Surficial geology of the Queen Charlotte Basin: evidence of submerged proglacial lakes at 170 m on the continental shelf of western Canada

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Josenhans, H.W., Barrie, J.V., Conway, K.W., Patterson, R.T., Mathewes, R.W., and Woodsworth, G.J., 1993: Surficial geology of the Queen Charlotte Basin: evidence of submerged proglacial lakes at 170 m on the continental shelf of western Canada; in Current Research, Part A; Geological Survey of Canada, Paper 93-1A, p. 119-127.

Abstract: A high resolution marine seismic and sampling program in the region was carried out during a 12 day cruise aboard the research vessel *CFAV Endeavour*. Preliminary results indicate that grounded glaciers deposited sediments in the deep troughs which indent the continental shelf as far west as the shelf break. Offlapping till tongues found in the troughs indicate that ice retreated stepwise from Queen Charlotte Sound at the close of the last (Late Wisconsinan) glaciation. Detailed studies of submerged shoreline deposits define the volume and frequency of failure of steeply dipping prograde sand and gravel deposits.

Partially eroded, proglacial lake deposits found in 170 m water depth were seismically surveyed and sampled in Hecate Strait near southeastern Moresby Island. Paleolacustrine deposits at this location on the shelf imply that sea level was locally lowered by at least 170 m. Data from the cruise suggest an east to west tilt and lowering of paleoshorelines of at least 60 m vertical per 50 km horizontal.

Résumé : On a réalisé un programme de levés sismiques de haute résolution et d'échantillonnage dans la région pendant une croisière de 12 jours à bord du navire de recherche *CFAV Endeavour*. Les résultats préliminaires indiquent que des glaciers échoués ont déposé des sédiments dans de profondes fosses qui entaillent la plate-forme continentale vers l'ouest jusqu'à la marge de la plate-forme. Les langues régressives de till rencontrées dans les fosses témoignent du retrait graduel de la glace du détroit de la Reine-Charlotte à la fin de la dernière glaciation (Wisconsinien tardif). Des études détaillées des dépôts littoraux submergés ont permis de définir le volume et la fréquence de rupture des dépôts prograde fortement inclinés composés de sable et de gravier.

Les dépôts lacustres proglaciaires partiellement érodés rencontrés dans une profondeur d'eau de 170 m ont fait l'objet de levés sismiques et d'échantillonnages dans le détroit d'Hecate près du sud-est de l'île Moresby. La présence de dépôts paléolacustres situés à cet endroit sur la plate-forme continentale implique que le niveau marin s'est abaissé d'au moins 170 m à cet endroit. Les données recueillies au cours de la croisière semblent indiquer un basculement d'est en ouest et un abaissement vertical des anciennes lignes de rivage d'au moins 60 m sur des distances horizontales de 50 km.

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INTRODUCTION

The Queen Charlotte Basin was the focus of surficial geological studies by the Geological Survey of Canada as part of the mandate of the Frontier Geoscience Program. The results of this work indicate extremely rapid relative sea level and environmental change at the end of the last glaciation (Luternauer et al., 1989). Sea levels on the inner continental shelf were much lower (100 m) than present while at the same time areas at the heads of mainland fiords were submerged by up to 200 m. This observation implies a degree of east to west tilting in sea level. Important questions as to the timing, spatial variation, and mechanisms of these sea level changes on the western Canadian shelf are outstanding.

Onshore data suggest that parts of the Queen Charlotte Islands may have been ice free during the last glaciation (Warner et al., 1982). Questions regarding the seaward limits of the last (Fraser) glaciation on the continental shelf remain unanswered.

In view of the above mentioned gaps in what is known about this region, Cruise PGC92-004, aboard the *CFAV Endeavour*, was mounted to address objectives including (i) an investigation of the regional glacial stratigraphy, (ii) examination of the stability of steeply sloping, former shoreline deposits, and (iii) a study of the paleoenvironments of surficial deposits to provide constraints on sea level reconstructions.

Seismic profiles were placed to determine the maximum seaward extent of glaciation and piston core samples from these glaciogenic deposits were collected to obtain dateable material to define the age and rate of ice retreat from the continental shelf. Additionally, lines were run in areas where previously collected data suggested good resolution of till sequences on the inner shelf might be obtained. These data were collected to provide insight into the mechanisms and rate of deglaciation.

Detailed site specific investigations were carried out on the eastern margin of Middle Bank in central Queen Charlotte Sound (Fig. 1) to determine the volume, composition, stability and age of a paleo-shoreline prograded spit deposit. Numerous similar large sand spits occur throughout Queen Charlotte Sound with steep prograde slopes which have failed repeatedly since their emplacement. Our objective was to acoustically image the detailed architecture of one of these features and to define the frequency and volume of slope failure at this site.

Our final area of detailed study focused on mapping and sampling a sequence of horizontally stratified, incised basin fill deposits found in the vicinity of south western Laskeek

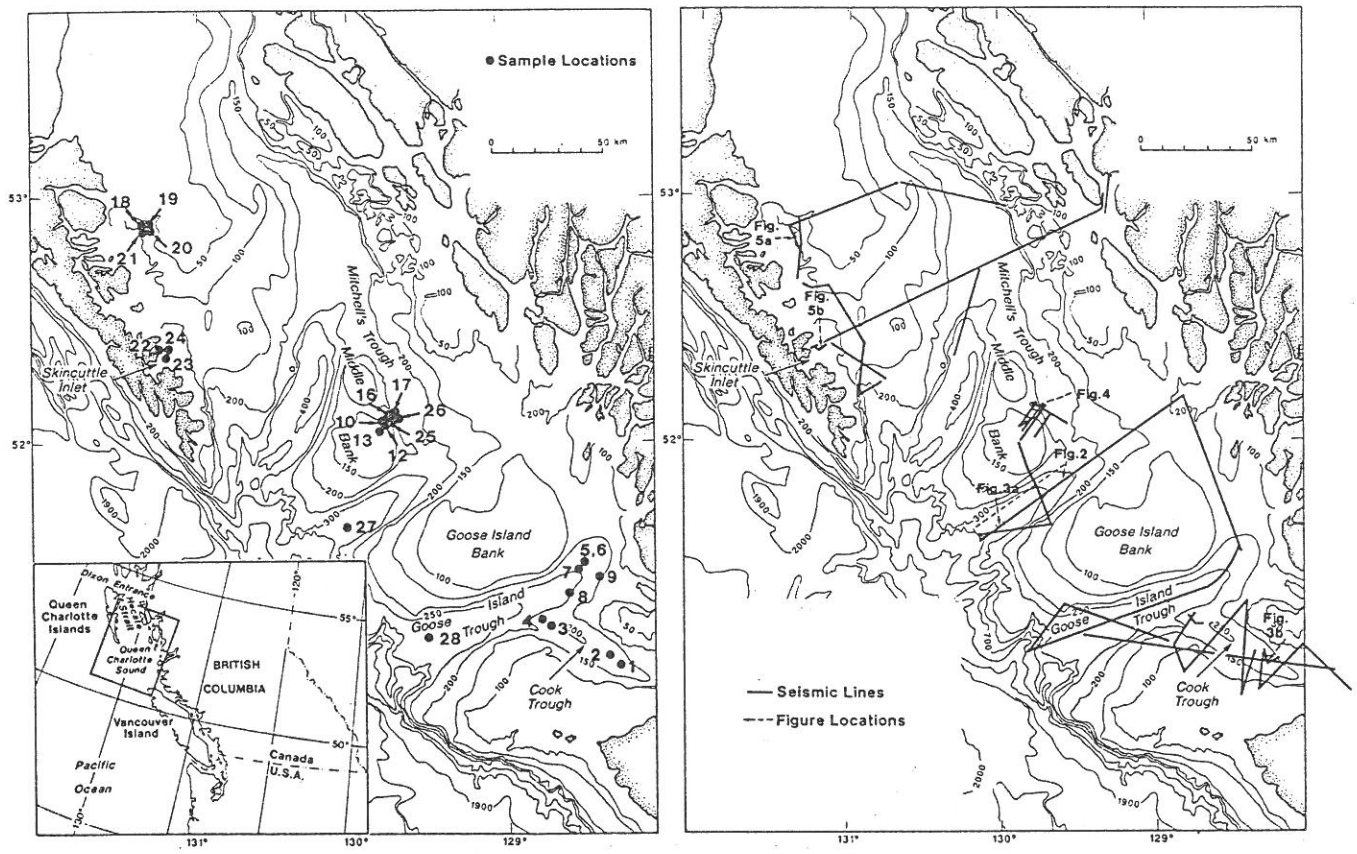

Figure 1. Bathymetry map of Queen Charlotte Sound showing location of seismic tracks and sample locations of Endeavour cruise 92A004.

Table 1. Endeavour 92-004 facts sheet

SAMPLE INVENTORY	NUMBER
PETERSON GRABS	1
BENTHOS PISTON CORES	18
VIBRACORES	5
TOTAL SAMPLES	24

DATA TYPE	KILOMETRES
3.5 KHz BATHYMETRY	180
12 KHz BATHYMETRY	1205
HUNTEC DTS	1301
SLEEVEGUN SEISMICS	1116
100 KHz SIDESCAN	1196
TOTAL LINES (#1-42)	1385

Bank off south Moresby Island in greater than 170 m water depth. Seismic profiles indicate that up to 25 m of material has been eroded from these deposits. A survey and sampling program was designed to determine the origin of the basin fill deposits and the cause of the incised relief.

The data collected during this cruise will be used to update maps of surficial geology and regional seismostratigraphy of the region published earlier by Barrie et al. (1990) and Luternauer et al. (1990), as well as to address specific questions relating to the maximum extent of glaciation and late glacial sea level history of Queen Charlotte Basin.

RESULTS

A summary listing of seismic and sample data collected in this cruise is shown in Table 1. Seismic lines and sample positions are shown in Figure 1.

Ice contact and ice retreat features

The acquired data has allowed acoustic imaging of the three dimensional distribution of glacial and postglacial sediments throughout Queen Charlotte Sound (QCS). An acoustically unstratified massive unit called "till" (Fig. 2) extends all the way to the shelf break and is interpreted to indicate that grounded glaciers flowed all the way to the shelf edge through Goose Island and Mitchell's Trough. The seismic profile illustrated in Figure 2 demonstrates the thickness and westward extent of multiple "tills" within the base of Mitchell's Trough. A piston core taken within the seismostratigraphically defined ice-proximal/ice-contact deposits associated with the uppermost "till" is illustrated in Figure 3a. The 5.5 m core sampled a poorly sorted gravelly mud at the base, which grades upwards into coarsely laminated sediments. These sedimentary features are consistent with an ice contact to ice proximal depositional setting and support the seismostratigraphic interpretation of "till".

Subsamples from core 27 (Fig. 3) were examined with a binocular microscope in an attempt to determine source terranes of the sediments. Two sand fractions were examined. At 414-416 cm this sand consisted of quartz, feldspar, epidote, hornblende, and garnet. Some tiny lithic clasts might be shale, siltstone, or aphanitic black volcanic material. The sample from 451-453 cm consists largely of quartz, feldspar, hornblende, epidote, sphene and other minerals. A few millimetre-sized clasts of intermediate(?) volcanic rocks do not appear to be highly altered and might be Miocene or younger. Given the fine grained nature of the sediments and the absence of distinctive, diagnostic lithologies, the provenance of these samples is uncertain.

Seismic profiles collected from the troughs indicate regionally extensive "till sheets", often superimposed and typically 30 m thick. Profiles from the transition of trough to bank tops show numerous disconformities and seismic reflector truncations. The data do not clearly resolve if glacial till occurred on the bank tops although acoustically massive deposits which may represent tills are observed locally. The question of ice cover on the bank tops remains unresolved.

No evidence for young (postglacial) faulting was observed on the seismic records. The unconformity developed at the base of the glacial deposit illustrated in Figure 2 is smooth and unbroken.

A series of seismically resolved ice retreat deposits called till tongues (King et al., 1991) were found and sampled in Cook's Trough. These features were believed to have been formed by the stepwise, southward retreat of a glacier in Cook's Trough. Similar ice retreat features are resolved seismically in all the major troughs of Queen Charlotte Sound (Fig. 2). Figure 3b illustrates the seismostratigraphic setting and sedimentary features of a piston core representative of ice proximal glaciomarine sediments deposited directly at a till tongue.

Four cores were taken along the axis of Cook's Trough (Fig. 1) within similar ice-proximal till tongue settings. These cores have been subsampled and shell fragments from the ice proximal deposits will be dated to determine the rate of ice retreat from Cook's Trough.

Paleo shoreline deposits

A closely spaced grid of seismic profiles from the eastern edge of Middle Bank (Fig. 1), shows a sequence of steeply dipping prograded reflectors (Fig. 4) which extend from a depth of 110 m at the bank top to approximately 200 m in Mitchell's Trough. Vibracore samples (Fig. 4) from the top of this prograde spit sequence, indicate beach sands and well rounded gravels which must have been deposited when sea levels were at least 110 m lower than present. Four vibracores were obtained from the oldest to the youngest member of the prograded sequence. Shell fragments found within these sands and well rounded gravels will be dated to determine the age of the deposit as well as to determine the rate of progradation. Three piston cores define the lateral extent and volume of numerous slump deposits observed at the base of these shoreface deposits. Piston cores obtained from above and below a large slump deposit (Fig. 4) will be analyzed to determine the age and frequency of these slope failure events. The number of slumps observed at the base of the slope

suggest that these depositional settings may be sensitive indicators of seismicity. Experience gained in studying the three dimensional configuration and frequency of failure of these former shoreline deposits has helped to develop an appropriate methodology for studying the stability of modern high angle prograding spits such as those found off Comox, British Columbia and Port Angeles and Dungeness spits in Juan de Fuca Strait.

Proglacial lake deposits

Southeast of Moresby Island,in up to 170 m water depth, the Huntec and airgun data reveal (Fig. 5a, b) a unique seismic unit which is interpreted to represent a proglacial lake deposit. The seismic data indicate that these horizontally stratified sediments were deposited as basin fill into the localized depressions formed on the volcanics of the Masset Formation.

A regional erosional event has subsequently incised these basin fill deposits by up to 25 m, resulting in numerous (submerged) cliff sections (Fig. 5). Piston cores and vibracores were taken from the flanks of these exposures and 25 m of (Quaternary) section was sampled. At the base of the section the recovered cores contain sand- to silt-sized sediments, in what appear to be rapidly deposited rythmites. These are overlain by a fining upward sequence of rythmites and massive silty clays. Above the clays, a veneer, up to 1.5 m thick contains coarse grained sands, gravels and shell fragments. The latter unit is thought to have developed when the area was transgressed at the end of the Late Wisconsinan. In contrast to the sterile sediments found at the base, the upper part of the section includes marine shells and forams.

Pollen analysis

Preliminary results of pollen analysis from the upper 280 cm of sediments (Fig. 5a) are consistent with an interpretation of a proglacial lake deposit, grading into late-glacial muds, in turn overlain by sediments of a marine transgression. The basal varve-like rythmites contain fine organic matter and are essentially barren of pollen and spores. Between 220-250 cm, pollen and spore frequencies increase, with an abundance of pine pollen, as well as soil fungi and fresh-water plant

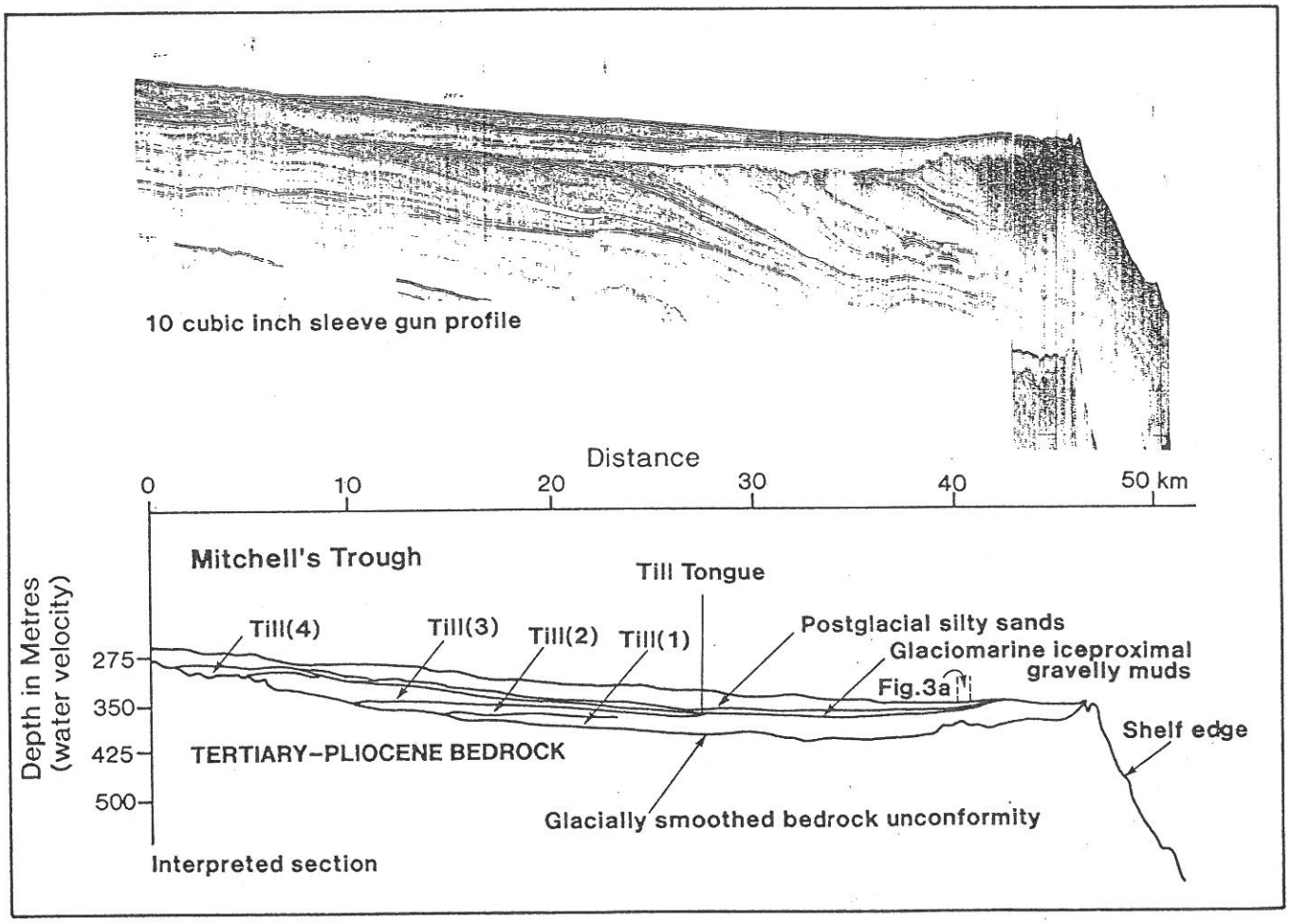

Figure 2. Sleeve gun seismic profile and interpreted section from axis of western Mitchell's Trough. The acoustically unstratified deposits above the bedrock unconformity are interpreted to represent superimposed glacial tills deposited by a waxing and waning ice margin which retreated toward the left of the diagram. For location see Figure 1.

remains. Pine pollen reaches very high values around 200 cm, and is soon joined by abundant and well preserved spruce grains by 184-186 cm. Comparison with terrestrial sequences on the Queen Charlotte Island suggests a late-glacial age of ca. 12 000 BP for initial pine expansion, and ca. 11 000 BP for the initial appearance of spruce. It appears that the sampled basin was a late-glacial fresh water lake, probably transgressed by the sea during the transition to the early Holocene.

Microfauna analysis

Twenty-seven samples from core END 92A-021 (Fig. 5a) were quantitatively examined for their foraminiferal and other microfossil group content. Fourteen of these samples contained at least some foraminifera and no sample was devoid of any useful micropaleontological specimens. Most of the non-foraminiferal bearing samples are from the Diatom

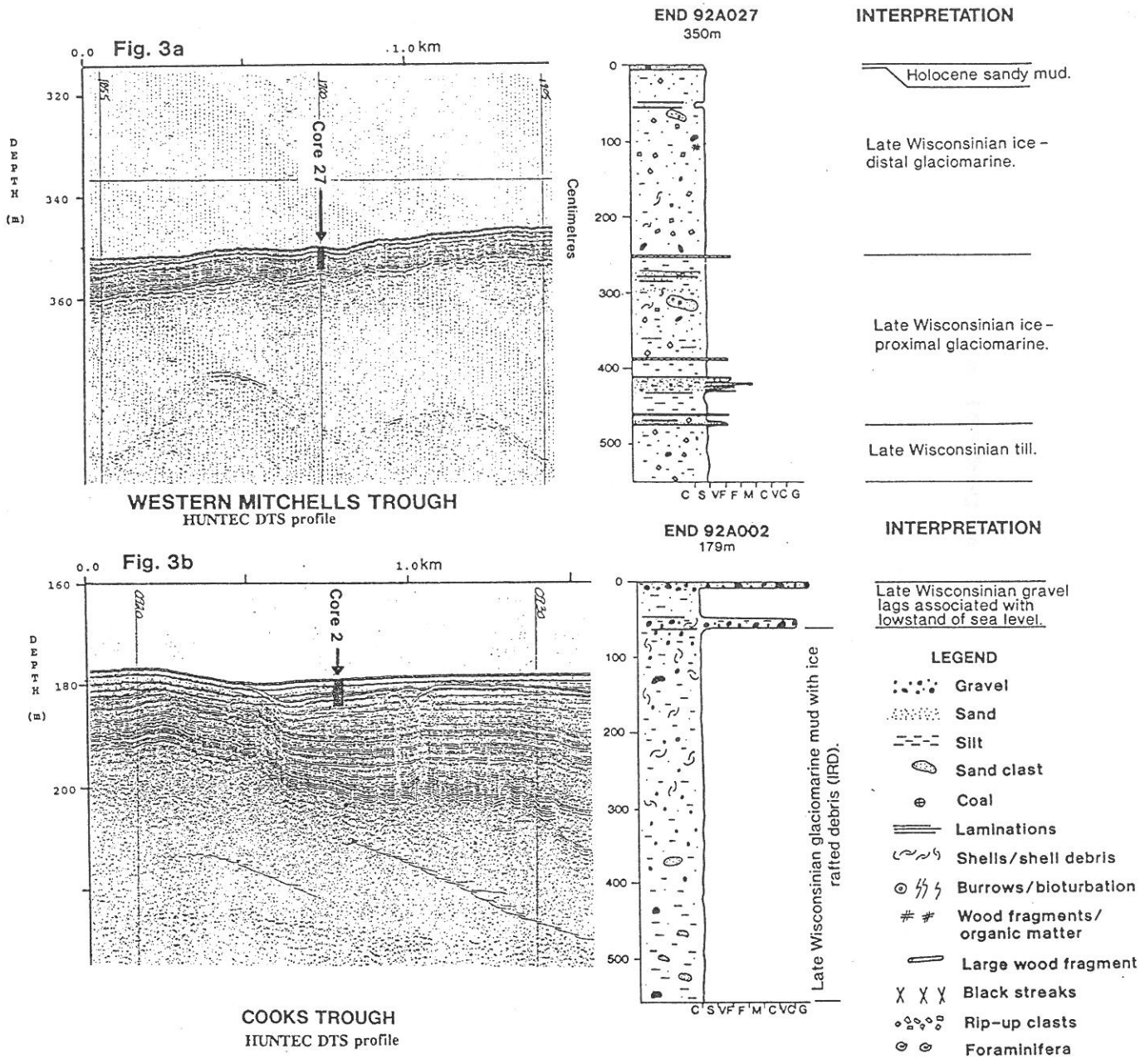

Figure 3. Huntec DTS seismic profiles interpreted to represent ice proximal stratified deposits above glacial till. The black bar indicates the actual penetration of the piston core (illustrated in the right column) with respect to the seismic profile. For location see Figure 1.

Biofacies (described below). The core could be divided into four distinct biofacies that correlated almost exactly with the various lithological units described in Figure 5a.

1. Ostracode biofacies: 274 cm - bottom of core

The sandy muds in the basal part of the core below 274 cm are characterized by very abundant populations of exclusively smooth walled ostracodes (probably Cypridae). This interval is also characterized by very rare centric diatoms (no pinnates were observed in this interval) and a single specimen of the foraminifera *Quinqueloculina triangularis*, a species common to neritic depths all along the Pacific coast. The presence of the probably transported foram suggests that the ocean was not far away. The lack of fresh water indicating pennate diatoms also suggests that perhaps conditions were brackish during deposition of this interval. The lake may have been subject to periodic marine incursions at this time.

2. Diatom biofacies: 128-274 cm

The organic rich varved muds found between 128 and 274 cm are characterized by very abundant populations of fresh water centric and pennate diatoms, characteristic of fresh water lakes. Most of the samples from this interval are also characterized by very abundant pollen taxa also characteristic

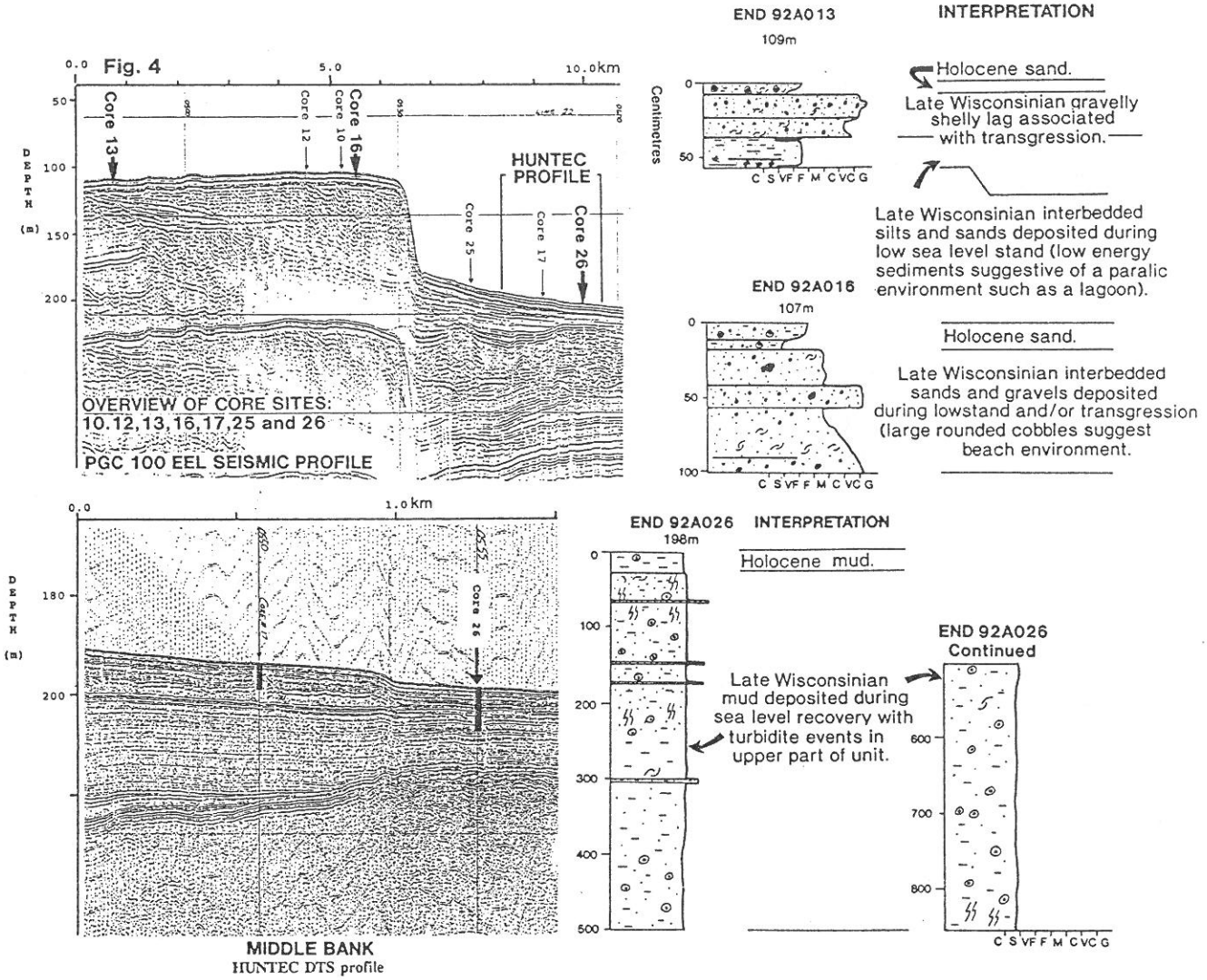

Figure 4. Sleeve gun seismic profile and Huntec DTS high resolution profile of prograde spit deposit from Eastern Middle Bank showing the positions of cores collected in order to determine the age and rate of progradation of this feature. The Huntec profile illustrates the acoustic character of a large slump deposit which has failed from the steep paleoshoreface. Core 92A026 has sampled horizons above and below the slump deposit and will be dated to determine the age of the failure event.

of onshore fresh water environments. The lack of bioturbation, microfossil assemblage, and the varved nature of the sediments indicate that the lake bottom had low oxygen content. One atypical interval of this biofacies found between 234 and 246 cm is characterized by a mixed lacustrine diatom and marine shelf foraminiferal fauna. In addition, specimens of the benthic fresh/brackish arcellacean *Centropyxis aculeata* are also found. The juxtaposition of these drama tically different faunas suggests again that the lake was subject to periodic marine incursions, most likely occurring during extreme storm events. However no sedimentological evidence of such a storm event is present at this horizon.

3. *Shelf foraminiferal biofacies: 62-128 cm*

The shelly sands found between 62 and 128 cm are characterized by an essentially modern high diversity, open shelf foraminiferal fauna. Typical species include *Buccella frigida, Buliminella elegantissima, Cribroelphidium excavatum, Elphidiella nitida, Epistominella vitrea, Gavelinopsis campanulata, Lobatula fletcheri* and numerous others. The lack of significant proportions of cold water indicator species such as *Cassidulina reniforme* and *Cribroelphidium excavatum* as observed elsewhere in Late Wisconsinan cores indicate water salinities and temperatures were similar to those found in the area presently (Patterson, in press). Slight abrasion and breakage of some specimens in addition to the abundant shell debris indicates minor reworking.

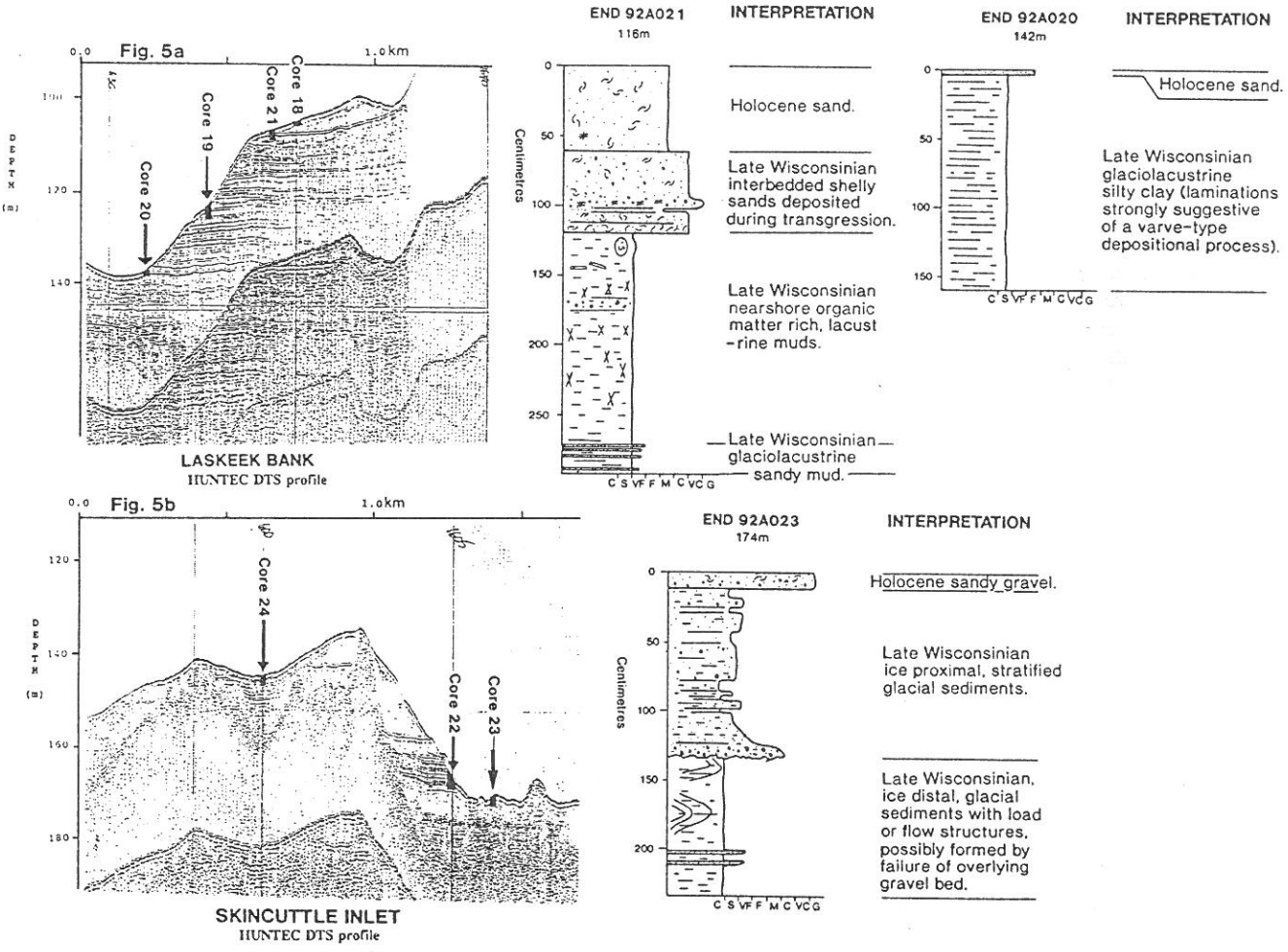

Figure 5. Huntec DTS profile of remnant horizontally stratified basin fill deposits located off Southeastern Moresby Island. For exact location refer to piston core position in Figure 1. The black bars indicate the amount of sample penetration in relation to the seismic section. Note that almost 30 m of composite section has been sampled. The origin of the erosional surface may be due to severe erosion during a transgression of the region or due to glacial erosion following emplacement of the stratified deposits.

4. Reworked Foraminiferal Biofacies: 0-50 cm

This biofacies is characterized by small populations of highly abraded shelf foraminiferal populations in a winnowed sand. Although essentially the same species as identified in the shelf foraminiferal biofacies, the extremely poor condition of specimens clearly differentiate the faunas found in this biofacies.

Provenance of selected samples

The sand and gravel fractions of subsamples of cores 18, 21, and 23 (Fig. 5) were examined with a binocular microscope in an attempt to determine possible source terranes for the cored sequences. The assumptions are that, if the sediments had an easterly source, they would reflect the lithologies found in the predominantly granitoid and high grade metamorphic bedrock of the Coast Mountains. If the sediments were derived from the Queen Charlotte Islands, the sediments should reflect the predominantly volcanic and sedimentary nature of the terrane. Preliminary descriptions and tentative interpretations are given below.

Core 18

The >.063 mm <2 mm (sand) fraction from 103-105 cm consists largely of quartz and feldspar grains, with subordinate hornblende and epidote. The more informative >2 mm fraction from the same interval consists mostly of dark, fine grained volcanic material or siltstone. One clast of dark green basalt has a strong textural resemblance to Upper Triassic Karmutsen basalts common on Queen Charlotte and Vancouver Islands. A small percentage of the clasts are hornblende-rich granitoid rocks. Several clasts are composed of fresh-looking, vesicular basalt, probably Miocene or younger.

The predominance of volcanic and sedimentary rocks in the lithic clasts strongly suggests that the sediments were derived from units now exposed on the Queen Charlotte Islands. The source of the the vesicular basalt is unknown; such rocks are rare on the Queen Charlotte Islands.

Core 21

Only a small amount of sample is present in the >2 mm fraction from 169-171 cm. The few large grains are dark, fine grained volcanics or siltstones. The sand fraction from 277-279 cm in the core consists largely of quartz and feldspar with significant hornblende and biotite and lesser other minerals, notably epidote.

The fact that the few large lithic clasts are volcanic or sediments, and the absence of granitoid material argues against a coast mountain origin for these sediments.

Core 23

The >2 mm fraction from 129-131 cm contains several conspicuous black, very fine grained, angular clasts that resemble hornfelsed siltstone. Most lithic clasts are grey, unfoliated, hornblende>biotite tonalite or granodiorite. One large clast appears to be grey-green, andesite volcanic rock. The >.063 mm <2 mm fraction from the same interval is composed of feldspar with subordinate quartz, hornblende, epidote and other minerals. Lithic clasts consist of fine grained siltstone or hornfels similar to that in the coarse fraction. Some sugary aggregates of diopside(?) may have been derived from contact metamorphosed carbonate rocks.

The abundant tonalite could have been derived from either the Coast Mountains or the Queen Charlotte Islands. The absence of foliation suggests a Queen Charlotte source. Fine grained, dark sedimentary rocks are common on the Queen Charlotte Islands and rare in the Coast Mountains. The diopsidic clasts probably represent metamorphosed carbonate rocks; these are found more commonly on the Queen Charlottes but are not diagnostic.

The examined sediments were probably derived from Mesozoic units now exposed on the Queen Charlotte Islands; nothing strongly points to an easterly source.

Erosional event

Two mechanisms for eroding this regional unconformity which has dissected the basin fill deposit are proposed:

1. The transgression may have had sufficient erosive power to produce the incised relief and remove the large volumes of basin fill sediment; and
2. A glacier originating from southern Moresby Island may have advanced over the basin fill sediments and eroded and transported the material. A subsequent transgression could then have modified the existing erosional surface to produce the coarse sand and gravel veneer.

A lack of (observed) glacial till below the transgressive sands argues in favour of mechanism #1. However, a surprising lack of transgressive and younger basin fill sediments within the enclosed and incised basins has resulted from the transgression which argues in favour of mechanism #2. Detailed analysis of the core samples to define environments of deposition, provenance, age and degree of compaction are needed to constrain further interpretations.

Implications for paleo-sealevels.

The prograding spit deposit investigated on the eastern margin of Middle Bank clearly indicates that sea level must have fallen to -110 m in order to deposit the clean sands and gravels which make up the paleoshoreline feature. We infer that sealevels must have stabilized at this elevation, at least locally for an extended period (1-2 ka) to produce the observed geomorphic features and the volumes of sediment contained therein.

The lacustrine deposits sampled at a depth of 170 m from the western margin of the continental shelf indicate that sealevel had fallen to at least -170 m. The lake sediments are up to 30 m thick which implies that a lake existed at these sites for an extended period of time (several hundreds of years at least).

The proglacial basin fill site with lacustrine deposits at 170 m is approximately 50 km west of the prograde spit which was deposited near sealevel at -110 m. A minimum tilt of paleoshorelines of 60 m over a horizontal distance of 50 km is indicated.

Additional work is required to define the lower limit of lacustrine conditions and to define the lateral extent and depth of the basin into which the proglacial lake sediments were deposited.

ACKNOWLEDGMENTS

We thank the officers and crew of the "*Endeavour*" for their willing and able support at sea. We also thank the technical support staff at PGC for making it possible to collect such high quality data. Tom Vandall, Jay Stravers, John Luternauer, Olav Lian, Raelyn Crossley, Michelle Packard and Gina L'Esperance are recognized for valuable assistance at sea. The report was reviewed by T.S. Hamilton.

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