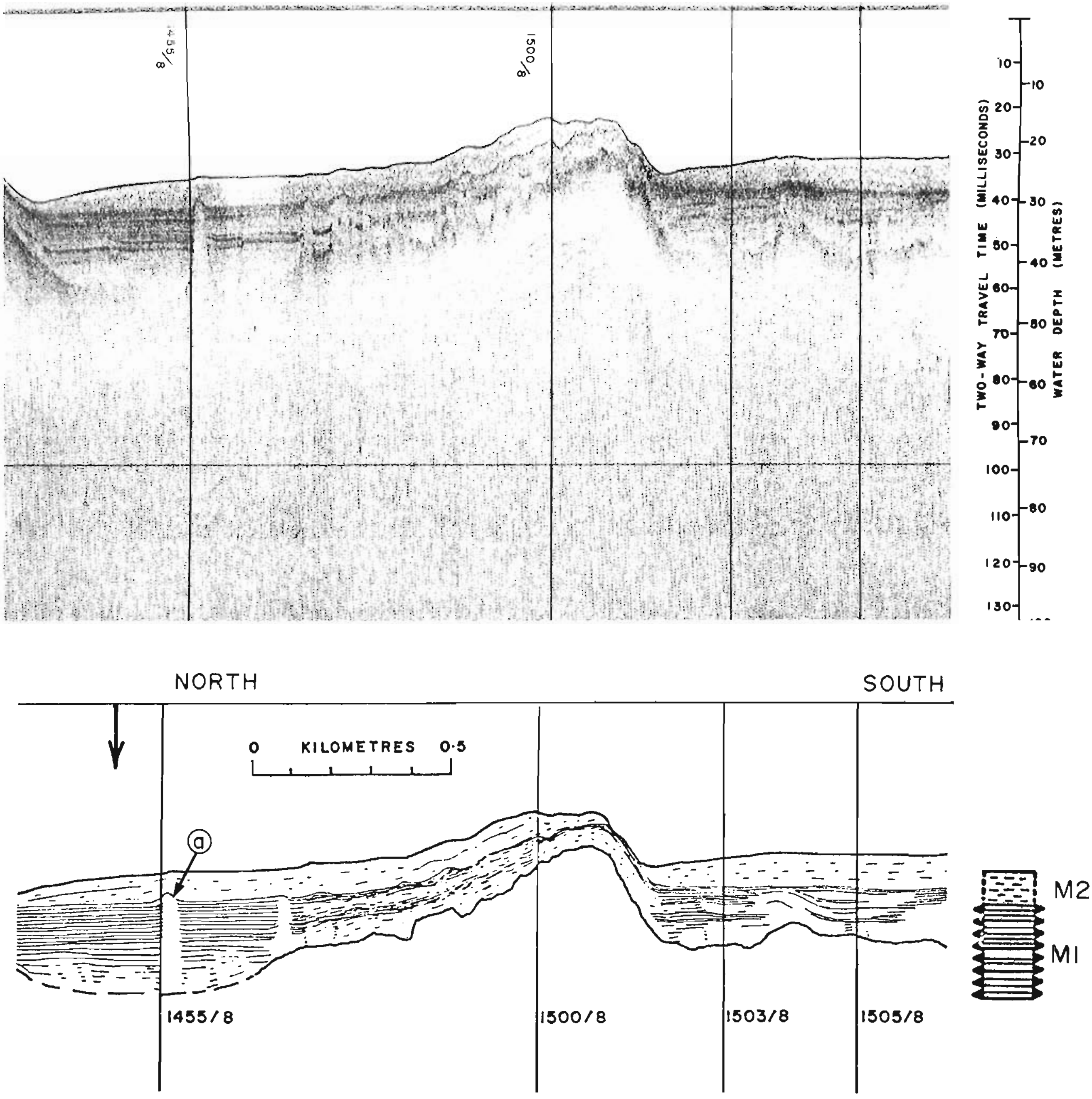


Figure 12. *3.5 kHz profile, line tracing and type acoustic section for basin M. For explanation of a, see text.*

with the basement. All individual horizons exhibit pronounced thinning downbay. Two other profiles of basin L suggest that below L1 there is a thin, continuous, onlapping unit adjacent to the basement. Acoustic facies L2 is approximately 18 metres thick and is characterized by onlapping basin-fill strata with weak to moderate, discontinuous reflectors. L2 onlaps the downbay flank up to a water depth of 30 metres where unit L1 is exposed (a, Fig. 11).

Four profiles were made of basin M, west of Burntwood Point. The clearest profile is shown in Fig. 12. The lower acoustic facies, M1, is 14 metres thick and has strong, continuous and conformable reflectors. As in the other Inner Bay basins, the acoustic nature adjacent to the basement is poorly defined. Within facies M1 are 50-100 m wide zones (a in Fig. 12) in which stratification is indistinct or absent, and in which seismic velocities are higher. Similar features are seen in the basal acoustic facies in Wild Bight. They might result from a lateral facies change (presumably developed in an ice-contact environment), or from a cap of high velocity material such as gravel and boulders. The upper acoustic facies, M2, is 5 metres thick with onlapping basin-fill style and weak, discontinuous reflectors.

Interbasin correlation of acoustic stratigraphy

Correlation of the descriptive stratigraphic columns for the thirteen basins is made in Figure 13. All columns are drawn with their respective positions along the axis of the bay using the present day sea level as a datum, with the exception of B, E, and H which are offset below the others to resemble their relative geographic position.

Four major acoustic units can be distinguished. From the surface down they are: an upper basin-fill unit, a conformable unit, a lower basin-fill unit, and a nonpenetrable unit (acoustic basement).

(1) Upper basin-fill unit. This consists principally of weak reflectors with an onlapping basin-fill style. Sequences with a ponded depositional style above the conformable cover unit are also included. Correlation is excellent throughout the Inner and Outer bays.

Correlation of the upper basin-fill unit in the Approaches is problematic. Although the upper unit A2 has weak reflectors, it appears conformable in places: this unit occurs throughout the Approaches. In basin B there is a thin veneer with weak reflectors and a conformable outline, possibly representing remnants of eroding upper basin-fill type sediments (as observed in the Outer Bay in basins D, E, and F).

The isopach map of the upper basin-fill unit (Fig. 14) shows that sediment thickness increases rapidly with depth for any basin. Maximum sediment thickness is greatest in the Outer Bay. The distance of the zero contour from the shoreline increases downbay.

(2) Conformable cover unit. This consists of strong reflectors with a conformable cover depositional style. The unit can be clearly correlated within the Inner and Outer bays and less certainly out to the Approaches, but here it is difficult to differentiate the conformable cover unit from the lower basin-fill unit (described below). Therefore, the isopach map (Fig. 15) includes both of these units.

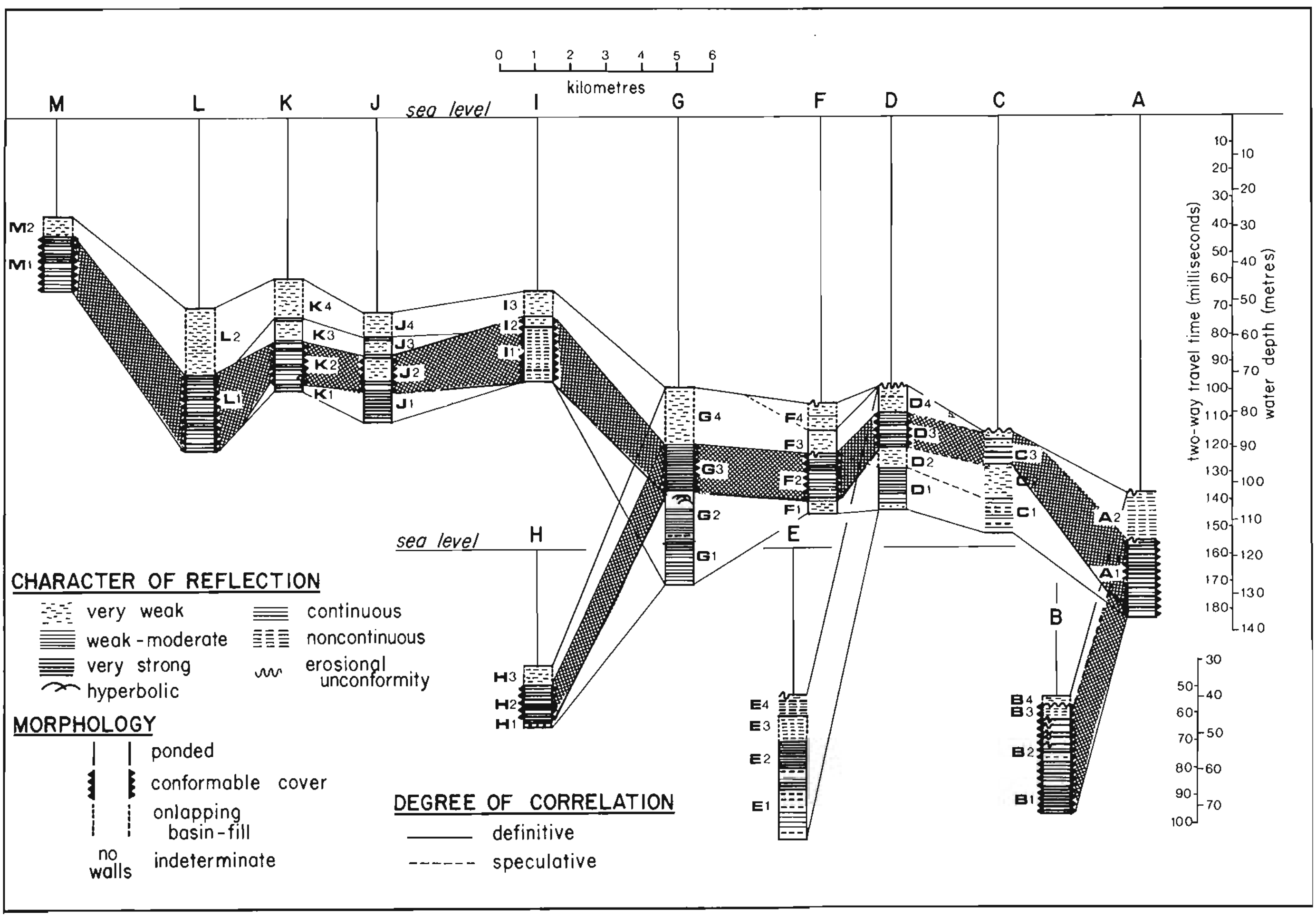


__Figure 13.__ Interbasin correlation chart of the type acoustic sections for each basin showing three major units: (1) upper basin-fill unit, (2) conformable cover unit (stippled correlation), (3) lower basin-fill unit. Basin locations in Figure 2.

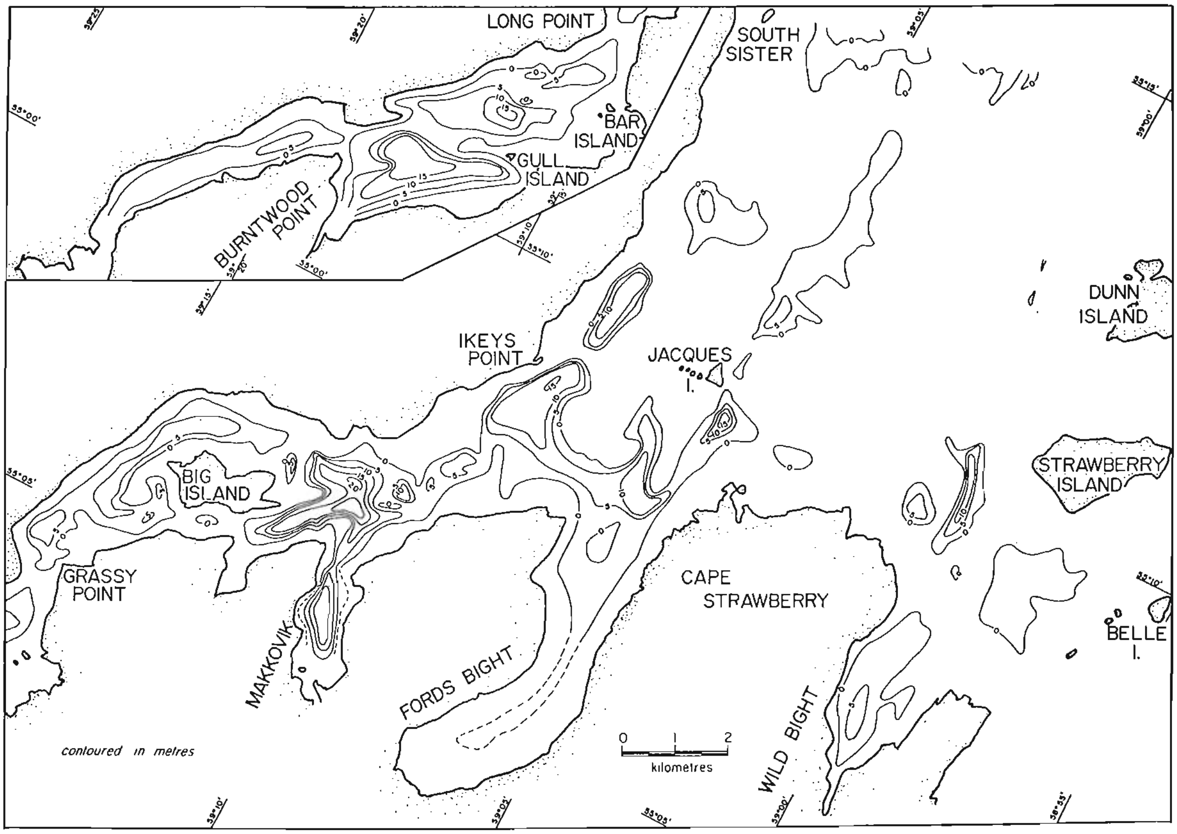


Figure 14. *Isopach map of upper basin-fill acoustic unit, contoured in metres (V = 1500 m/sec).*

The conformable style of the unit is emphasized on this map, which shows the thickness increasing only slightly with depth. Abrupt thickness changes are generally confined to the nearshore zone where the unit is being eroded. The maximum thickness probably varies by less than five metres from the Western Inner Bay to the Outer Bay, bearing in mind that Figure 15 also includes the lower basin-fill unit. Although the average basinal thickness of the conformable cover unit is constant from the inner bays to the outer fringes of the Approaches, the larger basins display a conspicuous downbay pinching at the top of the unit (e.g., Fig. 11). As in the upper basin-fill unit, the distance of the zero contour from the shore line increases downbay, but is always inshore of the zero contour of the upper basin-fill unit. Upbay from Big Island it was impossible to locate the zero contour because a nearshore sandy prism masked deeper sediments. At Kennedy's Cove and at the heads of Makkovik Harbour and Fords Bight, the unit extended to the intertidal zone, where a stiff grey clay outcrops.

(3) Lower basin-fill unit. This has reflectors of variable strength and generally possesses a ponded depositional style. It is observed primarily in the Outer Bay, where the sedimentary sequence is the thickest (Fig. 13) but may also correlate with units in basins H, J, and K in the Inner Bay. Alternatively, the ponded nature of these units may be an artefact of slope or side effects, and they may in reality be conformable. Interpolations are severely limited by poor data base.

(4) Nonpenetrable unit. This forms acoustic basement. It might be either bedrock, very coarse clastics or till. Airgun and Huntec deep towed seismic profiles from nearby Kaipokok Bay suggest till is very rare, and acoustic basement is usually bedrock. The nonpenetrable unit outcrops at the surface in high energy shoal areas, where bedrock or coarse clastics occur.

Erosional disconformities

A map of the surficial distribution ("outcrop") of the acoustic units can be produced by superimposing the two isopach maps (Fig. 16). The upper basin-fill unit occurs in the protected basins, at increasingly shallower depths upbay. The conformable cover unit is exposed along the upper flanks of the inner bays and the middle to lower flanks of the Outer Bay and Approaches. Flank erosion of the conformable cover unit has concentrated coarse lag sediments and, in places, has exposed the bedrock. Together these make up the shoal nonpenetrable unit.

Shallow moats and truncated reflectors at the bases of steep slopes suggest areas of low net deposition and, in places, erosion. Moats are observed along all the steep slopes in Makkovik Bay. For example, in basin F a surficial moat (c, Fig. 7) and truncation of deeper reflectors (a, Fig. 7) indicate that these processes have been operational to varying degrees throughout the depositional history.

A third type of erosion, basin wide erosion, occurs in the upper basin-fill unit in basins D, E, F, J, and K. For example, in basin F at b in Figure 7 a strong, continuous reflector truncates upward curving strata of acoustic facies F3. It is thought that basin wide erosion is responsible for removal of sediments, leaving the underlying strata with an apparent ponded depositional style.

Depositional interpretations

The systematic variations in acoustic reflectors suggest that the acoustic stratigraphic units, as defined by the relative strength of reflection and their depositional style are representative of different lithologies, and hence, different depositional environments (Fig. 17).

The acoustical transparency and homogeneity of the upper basin-fill unit suggest that the sediments are relatively

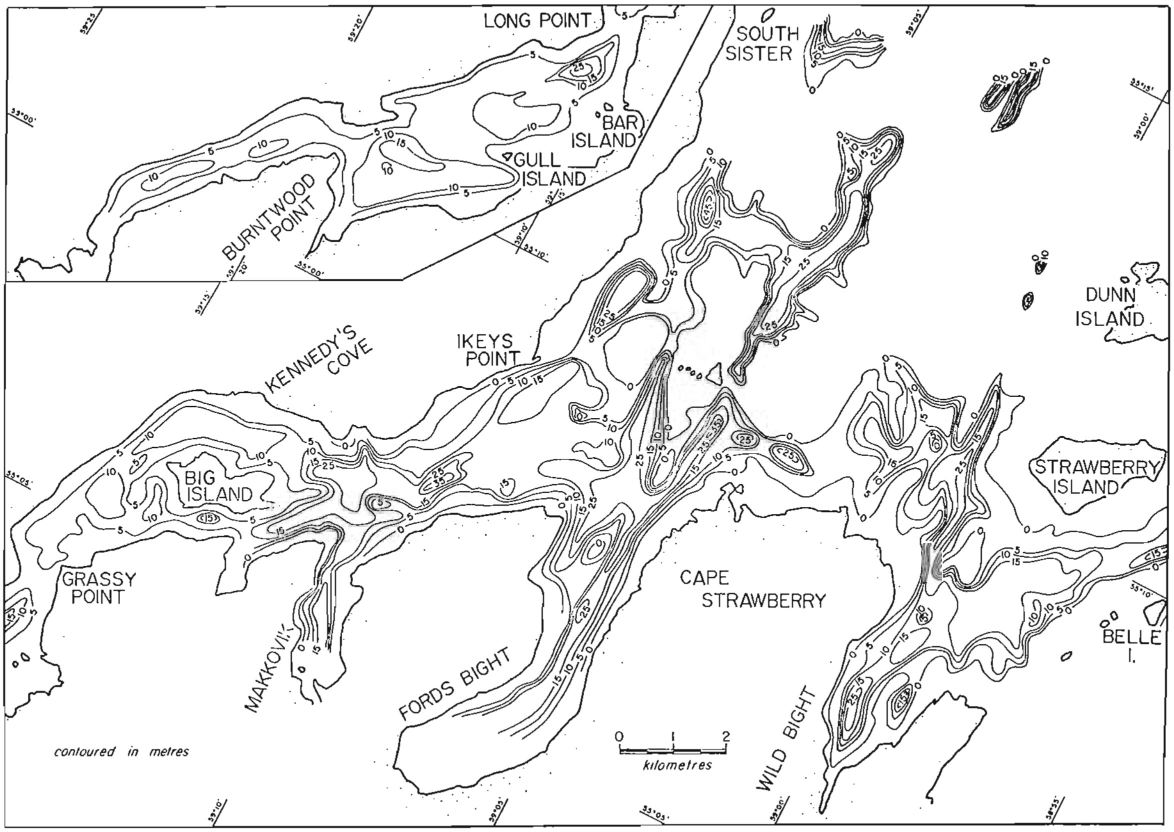


Figure 15. *Isopach map of the conformable cover unit and the lower basin-fill unit, contoured in metres (V = 1500 m/sec).*

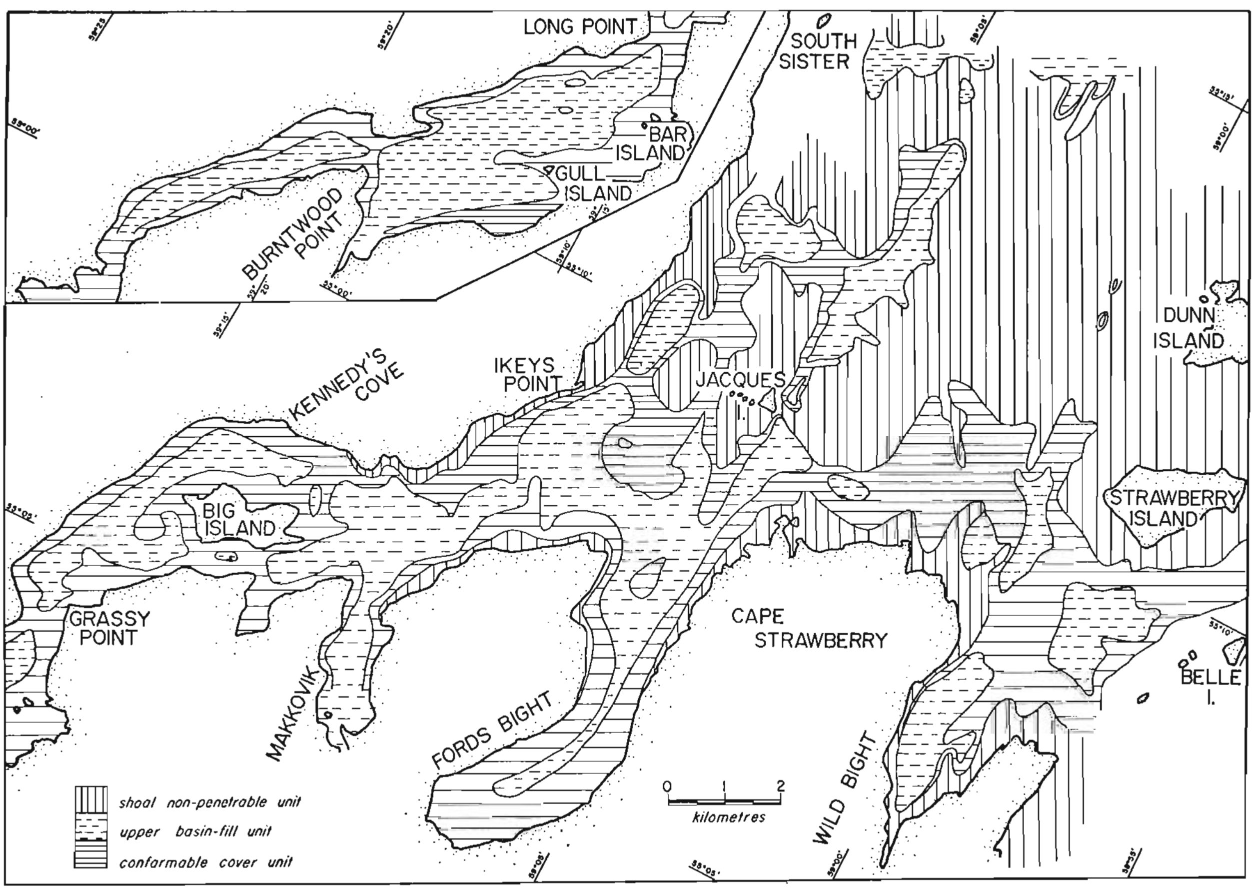
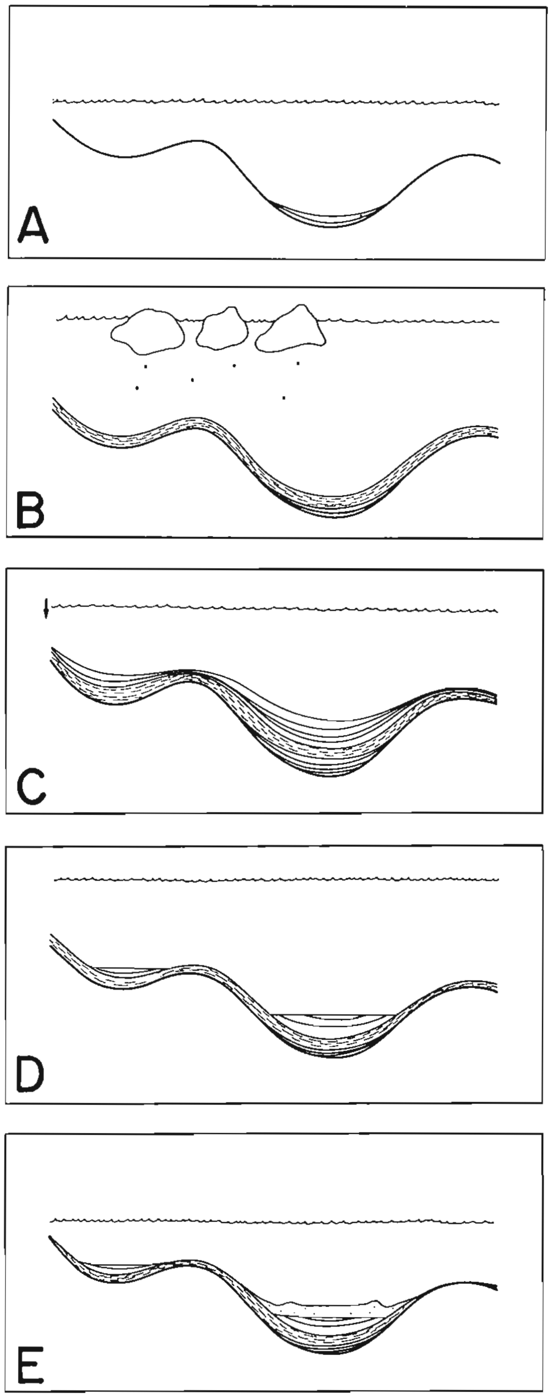


Figure 16. *Surficial distribution of acoustic stratigraphic units: (1) upper basin-fill unit, (2) conformable cover unit, (3) nonpenetrable unit.*



A *Lower basin-fill unit: depositional environment uncertain.*

B *Conformable cover environment: widespread deposition during high relative sea level with little influence of waves.*

C *Transition to basin-fill environment: major deposition in the basins during a decreasing relative sea level and an increasing influence of wave energy on the flanks.*

D *Period of basin-wide erosion: erosion in shallow and exposed basins, probably by waves.*

E *Basin-fill environment (contemporary): continued decrease in relative sea level and subsequent erosion of sediment along the upper flanks and deposition in the basins; moats form at the bases of steep slopes.*

Figure 17. *Model of postglacial development determined from the acoustic stratigraphy.*

homogeneous and fine grained. The depositional style implies that the currents and/or wave energy retard sedimentation on the flanks and topographical highs while fine grained sediments are deposited relatively uniformly in the basins.

The acoustic data indicate surface, basin-wide erosion occurs in the outer half of the Outer Bay and throughout most of the Approaches to a maximum depth of 50 m. The intensity of erosion is proportional to the adjacent shoreline energy type mapped by Rosen (1979a), suggesting that basin-wide erosive energy is related to surface waves.

The acoustic character of the conformable cover unit suggests that it is composed of fine grained sediments that contain thin, laterally persistent reflectors. Since the acoustic intensity is little reduced by these reflectors, they are unlikely to be continuous sand or gravel beds but rather may represent groups of silt laminae or sand and gravel disseminated in a muddy matrix (c.f. Dale, 1979).

The reflectors have been deposited without significant winnowing or erosion since reflectors are persistent at variable depths throughout the same basin, and the entire unit and the reflectors pinch together on steep slopes while maintaining the conformable style. If the reflectors arise from the presence of coarser clastics they would probably be ice rafted. Silt could have been transported and deposited from turbulent near surface water. Two examples of downbay pinching strata within the upper region of the conformable cover unit suggest local sediment sources during the waning stages of deposition.

The conformable style and the lack of moats or basin-wide erosion suggest that this unit was deposited during quieter conditions than the upper basin-fill unit. Furthermore, the presence of the five metre isopach in a present day water depth of only five metres in the Western Inner Bay (Fig. 15) suggests that the quiet water environment must have been accompanied by a substantial increase in water depth. The quiet conditions may have been augmented by increased ice cover. This quiet water requirement suggests that the conformable cover unit is time concordant throughout the bay.

There are not sufficient good quality acoustic profiles of the lower basin-fill to be able to make an interpretation solely on acoustic data.

SURFICIAL SEDIMENT DISTRIBUTION

General description of lithologic units

The surficial distribution of sediment types (Fig. 18) was studied from 257 grab samples and 15 short gravity cores collected by Piper and Iuliucci (1978) in 1977 and a further 134 short gravity cores and 56 grab samples collected in 1978 (Fig. 3). Visual and x-radiograph examination of the short cores led to a classification into three contemporary and one relict lithologic units.

All sorted sands and coarser sediments have been grouped into the <u>coarse veneer unit</u>. This includes sorted sands in the nearshore zone (3, Fig. 18); and pebble and cobble gravels, sometimes with comminuted shells, in patches on rocky shoals and along the coastline of the Approaches (4, Fig. 18). Gravelly and poorly sorted sands occur in deeper water at the edge of the shoals (5, Fig. 18).

Ponded within the quiet basins is a highly organic bioturbated olive mud (mostly 5Y4/2), referred to as the <u>basinal mud unit</u> (1, Fig. 18). Along the flanks of the bay, olive mud occurs, with frequent horizons of sand or gravelly mud, termed the <u>gravelly mud unit</u> (2, Fig. 18, Fig. 19a). It is abruptly overlain by the coarse veneer unit in the nearshore (Fig. 19b) and grades stratigraphically upwards into the basinal mud unit at basin margins (Fig. 19c).

An apparently relict stiff <u>grey clayey silt unit</u> outcrops in various sites of erosion within the bay. It outcrops and is overlain by the coarse veneer unit in the intertidal zone (Fig. 20) and around some shoals. Along the flanks, it is locally exposed or overlain by the gravelly mud unit. A series of cores along outcrops revealed by acoustic profiling suggest that grain size increases towards the base of the unit. Most of the unit appears relatively homogeneous and almost structureless, but a few cores sampling the base have alternating brownish-grey and olive-grey beds. Each bed is several centimetres thick with thin basal silt laminae passing rapidly upwards to mud.

Correlation with acoustic stratigraphy

The relationship between the outcrop areas of acoustic units (Fig. 16) and the distribution of the surficial units (Fig. 18) is as follows:

Acoustic Unit	Surficial Lithologic Unit
shoal nonpenetrable unit	I. coarse veneer unit
upper basin-fill unit	II. basinal mud unit
conformable cover unit	III. gravelly mud unit IV. grey clayey silt unit

These relationships do not necessarily imply that a particular acoustic unit is made up of the corresponding lithologic unit. For example, the coarse veneer unit frequently forms a very thin layer over bedrock, and may rest on the conformable cover acoustic unit. However, the acoustic character of the upper basin-fill unit suggests that it does consist of the basinal mud lithology.

The areas in which the conformable cover acoustic unit outcrops correspond to both the gravelly mud and the grey clayey silt lithologic units, although only the latter was sampled by short cores along erosionally truncated strata of the conformable cover acoustic unit. Since the gravelly mud lithologic unit is overlain by the basinal mud lithologic unit in some cores, and overlies the grey clayey silt lithologic unit in others, it might be interpreted as lying stratigraphically between the conformable cover and upper basin-fill acoustic units. Alternatively, the gravelly mud lithologic unit may represent a zone of slow reworking and sediment bypassing. In either case, the gravel is matrix supported, suggesting that it is deposited by ice rafting.

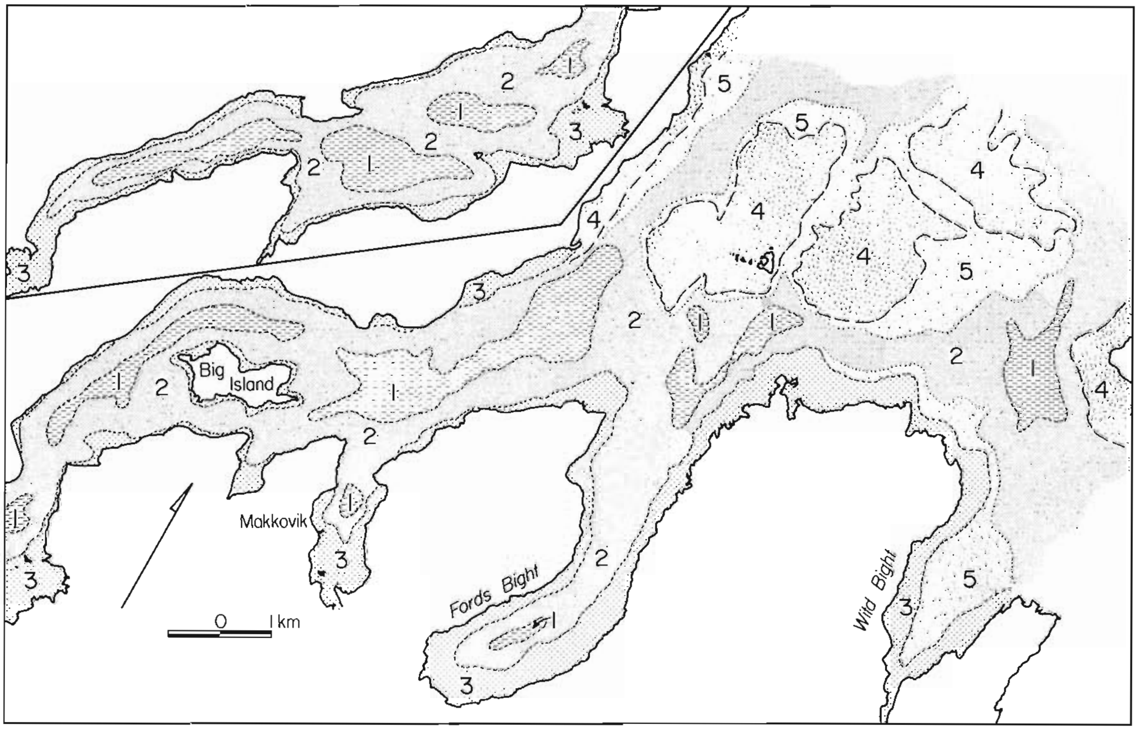
Detailed grain size distribution

A total of 133 detailed grain size analyses have been made by standard sieve and pipette techniques of grab samples and core tops representing all facies. The major trend in surficial sediment texture can be described by the percentage of sand (Fig. 21) since generally the gravel content is low and there are only slight variations in the silt to clay ratio.

A map of percent sand in surficial sediment gives no more information than the sediment distribution map based on lithologic units (Fig. 18), primarily due to local variability in sand content. Significant trends can be resolved if the data are examined in individual profiles from shallow to deep water, within a single major physiographic area (Fig. 22).

The Tom's Cove profile in the Outer Bay (Fig. 22b, 23) serves as an example. A medium sand (coarse veneer unit) predominates to a depth of 35 metres, decreasing in grain size rapidly to coarse silt (gravelly mud unit) which fines gradually to clayey silt (basinal mud unit) by 55-60 m depth.

There is gradual decrease in grain size both upbay and with increasing water depth. In the Approaches the percent sand ranges from over 50 per cent in shallow water to 15-45 per cent at 100 m depth, whereas in the Outer Bay the 15-40 per cent range is attained by 40 m depth. The Western Inner Bay has generally less than 35 per cent sand in shallow (<8 m) water and a range of 5-15 per cent in the basins.



I. coarse veneer unit, including a nearshore sandy prism (3), coarse sands and gravel among rocky shoals (4), and deep water veneer of sand and gravel at edge of shoals (5).

II. basinal mud unit (1).

III. gravelly mud unit (2).

Figure 18. *Surficial distribution of sediment lithologic units in Makkovik Bay, partly after Piper and Iuliucci (1978).*

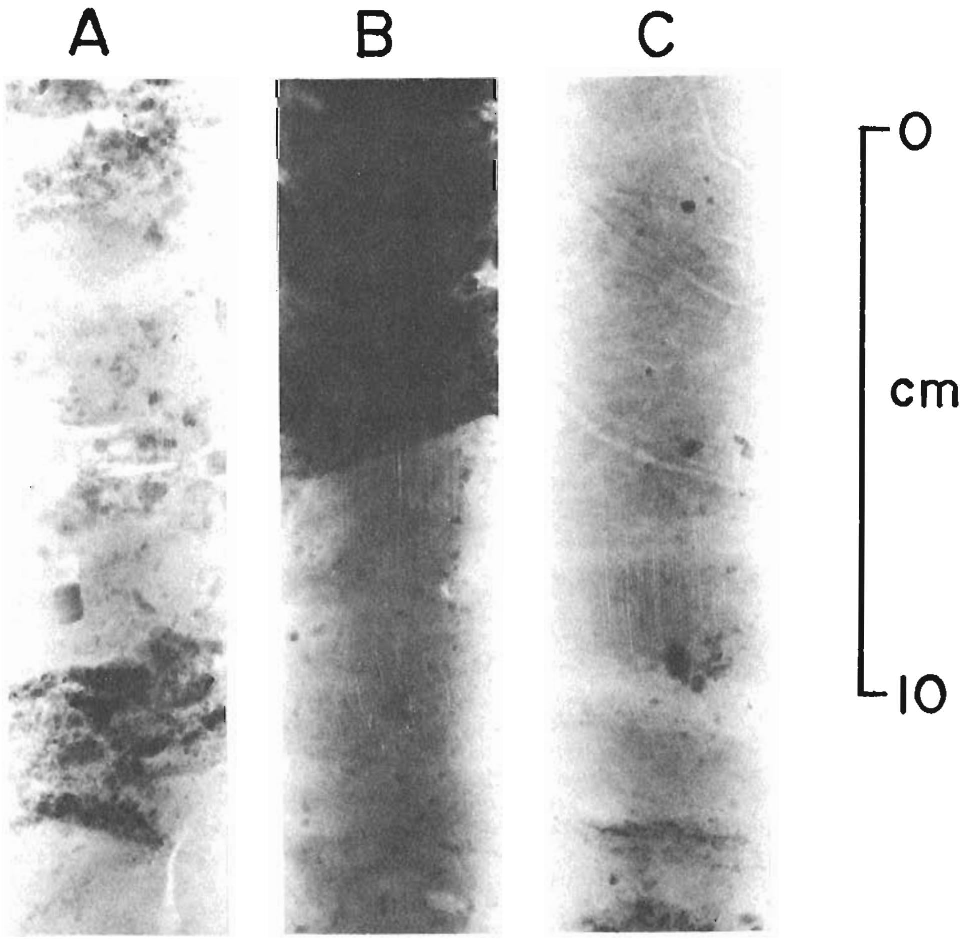


Figure 19

X-radiographs of three representative short cores of the gravelly mud unit, showing (A) characteristic gravelly horizons, (B) the coarse veneer unit sharply overlying the gravelly mud unit, (C) gravelly mud unit grading upwards into the basinal mud unit.

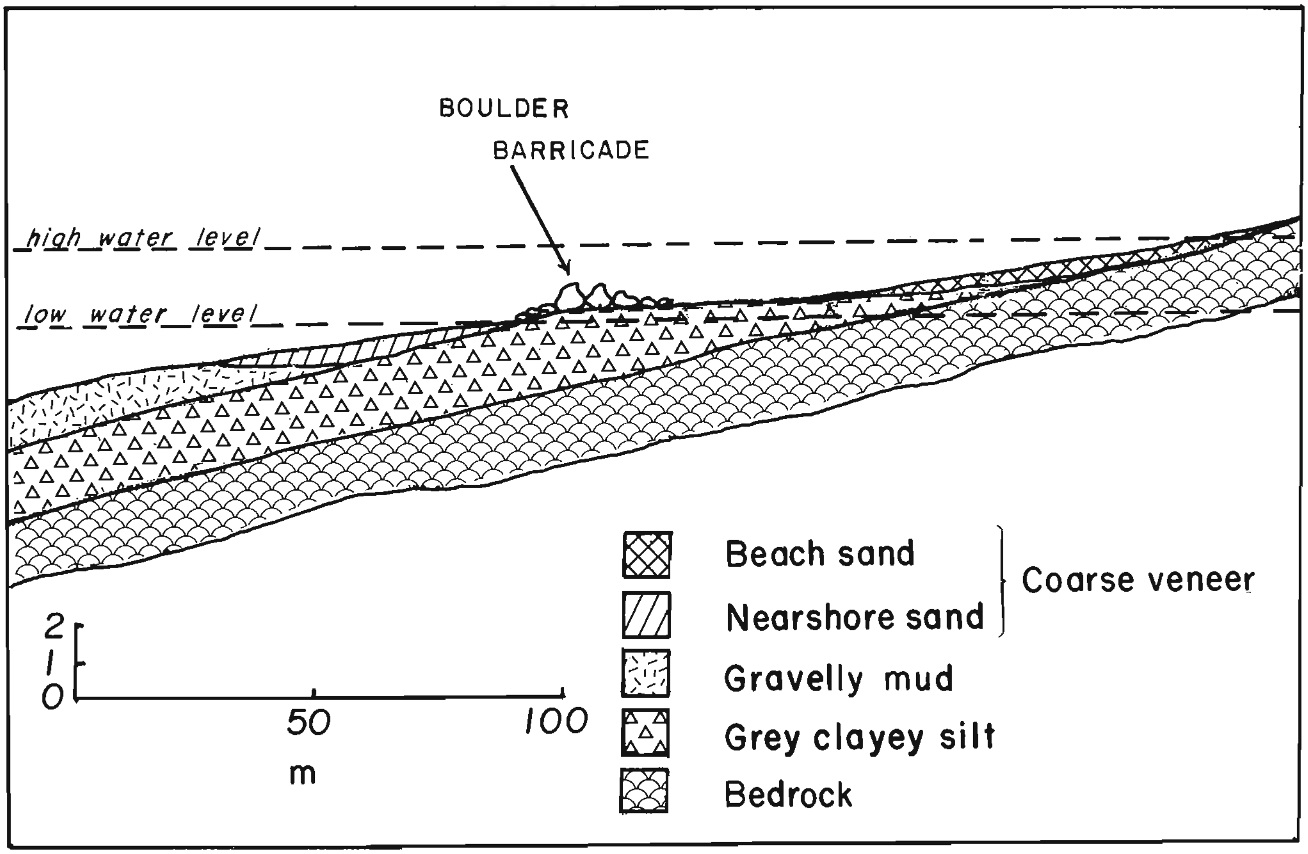


Figure 20. Cross-section of the clay intertidal platform west of Kennedy's Cove showing the coarse veneer unit overlying relict grey clayey silt.

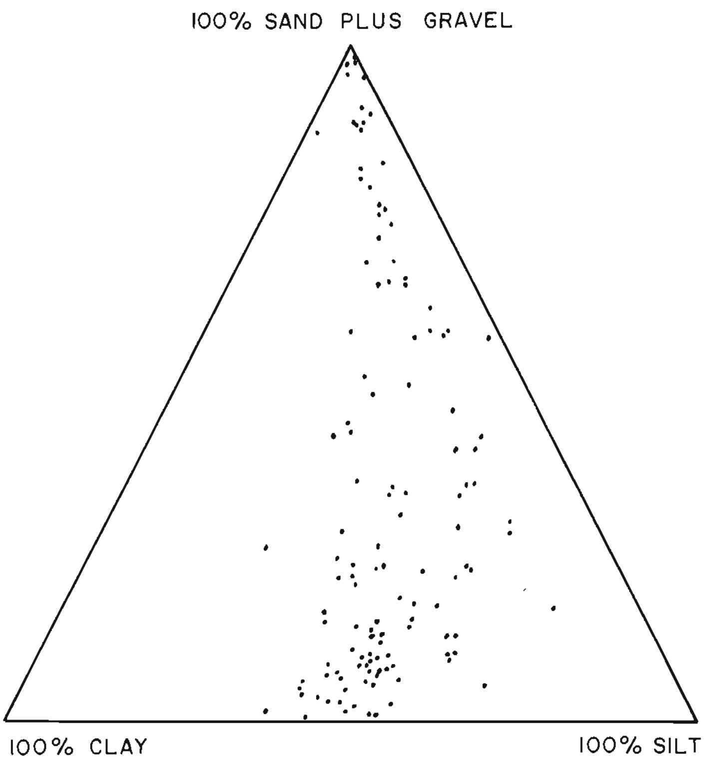


Figure 21. Ternary plot of grain size distributions from all surficial sedimentary units showing the dominant trend from sand to clayey silt.

The lower limit of the coarse veneer lithologic unit varies from approximately 80 m water depth for the Approaches, 30-50 m for the Outer Bay, and 10-20 m for the inner bays. These are proportional to the shoreline energy levels according to the height of the wave wash zone mapped by Rosen (1979a), suggesting that the distribution of this lithologic unit is controlled primarily by wave energy.

One exception to the trend of decreasing grain size with depth occurs in the Eastern Inner Bay where some samples appear abnormally coarse for their relative depth (65-85 per cent sand at 30-40 m depth, Fig. 22c). These samples all occur in areas of bay mouth constriction. Where the grey clayey silt unit outcrops in shoal to intertidal areas it is much finer grained than the surrounding contemporary sediment.

The systematic variation of surficial grain size with depth from the shoreline to the basins (Fig. 23) suggests a continuity in sediment processes from the sandy nearshore sediments which represent the coarse residue remaining from wave-reworked sediments, to the basinal olive muds consisting of the fines that are winnowed out and distributed in suspension throughout the bay, eventually being deposited in the quiet, deep basins. The flanks are intermediate in that there appears to be some winnowing of the gravelly mud unit and possibly minor deposition from the coarser, suspended fraction of the reworked coarse veneer. Although Tom's Cove Profile crosses different outcropping acoustic units, the grain size trends indicate a relatively uniform, depth-related change. Therefore, the contemporary environment can be regarded as wave-dominated.

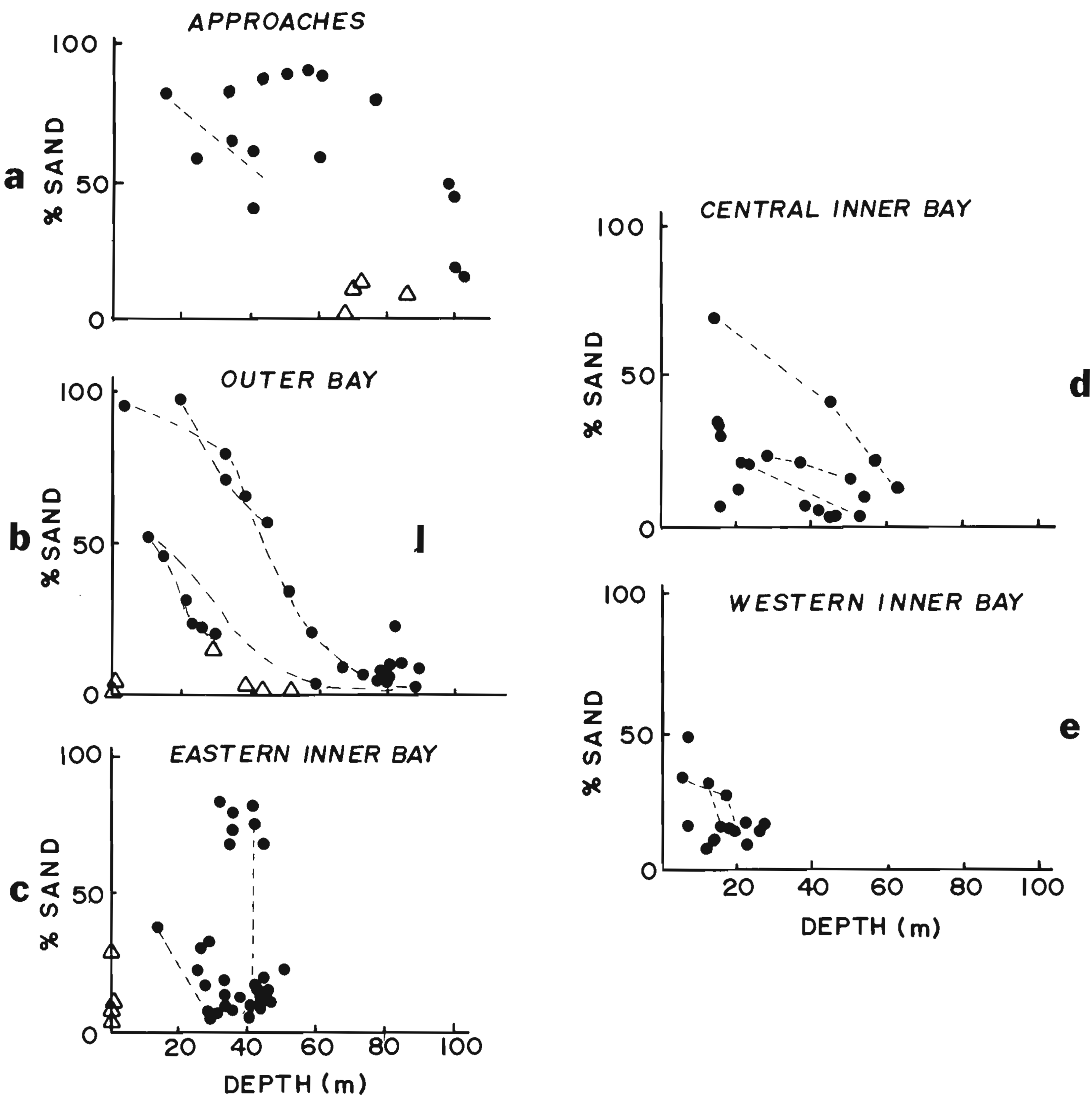


Figure 22. *Plots of per cent sand versus depth for the surficial samples showing an overall upbay fining: (a) the Approaches, (b) Outer Bay, (c) Eastern Inner Bay, (d) Central Inner Bay, (e) the Western Inner Bay. Lines joining data points represent individual profiles. Δ represents samples of the grey clayey silt unit.*

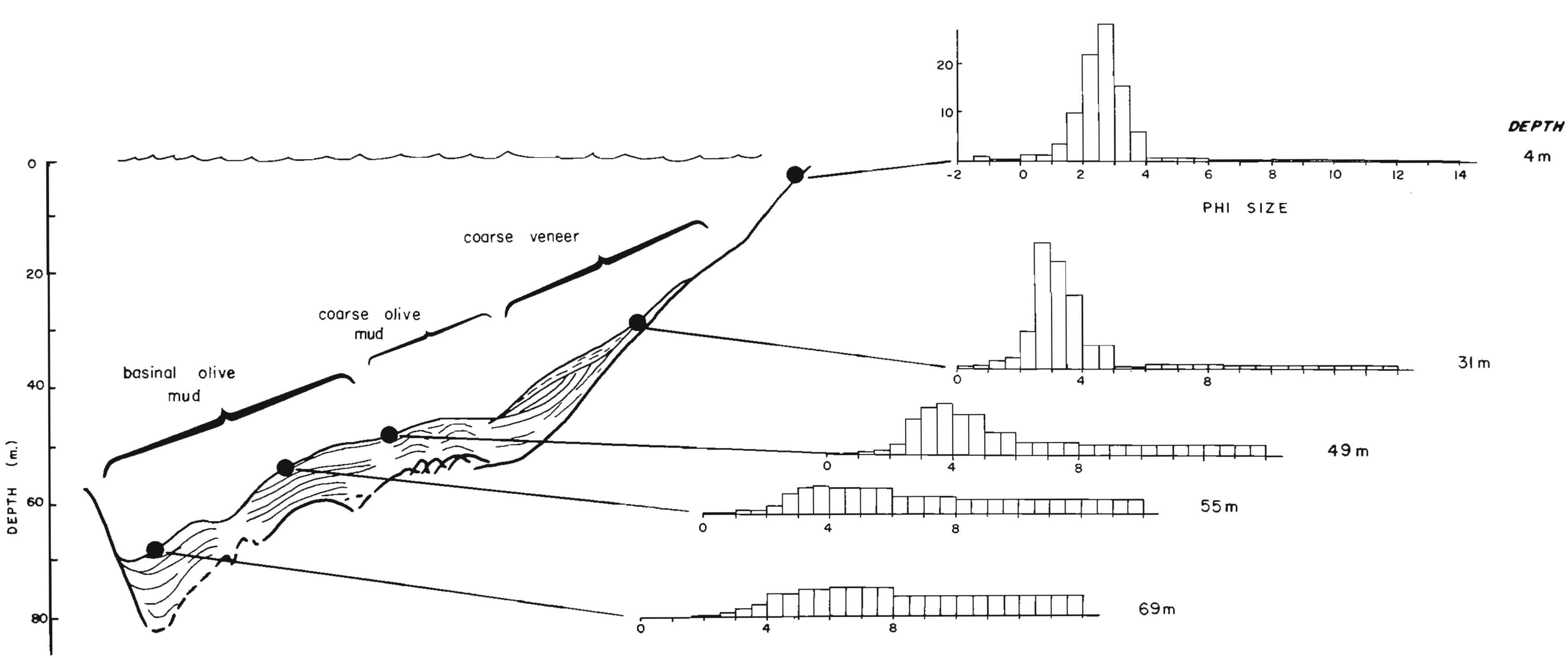


Figure 23. *3.5 kHz acoustic record of the Tom's Cove Profile showing grain-size distributions of surficial sediment. Note change from sorted sand on the flanks to poorly sorted clayey silt in the basin.*

PISTON CORES

Introduction

One piston core, 78-020-003 (Fig. 24) was taken in 102 m of water in the Approaches, southwest of Strawberry Island, and a second, 78-020-004 (Fig. 25) from the mouth of the Outer Bay, adjacent to Ikey's Point at a depth of 81 m (Fig. 3). Site locations were determined by radar fixes and adjusted according to bathymetry.

Facies description

The following facies and subfacies are identified on the basis of detailed core description, x-radiographs, smear slide examination and detailed grain size analysis (Fig. 24-26).

Facies A: Olive diatom-rich mud

Facies A is usually greyish olive (10 Y 4/2) except at core tops where it is medium olive grey (5 Y 4/2). It is poorly sorted clayey silt with approximately 10 per cent fine sand, and common microfossils (>5 per cent), principally discoid diatoms. It corresponds to the basinal mud surficial lithologic unit. Where facies A is located near the bottom of the core, it contains slightly fewer micro- and macrofossils but has numerous gas expansion cracks, attributed to methane production. X-radiographs show distinct small cycles of sediment types a few centimetres thick. At the base of each cycle is a continuous lamina of silt to fine sand (Fig. 27), containing fewer microfossils and grading upward into a poorly stratified bed of clayey silt with abundant shells and shell fragments. This grades upward into a highly bioturbated homogeneous bed of clayey silt. This upper division is not always present. There is an upward decrease in grain size through a cycle (Fig. 27) although the modal size is constant at approximately 5ϕ.

Facies B: Dark olive mud

This is a dark greyish-olive (10 Y 3/2), very poorly sorted clayey silt (Fig. 28) with a moderate abundance of microfossils (~1%), fewer macrofossils than facies A and variable bioturbation. Small, isolated dark iron sulphide mottles occur throughout facies B. Faint, wispy silt laminae are observed in the x-radiographs.

Facies C: Grey-brown mud

Facies C is a grey-brown (5 YR 3/2, 5 YR 4/1), clayey silt with less than 10 per cent fine sand. It is characterized by a positively skewed, coarse silt mode with a fine silt to clay tail (Fig. 28) and occasional silty, wispy laminations. Microfossils vary from traces to moderate abundance and shell material is infrequent. Bioturbation and worm-tube-shaped, solid pyritic growths are very common.

Facies D: Olive-grey mud

Facies D is an olive-grey (5 Y 4/1), poorly sorted, clayey silt (Fig. 28) with generally less than 6 per cent sand, variable bioturbation and dispersed pebbles. Only trace amounts of mostly comminuted microfossils are present.

Subfacies D1 is massive with minor to moderate bioturbation and shell fragments. Dispersed pebbles are generally rare in core 004, but in core 003 in the Approaches the gravel content increases upward to 10-30 per cent. Horizontal stratification occurs in gravelly areas whereas steeply inclined, faint strata occur in the mud. The x-radiographs suggest that the internal structures in the muddy portion have been deformed during coring, probably without changing the original unit thickness.

Subfacies D2 has bedded couplets (Fig. 29) of thin (<1 cm) olive-grey (5 Y 4/1) silt alternating with thicker (0.5-3 cm) dark yellowish-brown (10 YR 4/2) mud with minor sand and pebbles toward the top. The silt appears to be finely laminated in the x-radiographs, and in places, passes abruptly into mud. Core 003 contains only six relatively coarse couplets but core 004 has over 75 couplets with the ratio of silty laminations/mud decreasing upwards, eventually obliterated by bioturbation.

Facies E: Yellow-green gravelly mud

Facies E is a yellowish olive-green (5 GY 4/2), extremely poorly sorted, gravelly mud. The gravel content ranges from 30-40 per cent and is presumably ice rafted. The muddy fraction has a mode at 5ϕ, similar to the other facies (Fig. 28). Texturally, it resembles some short cores of the surficial gravelly mud lithologic unit. No internal bedding, macrofossil shell material or bioturbation was observed, and there were only trace amounts of microfossils.

Facies distribution

The distribution of lithofacies is shown in Figures 24 and 25. In core 004 from the Outer Bay, facies A occurs only in the trigger weight core and the top of the piston core is of facies B. However, x-radiographs, per cent sand and clay and skewness all indicate a continuous trend in sediment properties passing upwards in piston core 004 and its trigger weight. This suggests that there is probably negligible coretop loss between the trigger weight and the piston core. Facies B is 1.5 m thick and passes down into 3.5 m of facies C, then 4.5 m of facies D.

In core 003 from the Approaches, facies A occurs in both the trigger weight core and the top of the piston core. A distinctive lamina present in both cores suggests a 5-10 cm overlap. Facies A is 3.5 m thick in the piston core, and rests abruptly on 1.5 m of facies D, over 30 cm of facies E. Below this is a further 2.5 m of facies A, passing down into 1.5 m of facies B. In this core, facies D is inclined. This appears to be due to coring disturbance, although it might result from slumping.

Correlation with acoustic records

Unfortunately, no acoustic profiles pass directly over the core sites, and the core sequence must be compared with acoustic profiles 200-400 m away. Core 003 only samples the upper basin-fill acoustic unit. Strong reflectors within this unit presumably correlate with gravelly facies D and E. Facies A has weak reflectors that may correlate with sandy zones in the core. Facies B appears to possess a slightly enhanced reflector at the upper surface, perhaps as a consequence of upward coarsening (Fig. 24). The bottom of the piston core is approximately 3 m (v = 1500 m/sec) above the conformable cover unit.

Core 004 also only samples the upper basin-fill acoustic unit (Fig. 7). Two prominent acoustic reflectors are correlated with the upper and lower boundaries of facies D: the upper one marks a disconformity (b, Fig. 7). Generally, facies B and C have weak to transparent reflections. The upper portion of facies D (probably subfacies D1) possesses a weak acoustic record increasing downward to continuous, moderate strength reflectors, probably representing subfacies D2. This grades rapidly downward, through approximately 3 m (v = 1500 m/sec) of sediment, to the top of the conformable cover unit.

Radiocarbon dating

The total organic carbon content of five samples from the two piston cores have been ^{14}C dated by Krueger Enterprises Inc. In addition, a homogeneous sample of the grey clayey silt from the intertidal zone at the head of Makkovik Harbour, interpreted to be from the upper zone of

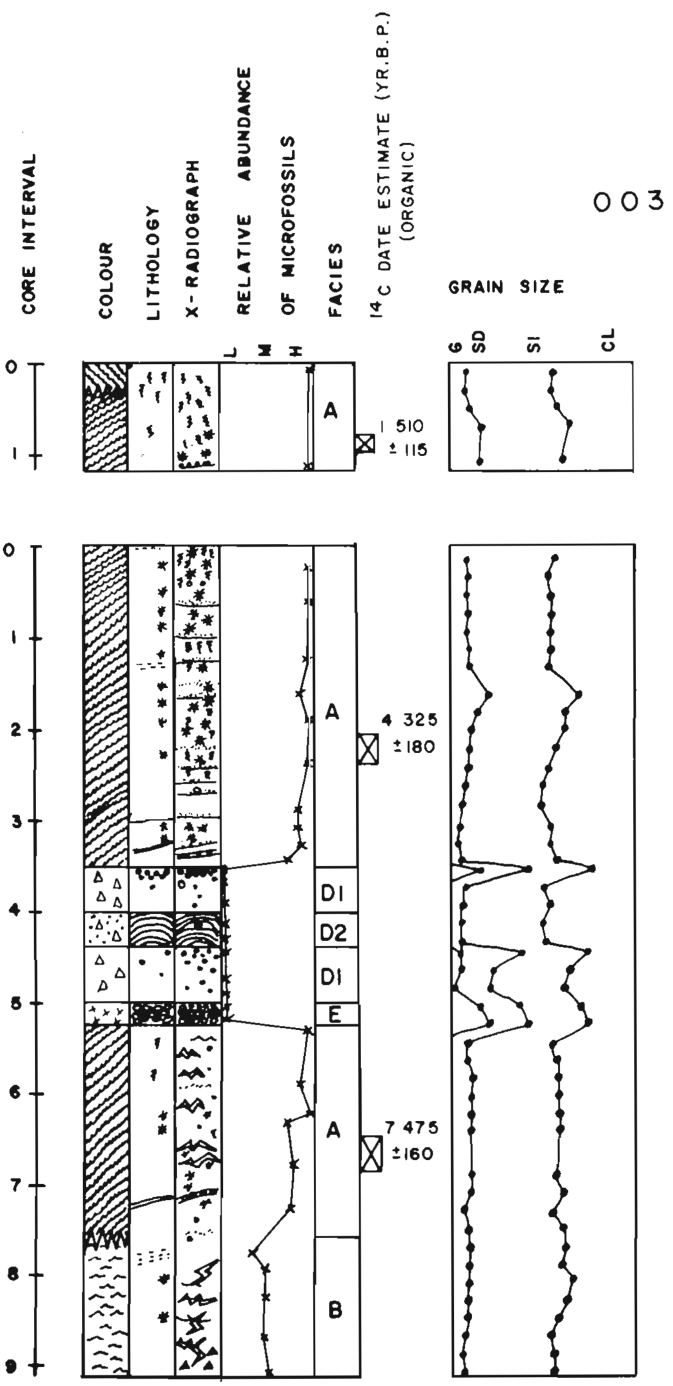


Figure 24. Colour, lithology, x-radiography, relative abundance of microfossils and granulometry of piston core 78-020-003. Key in Figure 26.

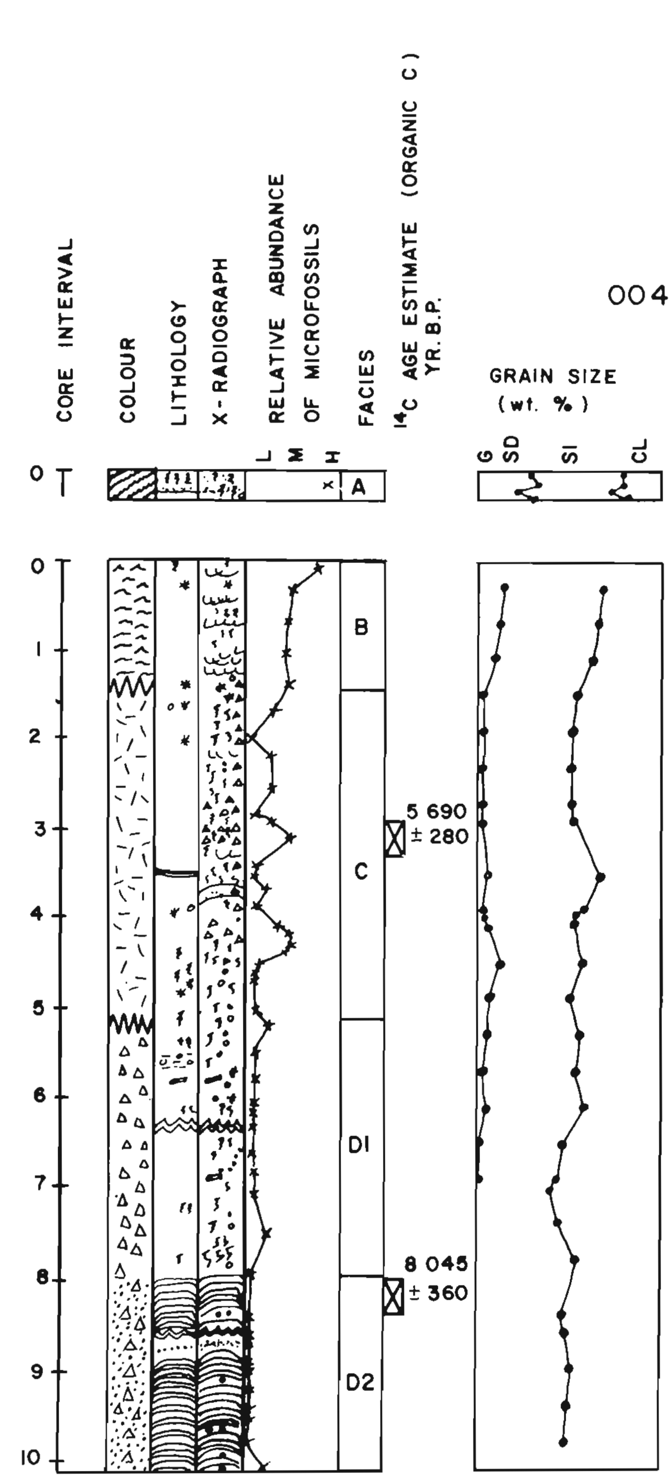


Figure 25. Colour, lithology, x-radiography, relative abundances of microfossils and granulometry of piston core 78-020-004. Key in Figure 26.

Figure 26. *Key to Figures 24 and 25.*

the acoustic conformable cover unit, was ^{14}C dated using the tests of calcareous foraminifera, primarily **Islandiella helenae** and **Cassidulina reniforme.** These dates are:

Facies	Core	Core Interval (cm)	^{14}C years B.P.	Laboratory Number
A	78-020-003	80-100	1510 ± 115	GX-5810
A	78-020-003	205-235	4325 ± 180	GX-6348
A	78-020-003	650-690	7475 ± 160	GX-5811
C	78-020-004	290-330	5690 ± 280	GX-6346
D	78-020-004	800-840	8045 ± 360	GX-6347
Grey Clayey Silt	Intertidal zone	Makkovik Harbour	10 275 ± 225	GX-6345

The dates are plotted on an age-depth diagram in Figure 30 along with the position of the upper boundary of the conformable cover unit based on correlation with the acoustic profiles. This confirms that there has been insignificant loss of depositional record at the top of core 003. Linear extrapolation of approximately 0.07 cm/a suggests an age of approximately 6500 years B.P. for the base of the upper unit of facies A in core 003. The lithology suggests that the lower units in core 003, especially facies D and E, have higher rates of sedimentation, approximately 0.3 cm/a. There is thus no evidence for a significant hiatus between facies D and A in core 003, nor between C and B in core 004, despite the acoustic evidence of a disconformity in the latter.

Interpolation of the age estimates of core 004 suggest that the C-D contact is approximately 6500 years B.P., coinciding with the A-D contact of core 003. Extrapolation of a reasonable sedimentation rate through facies B suggests the top of the piston core is approximately 2000 years B.P. This requires that either significant erosion has removed part of facies A or that the net rate of sedimentation is very low. Both the grain size distribution and acoustic stratigraphy favour the presence of contemporary erosion or winnowing at the core location.

The stratigraphic correlation of the piston core units (Fig. 31) suggests that at certain periods the deposition of the facies units was diachronous from the Approaches to the Outer Bay. Approximately 8000 years B.P., facies A and B were deposited in the Approaches while facies D was being deposited in the Outer Bay. By 6500 years B.P., facies D extended out to the Approaches as well. Since then, facies C, B and A were deposited in the Outer Bay, whereas only facies A is thought to have been deposited in the Approaches.

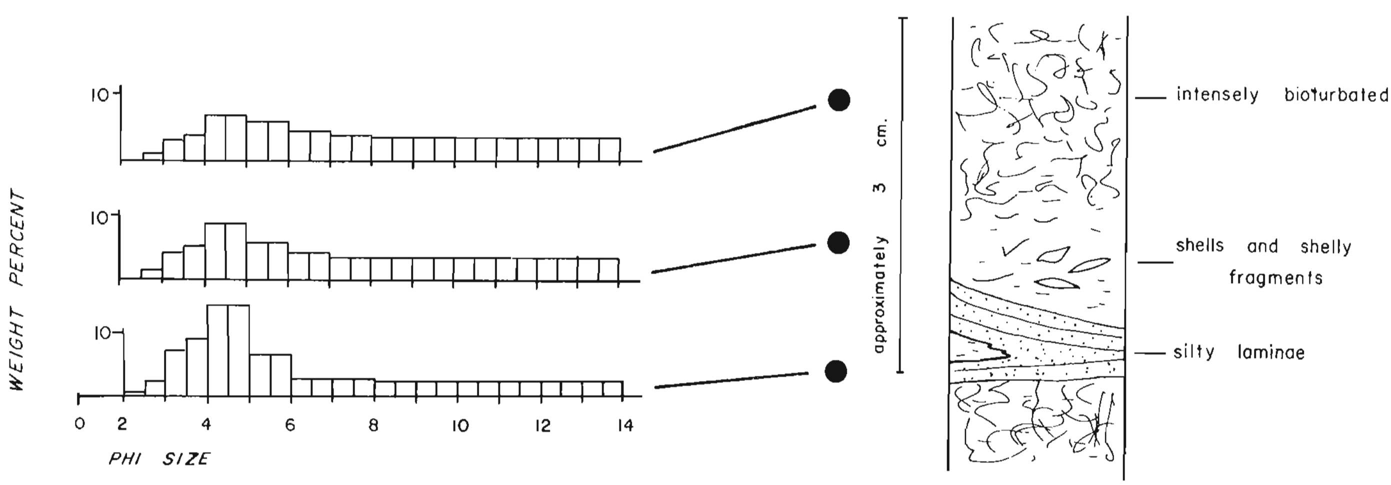


Figure 27. *Sketch of x-radiograph of depositional cycle in facies A, core 78-020-003 at 160 cm, and corresponding grain size analyses showing the flat based silty laminae, passing up into mud with shell fragments and then the upper intensely bioturbated mud. Modal analysis of facies A shows a decreasing primary mode, a shift of the dominant shoulder from 3 1/2 to 6 phi, and an increasing fine tail proceeding from (a) silty laminations through (b) shell and shelly fragment beds to (c) bioturbated clayey silt.*

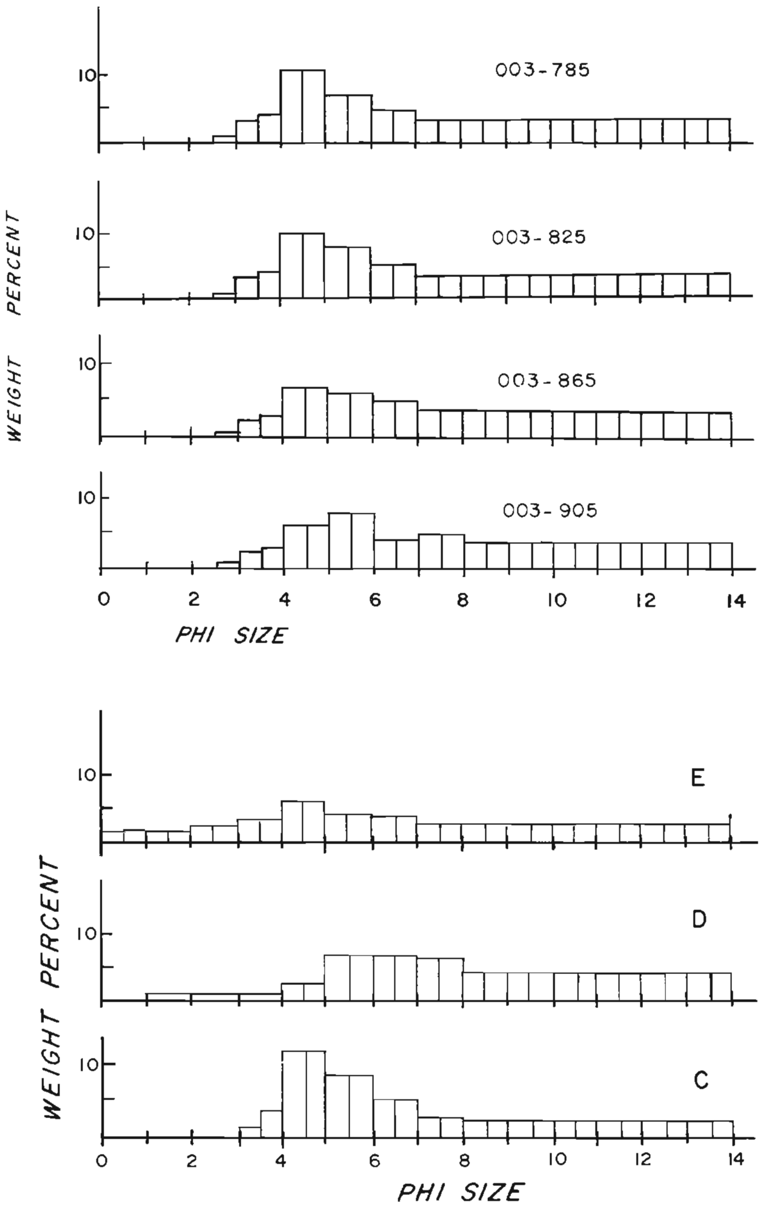


Figure 28. *A series of analyses showing upward change in grain size in facies B of core 003 (core depth in cm); and representative grain-size analysis of facies C, D, and E in piston cores.*

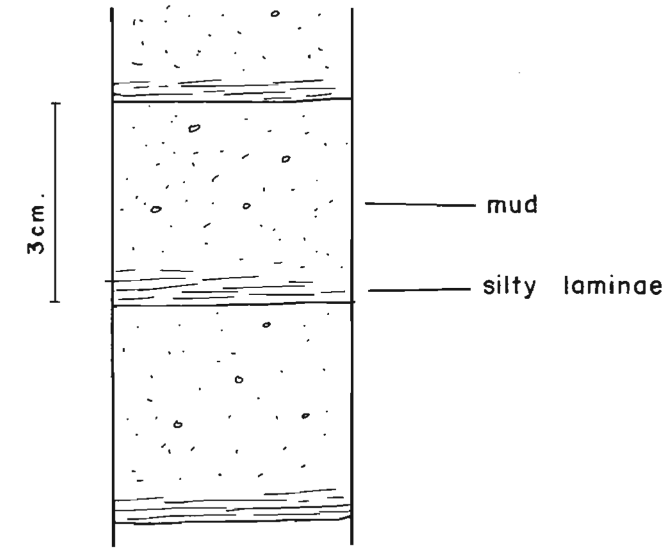


Figure 29. *Sketch of x-radiograph of subfacies D2 (78-020-004/910) showing the silt-mud couplets.*

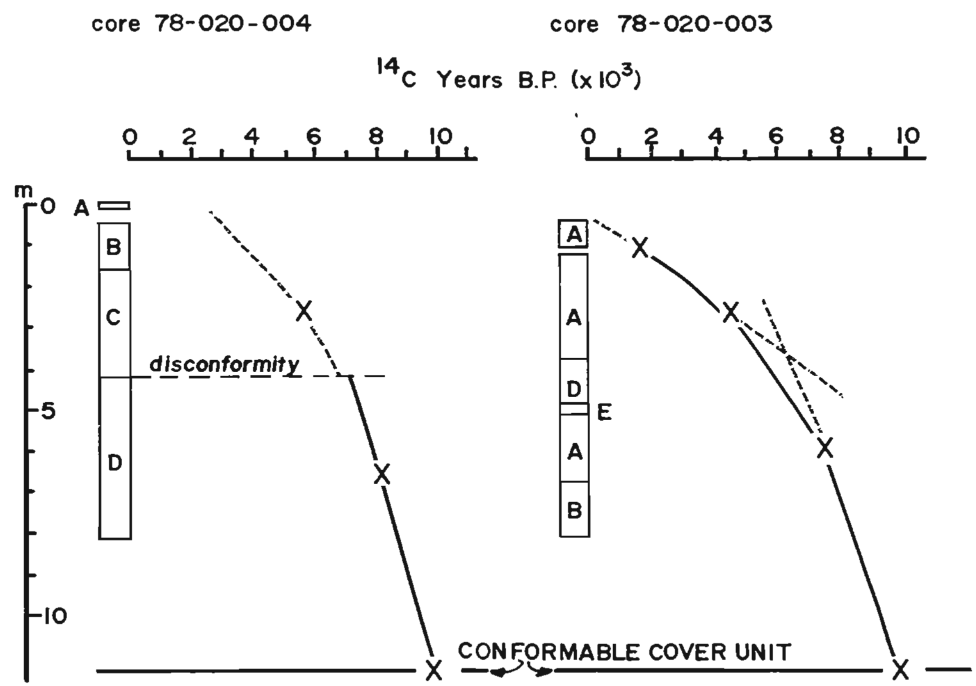


Figure 30. *Chronology of piston cores and conformable cover unit.*

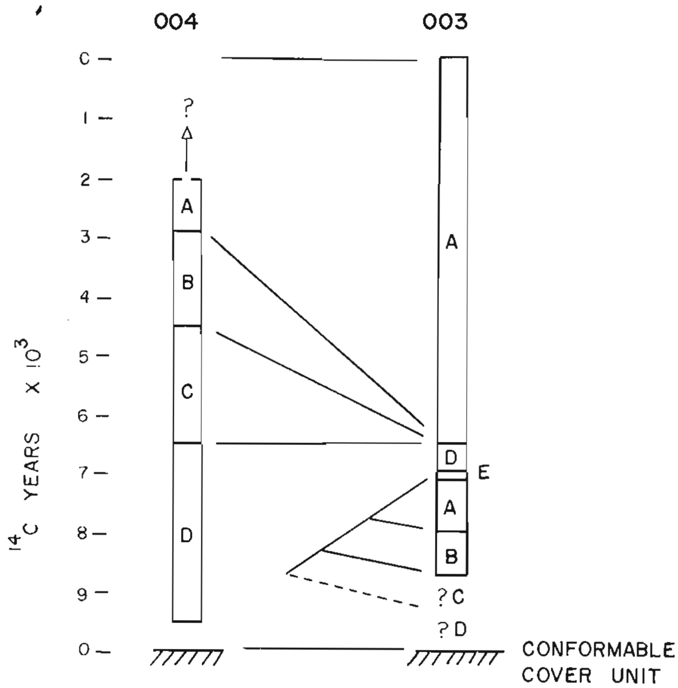


Figure 31. *Stratigraphic correlation of piston core facies.*

MINERALOGY OF THE CLAY-SIZED FRACTION

General results

Semi-quantitative x-ray diffraction analyses of the less than 2 μ fraction were made from 31 piston core samples and 34 surficial samples according to the methods of Piper and Slatt (1977). Clay minerals were identified using the data of Thorez (1975). Although slow scans were made over the chlorite-kaolinite peaks (24.5° to 25.5° 2Θ), the kaolinite (sensu lato) peak was frequently difficult to resolve. In addition, the "montmorillonite peak" represents all minerals with smectite-like expansion, probably including mixed layer clays. The results of three Labrador till samples were obtained from Piper and Slatt (1977), one of their samples (L-20) being taken approximately 35 km inland from Makkovik Bay.

In all samples, the principal minerals are clay sized feldspar and mica, with lesser amounts of quartz, chlorite and amphibole and minor quantities of montmorillonites and kaolinites (Fig. 32).

Feldspar predominates in most till and raised delta samples (Fig. 33). Within the grey clayey silt unit, samples from the south side of Outer Makkovik Bay are enriched in clay mica ("illite"). Other grey clayey silt samples are richer in feldspar, and have more chlorite than the glacial land samples. The basinal mud unit also has a relatively high feldspar and chlorite content. In the piston cores, facies A and B resemble the basinal mud unit, whereas facies C, D and E are more similar to the grey clayey silt unit. Up-core changes in clay mineral assemblages indicate a gradual decrease in the mica/feldspar ratio, except in the middle of core 003 (Fig. 34).

Interpretation

The dominant feldspar-mica-chlorite suite is common in northern latitudes (Biscaye, 1965; Lisitzin, 1972; Piper and Slatt, 1977) and is the result of detrital inheritance from mechanically weathered granitic and metamorphic rocks (Millot, 1970). The similarity of the marine clays of Makkovik Bay with those of local kames and tills suggests that glacial detritus is probably the intermediate source.

Estuarine sediments may be derived from fluvial input, shoreline erosion or landward migration of shelf sediments (e.g. Pinet and Morgan, 1979). The clay mineralogy of the basinal mud unit is very similar to that of the eroding grey clayey silt unit and raised deltaic deposits, suggesting that these are the primary source of the contemporary muds. This interpretation is consistent with the relatively small rivers and the emergent coastline which has exposed marginal sediments to continued erosion.

Although sediments of the outer Labrador shelf have significant amounts of montmorillonites and kaolinites and might therefore be a source, the lack of these minerals along the Labrador nearshore zone suggests that there is no significant net landward migration of shelf clays. Furthermore, of the three Labrador tills examined by Piper and Slatt (1977), two had significant amounts of montmorillonites and one had a relatively large proportion of kaolinite. Gandhi et al. (1969) have observed significant proportions of kaolin in several rock samples from Makkovik Bay area. Therefore, it is suggested that, although the marine environment may have an influence by reworking and redistributing, most of the clays have an ultimate detrital inheritance from the surrounding terrain with an insignificant clay flux from ocean sources.

Lateral and vertical variations in the relative proportions of clay and clay-size minerals suggest that different distribution processes have operated at different times in Makkovik Bay. The grey clayey silt unit shows conspicuous mineral segregation; mica is concentrated along the south shore of the Outer Bay and feldspar responds inversely (Fig. 33). In contrast, the contemporary basinal olive mud shows an overall random downbay distribution in the proportions of clay-size minerals. The change from the former depositional regime to the contemporary regime is shown in the piston cores (Fig. 34), where facies C and D are most similar to the grey clayey silt unit, with a downbay decrease in the mica-feldspar ratio. Facies A and B show an upward decrease in the mica-feldspar ratio for a given locality, indicating a change in source or nature of segregation.

FORAMINIFERA

Introduction

Counts of foraminiferal species present were made on 26 piston core and 23 surficial samples. The processing procedures of Scott et al. (1977) were followed: further details and counts are given in Barrie (1980). Identifications were based on plates and descriptions given by Gregory (1970), Scott (1973, 1977), Hume (1972) and Feyling-Hanssen et al. (1971). Miller and Scott (personal communication) have made a preliminary examination of living/total population in 20 stained surficial samples, and have verified downcore species identification. They found that total populations corresponded approximately to the living assemblages, but were 1 to 2 orders of magnitude more abundant.

Surface samples

The contemporary surficial sediments are characterized by an agglutinated assemblage, primarily dominated by **Eggerella advena** and **Reophax arctica.** Other species include **Cribrostomoides crassimargo, Spiroplectammina biformis, Astrammina rara, Textularia torquata** and **Trochammina** spp. (mainly **T. nana**). The major calcareous forms are **Islandiella helenae, Cassidulina reniforme,** and **Elphidium excavatum** forma **clavata.** There is an increase in the total population and the percentage of calcareous types in a downbay direction.

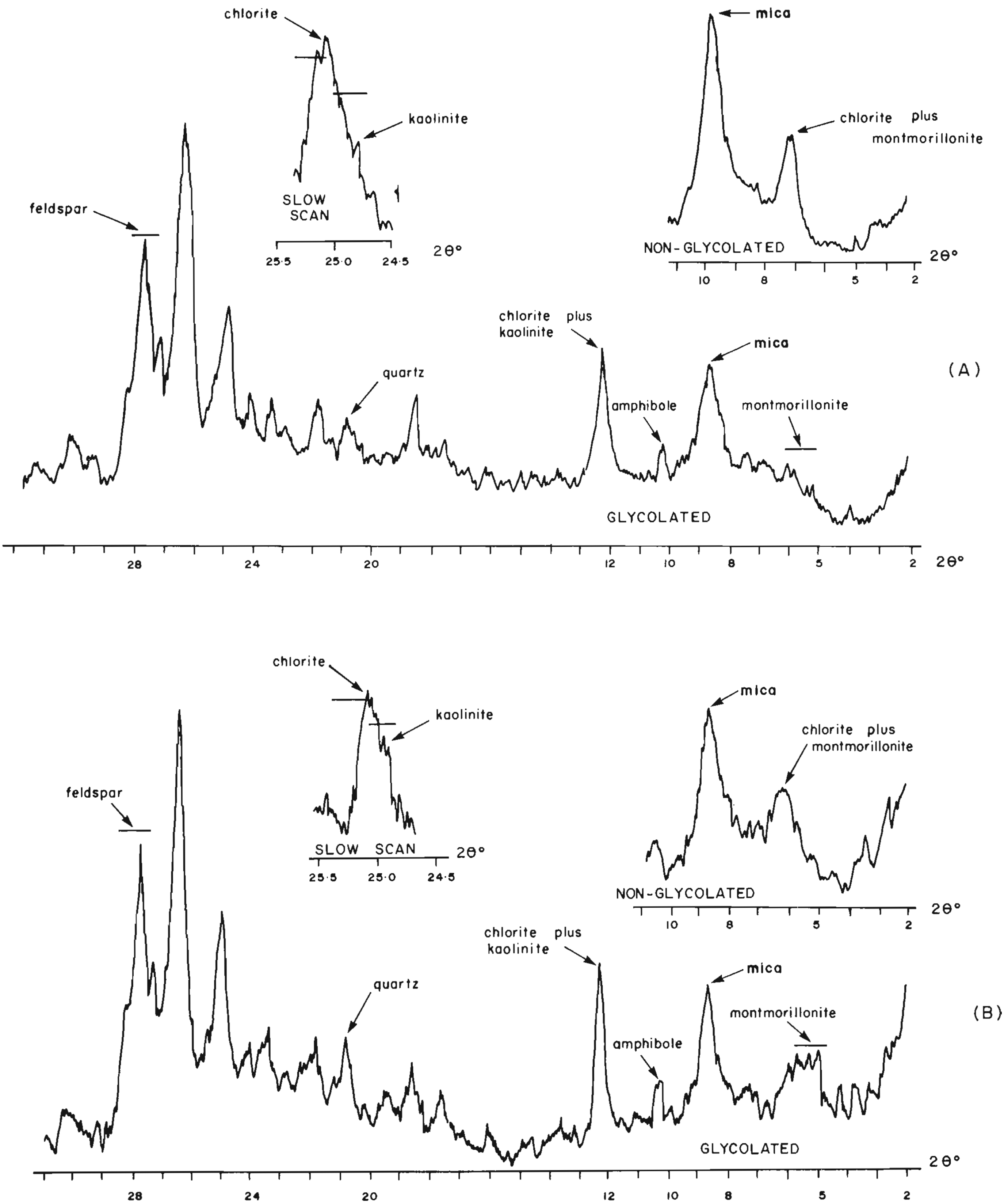


Figure 32. *Representative x-ray diffractograms of oriented mounts of the less than 2 micron fraction of (a) grey clayey silt unit and (b) basinal mud unit.*

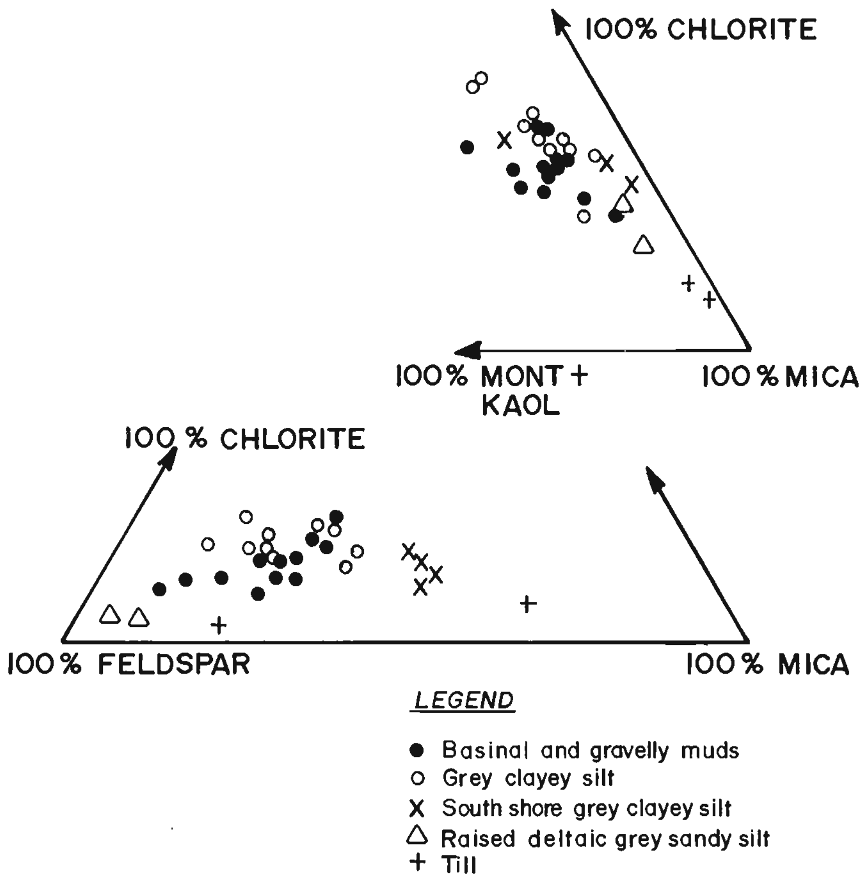


Figure 33.
Ternary diagrams illustrating mineralogy of <2 µ fraction of sediments.

The relict, grey clayey silt unit is characterized by a calcareous assemblage, strongly dominated by the three calcareous species listed above.

The minor species include all those present in the surficial olive sediment plus **Buccella frigida, Cibicides lobatulus, Elphidium bartletti, Fursenkoina fusiformis, Nonionellina labradorica, Oolina borealis, Protelphidium orbiculare, Pseudopolymorphina norvangliae** and **Quinqueloculina agglutinata.** One grey clayey silt sample from the Inner Bay had an assemblage dominated by agglutinated species.

Of eight land samples examined, all were barren except for a grey sand from the base of the Makkovik Harbour raised delta, which contained only ten individuals per gram of **Eggerella advena.**

Distribution within piston cores

The most prominent distribution trends in the piston cores are shown in the numbers of foraminifera per gram of sediment, the agglutinated-calcareous ratio, and the dominant species (Fig. 35).

In both cores, total numbers are low at the very base and the very top of each core, where the assemblage is dominated by the agglutinated forms **Eggerella advena** and **Reophax** spp. Above the agglutinated fauna at the base of core 003, facies D has low total numbers (perhaps indicating a high rate of sedimentation) and a high proportion of **Elphidium excavatum, Cassidulina reniforme** and **Islandiella helenae.** The overlying part of facies A has high total numbers, predominantly agglutinated, but with some **E. excavatum.**

Core 004 shows a more gradual progression up the core. Above the basal agglutinated fauna are intervals progressively dominated by **C. reniforme** (base of D1) through **I. helenae, E. excavatum** at the base of C1, passing up into the core top agglutinated assemblage, first **R. arctica** and then **E. advena.** There is a peak in total numbers within the interval dominated by **E. excavatum.**

Interpretation

The surficial distribution of foraminifera agrees with results of Bartlett (1966) and Scott et al. (1977, 1980), suggesting that agglutinated forms dominate in estuaries with salinities of 20 ‰. This salinity limit on calcareous forms is probably higher in the colder waters of Makkovik Bay (Greiner, 1970).

Carbonate dissolution is common in shallow waters in high latitudes (e.g. Osterman and Kellogg, 1979). However, dissolution is not favoured as a major controlling factor in Makkovik Bay because the extremely low absolute populations of calcareous and agglutinated forms occur synchronously; and comminuted macrofossil carbonate material is abundant, without obvious dissolution textures, in marine sediments containing relatively few calcareous foraminifera.

The **Eggerella advena** – **Reophax arctica** agglutinated assemblage of the Inner Bay is comparable to the fauna found in the transition zone of deep, subtidal estuaries in the Maritimes (Scott et al., 1980), in particular Restigouche Estuary (Schafer and Cole, 1978), Halifax Harbour (Gregory, 1970) and Bedford Basin (Miller et al., 1980). However, these faunas generally have a higher diversity, perhaps reflecting a more temperate environment than in Makkovik.

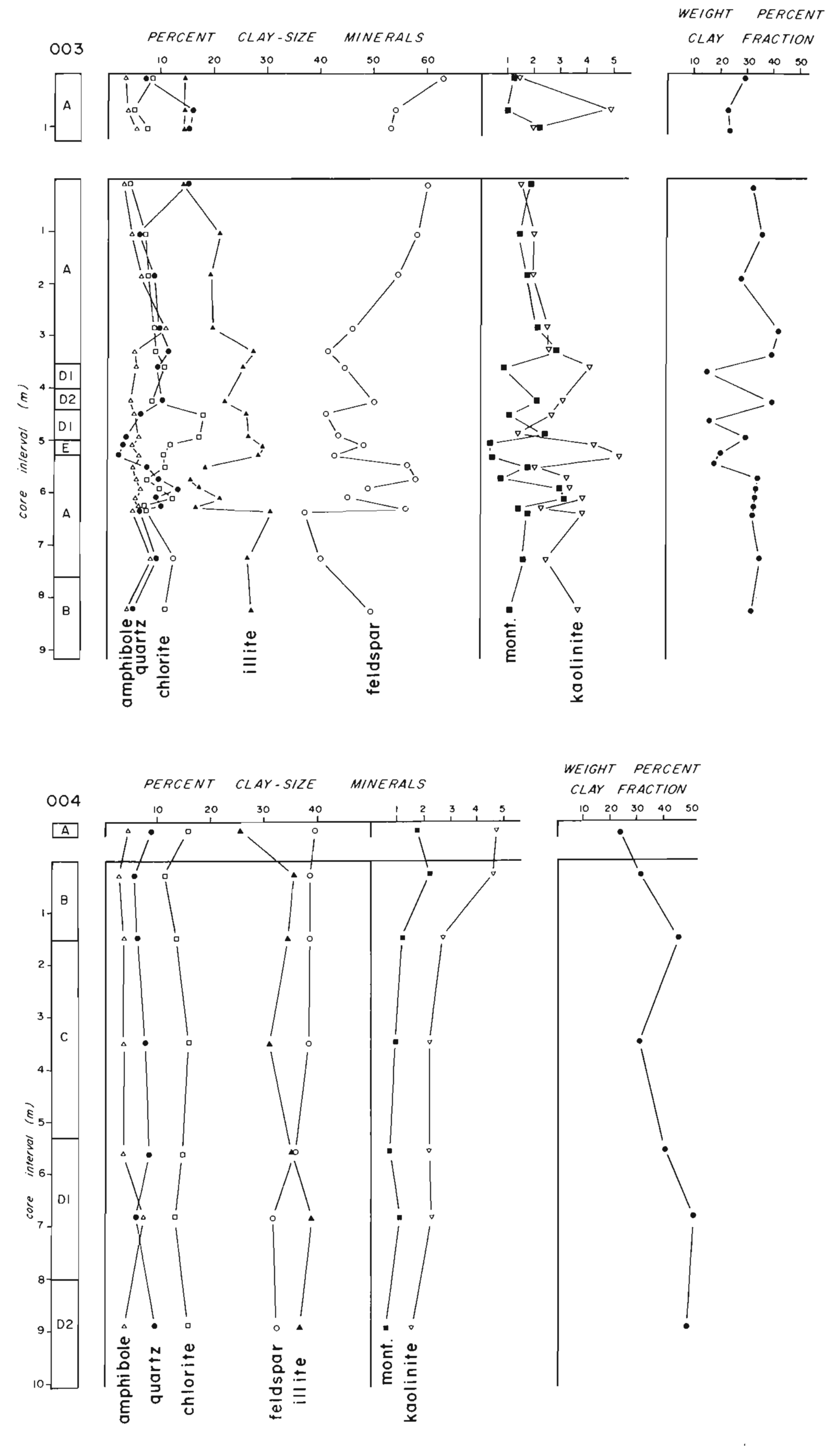


Figure 34. *Variations in mineralogy of <2 μ fraction in the piston cores.*

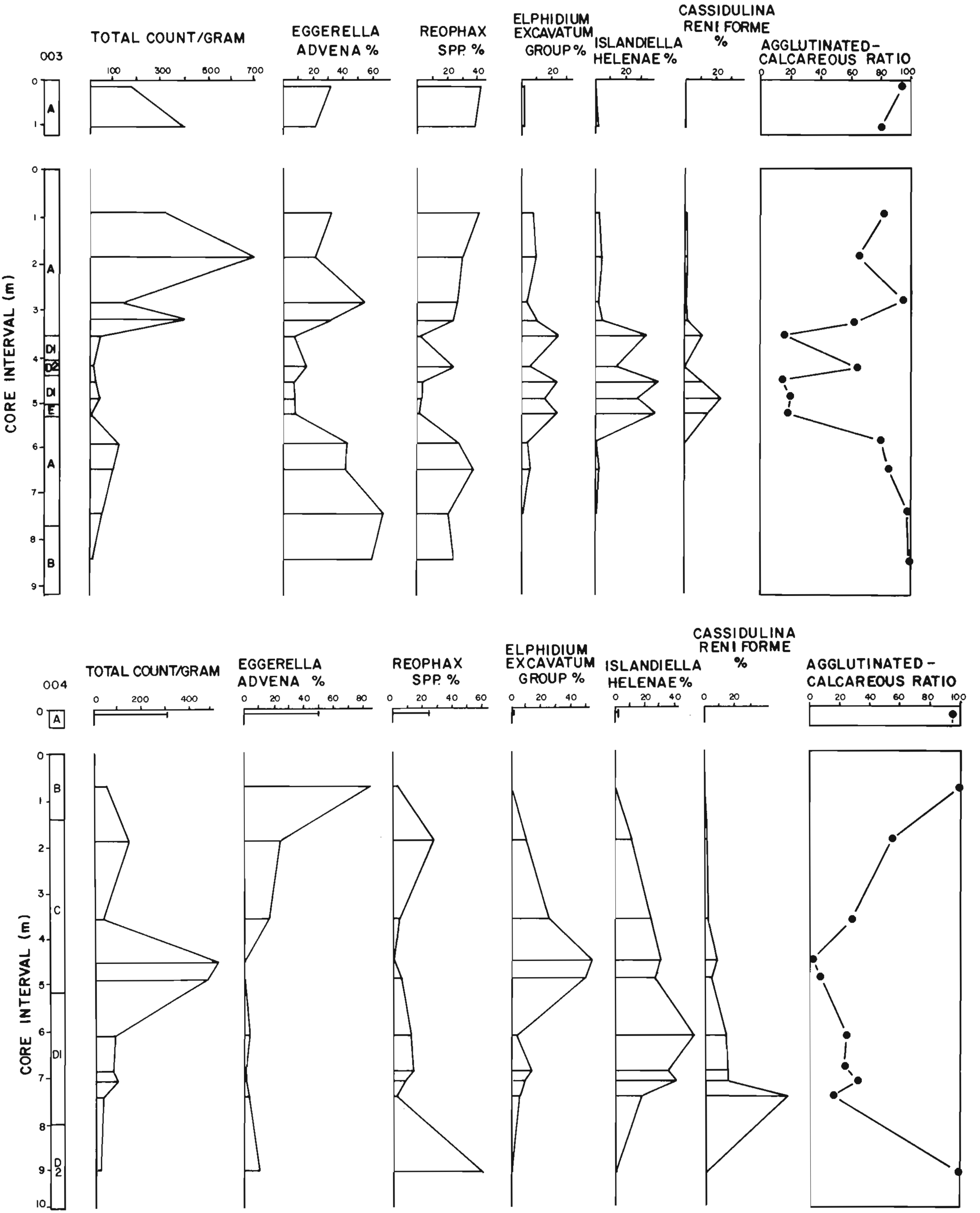


Figure 35. *Distribution of foraminifera in piston cores.*

The calcareous fauna from the Approaches and Outer Bay corresponds to the marginal marine fauna of temperate estuaries (Scott et al., 1980); however, again diversity is lower. Interpretation of surficial calcareous assemblages is complicated by reworking of the relict grey silty clay, known to contain these same calcareous faunas. Only two formae of **Elphidium excavatum** (formae **clavata** and **excavata**) are found in Makkovik Bay, compared with up to five formae in more temperate estuaries (Miller et al., in press). This again reflects the arctic aspect of the assemblage and low seasonal variability of the environment. The **Cassidulina reniforme-Islandiella helenae** fauna is a cold temperate outer bay – inner shelf assemblage comparable to the deep bay fauna dominated by **I. helenae** (reported as **I. teretis**) found in Restigouche Estuary by Schafer and Cole (1978). It is difficult to comment on the occurrence of **C. reniforme** as there are many taxonomic problems with this species (Sejrup and Guilbault, 1980).

The changes in foraminifera within the cores can thus be interpreted as follows. During deposition of the conformable cover unit (around 10 000 years B.P.), outer bay-inner shelf assemblages occur, but by the base of the cores (8000 years B.P.) estuarine assemblages predominate. In the middle of the cores (around 6000 years B.P.), there is a return to outer bay assemblages, changing gradually to estuarine assemblages at the top of the cores.

FACIES MODELS OF POSTGLACIAL DEPOSITION

Factors controlling deposition

Two dominant factors have probably controlled the depositional environment since deglaciation. These are: (1) changes in relative sea level and (2) fluctuations in fresh water discharge to the bay.

Changes in relative sea level have three major effects on the estuarine environment. A falling relative sea level would a) increase the restrictive influence of sills altering the physical oceanography, b) erode marine sediments along the basin flanks and c) alter the depositional style and size distribution of the sediments being deposited in the basins (Fig. 36).

The other major controlling factor, the quantity of runoff, has two influences on the estuarine environment (Fig. 37). Firstly, large fresh water discharges are often associated with large sediment discharges, especially when derived from glaciers. Secondly, increased fresh water discharge enhances estuarine stratification and hence circulation, and increases seawater exchange across the sill for any particular mixed estuary. As the fresh water input increases past some critical level, the fiord becomes a highly stratified, two-layer type estuary (Pickard, 1961; Pederson, 1977) with a fresh water upper layer, a marine base and greatly reduced salt balance mixing along the interface. However, in both types of estuaries, basal marine water is maintained.

The duration of winter ice cover is a third, but unevaluated, factor that controls deposition. A decreased length of winter sea ice cover would effectively depress the lower limit of wave erosion during the spring and fall storm periods, while conversely, an increased ice cover would dampen the activity of waves.

Deposition of conformable cover unit

The conformable cover acoustic unit, corresponding to the terrestrially derived grey clayey silt lithologic unit, must have been deposited at a time of higher sea level (Fig. 38), since it presently outcrops on intertidal flats. Contemporary sediments of the same grain size are accumulating in water depths of more than 50 m.

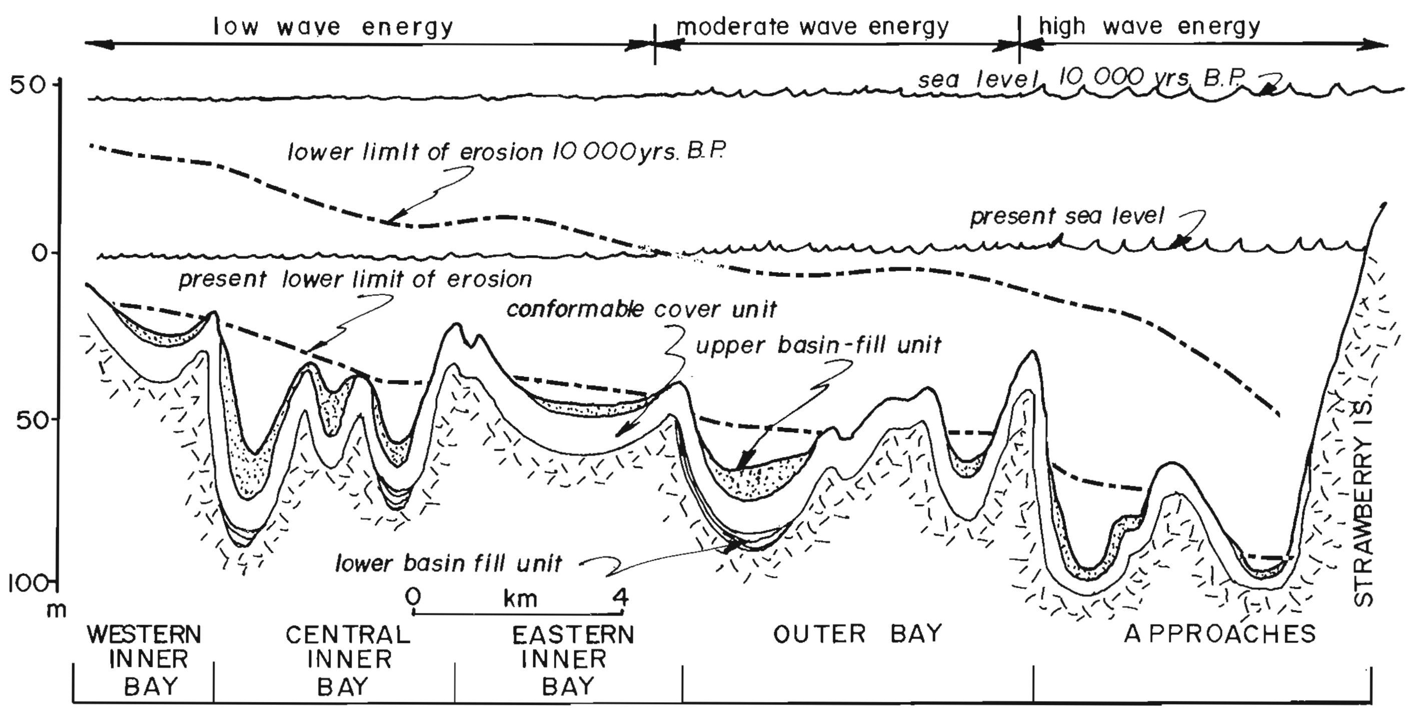


Figure 36. *Longitudinal profile of Makkovik Bay showing the distribution of the contemporary and basinal muds and the relict conformable cover unit. The dashed lines indicate the temporary lower limit of erosion (or no net deposition) and that for 10 000 years ago, demonstrating the influence of a 50 m rise in sea level on sedimentation.*

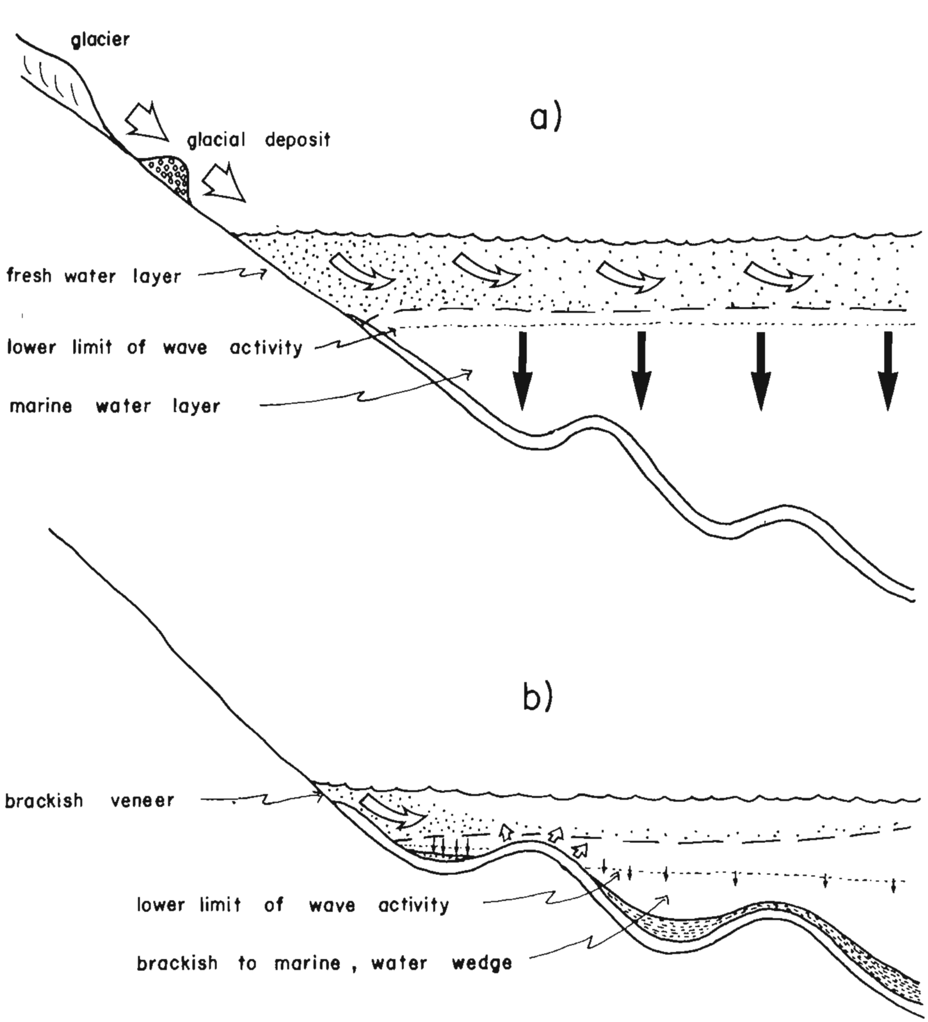


Figure 37

Schematic illustration contrasting (a) deep water, runoff-dominated deposition in a highly stratified 2-layer type estuary with (b) shallow water, wave-dominated deposition in a partially mixed estuary. Solid arrows denote deposition, open arrows denote transport.

The foraminiferal assemblage indicates saline open bay bottom water (except in the Inner Bay), resulting from a better exchange of marine water over the sill. This could result from either a higher sea level, or higher fresh water discharge, or both. The low total foraminifera population suggests a high sedimentation rate.

Higher sea level by itself does not account for the uniform thickness of the conformable cover unit throughout the bay. Suspended sediment must have been distributed throughout the entire bay in a brackish or fresh water veneer, and sedimented at a rather uniform rate. This implies highly stratified two-layer type estuary (Fig. 37a) at times of peak discharge, probably with much of the sediment discharge exported from the bay. Uniform rapid runoff-dominated sedimentation would take place as glacially derived sediments flocculated at the horizontal salt water interface. The alternative hypothesis of deposition from beneath an ice shelf is not supported by the foraminifera data.

Deposition of upper basin-fill unit

The upper basin-fill unit, corresponding to core facies E to A (Fig. 38), has probably accumulated as relative sea level fell. At first, runoff-dominated sedimentation of facies D occurred in the Outer Bay, while wave-dominated deposition of facies B prevailed in the more exposed Approaches. In the partially mixed estuarine stratification, there was insufficient basal saline water to support an open bay foraminiferal assemblage in either area. Presumably runoff increased, re-establishing a highly stratified estuary, capable of supporting open bay foraminiferal assemblages. Runoff-dominated deposition of facies D then took place in both the Outer Bay and Approaches.

Facies C, found in the more sheltered Outer Bay, represents a transition towards estuarine, wave-dominated deposition of marginally eroding marine sediments exposed by a falling sea level. This is indicated by the upcore gradual change to estuarine foraminiferal assemblages, and by the increase in grain size, proportion of wispy laminations and feldspar content in clays. The increased bioturbation and microfossil abundances, and the interpreted chronologies suggest a decreased sedimentation rate.

These trends continue with the deposition of facies A and B, with a further fall in relative sea level. Sediment has been derived largely from reworking of older marginal marine sediments, and sediment redistribution is wave-dominated (Fig. 37b), giving an onlapping basin-fill depositional style. The entire fiord is a partially mixed estuary dominated by agglutinated foraminiferal assemblages.

Depositional history of Makkovik Bay

(a) Glaciation

The lack of thick sequences beneath the conformable cover unit, the interpretation of the lower basin-fill unit as a proglacial delta, and the young age of the conformable cover unit suggest that most or all of Makkovik Bay was filled with grounded ice during the late Wisconsinan maximum. This interpretation is supported by work in nearby Kaipokok Bay, where more seismic reflection profiles are available that show till is absent. The subsequent fluctuations in sea level also suggest both the maximum ice margin and peripheral bulge (G. Quinlan, personal communication, 1980) were located seaward of Makkovik.

(b) Lower basin-fill acoustic unit (prior to 11 000 B.P.)

This unit is not well represented in acoustic profiles, and has not been sampled in Makkovik Bay. In Kaipokok Bay to the north it consists of a fining up sequence of gravels, sands and sand-silt-mud couplets apparently deposited in a proglacial delta environment (similar to that described by Wightman, 1980 from northern Nova Scotia): a fining upwards sequence suggests a rising sea level. If the unit has a similar origin in Makkovik Bay, its basin-fill depositional style might result from the importance of bed load transport in this proximal environment.

(c) Conformable cover acoustic unit (? 11 000-10 000 B.P.)

This unit apparently represents more distal widespread deposition of proglacial deltaic sediment from suspension in a highly stratified two-layer type estuary. Cores from lower in the unit contain more proximal facies, suggesting that maximum height of sea level was reached late in the unit. The reworking of the Ranger Bight Kame suggests that the sea was at least 50 m above its present level. The unit shows local late stage downbay thinning, but overall maintains a uniform thickness, suggesting that sediment was supplied at several points along the south side of the Bay (Fig. 39).

(d) Phase 1 of upper basin-fill unit (10 000-8000 B.P.)

The earliest indication of slope base erosion is observed at the top of the conformable cover unit, and the overlying strata have a transitional depositional style from conformable to onlapping basin-fill. This is consistent with the sedimentologic and paleontologic interpretations. Runoff-dominated sediments occur upbay; wave-dominated sediments downbay. Phase 1 thus represents a transition from the conformable cover unit with a decrease in fresh water and sediment discharge, so that waves and currents played an increased role.

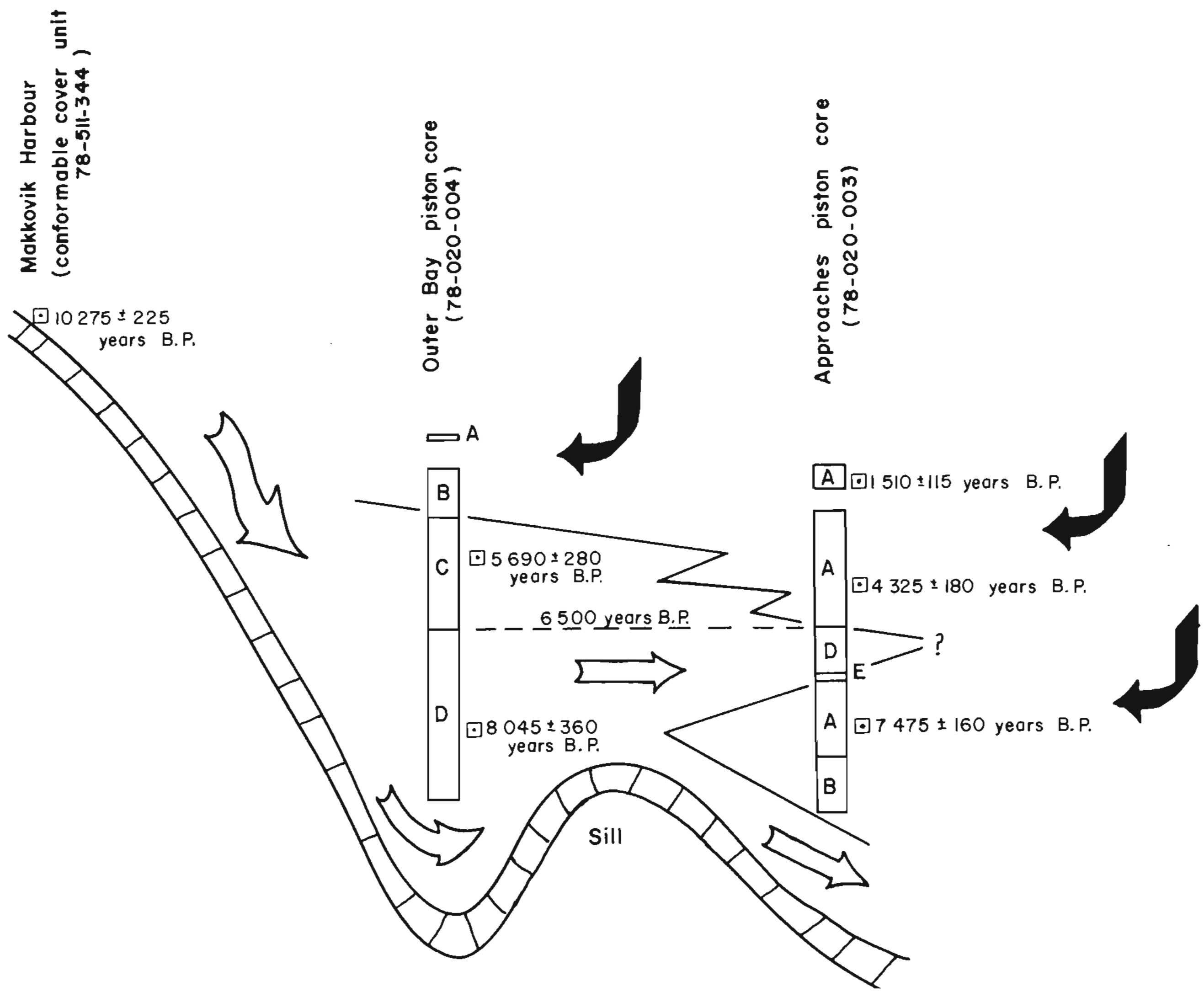


__Figure 38.__ Stratigraphic model of deposition. Solid correlation line discriminates wave-dominated deposition (facies A and B) from transitional and runoff- to wave-dominated deposition (facies C and D and conformable cover unit). Open arrows represent input of glacial detritus during period of high runoff. Solid arrows represent sedimentation of marginally eroding marine sediments.

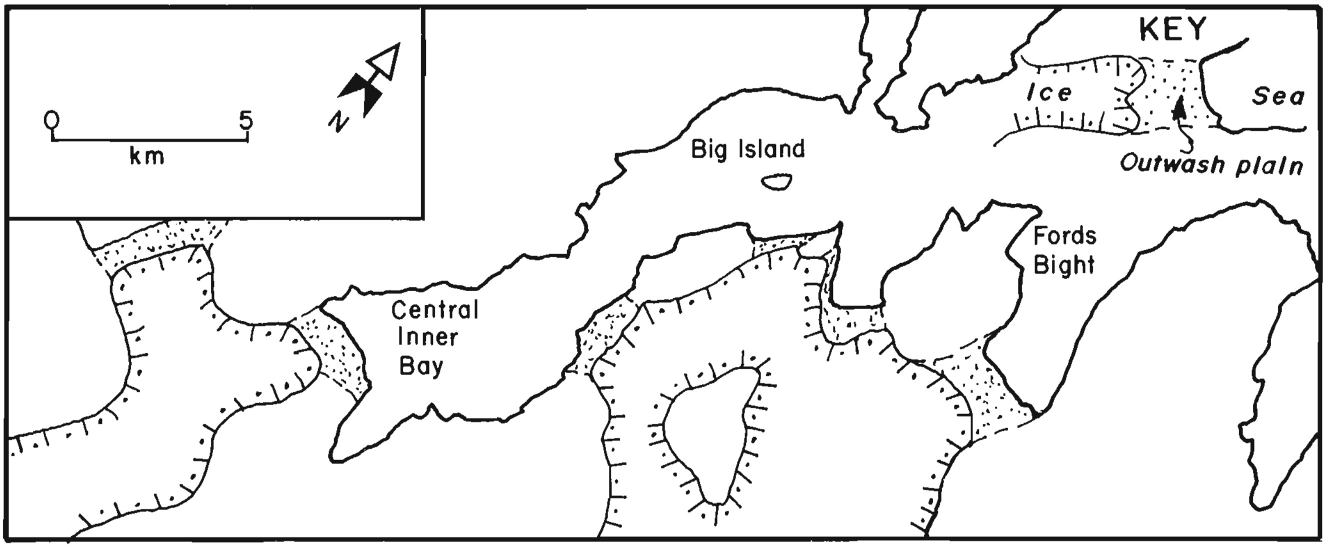


Figure 39. *Schematic map of Makkovik Bay 10 500 years B.P. during the deposition of the conformable cover unit showing higher sea level and possible location of ice margin.*

(e) Phase 2 of upper basin-fill unit (8000-7000 B.P.)

Phase 2 coincides with facies D1 in the Outer Bay and A in the Approaches. The distribution of these facies with their depositional interpretations implies that runoff-dominated deposition extended as far seaward as the Outer Bay, characterized by terrestrially-derived clays. The development of a rich calcareous foraminiferal assemblage suggests highly stratified estuarine waters extended at least to the Outer Bay.

(f) Phase 3 of upper basin-fill unit (7000-6500 B.P.)

This time interval includes the top of facies D1 in core 004 from the Outer Bay, and facies D and E in core 003 from the Approaches. The acoustic, sedimentologic and foraminiferal interpretations suggest that phase 3 occurred during peak conditions of fresh water runoff, probably accompanied by an increase in sediment discharge, giving conditions similar to those that deposited the conformable cover unit. This is the highest level at which ice-rafted sedimentation of gravels is common. The deposition of the gravelly mud surficial lithologic unit may date from this time or earlier. This event corresponds approximately to the peak of the postglacial hypsithermal recognised in pollen assemblages from coastal lakes (Jordan, 1975; Short and Nichols, 1977) and shelf basins (Vilks and Mudie, 1978; Mudie, 1980).

(g) Basin-wide erosion event (6500 B.P.)

The basin-wide erosional event seen in several basins terminates the runoff-dominated event discussed above. It might be due to either wave controlled winnowing following a short period of conformable cover type sedimentation, or more probably, to shorter winter ice cover during the hypsithermal period exposing the sediment to more wave activity during early spring and late fall storms.

(h) Phase 4 of upper basin-fill unit (6500-3000 B.P.)

This coincides with facies C in the Outer Bay and the lower portion of facies A in the Approaches. The distribution and interpretations of these facies suggest a transitional depositional style from runoff-dominated sedimentation in a highly stratified two-layer type estuary to wave-dominated sedimentation in a partially mixed estuary. This was probably accompanied by a significant fall in the relative sea level resulting in the general erosion of the conformable cover unit on the flanks of the bay. This was presumably a gradual process produced by increased wave and tidal current action as sea level fell. Clay mineral assemblages in cores suggest most of this erosion has taken place since 6000 years B.P.

(i) Phase 5 of upper basin-fill unit

The trends above continue with the stabilization of wave-dominated deposition in a partially mixed estuary with a probable continued fall in relative sea level, decreased sedimentation rate and increased wave energy and reworking of marginal marine sediments. The decrease in the total foraminiferal population and the proportion of calcareous foraminifera is consistent with the cooling trend observed elsewhere on the eastern Canadian coastline (Andrews, 1972; Bradley and Miller, 1972).

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Ann Miller corrected and revised the foraminifera taxonomy where necessary: she and David Scott assisted with the foraminifera interpretations.

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