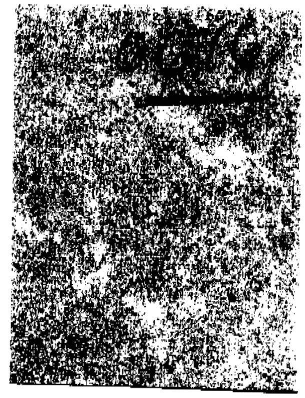
" INTERPRETATION OF HIGH RESOLUTION, 24-CHANNEL REFRACTION DATA GATHERED BY MEANS OF A PROTOTYPE HYDROPHONE EEL. "

Beaufort Sea, 1988



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ABSTRACT

The last of a series of four high resolution refraction surveys was carried out by the Geological Survey of Canada (GSC) in the Akpak Plateau area of the Southern Beaufort Sea, in order to carry on the sea trials of the latest prototype of a 24-channel, deep-towed refraction array. This new refraction technique is utilized for the detection of anomalously high compressional wave velocities indicative of subsea permafrost. The refraction system was deployed from the C.G.S. Nahidik along with a suite of reflection profilers including a 3.5 kHz pinger, a Uniboom, and a small airgun array.

The objective of the survey was to increase the coverage of reconnaissance lines in order to map the regional distribution of the shallow ice-bearing permafrost present across the southern Akpak Plateau. In addition, a site specific survey was conducted over a geologically complex zone in order to evaluate the effectiveness of the new technique in mapping ice-bearing sediments throughout a pattern of closely spaced seismic lines.

The results indicate that the measurement of P-wave velocities provides conclusive evidence of occurrences of frozen sediments that are only 'acoustically' pictured on the reflection records; and moreover the refraction technique can detect thin, marginally frozen beds that are not easily recognized on the reflection records. On the basis of velocity observations and interpretation of high resolution reflection profiles, a new seismio-stratigraphic model is proposed to account for the thick (up to 20m) sequence that deposited during deglaciation and the subsequent submergence of this region of the Akpak Plateau.

RESUME

Le dernier relevé d'une série de quatre effectués au moyen de la sismique réfraction a été réalisé par la Commission Géologique du Canada (CGC) dans les eaux côtières du Plateau Akpak qui se situe dans la partie sud de la mer de Beaufort. Ceci afin de poursuivre les essais en mer d'une flûte comprenant 24 traces et qui est remorquée près du fond de la mer. Cette technique permet de détecter et de cartographier le pergélisol présent sous les fonds marins à partir des vitesses sismiques de compression qui sont anormalement élevées dans les sols gelés. Le système présentement à l'essai, ainsi que différents sondeurs de sédiments (3.5 kHz pinger, Uniboom, et canons à air), ont été mis en oeuvre à partir du navire C.G.S. Nahidik.

L'objectif des sondages était d'augmenter le nombre de profils obtenus à l'échelle régionale afin de mieux comprendre la distribution du niveau supérieur de pergélisol présent sous le plateau. Un relevé plus détaillé a été aussi realisé dans une zone géologiquement complexe afin d'évaluer l'efficacité du nouvel appareillage de sismique refraction lors de la cartographie du pergélisol le long de traverses rapprochées.

Les résultats ont démontré que les mesures de vitesse de propagation obtenues sur les mêmes profils que ceux traversés en sismique réflexion, permettent d'identifier avec une plus grande certitude la présence de sédiments gelés dont l'existence ne peut être que déduite lors de l'interprétation des caractères (amplitude, signature) des réflecteurs. L'analyse des vitesses acoustiques permet également de détecter de minces lits de pergélisol qui ne sont pas toujours visibles sur les euregistrements de sismique réflexion. A partir de l'étude des vitesses de propagation et de l'analyse des sondages sismiques continus, l'auteur présente un model lithosismique des dépôts que l'on retrouve sur cette partie du Plateau. Ces dépôts, d'une épaisseur pouvant atteindre 20m, ont accumulé durant la déglaciation de cette région et lors de la transgression marine subséquente.

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SECTION 1 - INTRODUCTION

1.1 INTRODUCTION

Following similar programs conducted in 1985 through 1987, a forth combined high resolution refraction/reflection survey was carried out by the Geological Survey of Canada (GSC), during the open water season of 1988 in the Akpak Plateau area of the Southern Beaufort Sea (Figure 1). The field investigation was a joint effort between the Atlantic Geoscience Centre of the Bedford Institute of Oceanography in Dartmouth and the Terrain Sciences Division in Ottawa. The geophysical field work was conducted onboard the C.G.S. Nahidik, a shallow draft vessel of a length of approximately 55m from Hay River home port.

The present report covers only the combined refraction and reflection data that totalize about 2,500 refraction seismograms collected along with about 310 km of reflection profiles including 3.5 kHz subbottom profiler, Uniboom, and airgun records. This phase of the seismic program, undertaken under the direction of Dr J.A.M. Hunter of the Terrain Sciences Division, aimed to carry on with the sea trials of deep-tow refraction arrays which are utilized primarily for the detection of shallow subsea permafrost. The remainding line coverage, or about 905 km for a total of 1,215 km traversed during the entire survey, is concurrently being interpreted as part of a regional geology program under the leadership of Mr. S.M. Blasco of the

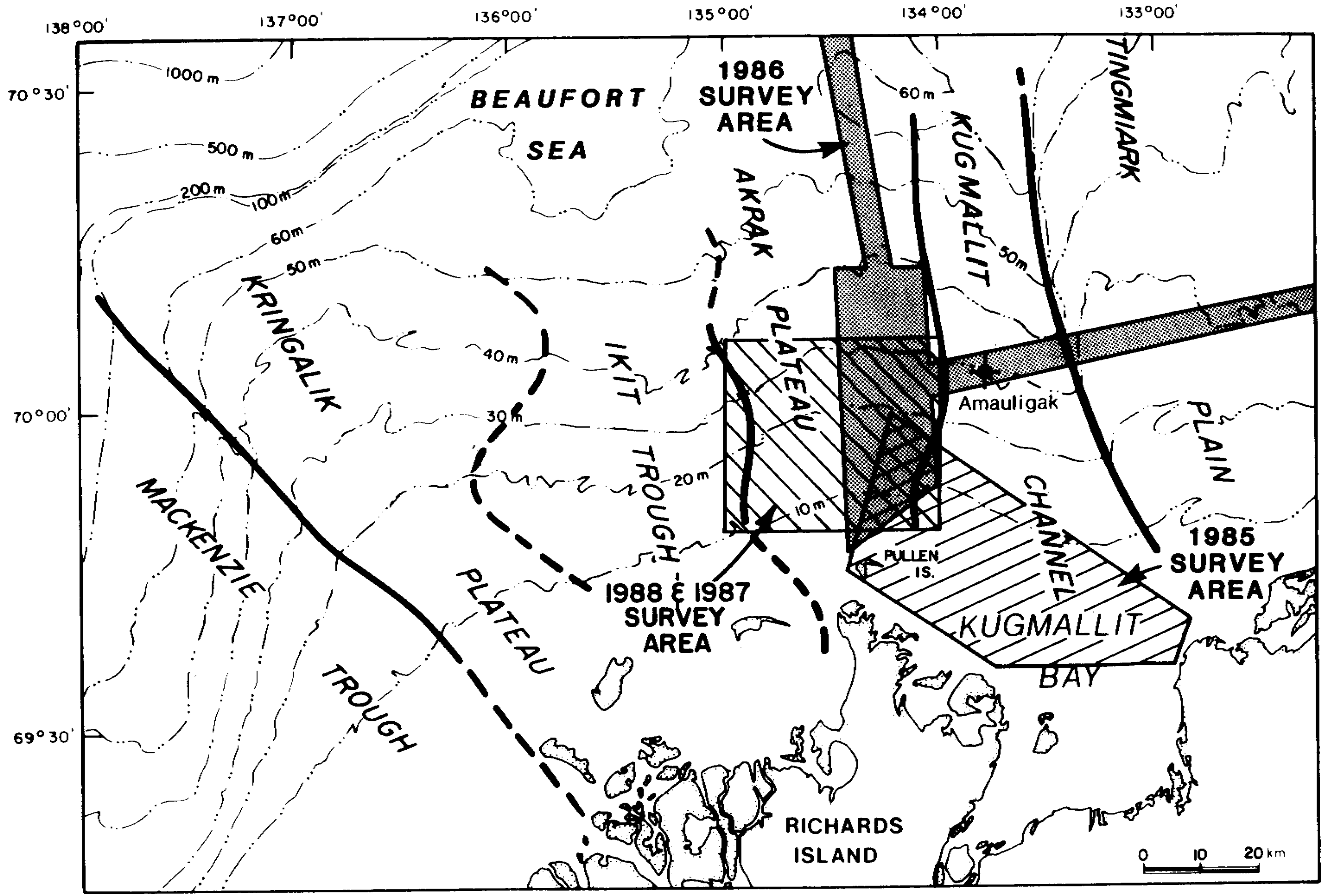

FIG. 1 LOCATION OF THE SURVEY AREAS.

Atlantic Geoscience Centre.

The survey area concerned was previously surveyed by the Terrain Sciences Division during three distinct field operations which were conducted in 1985, 1986 and 1987 across the Akpak Plateau, Kugmallit Channel and Tingmiark Plain (Figure 1). The results of the 1985 through 1987 field programs were presented to the GSC under separate covers (Fortin, 1986, 1987 and 1988).

1.2 OBJECTIVES

The primary objective of each of the 1985 through 1988 survey was to test various prototypes of deep-towed 12 and 24 channel refraction arrays that provide continuous measurement of compressional wave velocities. These experimentations were focused chiefly on the detection of shallow ice-bearing permafrost to a depth of about 20-25m below seabed. A secondary objective was to evaluate the efficiency of the new refraction system in distinguishing seabed materials and shallow subbottom layering in terms of acoustic properties and inferred lithofacies.

More specifically, the objective of the 1988 field investigations was of two folds: firstly, to increase the reconnaissance-level line coverage across the southern Akpak Plateau in order to study the regional distribution of shallow ice-bearing permafrost and to reconstruct the paleogeography of this sector of the Plateau, and: secondly, to evaluate the effectiveness of the technique in mapping the distribution of ice-bearing sediments throughout a closely spaced pattern of seismic lines.

1.3 AUTHORIZATION AND DISCLAIMERS

Authorization to undertake the work was granted to **H.R. Seismic Interpretation Services Inc.**, hereafter **S.I.S.**, of Hull, Qc, by the department of Supply and Services Canada (SSC) under SCC file No. 0345Z.23233-8-1405. Dr J.A.M. Hunter of the Terrain Sciences Division was the Scientific Authority for the study.

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1.4 ACKNOWLEDGEMENT

This study was funded by the Panel of Energy Research and Development (PERD) through the following program: Program 6.1; Permafrost. Special thanks are extended to Mr. S.M. Blasco (PERD Program 6.3; Offshore Geotechnics) who kindly supplied high quality copies of the reflection records used in the preparation of this report.

SECTION 2 - GEOLOGICAL BACKGROUND

2.1 SURFICIAL GEOLOGY OF THE OFFSHORE AREA

The interpretation of the shallow stratigraphic units delineated along the refraction/reflection survey lines is generally based on the model proposed by the GSC for the surficial geology of the Canadian Beaufort Sea (Figure 2). Basically, it is a generalized surficial geologic model of the continental shelf and consists of three basic stratigraphic units (O'Connor, 1980):

"**Unit A**" - a horizontal sequence of recent marine sediment deposited on the shelf following the last sea level rise which grades into;

"**Unit B**" - a transgressive sequence which includes deltaic, lagoonal and littoral sediments deposited in a complex transitional environment which existed during the last sea level rise.

"Unit C unconformity" - Units A and B overlie a regional unconformity that marks the top of an older unit. The Unit C unconformity represents a previous land surface which was subaerially exposed to arctic conditions and permafrost aggradation during Late Wisconsin glaciation.

"**Unit C**" - an underlying, much older sequence whose original depositional environment is poorly known, and probably contains sediments derived from former continental (glacial, fluvial and eolian) and transitional (deltaic, littoral) environments.

In the present report, Units A and B are designated collectively as the "**surficial sediment**". The acoustic horizon

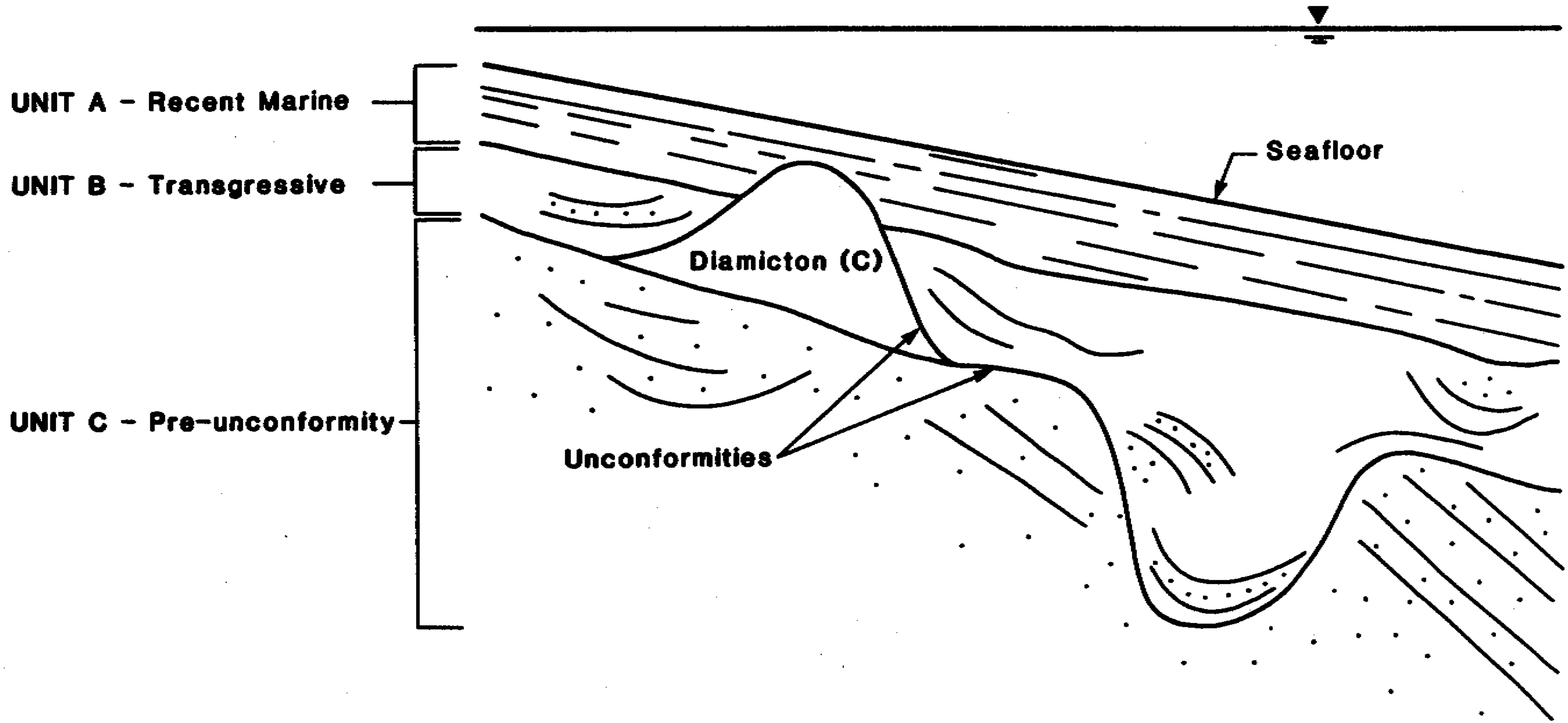


FIG.2 O'CONNOR's GEOLOGIC MODEL.

depicting the surface of the underlying Unit C unconformity is labelled "**U/C1**" on the interpretative cross sections, and generally refers to the top of Unit C of the O'Connor model.

In several places beneath the shelf, the distinction between Unit A and Unit B is fraught with numerous problems. One of the most serious difficulties in delineating the shallow stratigraphic units on the reflection records is the gouging of the ice keels into the seabottom, or the ice-scouring process. As a result of ice-scouring, the surficial sediment is remoulded at various degree and, hence their original sedimentary structures and geotechnical properties may be severely modified to a certain depth below the seabed. In addition, Hill **et al.** (1985) indicated that, in some parts of the Beaufort Sea, Units B and C are interpreted to be laterally equivalent and contemporaneous, making the correlations difficult between the observed acoustic horizons and specific units of the model. For these reasons, the O'Connor model is used only as a reference for the gross surficial geologic units of the Beaufort Sea. In complex areas, additional sub-units, unconformities and new interpretations are introduced if necessary.

The physiographic provinces adopted throughout this report (Figure 1) are those proposed by the GSC for the Canadian Beaufort continental shelf (O'Connor, 1982a). The shelf has been subdivided into nine physiographic regions which had been established by O'Connor after reviewing the shallow stratigraphic conditions evident on regional high resolution seismic records. The 1988 survey lines traverse three broad physiographic regions: the Akpak Plateau, the Kugmallit Channel, and the Ikit Trough. As most of the seismic coverage was obtained over the Akpak Plateau, a particular attention is given to this region in the following discussion.

According to O'Connor (1982a), Unit A on the Akpak Plateau is generally thin, averaging about 3m in thickness, but may be locally absent on the elevated Plateau (e.g. Isserk borrow pit). The paleotopography of the Unit C unconformity is characterized by numerous shallow lakes that have been infilled by variable Unit B sediments during the subsequent transgression.

Early work of O'Connor (1977; in O'Connor 1982b) indicated that the occurrence of hummocky Acoustically defined PermaFrost, or the acronym **APF**, in the nearshore area immediately north of Pullen Island is widespread but extremely complex. A later study by the same author (O'Connor, 1982b), based on a limited number of seismic profiles, tends to confirm his earlier findings in the area north of Pullen Island. However, the distribution of the APF reflectors shown in this study (O'Connor, 1982b; drawing No. 3.9) indicates that the occurrence of APF reflectors is significantly less frequent in the area north of Pullen Island (south of approximately Latitude

69° 55'N) than anywhere on the Akpak Plateau. Further offshore, O'Connor (1982b) indicated that hummocky APF is common between 134° and 135° W Longitude in water depths up to approximately 60m.

In a more recent study, based on a comparison of geotechnical and shallow seismic evidence, O'Connor (1984) indicated that beneath the continental shelf east of approximately 135° W Longitude:

"some of the hummocks occur only as sporadic outliers or islands, while others occur in close proximity to one another. Each may be separated from its neighbour by a zone where no ice-bonding is apparent. Hummocky APF island may vary from a few tens of metres to many kilometres in the lateral dimension. Many of the smaller APF islands are believed to be limited in thickness, but it is postulated that larger ones may be directly connected to the deeper, thicker, ice-bounded permafrost which is known to occur at depth".

"Hummochy APF is a characteristic feature of the upper 50m of sediments on both the Akpak Plateau and the Tingmiark Plain, but it also underlies the shallow waters of Kugmallit Bay and part of the nearshore zone along the Tuk Peninsula".

According to O'Connor (1984), approximately 70% of the hummocky APF consists of non-visible ground ice, and only about 20% consists of visible ice. Where hummocky APF could be directly correlated to visible ice in the borehole, the ice contents ranged from merely a trace to approximately 10%. Most of the sediments probably have less than 5% ice by volume (O'Connor, 1984).

On the basis of borehole, refraction and reflection data, O'Connor (1984) has produced two maps of the distribution of acoustic permafrost at the 1:50 000 scale (Maps A.3 and A.4, <u>in</u> O'Connor, 1984). These maps cover the portion of the Akpak Plateau that is comprised between the latitudes 70° and 71° N, and the longitudes 134° and 135° W. The maps display three levels of ice-bonding beneath the Akpak Plateau. Of interest for the present report, is the shallowest level of APF which occurs from approximately 15m to 50m below the seabed and comprises mostly discontinuous hummocky APF islands. The depth of the hummocky APF becomes significantly shallower at the southern boundary (70° Latitude N) of the mapped area; APF features within 5-6m of the seabed were noted west of Issungnak O-61 wellsite.

The Kugmallit Channel has been extensively infilled by a fine-grained sediment that may exceed 20m in thickness in the southern part of the Channel. The channel infillings are thought to include Unit A sediment which has been remoulded towards its base by the ice-scouring process and mixed with Unit B sediment; this resulted in a thick paleoscour zone which reaches almost to the Unit C unconformity (Fortin **et al.**, 1987). The occurrences of shallow APF are much less frequent underneath the Kugmallit Channel than under the adjacent physiographic provinces, i.e. the Akpak Plateau and the Tingmiark Plain. The near absence of shallow APF beneath the Channel is attributed to a wide and deep talik zone which was present underneath the ancestral Kugmallit River (Fortin, 1988a).

O'Connor (1982a) described the Ikit Trough as a stratigraphically complex relic lowland in which shallow strata appear to be generally fine-grained and laminated. In water depths of 50m or less, the shallow geology of the Ikit Trough is characterized by a series of deep, steep-sided and flat-bottomed depressions (e.g. Hooper Channel <u>in</u> Fortin, 1988b). O'Connor (op. cit.) reported that these depressions are extremely complex, having been infilled in a series of stages which have included slumping, prograding margins, and the subsequent deposition of laminated, flat-lying sediments in the centre. The presence of two unconformities in the shallow section is another important characteristic of the Ikit Trough.

According to Hill **et al.** (1985), the relative sea-level (RSL) rose of 140m since 27,000 years BP (Figure 3). During this period of sea level depression, the continental shelf was exposed to a periglacial climate which was prevailing during the last Wisconsin glaciation, and consequent permafrost aggradation. As the sea level rose during the following deglaciation, the shallow permafrost degraded and the permafrost table was depressed to its present level due to the thawing in response to a warmer transgressive sea and saline advection (Fortin, 1988a).

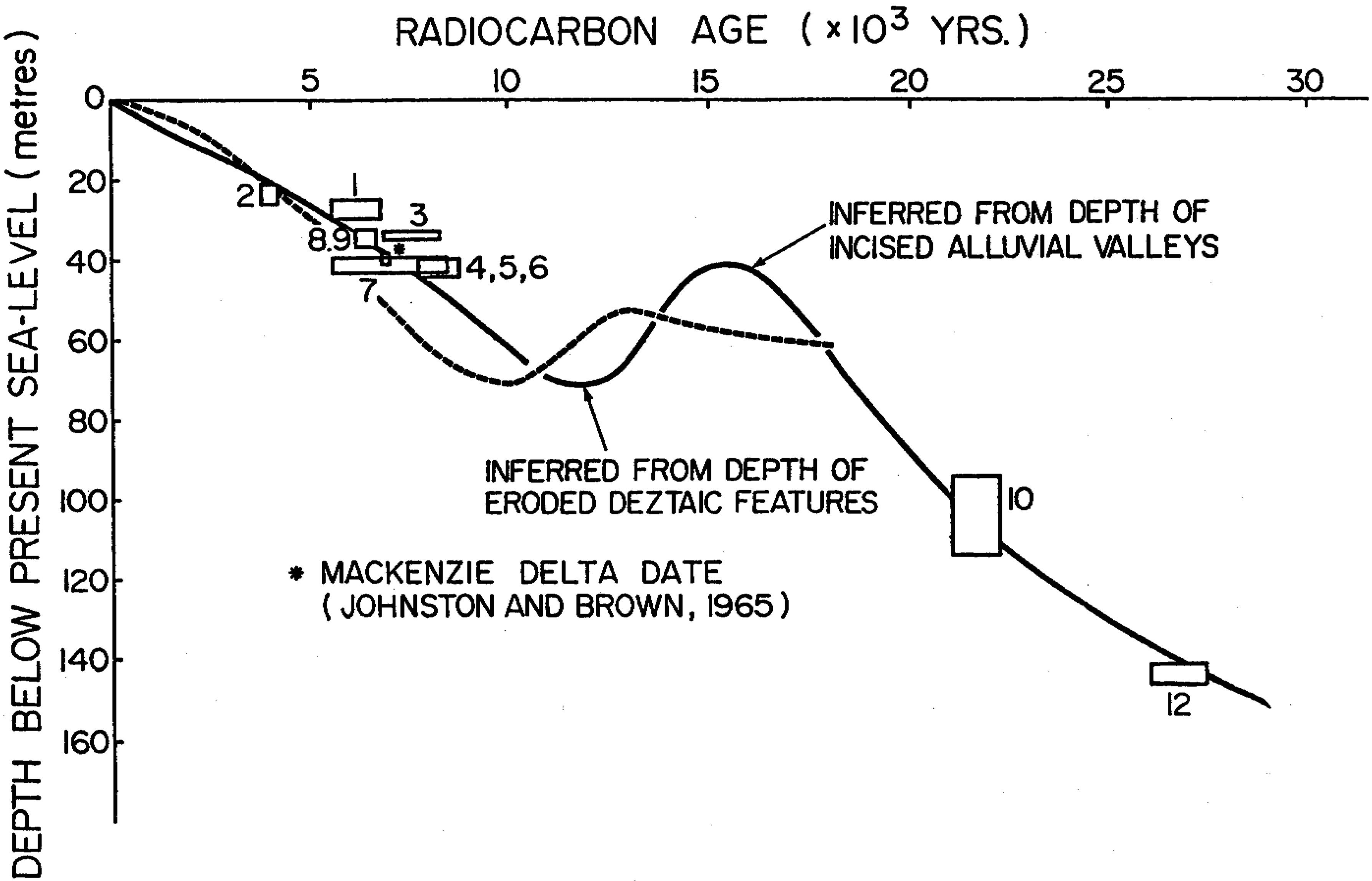


FIG. 3 RELATIVE SEA-LEVEL CURVE FOR THE CANADIAN BEAUFORT SHELF (After Hill et al.,1985).

2.2 QUATERNARY GEOLOGY OF THE ADJACENT MAINLAND

A significant contribution to the study of the Quaternary geology of the Tuktoyaktuk Coastlands has been provided by Rampton (1988). The following discussion on the Quaternary geology of the adjacent mainland (Richards Island) summarizes the results of this worker.

In the immediate vicinity of the survey area, the surficial geology of Pullen Island and North Point is dominated by two deposits: a thin veneer, generally less than one metre, of morainal deposits of Early Wisconsinan Age, that blankets the Kittigazuit Formation of Middle Plesitocene Age.

The morainal deposits (Unit M T/V of Rampton, 1987), primarily the till and till-related facies, have been assigned to the Toker Point Member of the Tuktoyaktuk Formation. Morainal deposits of the Toker Point Member consist primarily of a stony clayey diamicton. Typically the material contains 3 to 25% clasts greater than 2mm in size and the remainder contains 10 to 30% sand, 25 to 45% silt, and 30 to 50% clay. Rampton and Bouchard (1975 in Rampton 1988, p.49) noted that "beds and lenses of sandy, stony, diamicton occasionally occur within this unit where it abuts against or is underlain by gravel" in the Tuktoyaktuk area.

Rampton (1988) described a mechanism in which the upper part of the morainal deposits are reworked into colluvium and lacustrine deposits:

"these materials (the colluvium and lacustrine deposits) have become incorporated into the morainal deposits as a result of thermokarst processes. The colluvium may be formed via downslope creep or solifluction, but primarily it is the product of retrogressive-thaw flow sides. These features, which result from the thawing of steep ice-rich slopes, lead to till and other materials (including organic materials) sliding down a steep face and mixing with the water from thawing ground ice. This soupy mixture then flows farther downslope until it is dehydrated to a point where it stabilizes and accumulates. The redeposited till resembles the original material; occasional alluvial bedding structure formed by flowing water and incorporated loose peat in the material are the only clues to its redeposited origin".

The Kittigazuit Formation is typically a light brown, thinly bedded sand; individual beds are commonly 0.5-8 cm thick, and rarely up to 20 cm thick. Individual beds may grade from silty fine sand to a clean fine sand or from a clean fine sand to a medium-fine sand. The most conspicuous characteristic of the Kittigazuit Formation is the presence of thick foreset beds with a common strike and dip; they are up to 12m thick on northern Richards Island and dip in northerly directions on Richards Island. In this area, the Kittigazuit Formation may have a minimum thickness of 18-20m. Rampton (1988) indicated that the Kittigazuit Formation with it's large foresets represent deltaic deposition. A rapid influx of terrestrial material into the sea is suggested by the sparseness of marine fossils within the formation. Most fossils identified within the Kittigazuit

Formation suggest a cold dry climate during its deposition. Alternatively, J.-S. Vincent (GSC, pers. comm. 1988) suggested that the Kittigazuit Formation may be large sand dunes which would be oriented in a northeast direction.

Much of Richards Island is underlain by more than 600m of permafrost, with an active layer having thicknesses generally comprise between 0.2 and 0.5m in vegetation-covered terrain and slightly thicker in bare sandy or gravelly areas (Rampton, 1988).

Figure 4 illustrates the glacial limits during Middle Pleistocene Mason River Glaciation, and the Early Wisconsinan Toker Point and Franklin Bay stades. This figure shows that glacial maximum during the Toker Point Stade reached a NW-SE oriented limit some 30 km northeast of Pullen Island. On the Tuk Peninsula (Rampton, 1987), this glacial limit delineates the northern boundary of ice-contact deposits and local areas of morainal deposits (Unit G T/X, Map 1647A), generally 5 to 20m thick. North of this limit, thick outwash plains and valley trains (Unit G T/P, Map 1647A), generally 3 to 30m thick, have been mapped in the northern edge of the Tuk Peninsula (assigned to the Cape Dalhousie Sands). Rampton (1988) indicated that when Early Wisconsinan ice stood at its maximum extent, meltwater undoubtedly flowed northward into the Beaufort Sea and deposited large volumes of outwash.

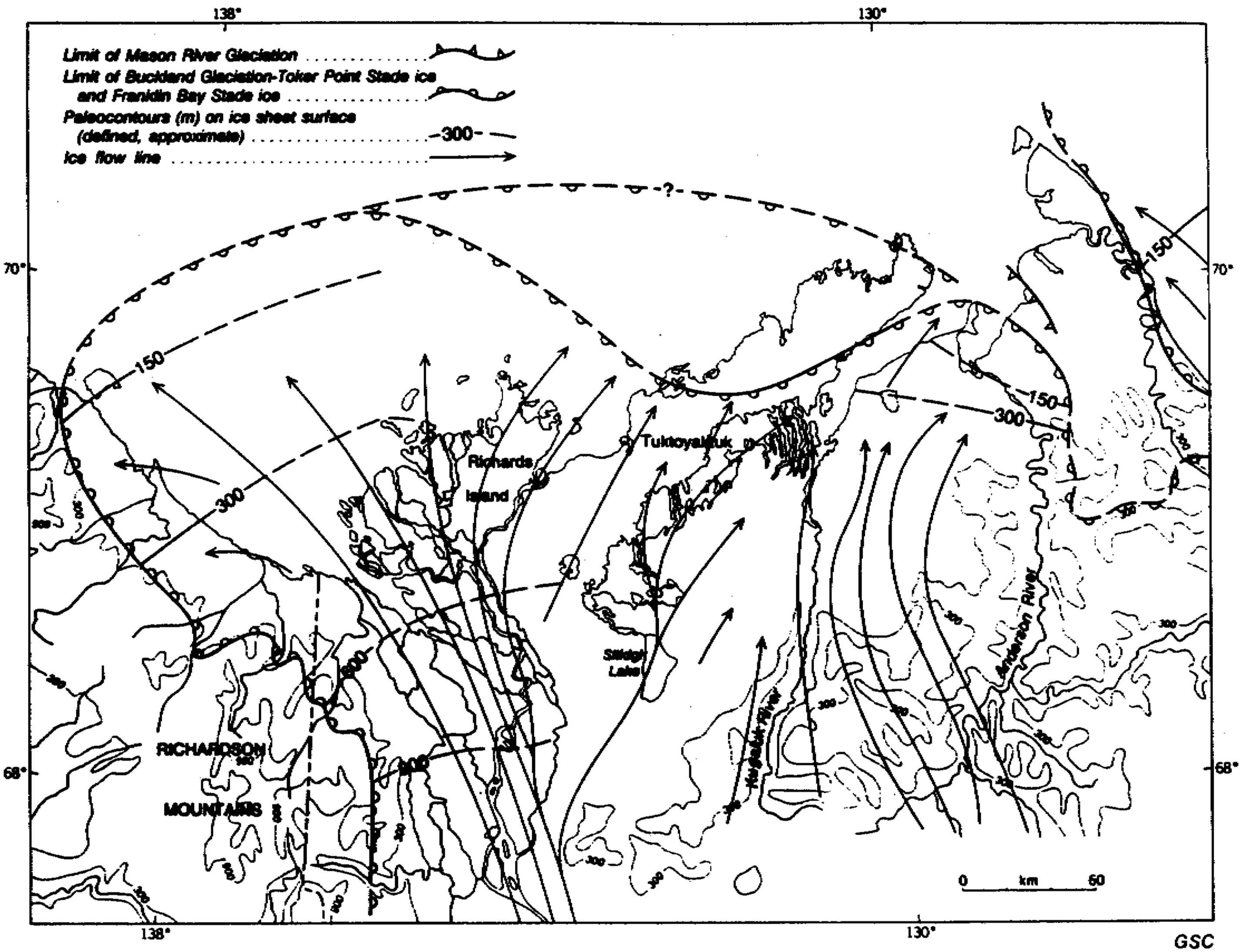


Figure 4 - Ice flow and glacial limits during the Middle Pleistocene Mason River Glaciation, and the Early Wisconsinan Toker Point (Buckland Glaciation) and Franklin Bay stades. (After Rampton, 1988)

Rampton (1988) has indicated a tentative Early Wisconsinan age for the Toker Point Stade glacial limit on the Tuk Peninsula, although Hughes (1987) suggested that this limit is that of a glaciation younger than the Hungry Creek Glaciation in Bonnet Plume Basin and the correlative Buckland Glaciation in northern Yukon. According to Hughes (op. cit.), the advance of the Laurentide ice sheet to its all-time limit culminated as late as 30,000 BP during the Hungry Creek Glaciation. This author reported that the Hungry Creek Glaciation was followed by two significant readvances on the mainland: the Tutsieta Lake Phase culminating at or before 13,000 years ago, and the Killy Lake Phase before 10,600 years ago.

SECTION 3 - PREVIOUS WORKS

During the last decade, the GSC have tested various refraction arrays in order to measure the compressional wave velocities associated with ice-bearing sediments, seabed materials, and subbottom layering. The use of surface-towed arrays has been discarded during the early phase of the project because the field geometry is complicated by the presence of a thick water layer (Hunter **et al.**, 1976). The first generation of refraction arrays was designed for deployment on the seafloor from the ice surface (Hunter **et al.**, 1979) or from a ship (Hunter **et al.**, 1982). Although the seabottom-laid refraction arrays are capable of providing velocity measurements and information on the sediment types, this technique is time-consuming being currently limited either to available leads in sea-ice, or by frequent stopping and anchoring during shipborne operations. Hence, the seabottom-laid refraction arrays can only be considered for reconnaissance surveys rather than pipeline routing and site investigations (Hunter **et al.**, 1979).

This problem was largely overcome during the field seasons of 1985 and 1986, by using a 12-channel, deep-towed hydrophone array (Good **et al.**, 1984). The main advantage of a deep-towed marine eel over a similar bottom-laid array is the capability of acquiring velocity data in a continuous mode while the ship is cruising at a normal survey speed of 3 to 5 knots.

The field experiment with the 12-channel deep-towed eel has shown that this technique is accurate and can be used in the various environments found in the southern Beaufort Sea. In an attempt to assess the consistency and precision of the seismic compressional wave velocities obtained by means of the 12-channel array, McKay **et al.**(1985) collected 529 velocity observations (seismograms) on the Scotian Shelf at a ship speed of about 3 knots; the measurements were made in clusters over a relatively uniform sand-gravel sediment unit. McKay **et al.** (op. cit.) concluded that the method appears to yield consistent acoustic velocity results for seabed sediments in the area studied with an accuracy of about 3% or better.

Fortin (1986) compiled the 1985 high resolution seismic data which consisted of 792 velocity observations and about 110 km of seismic reflection profiles; these data were collected across the Akpak Plateau and Kugmallit Channel in the southern Beaufort Sea (see Figure 1). Fortin (1986) and Fortin **et al.** (1987) concluded that the 12-channel refraction array has the penetration required to map the distribution and depth of Ice-Bearing PermaFrost (2.0 to 4.0 km/sec), or IBPF, within about 20m of the seabottom. In addition, Fortin (1986) indicated that this refraction eel performed well in obtaining compressional wave velocities from seabed and shallow subbottom horizons to a depth of 7-8m.

In 1986, as part of the testing program of the 12-channel deep-towed eel, a second and more extensive refraction/reflection seismic survey was carried out in the coastal waters of the southern Beaufort Sea, including the Akpak Plateau, the Kugmallit Channel and the Tingmiark Plain (see Figure 1). During the 1986 field investigation, 3,125 seismograms were collected along with approximately 430 km of reflection seismic profiles. On the basis of the reconnaissance seismic profiles, Fortin (1987) attempted to reconstruct the paleogeography which existed in this area prior to the last marine submergence. The resulting paleogeographic reconstruction in Figure 5 revealed a network of paleochannels in the pre-transgressive land surface. Fortin (1987) suggested that these channels are the remnants of an ancient braided delta system that strongly influenced the present day geographical distribution of the ice-bearing sediments in this region of the Akpak Plateau.

Fortin (1987) utilized the 1986 velocity observations associated with the shallow seismic discontinuities to establish the first outline of a geo-acoustic model for the surficial geology of the southern sector of the Akpak Plateau. Fortin (1987) observed a significant increase in the velocity of the surficial sediment in the vicinity of topographic highs (Figure 6), suggesting that a sediment coarsening occurs in the deposits overlying heights in the former land surface (U/C1).

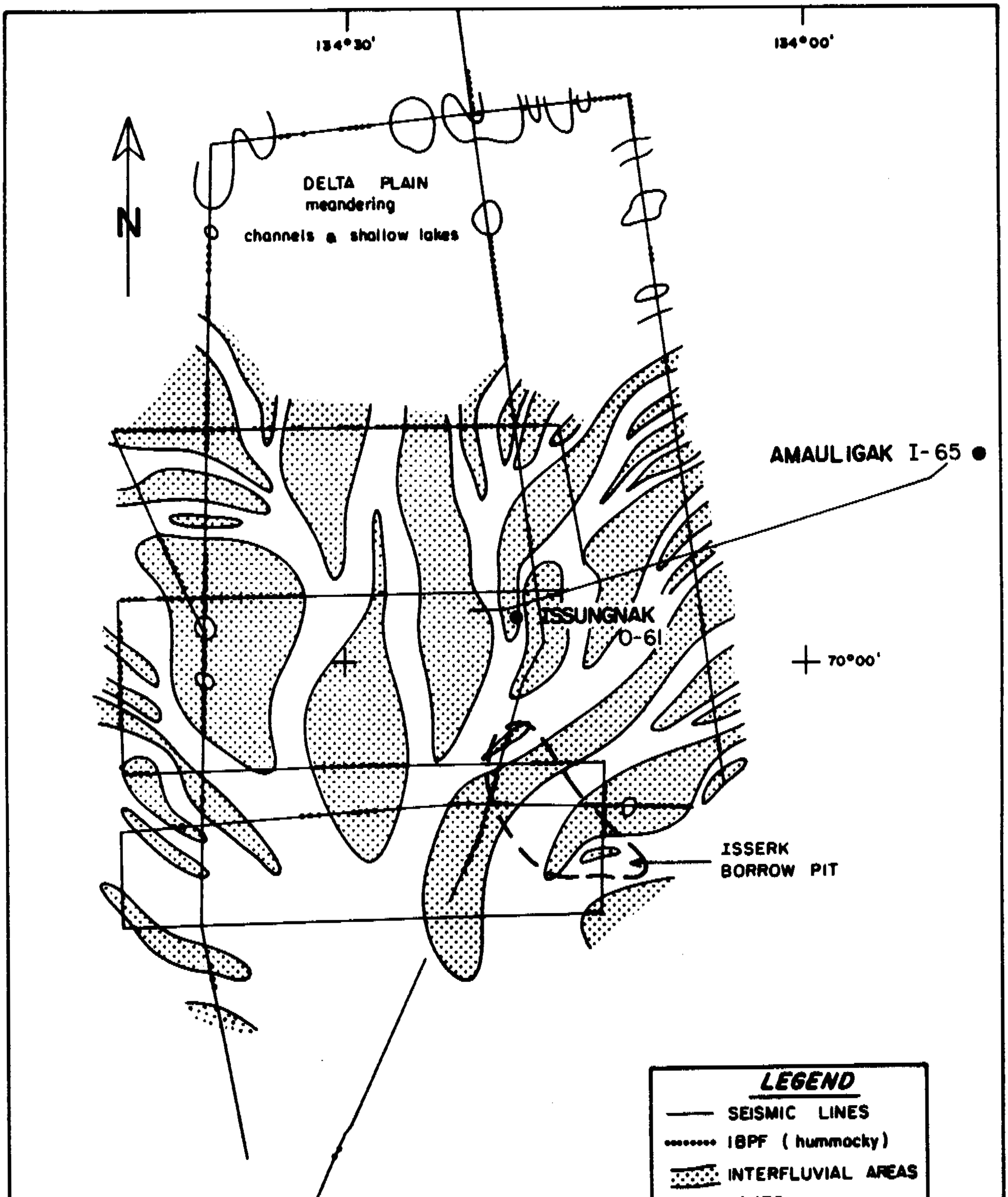


FIG. 5 PALEOCHANNEL NETWORK AND IBPF DISTRIBUTION, AKPAK PLATEAU.

Fortin (op. cit.) reported that abnormally high seismic velocities (2.0-4.0 km/sec) typical of ice-bearing sediments were measured solely within the pre-transgressive Unit C sediment (Figure 6).

In order to improve the understanding of the post-glacial seismo-stratigraphy of this sector of the Akpak Plateau, Fortin (1988b) updated his first reconstruction of the paleoenvironment (Figure 5) that may have prevailed in this region prior to the last marine transgression(s). Towards this end, Fortin (op. cit.) undertook a synthesis of the 1985 through 1987 refraction and reflection data. Figure 7 illustrates the residual topography of the former land surface following the erosion of progressive coastlines. This presentation is believed to be a powerful tool for the analysis of the distribution of shallow ice-bearing sediments beneath the southern Akpak Plateau.

Examination of the 1987 seismograms by Fortin (1988b) has shown that high velocity (1,800-2,000 m/sec) materials are present near the unconformity U/C1 surface. Although these velocities may also result from the presence of frozen sediments having a marginal ice content, they were interpreted as indications of very coarse-grained sediments (ice contact and morainal deposits ?). This interpretation is supported by the various acoustic signatures visible on the reflection records. The boomer record in Figure 8 exhibits a chaotic seismic facies

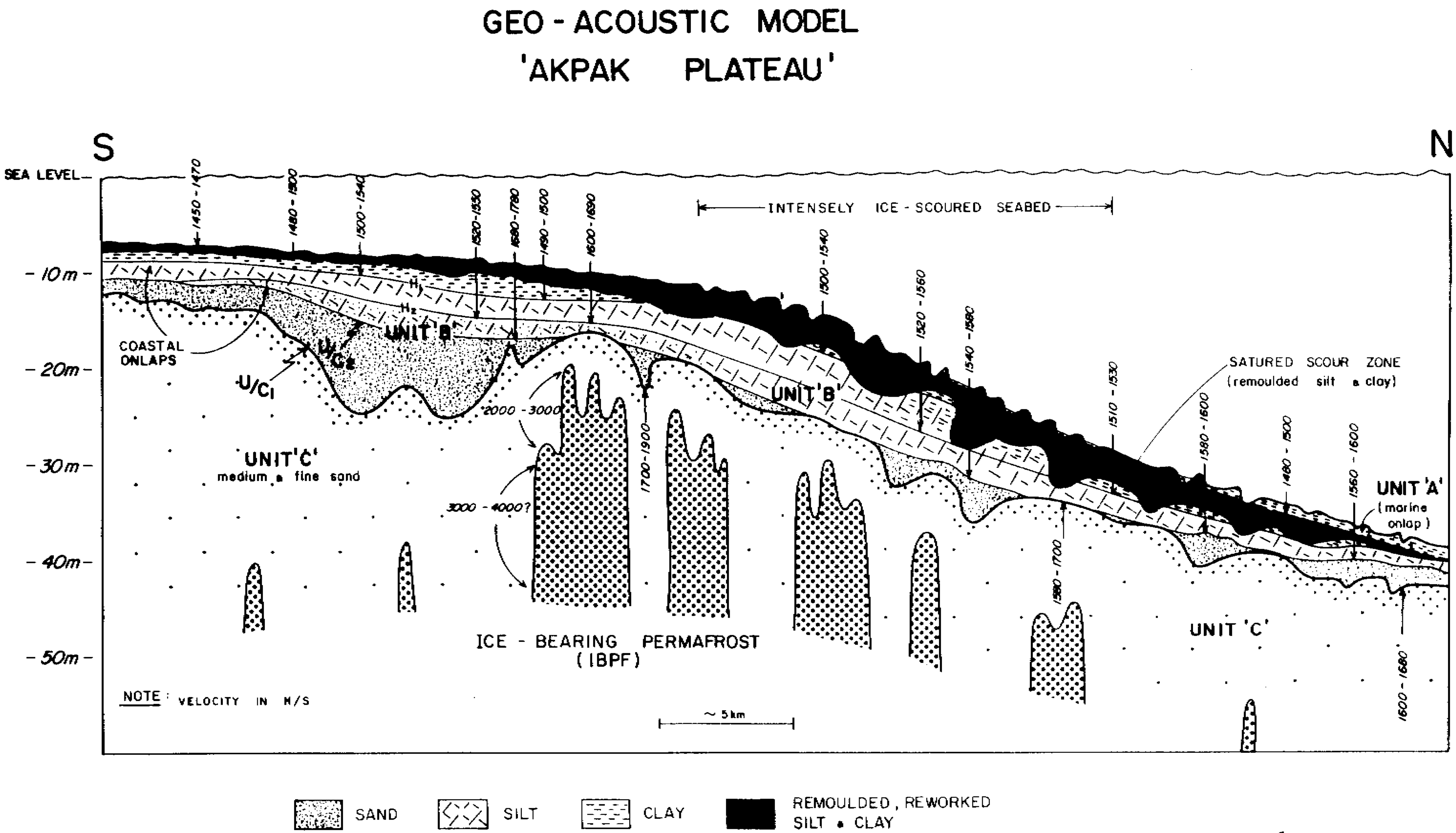

GEO - ACOUSTIC MODEL
'AKPAK PLATEAU'
S
N
SEA LEVEL
- 10m -
- 20m -
- 30m -
- 40m -
- 50m -
1450 - 1470
1480 - 1500
1500 - 1540
1520 - 1530
1680 - 1780
1490 - 1500
1600 - 1690
INTENSELY ICE - SCOURED SEABED
1500 - 1540
1520 - 1560
1540 - 1580
1510 - 1530
1580 - 1600
1480 - 1500
1560 - 1600
H₁
H₂
UNIT 'B'
COASTAL ONLAPS
U/C₂
U/C₁
UNIT 'C'
medium & fine sand
2000 - 3000
3000 - 4000?
1700 - 1900
UNIT 'B'
SATURED SCOUR ZONE
(remoulded silt & clay)
UNIT 'A'
(marine onlap)
1580 - 1700
ICE - BEARING PERMAFROST
(IBPF)
UNIT 'C'
1600 - 1680
NOTE : VELOCITY IN M/S
~ 5 km
SAND
SILT
CLAY
REMOULDED, REWORKED SILT & CLAY

FIGURE 6

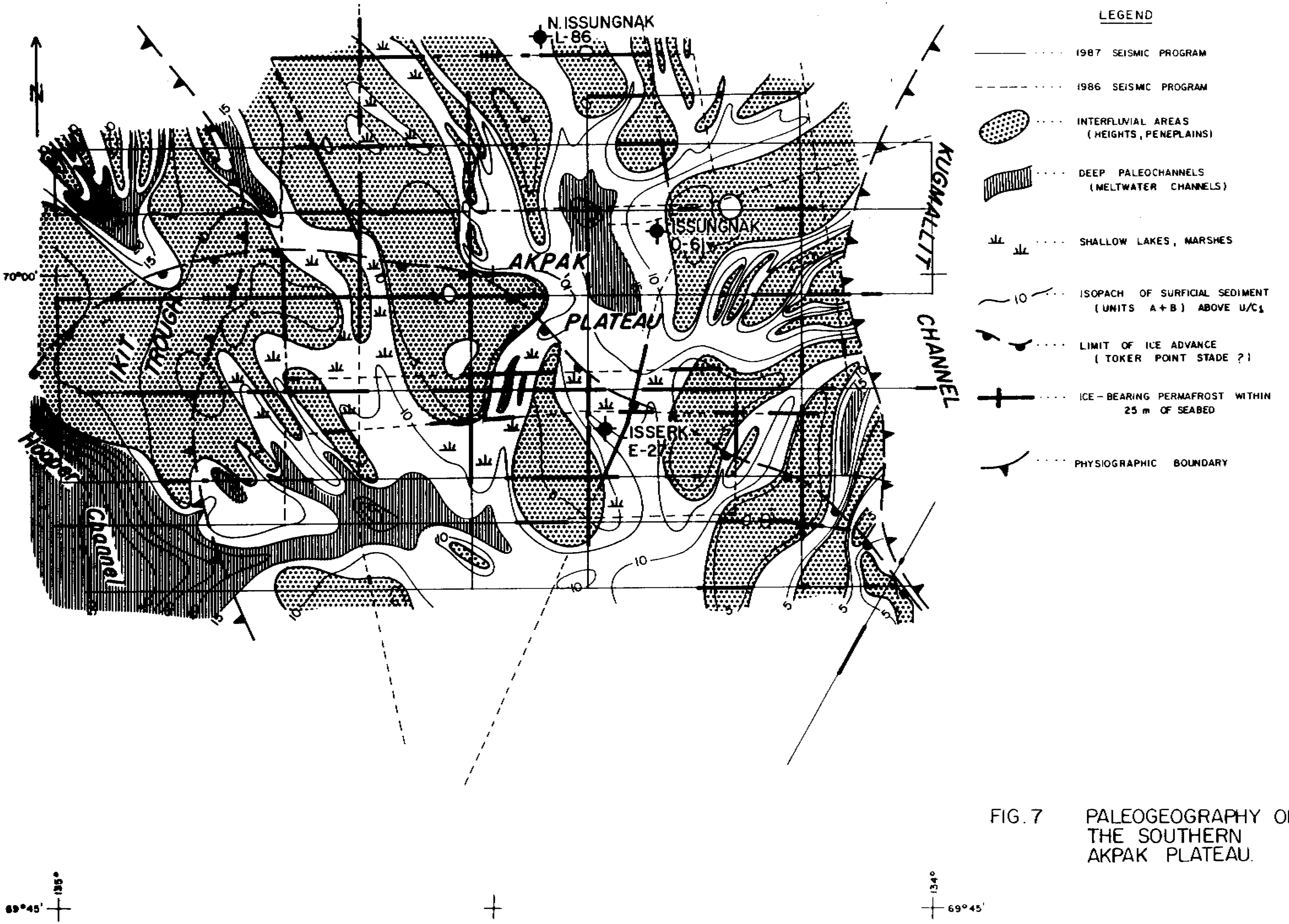


FIG. 7 PALEOGEOGRAPHY OF THE SOUTHERN AKPAK PLATEAU.

typical of very coarse deposits that may include sand and gravel, as well as diffraction point sources that are characteristic of boulder beds. In addition, high compressional wave velocities on the order of 1,700-2,000 m/sec are associated with the upper (reworked) zone of the deposit. The fact that both pieces of evidence, diagnostic seismic facies and high acoustic velocities, occur above the unconformity U/C1 reinforces the interpretation of very coarse glacial deposits; furthermore, the presence of frozen ground above U/C1 , i.e. within the surficial sediment, has not been satisfactorily reported elsewhere to date.

In the light of the recent observations made on the adjacent mainland by Rampton (1988), Fortin (1988b) speculated that the northernmost occurrences of the interpreted very coarse deposits delineate a limit of ice advance on the Akpak Plateau. This possible limit of ice advance (Figure 7) shows a good correlation with the offshore extension of the limit of the Toker Point Stade ice (Cf. Figure 4) such as delineated onshore by Rampton (1987). Although no geological evidence has been provided yet, Rampton (1988) proposed an alternative limit for the Toker Point Stade ice (Cf. Figure 4), which introduces the possibility that ice contact and morainal deposits might be present in the northern sector of the Akpak Plateau. Except for some possible lag deposits (thin patches of gravel near U/C1), there is little evidence for this alternative glacial limit in the 1985 through 1987 seismic data base.

Based on the hypothesis that the Toker Point Stade ice stopped near the glacial maximum shown on the paleogeographic map in Figure 7, Fortin (1988b) opined that the deep paleochannels outlined north of this boundary may have been meltwater channels. These channels (valley trains ?) may have resulted from streamlined fluting with the main discharge directed towards the Ikit Trough to the west and Kugmallit Channel to the east. Early deglaciation was likely accompanied by ice retreat that occurred southward into Richards Island leaving a relatively thin (presumably ?) layer of ice contact and morainal deposits (J.-S. Vincent, GSC, pers.comm., 1988), which were deposited south of the mapped maximum ice advance (Figure 7). These granular materials, which are not easily eroded by glacial meltwater, may have formed a resistive barrier paralleling the limit of ice advance (Figure 7). As a result of this resistive hilly belt, large volumes of meltwater and outwash were deflected westward and funelled through a major meltwater channel debouching into the Hooper Channel to the west (Figure 7).

In the southern Akpak Plateau, most of the shallow IBPF occurrences (less than 20m below seabed) were delineated beneath the interfluvial areas, while the shallow IBPF table is much deeper and may be absent underneath the deepest meltwater channels (Fortin 1986, 1987 and 1988b). The above paleoenvironment reconstruction highlights the dominance of relic features resulting from glacial advance(s) over the former land surface, and the subsequent marine transgression(s) as important controlling factors in the depth and form of the shallow IBPF table.

SECTION 4 - FIELD OPERATIONS

4.1 GEOPHYSICAL EQUIPMENT

The geophysical equipment utilized during the 1988 field operations consisted of: a 24-channel refraction system, a Raytheon PTR 3.5 kHz profiler, an EGG Uniboom system, and a small array airgun profiler. Two different size of airguns, a 1.32 liter (80 cu. in.) and a 0.66 liter (40 cu. in.)airguns were used as the seismic energy source for the refraction shooting. Horizontal positioning of the survey vessel was obtained by means of a Sercel Syledis which was provided and operated by Canadian Engineering Services Co. Ltd. of Edmonton, Alberta. Details of the seismic survey program, including seismic reflection and refraction systems, equipment towing configurations, operational summary and personnel are provided in Appendix "A".

The current GSC prototype of the 24-channel, deep-tow eel is illustrated in schematic form in Figure 9. The active portion of the eel consists of 24 groups of hydrophones with 5m between groups, and each group include 2 elements (AQ Benthos 300) spaced at 30 cm. The hydrophones are fitted inside an oil-filled hose with an outer diametre of 5 cm. The hydrophone array is built in a conventional manner and includes 6 active sections, each 20m long. Ahead of the active portion of the eel, a neutral oil-filled section, 15m in length, acts as a buffer for additional noise decoupling. The separation between the airgun

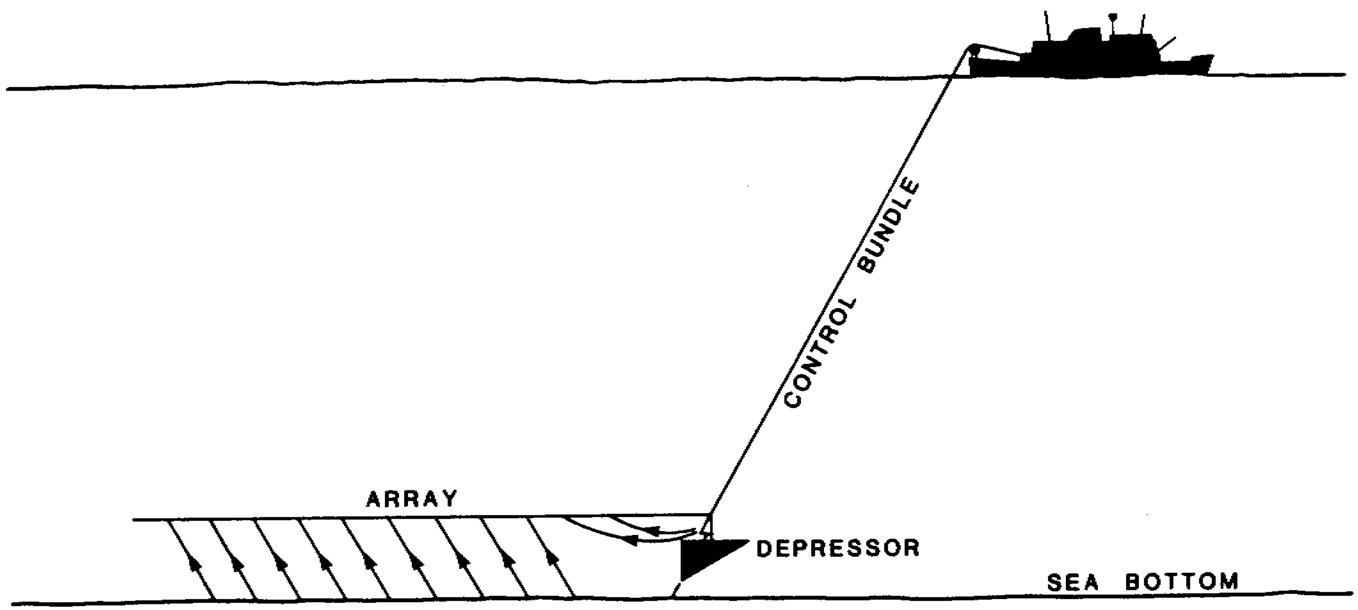


FIG. 9 MULTICHANNEL, DEEP-TOWED REFRACTION EEL.

and first hydrophone is selectable; spacings of 20m (deep-tow mode) and 40m (surface-tow mode) were used during the 1988 survey operations. The refraction data from the hydrophone array, in a digital format, are captured by a prototype Scintrex 24-channel digital acquisition system and transferred directly to a Data General microcomputer data logging system.

As illustrated in Figure 10, the forward unit of the eel consists of a tow bar, an airgun and mounting bracket, and a Endeco delta wing depressor. The depressor fin is 1.1m wide and includes a high frequency transducer to monitor the position of the leading end of the eel with respect to seabottom. The towing umbilical contains a multi-conductor seismic cable for the hydrophone signals, a high pressure airline, and electrical control cables for the airgun and the sounding transducer. On board the survey vessel, the umbilical is wound on a winch fitted with an electrical and airline slip ring assembly.

The various profiling systems were in operation simultaneously with the refraction shooting. As a result, reflection records are available for all the survey lines. The reflection profiles are used to picture the seafloor morphology and to investigate the thickness and acoustic signature of the shallow stratigraphic units, or the seismo-stratigraphy. In addition, these records serve to delineate shallow acoustic permafrost and shallow gas accumulations. A detailed description

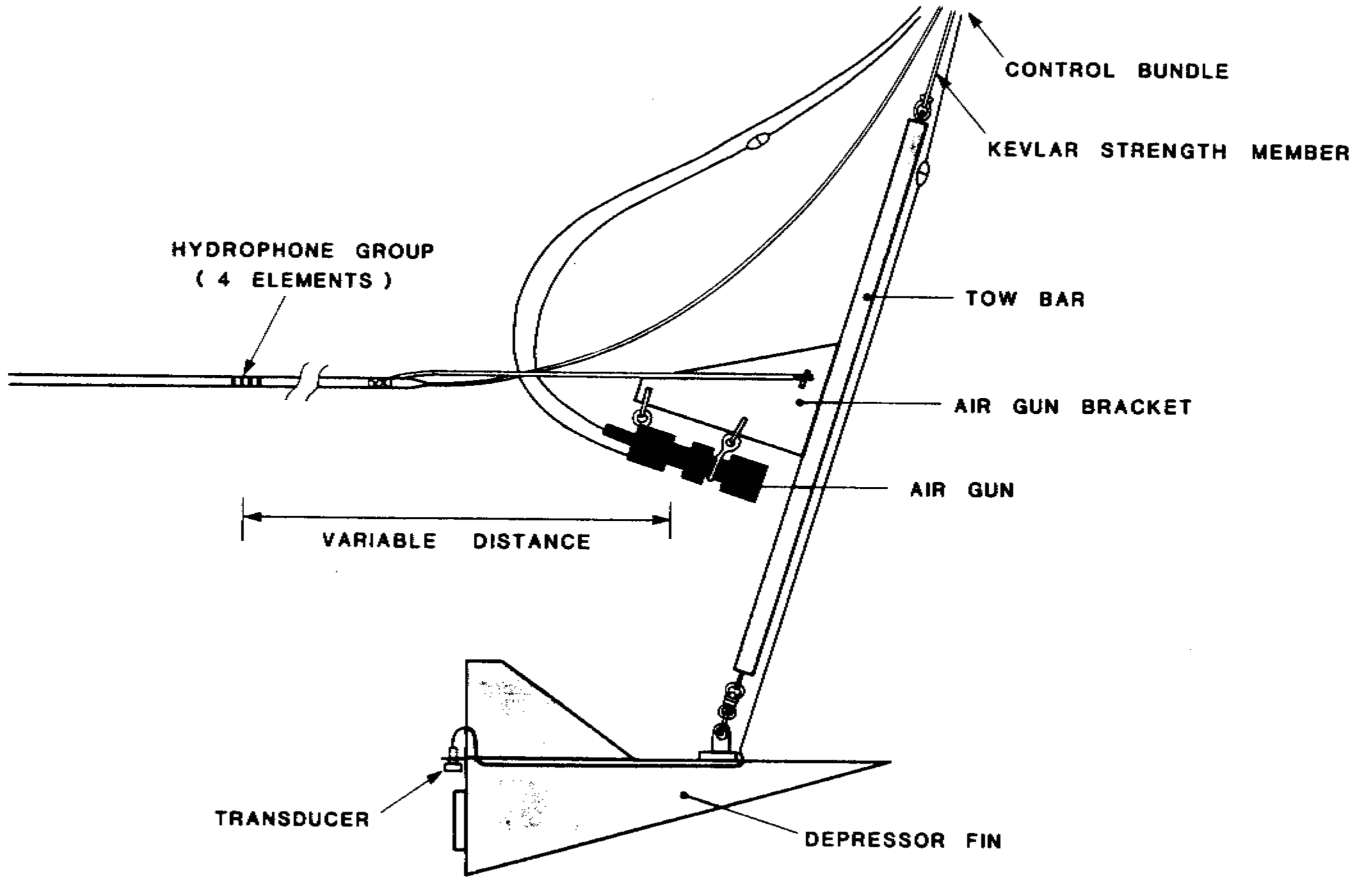


FIG. 10 FORWARD UNIT OF THE EEL.

of the reflection systems characteristics is presented in Appendix "A".

4.2 SEISMIC DATA BASE

During the 1988 survey operations, a total of approximately 2,500 refraction seismograms were collected along with about 310 km of reflection seismic profiles on a 12hr per day basis. Plate I shows the line names, the positions and numbers of the shotpoints such as provided by Canadian Engineering Services Co. Ltd. Not counting for the run-in and cross lines (while the ship was altering its course to approach a new line), two rerun lines (FHR88-06 and -07), and one test line (FHR88-05), a total of 2,025 seismograms were retained in the present study for analysis of compressional wave velocities, as well as 285 km of reflection profiles which were examined for identification of shallow stratigraphic units and depositional facies.

4.2.1 Refraction Data Base

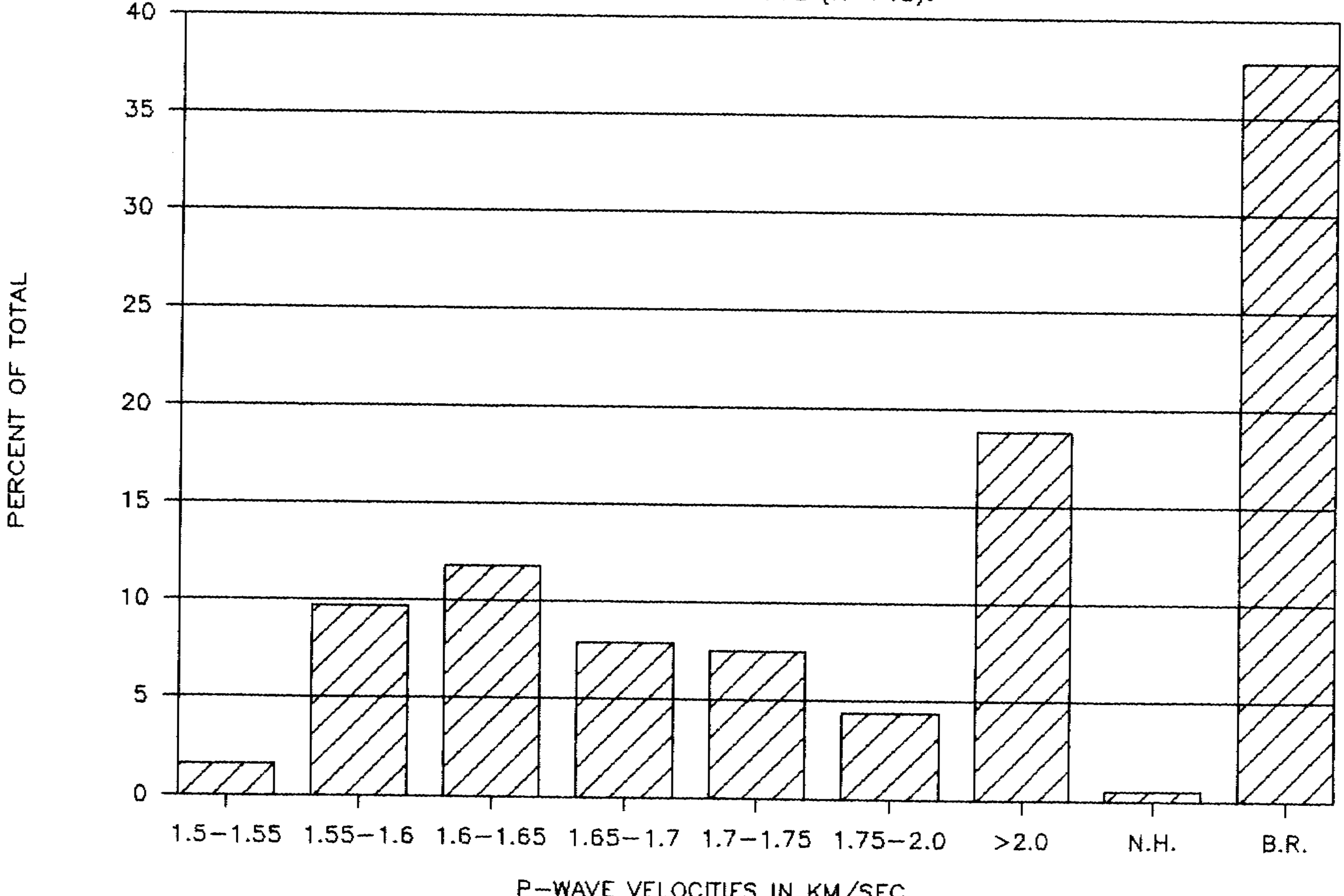
Based on the mode of deployment (surface- or deep-tow) of the 24-channel refraction array and the type of survey (reconnaissance-level or site specific study) the refraction data base can be divided into three distinct data sets: (1) reconnaissance program with the eel in deep-tow mode; (2) reconnaissance program with the eel in surface-tow mode, and; (3) site specific survey with the eel in surface-tow mode.

Initially, the reconnaissance works across the Akpak Plateau were carried out using the refraction eel in a deep-tow mode, until a serious break in the airgun trigger cable and unsuccessful attempts to repair forced the seismic crew to rig a surface-tow array. The modified towing configuration allowed the geoscientists to minimize down-time and gather additional seismic records during the remaining survey period.

Graph 1 shows that 745 velocity observations were obtained in deep-tow mode along the course of Regional Lines FHR88-01/02/03/ and 04 (Table 1). Note that more than one velocity measurement can be counted occasionnally on the same seismogram. Also, the velocity values comprise in a given class interval are equal or greater than the lower class boundary but smaller than the upper boundary. Among the 745 velocity observations, about 38% of the time-distance plots are classified as bad records (B.R.) because they do not provide reliable velocity observations. About 19% of the observations indicate abnormally high compressional wave velocities (>2.0 km/sec) that are believed to be associated with ice-bearing sediments. Except for a small percentage (0.5%) of time-distance plots that display no headwaves (N.H.), the remaining observations exhibit first arrival events that propagate in the shallow subbottom with velocities ranging between 1.5 and 2.0 km/sec.

GRAPH 1. RECONNAISSANCE PROGRAM, 1988.

EEL IN DEEP-TOW MODE (N=745).

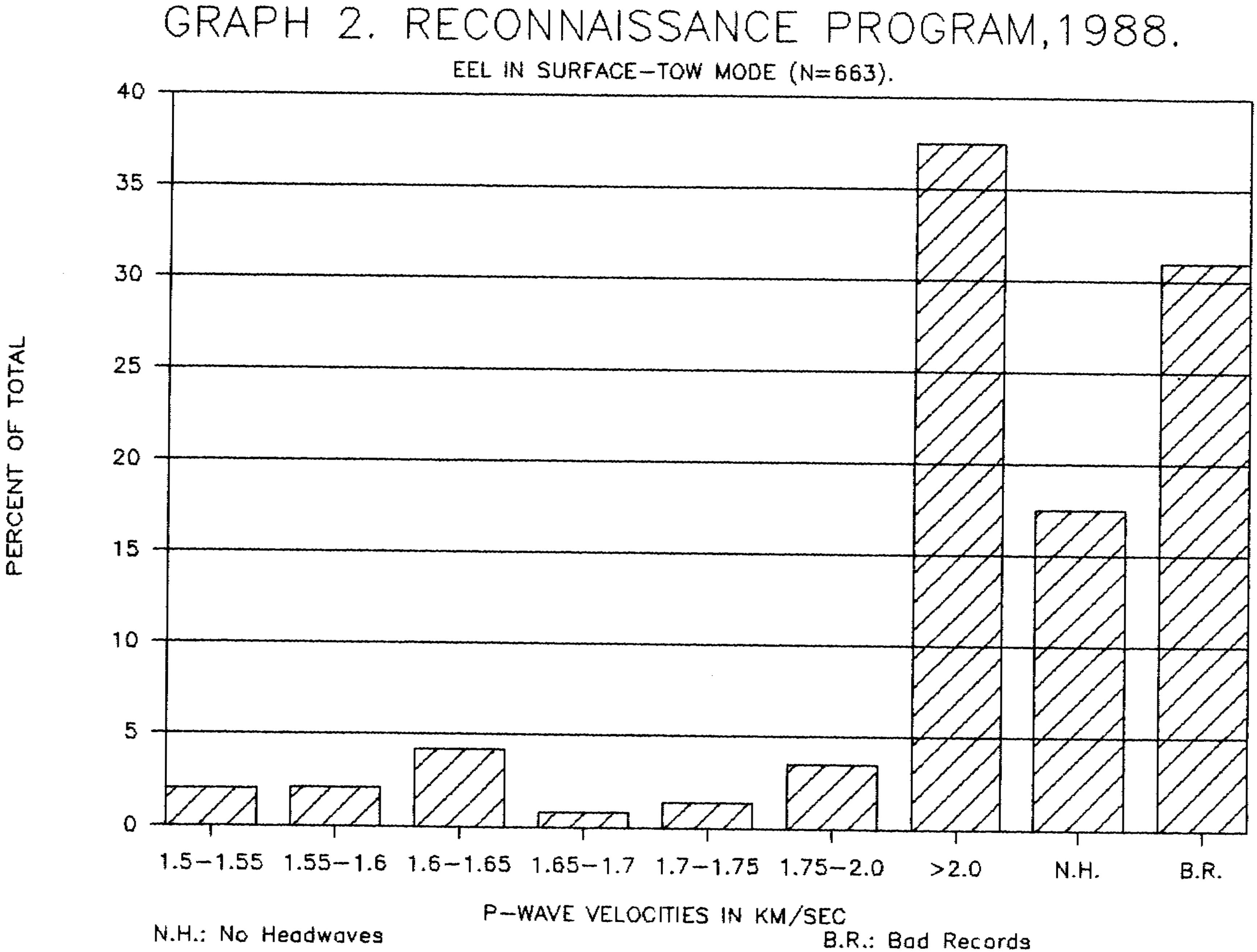


N.H: No Headwaves

B.R.: Bad Records

The second set of refraction records yields 663 velocity measurements obtained in a surface-tow mode along Regional Lines FHR88-18/19/20/ and 21. As illustrated in Graph 2, a high proportion (31%) of the time-distance plots were ruled out as bad records while almost 38% of the observations show permafrost velocities (>2.0 km/sec). It is interesting to note the effect of towing the array near the sea surface on the refraction data. A substantial amount (17.5%) of observations are devoid of headwave arrivals and significantly less velocity measurements, in the class intervals comprised between 1.5 and 2.0 km/sec, were obtained using the surface-tow mode (Graph 2) versus the deep-tow mode (Graph 1). This may be explained by the increase in thickness of the low velocity (1.46 km/sec) water layer between the refraction eel and the seabottom. The water layer increases from about 5m in deep-tow mode to thicknesses ranging between 10m and 28m in surface tow-mode. The presence of a thick low velocity layer reduces considerably the effective detection depth through shallow horizons along which compressional waves travel with relatively low velocities (1.5 to 1.75 km/sec).

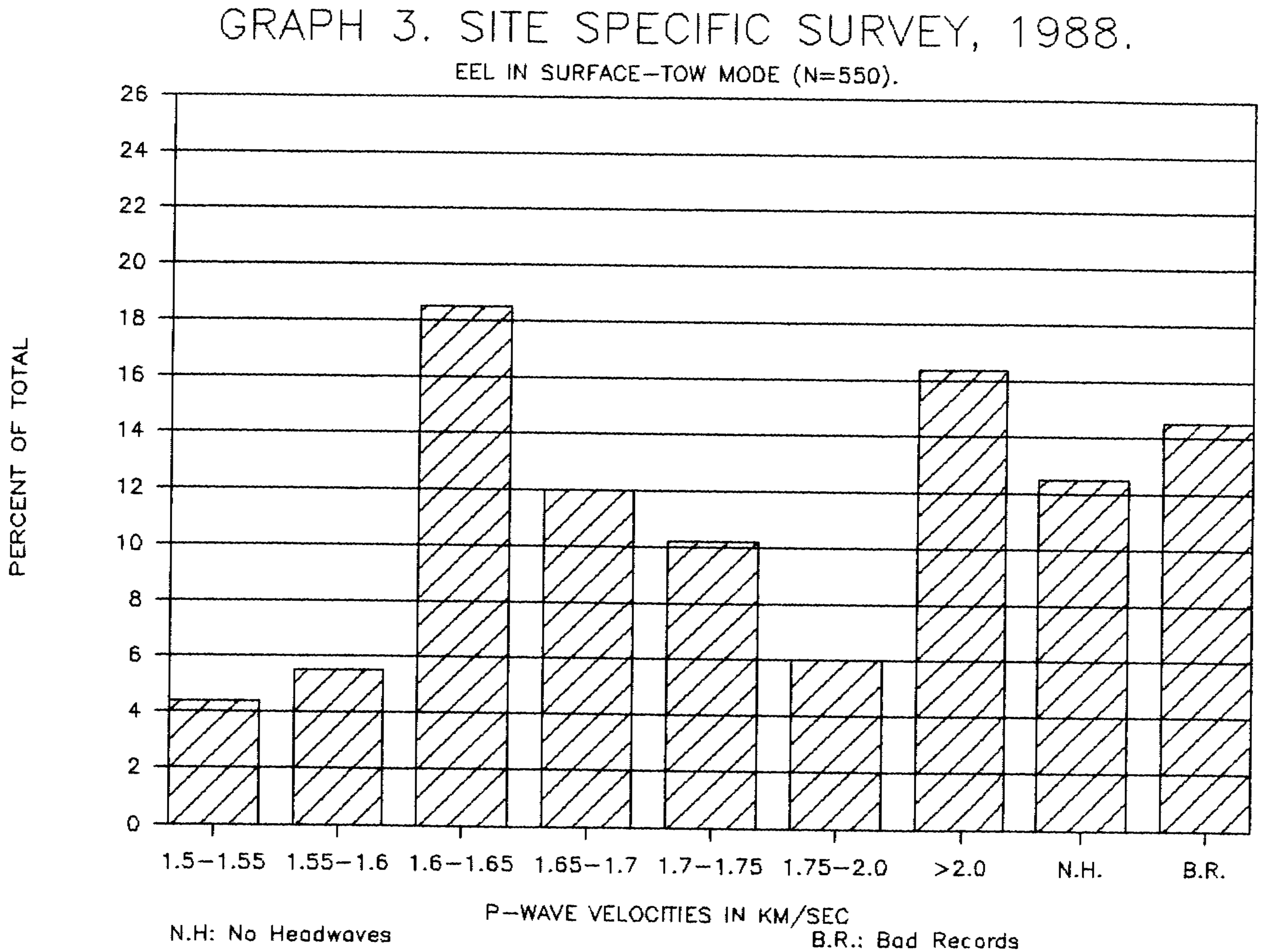
The third data set consists of 550 velocity observations obtained in surface-tow mode during a site specific survey (Lines FHR88-08 to FHR88-17; Table 1). The site covers an area of about 70 square km and was surveyed with a line spacing varying between 400m and 800m. The water depth over the site ranges from 7m to 10m. Hence, the refraction eel was generally


GRAPH 2. RECONNAISSANCE PROGRAM, 1988.
EEL IN SURFACE-TOW MODE (N=663).
PERCENT OF TOTAL
40
35
30
25
20
15
10
5
0
1.5-1.55
1.55-1.6
1.6-1.65
1.65-1.7
1.7-1.75
1.75-2.0
>2.0
N.H.
B.R.
P-WAVE VELOCITIES IN KM/SEC
N.H.: No Headwaves
B.R.: Bad Records

towed at a maximum elevation of 7m to 10m above seabed, which is near to the conditions encountered when surveying in a deep-tow mode. The decrease in the thickness of the water layer has a notable effect on the proportion of velocity measurements obtained from shallow refractors. As illustrated in Graph 3, 57% of the observed first arrival events propagate with P-wave velocities slower than 2.0 km/sec, which indicates that the near surface deployment of the eel in shallow waters yielded satisfactory results over this region. The fairly high proportion (12.5%) of time-distance plots displaying no headwave arrivals is believed to be more a result of the terrain conditions (shallow gas pockets) than the towing configuration. The proportion of bad records (14.5%) is significantly lower than during the reconnaissance works (Graphs 1 and 2). Over 16% of the observations show P-wave velocities greater than 2.0 km/sec which are evidence of the occurrence of ice-bearing sediments throughout the site area. Note that for the three data sets (Graphs 1, 2 and 3), the highest proportion of P-wave velocities associated with near seabed (unfrozen) materials is observed in the 1.6-1.65 km/sec class interval.

4.2.2 Reflection Data Base

Table 1 summarizes the reflection profiles for which copies were gracefully provided to the Terrain Sciences Division by the Atlantic Geoscience Centre in Dartmouth. Except for Lines FHR88-06 and 07 which are of poor data quality and hence have


GRAPH 3. SITE SPECIFIC SURVEY, 1988.
EEL IN SURFACE-TOW MODE (N=550).
PERCENT OF TOTAL
0
2
4
6
8
10
12
14
16
18
20
22
24
26
1.5-1.55
1.55-1.6
1.6-1.65
1.65-1.7
1.7-1.75
1.75-2.0
>2.0
N.H.
B.R.
P-WAVE VELOCITIES IN KM/SEC
N.H: No Headwaves
B.R.: Bad Records

been rerun, the quality of the reflection records varies from good to reasonably good.

TABLE 1 : 1988 NAHIDIK REFLECTION/REFRACTION DATA BASE.

LINE NO.	REFRACTION	PROFILING SYSTEMS			DATA QUALITY	
	SHOTPOINTS	PTR	BOOMER	AIRGUN	REFLECTION	REFRACTION
FHR88-01	2636-2794			X	Fair	Fair
FHR88-02	2835-2976	X	X	X	Fair	Fair
FHR88-03	3717-3797	X	X	X	Good	Poor
FHR88-04	3814-4047	X	X	X	Good	Poor
FHR88-05[1]						
FHR88-06[2]	4925-4977			X	Poor	Poor
FHR88-07[2]	4984-5035			X	Poor	Poor
FHR88-08[3]	5691-5745	X	X	X	Good	Good
FHR88-09[3]	5762-5815	X	X	X	Good	Good
FHR88-10[3]	5833-5886	X	X	X	Good	Fair
FHR88-11[3]	5899-5952	X	X	X	Good	Fair
FHR88-12[3]	5970-6022	X	X	X	Good	Fair
FHR88-13[3]	6034-6087	X	X	X	Good	Fair
FHR88-14[3]	6117-6160	X	X	X	Good	Fair
FHR88-15[3]	6178-6230	X	X	X	Fair	Fair
FHR88-16[3]	6255-6308	X	X	X	Fair	Fair
FHR88-17[3]	6317-6370	X	X	X	Fair	Fair
FHR88-18	7025-7260	X	X	X	Good	Fair
FHR88-19	7298-7538	X	X	X	Good	Fair
FHR88-20	8085-8203	X	X	X	Good	Good
FHR88-21	8245-8365	X	X	X	Fair	Fair

NOTE:

[1] This line was run as a refraction test line.
[2] These lines have been rerun due to poor data quality.
[3] Site specific survey lines (See Plates IV and V).

SECTION 5 - DATA HANDLING

5.1 INTERPRETATION PROCEDURES

The interpretative cross sections and the plan of view maps presented in this report incorporated the results obtained by means of two different high resolution seismic techniques: the seismic refraction method (24-channel array) and various seismic profiling devices (3.5 subbottom profiler, boomer and airgun). As shown in Table 1, the seismic reflection devices were operating simultaneously with the refraction system along the course of the survey lines.

5.1.1 Seabed Profile

The seabed profile displayed onto the cross sections was traced from the 3.5 kHz subbottom profiler record since no echograms were collected by the seismic crew during the field operations. The water depths were picked on the 3.5 kHz records using a sound velocity in water of 1,460 m/sec. The water depths are not corrected for tidal fluctuations and, therefore cannot be reduced to an establish sea level datum. A comparison between the water depths taken from the smoothed seabed profiles (i.e. seabed smoothed for ice-scouring effect) on the cross sections and the isobaths drawn on the bathymetric chart of the Natural Resource Series (1973), indicated that both data sources agree generally within 1 or 2m.

relative importance may vary considerably among seismic interpreters. The interpretations and inferences proposed in this report are calibrated with the results obtained from both geophysical and geotechnical site investigations using similar high resolution devices. These investigations were conducted in various environments found in the southern Beaufort Sea; in particular, in the Amauligak area and Isserk borrow pit area. Due to the absence of supportive evidence such as boreholes and coreholes along the lines traversed during the survey, the lithological nature of the shallow stratigraphic units can only be interpreted from the acoustic character of the signal reflected by the different geologic horizons, and their associated compressional wave velocities. The author acknowledges that some inferences may not be exact at specific sites, but it is his opinion that many of the regional interpretations, and their probable geologic significance, are still valuable in the overall interpretation of the general surficial geology, depositional environments, and permafrost distribution.

5.1.3 High Resolution Refraction Data

Analysis of the headwave arrivals was undertaken manually on the annotated paper print out of the seismograms (Figure 11). Straight lines were fitted on the time-distance plots of the observed arrival times. If no seabottom or subbottom refractors were present, the first arrival events were believed to be

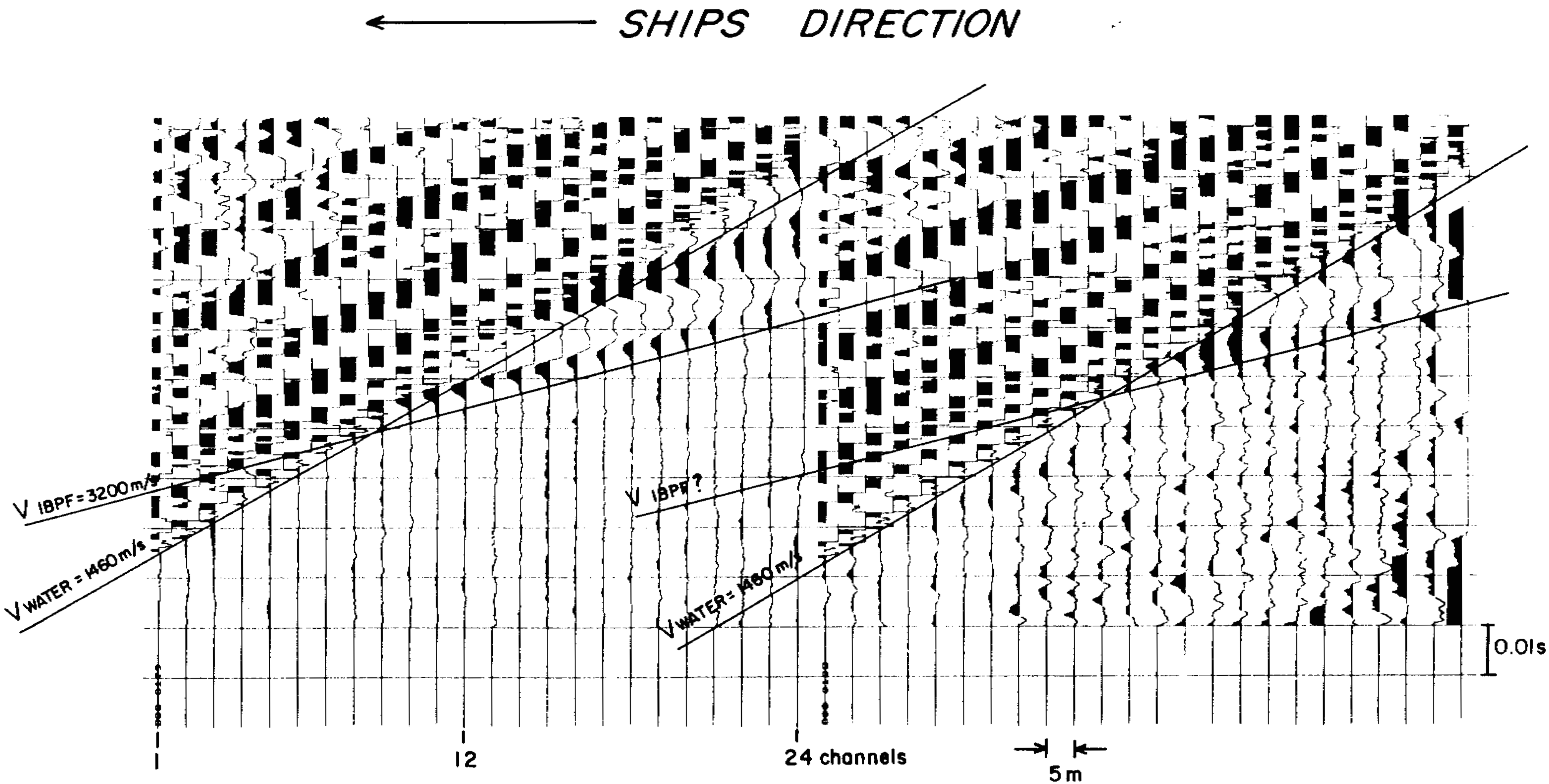


FIG. 11 SEISMOGRAMS SHOWING REFRACTED EVENTS ASSOCIATED WITH ICE - BEARING PERMAFROST (IBPF).

NOTE: ORIGINAL SIZE REDUCED APPROX. 2.5 TIMES.

associated with propagation through the seawater. Where one or more refracted events could be identified on the seismogram, velocities were derived from the gradient of a straight line fitted through at least three points.

The depth of the refractors was computed using the critical distance method where:

$$H = \frac{X_c}{2}\sqrt{\frac{V_2 - V_1}{V_2 + V_1}} \qquad (1)$$

H = depth to the V_2 layer
X_c = critical distance
V_1 = velocity of the direct wave
V_2 = velocity of the refracted headwave.

Because of the uncertainty in locating time zero to the desired accuracy, this method was preferred over the intercept time method which required precise values of time. The formula using the intercept time is:

$$H = \frac{V_1 V_2 T_o}{2\sqrt{V_2^2 - V_1^2}} \qquad (2)$$

H = depth to the V_2 layer
T_o = intercept time of the V_2 curve on the time axis
V_1 = velocity of the direct wave
V_2 = velocity of the refracted wave.

It is recognized that a time delay occurs between the firing electrical impulse and the actual firing of the airgun. Although the time for the electrical impulse to reach the gun is relatively short (Graph 4), slight time variations in the time of firing may be significant in high resolution seismic work. For this reason, and also because the distance between the airgun and the first hydrophone is precisely known, it was believed that the critical distance could be measured more accurately than the intercept time.

Several seismograms display abnormally high seismic velocities (> 2,000 m/sec) that are indicative of ice-bearing sediments at various depths (5-25m) below seabed. In general, these high velocity arrivals are recorded as a first event on most traces, then introducing the possibility of "**hidden**" layers between the seabed and the permafrost horizon. The presence of hidden layers is usually confirmed by the interpretation of the high resolution reflection profiles. In a attempt to overcome the problem of hidden layers having velocities significantly higher than the observed velocity of the direct wave (V_1= 1,450-1,460 m/sec) that propagates directly through the seawater, the hidden layer were considered to be uniform in velocity. Then the analysis of the headwave arrivals was based upon a simple layered model of the ground which model assumes a velocity of 1,500 m/sec for the direct wave (V_1) and a single discontinuity at the depth of the permafrost horizon. As a result, the method for determining the refractor depth, H in equation (1), is analytically very simple in comparison with multilayered cases.

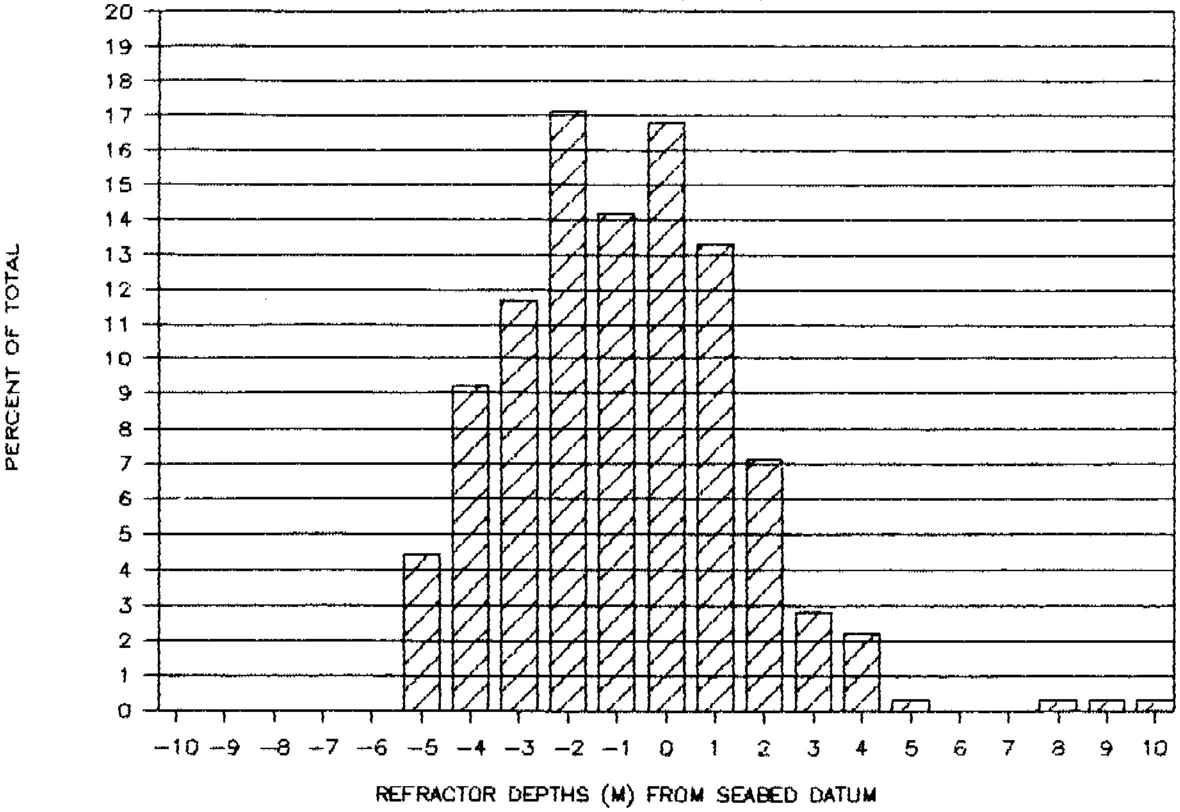
In deep-tow mode, the resulting depth values are corrected to the seabed datum by subtracting the elevation of the eel, which are obtained from the depth transducer records, and the distance between the depth transducer and the airgun (approximately 1m in Figure 10). In surface-tow mode, the refractor depths are reduced to the seabed datum by subtracting the thickness of the water layer which is taken from the 3.5 kHz subbottom profiler records.

5.1.4 Accuracy of the Refractor Depths

The results obtained during similar refraction surveys on the Akpak Plateau (Fortin 1986, 1987 and 1988b) have demonstrated that in normal conditions and for the same acoustic discontinuity, the refractor depths computed using the critical distance method are in close agreement (about 1m) with the reflector depths picked on the high resolution profiles using an average velocity of 1,500 m/sec for time-depth conversions. However, the refractor depths computed in the present study appear to be systematically too shallow after correction to seabed datum. Graphs 5 and 6 are histogram representations of the shallow refractor depths at a class intervals of 1m. These depths were obtained along the reconnaissance lines which were traversed either in a deep-tow mode (Graph 5) or in a surface-tow mode (Graph 6); the permafrost depths are not included in the

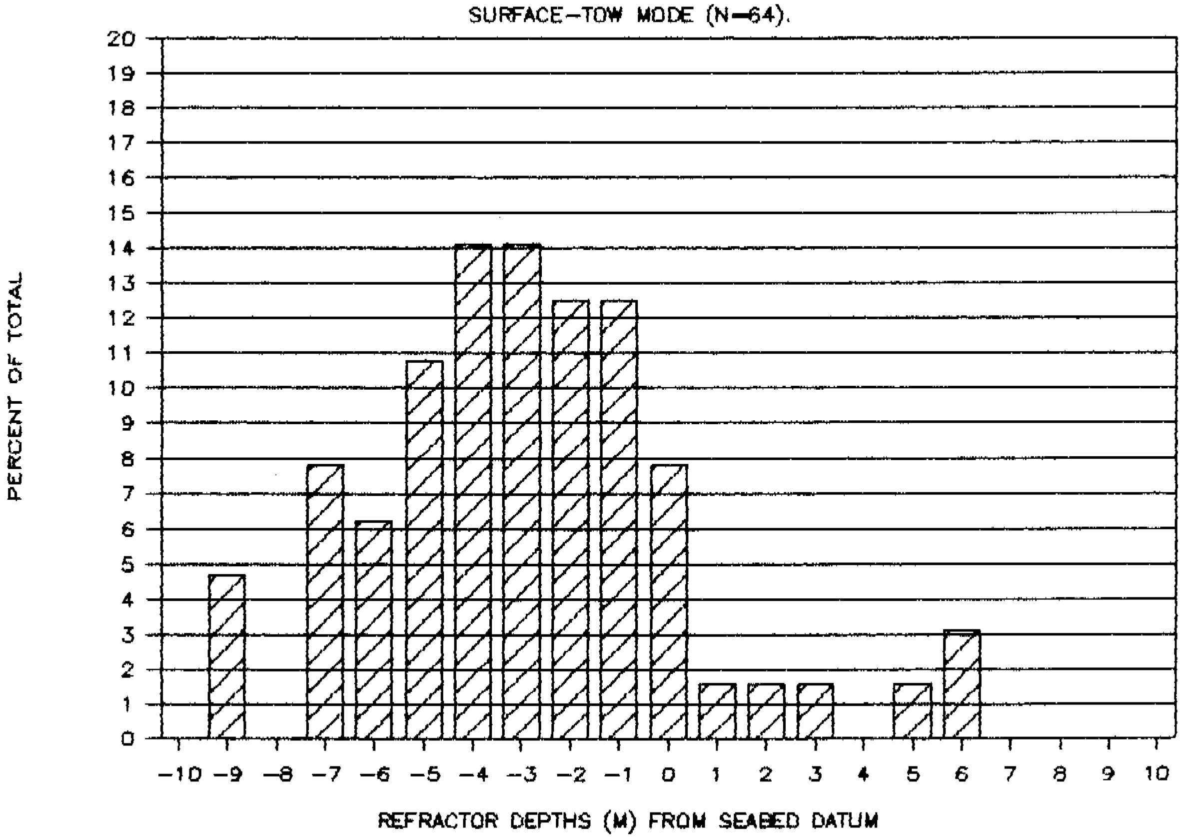
GRAPH 5. SHALLOW REFRACTOR DEPTHS.

DEEP-TOW MODE (N=316).



GRAPH 6. SHALLOW REFRACTOR DEPTHS.

SURFACE-TOW MODE (N=64).



samples. A negative value indicates that the refractor depth would occur above seabed. Graph 5 shows that more than half (57%) of the total depth count (N=316) would occur above seabed. Although the small number (N=64) of depth counts obtained in surface-tow mode (Graph 6) cannot yield statistically reliable results, it appears that a very high proportion (83%) of the computed depths fall above seabed. Most of the extreme negative values (-5m and -4m) in Graph 5 were computed from compressional wave velocities in the order of 1,550-1,570 m/sec that are grouped in the second lowermost velocity class (see Graph 1). These slow velocities are thought to travel near the seabed and hence, the refractor depths may be in error by as much as 5m.

5.2 PRESENTATION OF RESULTS

The position of the navigation shotpoints, which were given at 175m intervals along the reconnaissance lines, are presented at a scale of 1:150 000 on Plate I. The site specific permafrost study was carried out according to a detailed survey grid shown on Plates IV and V at a acale of 1:20 000; the line spacing is variable (400m to 800m) and shotpoints were also provided by the positioning system at 175m intervals. Note that the shotpoint position along the shiptracks indicates the centre of the refraction array.

The results of the reconnaissance field works are displayed as a series of cross sections which are mounted on two plates enclosed at the back of the report (Plates II and III). The sections have a vertical scale of 1:400 and a horizontal scale of 1:50 000. The equivalent vertical exaggeration is 125 times. The results of the site specific study are presented as plan of view maps on Plates IV and V which are also enclosed at the back of the report.

In order to present the final, processed results in a comprehensive format, a particular effort has been made to display the interpretative cross sections according to both their geographic orientation and location. In the Akpak Plateau area, four regional lines are oriented east-west, while four tie lines were traversed according to a north-south orientation. To visualize the variation in both surficial geology and permafrost conditions according to these two directions, the east-west cross sections which are constructed from Lines FHR88-01/04/18/ and 19, are mounted on the same plate (Plate II). Similarly, the north-south cross sections FHR88-02/03/20/ and 21 are displayed on Plate III.

5.2.1 High Resolution Reflection Data

Due to different factors such as: variation in data quality, variable subbottom penetration, occurrence of shallow gas, etc., the tracing of the seismic reflectors necessitates the use of both solid and broken lines on the cross sections.

A solid line represents a generally well defined reflector that exhibits on the reflection record a good to fairly good continuity (e.g. U/C1 unconformity), while a broken line symbolizes a faint and discontinuous reflector whose position has been approximated by following the "grain" of the seismic reflection (e.g. U/C3 unconformity). On the plan of view maps, the picks on the reflection records have been posted at shotpoints and contoured in order to best present the structural appearance of seismic horizons that are though to have an important geological significance.

5.2.2 High Resolution Refraction Data

Although most of the abnormally high compressional wave velocities (> 2.0 km/sec) are displayed onto the cross sections, only a few velocity measurements associated with shallow (unfrozen?) materials were plotted on the sections due to the questionable reliability of the depth calculations (see Sect. 5.1.4). In most cases, the velocities shown on the sections are in the order of 1,750 to 2,000 m/sec, and they are associated with acoustic signatures (chaotic reflections, diffraction patterns) on the boomer records that suggest very coarse-grained deposits. The only exceptions to this generalization occur in the Isserk Borrow Pit area where first arrival events having velocities ranging between 1,600 and 1,650 m/sec are believed to propagate along or at shallow depths below the seabed.

The deployment of an adequate suite of acoustic profiling systems and the recording of generally good quality reflection profiles along most of the reconnaissance lines, allowed the seismic interpreter to outline on the cross sections high amplitude reflections that are usually interpreted as acoustically defined permafrost (APF). The abnormally high seismic velocities (> 2.0 km/sec) associated with these anomalous reflectors provide evidence of the occurrences of ice-bearing sediments.

The situation is different over the site-specific area where in several places, the shallow water combined with the acoustic hardness of the seabed to give rise to a strong water bottom multiple. The effect of the bottom multiple on the reflection records is to mask completely, or partially, the deep part of the reflection profiles precluding a thorough interpretation of the deeper stratigraphic features. In addition, the acoustic signals transmitted by the profiling systems were blocked by frequent occurrences of shallow gas pockets present throughout the site area. Although the propagation of the refracted compressional waves is also affected by shallow gas, the acoustic blanking effect appears to be slightly less severe on the refraction seismograms than on the reflection profiles; perhaps, as a result of the high acoustic energy generated by the 80 cu.in. airgun that was utilized as the sound source over the detailed site survey.

In very shallow water areas, the main advantage of the refraction shooting over the reflection profiling is that, beyond the critical distance, the refracted headwave arrivals do not interfer with other seismic waves. For these reasons, the refraction seismograms were used almost exclusively to detect ice-bearing sediments and to map their distribution throughout the survey grid.

SECTION 6 - INTERPPRETATION OF RESULTS

The series of east-west and north-south cross sections, which are presented on Plates II and III respectively, illustrate the surficial geology and permafrost conditions for the upper 30-35m of sediments beneath the southern Akpak Plateau. The 1988 reconnaissance lines traverse a region of the Plateau that is delimited by Longitudes 135° to the west and 134° to the east, and by Latitudes 69° 57' to the south and 70° 05' to the north. In this sector, the water depth ranges from about 8m at some 9 km north of Pullen Island (Line FHR88-02) to about 30m in the northwest corner (Line FHR88-01) of the survey area.

The results of the site specific survey are presented on plan of view maps (Plates IV and V) that involve the contouring of seismic time-to-depth values in depicting the structural style of two regional unconformities (U/C1 and U/C3). In addition, Plate IV illustrates the possible relationships between the structure of a major unconformity (U/C1) and the distribution of ice-bearing permafrost in a zone where the water depth varies from 7m to 10m.

6.1 RECONNAISSANCE LINES (Plates II and III)

The interpretation of the seismic data collected along Line FHR88-01 (Plate II) suffers from the absence of high resolution 3.5 kHz subbottom profiler and boomer records. The shallow acoustic horizons were traced from one acoustic profile recorded by means of the airgun system. The low frequency acoustic signal generated by the airgun penetrates the subbottom at depths (several tens of metres), but to the detriment of a significant decrease in the seismic resolution. As a result, the interpretative cross section constructed from line FHR88-01 is considerably less detailed than those obtained from the other survey lines along which all profiling systems were in operation.

On the basis of bounding unconformities, the surficial sediment has been subdivided into three gross sequences corresponding on the cross sections to Units B+A, Unit B, and Unit C. Units B+A is bounded to its top by the seabed and to its base by unconformity U/C3. Unit B is bounded by U/C3 and U/C1 at its top and base respectively. Evidence of additional seismic discontinuities have been recognized within Unit B which suggests that this seismo-stratigraphic unit consists of a number of superposed depositional sequences. However, due to the wide spacing of the reconnaissances lines, it is difficult to evaluate the regional significance of these internal unconformities. One exception may be an unconformity (labelled U/C2 onto the sections) that appears to have a regional extent throughout the surveyed area allowing subdivision of Unit B into at least two subunits. The top of Unit C is delineated by unconformity U/C1 while its basal boundary, with the exception of Line FHR88-21 (Plate III), is not shown on the cross sections. Indeed, the lower bounding unconformity occurs at depths that largely exceed the detection depth of 25-30m achieved by the refraction array. This depth represents roughly the subbottom limit of the present investigation.

Figure 12 illustrates a high quality boomer record that allows the seismic interpreter to characterize the various seismo-stratigraphic units in term of seismic facies. Although some of the reflections visible within Unit B+A are continuous over short distances, they are generally very incoherent. This reflection pattern is believed to result from two major depositional environments: first, a reworked zone associated with progressive coastlines that prevailed during the last sea level rise; and second, the remoulding effect of the ice keels into the subbottom. Although it is difficult to evaluate the relative importance of these two processes, the flat-lying appearance of U/C3 in this area suggests that shoreface erosion and reworking during a wave-dominated period predominate over the ice-scouring effect. The hiatus represented by U/C3 may decrease basinward and eventually, the unconformity might be traced into concordant reflections that would occur seaward of the sea level lowstand. In this zone, the effect of the ice-scouring on the remoulding of the shallow layering may be an important mechanism to explain the near absence of continuous reflections within Units B+A.

Unit B displays a variety of seismic facies that may result from different depositional environments. The sequence comprised between U/C3 and U/C2 (Unit **GF**) is characterized by continuous, moderately high amplitude reflections which are best developed near the base of the subunit and within large depressions (Figure 12). These reflections become gradually incoherent towards the top of the sequence where the seismic facies, except for the reflection amplitude, resembles to that observed in Units B+A. The baselap reflection terminations over U/C2 indicate a seaward progradation during the deposition of the lower part of the subunit. The basal seismic facies suggests a sustained influx of sediments deposited in a high energy environment, that was followed towards the top of the subunit, by a decrease in the sediment supply deposited in a quieter environment.

The lower subunit of Unit B (Unit **VT**) is characterized by low amplitude reflections having a good continuity. The reflections are concordant with U/C2 which indicates that unconformity U/C2 represents likely a non-depositional hiatus rather than an erosional surface. In the depression (Figure 12), the reflections exhibit onlap terminations either over U/C1 or over an irregular deposit (Unit **CD**). These seismic facies properties and the presence of a levee-like feature along the southern flank of the basin, suggest that this subunit was deposited in a river-dominated (valley train) environment.

In localized areas, a third subunit (Unit **CD**) of Unit B has deposited on the depression bottoms. This subunit displays a generally mounded reflection configuration with complex and variable reflection patterns (chaotic, parallel, divergent and incoherent) that are thought to result from mass slumping. The occurrence of ice-rich sediments in both sides of the depression and steep slopes (Figure 12) are favourable terrain conditions for retrogressive-thaw flow slides. The mass wasting may be triggered by a mechanism similar to that described by Rampton (1988; see Sect. 3.2 of this report) for the formation of thermokarst basins in the Tuktoyaktuk Coastlands. The shallow gas present in the depression bottom, as evidenced by incoherent reflections (Figure 12), may result from the in situ decomposition of organic-rich materials (loose peat) that are commonly redeposited along with other materials (till) sliding down the slopes.

In general, a chaotic reflection pattern typifies the seismic facies of the uppermost zone of Unit C. As illustrated in Figure 12, this configuration may be interrupted at greater depths by hummocky and subparallel reflections that display on the boomer record a relatively high amplitude for events occurring at these 2-way seismic times. In several places, the analysis of the refraction seismograms provides important information regarding the nature of these anomalous reflectors.

For instance, the high compressional wave velocities (2,600 and 2,700 m/sec) that are associated with a moderately high amplitude, subhorizontal reflector in Figure 12, indicate that this seismic event is caused likely by a bed having a relatively low ice content. In addition, the notable decrease in amplitude towards the far traces suggests that these refracted headwaves have propagated along a thin layer. The hummocky reflector present in the southern part of this line segment (Figure 12), is interpreted tentatively as a rolling moraine (**RM**) because the shallowest seismic indications of the occurrence of frozen ground occur at about 10m deeper than the hummocky feature. Unfortunately, as a result of a number of adverse conditions such as: the sea-surface towing configuration (limiting detection depth); the presence of first arrivals having velocities of 3,200 and 3,600 m/sec (hidding shallow unfrozen layers); the occurrences of shallow gas at shotpoints 8137, 8138 and 8139 (reducing subbottom penetration); and noisy far traces (reducing detection depth), no velocity measurement was obtained from this hummocky horizon. In normal conditions, P-wave velocities on the order of 1,750 to 2,000 m/sec indicative of very coarse deposits were measured from similar hummocky features (see Figure 19 in Fortin, 1988b).

Most of the area traversed by the reconnaissance lines (Plates II and III) is believed to be covered by reworked silt and clay. This may result from Units B+A being underlain by fine deposits throughout much of its extent. As a result of ice-scouring, a variable fraction of recent marine sediment (Unit A) may have been incorporated into the reworked (transgressive) silt and clay; this explained the use of the term "Units B+A" on the cross sections. The proportion of Unit A sediment is believed to be marginal but would depend on the changing hydrodynamic conditions across this sector of the Akpak Plateau. The Isserk Borrow Pit provides evidence for locally concentrations of sand that is present within Units B+A and exposed right at the seafloor. The granular deposit may originate from a shoreline eroding localized areas of more sandy beds within the source deposit (glaciofluvial outwash), redepositing the sand-sized sediment over the area, and washing out the finer-grained sediment seaward and towards the Kugmallit Channel to the east. Landforms and sedimentary structures (foreset beds) delineated near U/C1 in the Isserk Borrow Pit area (Line FHR88-18, SP.7070-7080) may be vestiges of ice-contact features (kames?) that deposited near the inferred glacial maximum (Cf. Figure 7).

The Unit B upper facies, that is comprised between U/C2 and U/C3, is widespread throughout the surveyed area. The sequence is stratified to partially stratified within major depressions and reflection-free over elevated areas of the former land surface (U/C1). The associated lithofacies may be glaciofluvial deposits, or outwash plains (Unit **GF**, Figure 12). which would consist of interbedded clay, silt and sand, with a coarsening facies change towards the topographic highs. The Unit B lower facies, that is bounded by U/C1 and U/C2, is common within the largest channels. This sequence is stratified to partially stratified, although locally the sequence may be reflection-free (if not a result of seismic signal attenuation). The inferred lithofacies is valley train deposits (Unit VT, Figure 12), which would be formed of interbedded clay, silt and sand, with sand being concentrated locally in active sections of the valley trains.

The seismic facies present in the upper zone of Unit C suggests that this deposit consists primarily of non-cohesive materials (sand). Those hummocky features, which are not associated with permafrost velocities, are interpreted to be morainal and ice-contact deposits. Their location relative to the inferred glacial maximum indicates that they could reasonably have been deposited during this extreme glacial advance.

Except for the eastern portions of Lines FHR88-04 and -18 where the APF horizons delineate deep and hummocky islands of acoustic permafrost, the ice-bearing sediments are very common in the region traversed by the four east-west lines (Plate II). Although nearly continuous in a east-west direction, the IBPF table appears discontinuous along the north-south tie-lines (Plate III). As it can be expected from the hummocky nature of the shallow ice-bearing permafrost in this region of the Beaufort

Sea, the APF features are generally very irregular with steeply dipping margins in the vicinity of channel-like depressions. Beneath these topographic lows in U/C1, the APF horizons deepen quite abruptly and they may be locally absent (taliks) underneath the deepest paleochannels (e.g. Lines FHR88-4, SP.3860-3900; and FHR88-21, SP.8310-8360).

The APF horizons shown on the cross sections (Plates II and III) give rise to anomalously high amplitude reflections that can be traced easily on the boomer and/or airgun records. Similarly, these seismic discontinuities propagate refracted headwaves with abnormally high P-wave velocities (2,000-4,000 m/sec) that are easily recognized on the seismograms. For these reasons, and also bacause it is difficult to achieve absolute spatial correlations between the APF depths picked on the reflection records and the IBPF depths computed from the time-distance plots, the IBPF velocities plotted onto the cross sections were correlated directly with the APF horizons delineated by the reflection devices. The difference in depth between the APF reflector (picked on the reflection profile) and the IBPF refractor (computed using the critical distance method) gives the inferred eel elevation, which is shown only for the lines traversed with the refraction array in a surface-tow mode (see Plates II and III).

Although generally close to the sea surface, the departures from sea level in the inferred eel elevation may exceed 5m. Assuming that the refraction array was towed at or very near of the sea surface, the difference in depth may result from a number of factors such as: inadequate offset corrections between the various seismic systems; uncorrected depth values for steeply dipping refractors; and more interestingly, the fact that correlating IBPF with APF depths may be misleading in certain areas.

Figure 13 illustrates a good quality airgun record that exhibits a very distinct APF reflector between Shotpoints 3,817 and 3,832. Along this profile, the refraction array was deployed in a deep-tow mode and thence, a eel elevation transducer record is available for correction to seabed datum. In addition, the shape and length of the APF reflector suggest that the seismic profile transects a large and relatively flat surface of acoustic permafrost. These conditions should minimize both slope effect and uncertainty in the offset corrections between the various seismic systems. The P-wave velocities and the refractor depths shown in Figure 13 are corrected for the offset between the airgun and the centre of the refraction array (about 100m). Except for a velocity observation of 4,000 m/sec (between SP. 3826 and 3827) that coincides with the prominant APF reflector, all the other velocity measurements would occur at depths shallower than the APF horizon. A closer examination of the airgun record reveals that a weaker reflector can be traced through or in the immediate vicinity of these otherwise untied velocity measurements. This introduces the possibility that the refracted headwaves may have travelled along a thin ice-bearing layer at shallow depths, rather than along the upper surface of the underlying (presumably thick) APF feature.

The airgun profile in Figure 13 depicts well the shallow permafrost conditions present underneath large channels and near the boundary between the Akpak Plateau and the Kugmallit Channel. Fortin (1988a) reported that the base of the shallow APF hummocks may be coincident with the contact between a sandy unit (Unit C) and a underlying marine clay unit (Unit D). A second level of ice-bearing sediments, generally considered as the top of the main permafost body, occurs at the top of a second sand unit (unit E). Deep basins, similar to the channel delineated in Figure 13 (SP. 3832 to 3837), are underlain by through-going talik zones that can reached the main permafrost body. In this example, thawing underneath the channel have occurred down to about 100m where the shallowest APF horizon was detected in this zone. Near the boundary between the Akpak Plateau and the Kugmallit Channel (Figure 13), the shallow APF horizon deepens gradually until it reaches the clay unit. Although in this location the clay unit may content marginal ice-bonding, the shallowest indication of "acoustic" permafrost (APF? in Figure 13) occurs at the top of the second sand unit (Unit E).

6.2 SITE SPECIFIC SURVEY (Plates IV and V)

A site specific survey was carried out during the 1988 field operations in order to obtain additional seismic information regarding a geologically complex zone. In this zone, where the water depth ranges between 7m and 10m, ice-bearing sediments were encountered at shallow depths (5-20m) below seabed. This zone was recognized in 1987 (Fortin, 1988b) while surveying a proposed pipeline route from Amauligak to North Point. On the basis of subseabottom temperature measurements recorded along several transects running north of Pullen Island, it was concluded that the observed variations in the annual temperature regime would not allow shallow ice-bearing permafrost to survive a marine transgression and be preserved in water depths shallower than about 10m (J.A.M. Hunter, GSC, pers. comm., 1988). As a result, the geoscientists involved in the present project are making every effort to resolve this problem. Towards this end, a thorought interpretation of the seismic data gathered across the detailed site survey is presented in this section. The results are currently used for the planning of follow-up works (coring, temperature and seismic profiling) that will be conducted by the GSC during the spring of 1989.

The site specific survey also provides a close-up on the inferred glacial maximum that is mapped across the Akpak Plateau (Cf. Figure 7). The surficial geology of the site area is characterized by seismically complex topographic highs and by both flat-bottomed and steep depressions. Unfortunately, the acoustic blanking that may result from frequent occurrences of gas-charged sediments present at shallow depths (1-8m), hampers considerably the analysis of the underlying stratigraphic features.Figures 14 and 15 illustrate the offshore and the inshore zones of the elevated land features delineated by U/C1. The seismic facies in these heights is characterized by a chaotic reflection configuration with locally diffraction point sources. This acoustic character coupled with the high P-wave velocities (1,700-2,040 m/sec) suggest that these features include a variety of very coarse or highly compacted materials. Based on their seismic properties, morphology, and location relatively to the inferred glacial maximum, these elevated features are interpreted as morainal deposits (**MD** in Figures 14 and 15).

In the seaward direction (Figure 14), a stratified deposit abuts against the morainal deposits. Several reflections visible within the stratified unit (silt and clay) display a gradual decrease in amplitude in a seaward direction where they can be traced into foreset reflections (sand). This sequence may be formed of glaciofluvial deposits (Unit **GF**) that were carried out from east (ancestral Kugmallit river?) with westward progradation over U/C1. The glaciofluvial deposits are truncated by a distinct erosional unconformity (U/C3) that results likely from shoreface erosion during the last marine transgression.

Unconformity U/C3 is covered by a chaotic to weakly stratified sequence that consists primarily of reworked sediments (Unit **RS**). The thickness of the reworked layer decreases progressively towards the U/C1 high where the reworked deposits are whether too thin to be resolved by the boomer system or absent.

In a shoreward direction (Figure 15), a poorly stratified (top) to stratified (base), slab-shaped unit covers the inland face of the morainal deposits. This unit may be formed of coarse outwash (Unit **CO**) that deposited at the front of a glacier; the fact that unit CO is present within a depression suggests a valley train environment. Unit CO appears to have been cut by the eastern side (U/C2?) of a large depression that may have been infilled by fine glaciofluvial deposits (Unit **GF**). An apparent seaward progradation of the basal beds of Unit GF suggests that these sediments originated chiefly from western sources. A relatively thin veneer (1-3m) of reworked sediments blankets the inshore zone when compared to the offshore zone (Figure 15). This may be explained by the highlands (Unit **MD**) forming a resistive barrier (morainal terrace) that protected the backbarrier zone from wave erosion.

Both data sets, seismic reflection and refraction, indicate that the elevated Plateau areas in this sector are underlain by shallow ice-bearing permafrost. In Figure 15, abnormally high seismic velocities (2,600 and 4,000 m/sec) on the refraction seismograms, which are associated with an hummocky APF reflector on the boomer record, are conclusive evidence of the occurrence of ice-bearing sediments at shallow depths (5-15m) within Unit MD. The ice-bearing permafrost does not appear to be restricted to the topographic highs. Anomalous velocities of 3,800 and 4,000 m/sec were also measured in the vicinity of an APF feature that occurs at depth of about 20-25m underneath a large depression delineated inshore of the highland (Figure 15, SP. 6183-6186).

In order to evaluate the relationships that may exist between the observed IBPF distribution and drowned landforms, an isopach map of the thickness of the surficial sediment overlying U/C1 has been constructed and is presented as Plate IV. The resulting map portrays the residual relief of U/C1 following the shoreface erosion associated with the passage of a generally transgressive coastline over the area. The residual paleotopography of U/C1 is characterized by three zones. In the eastern sector, short and narrow channels were incised to depths exceeding often 8m into the pre-unconformity sediments. These channel characteristics suggest streamlined fluting under or at the front of a glacier ice. The western sector is characterized by a series of flat-bottomed depressions that may have been carved by a glacier, modified by meltwater running, and buried by outwash deposits. Although they may be interconnected to the south, the eastern and western lowlands are separated by a zone of NW-SE trending topographic highs that culminate at a few metres below seabed. The hommocky reliefs often present within this hilly belt suggest a ice-thrust origin for these (morainal) deposits that delineated the inferred position of the glacial maximum across the Akpak Plateau.

Most of the high velocity (2,000-4,000 m/sec) measurements obtained throughout the site occur within the elevated landforms. This suggests that the geological conditions present in these zones allowed permafrost to degrade less extensively during the deglaciation than in the periphery, where channelling appears to have accentuated permafrost degradation. Alternatively, the elevated U/C1 features may represent preferred areas where permafrost would re-establish itself under favourable thermodynamic conditions (e.g. intrusion of cold seawater over the area). As illustrated in Figures 14 and 15, the thickness of the post-transgressive, reworked sediments (Unit RS) is minimal over the U/C1 highs.

The isopach presentation of the reworked sediments on Plate V provides a picture of the spatial distribution of this unit across the survey site. The isopachs indicate clearly that shoreface erosion was a very active process in the offshore zone where more than 8m of reworked materials have accumulated. Although present in the backbarrier zone, this environment was less dominant than in the offshore zone, as evidenced by the relatively thin veneer (1-3m) of reworked sediments covering the inshore region. The reworked unit is very thin (<1m) over the elevated land features, and it is likely that a coarsening facies change occurs over these highlands. These conditions may provide better avenues for temperature exchanges (and also salt advection) between the cold seawater and the subbottom, than in the zones covered by a thick layer of fine reworked sediments. Both the nature of the elevated land features (Plate IV) and the corresponding thin veneer of reworked sediments (Plate V), may represent clues for the solution of problem resulting from the presence of ice-bearing sediments in a zone where the today temperature regime does not allow shallow permafrost to be preserved.

SECTION 7 - DISCUSSION OF RESULTS

APF versus IBPF

Evidence from the examination of the 1988 seismic data indicates that the direct correlation between APF features on reflection profiles, and depths of ice-bearing permafrost (IBPF) computed from the refraction seismograms is equivocal in certain areas of the southern Akpak Plateau. Both techniques involve the strong velocity contrast that exists usually between unfrozen and ice-bearing sediments for the detection of subsea permafrost. However, the interpretation of permafrost on reflection profiles relies heavily on indirect evidence such as anomalous APF reflectors having generaly a very high amplitude, while the refraction method provides **in situ** velocity measurements of compressional headwaves which propagate along the boundary between unfrozen and frozen sediments with anomalously high seismic velocities (2,000-4,000 m/sec).

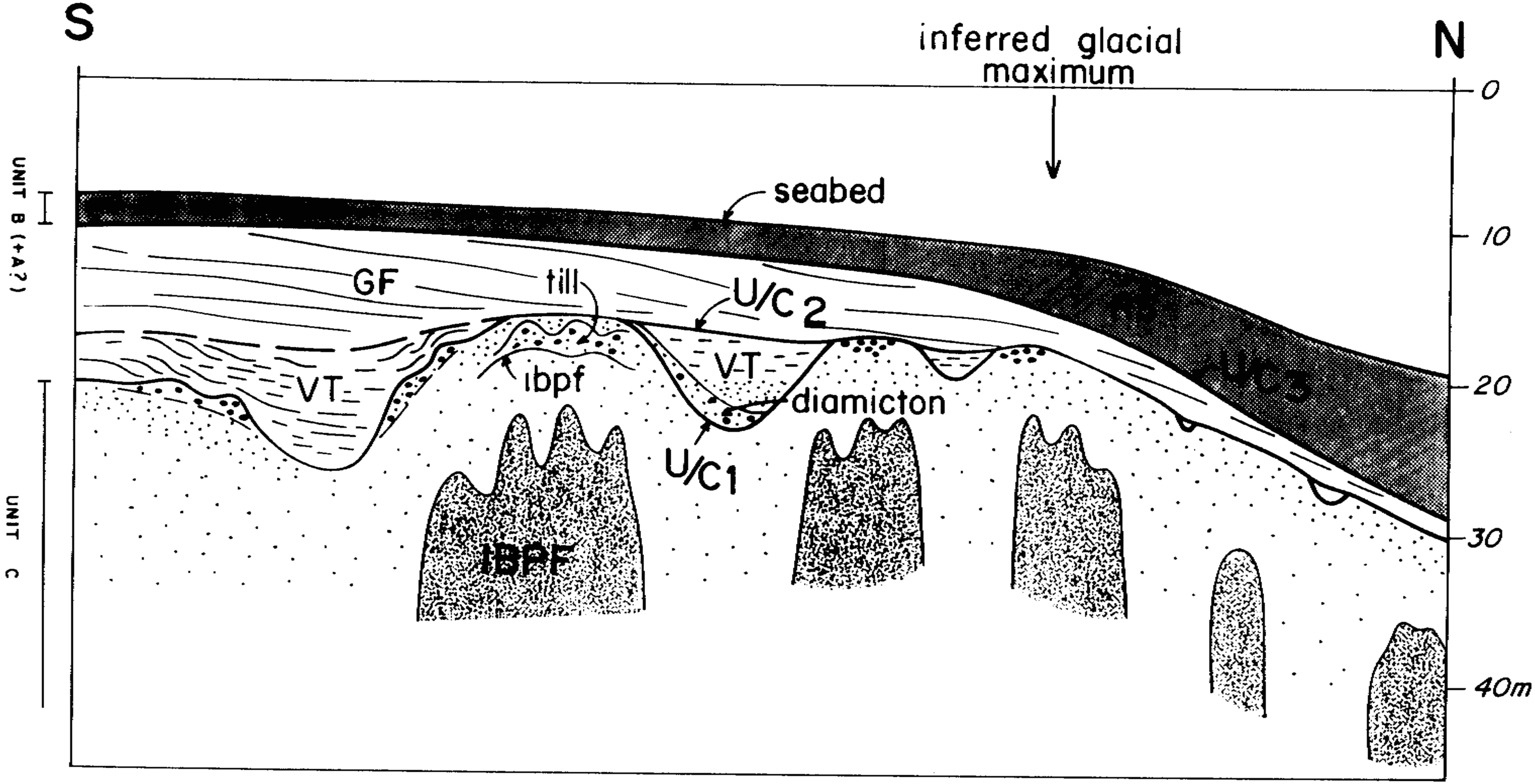
Assuming that reflection surveying is carried out by means of an adequate profiling system (e.g. airgun system) in calm weather, the shallow APF table beneath the Akpak Plateau would give rise to strikingly sharp and hummochy reflections of high amplitude that are easily traceable on the acoustic profiles (Cf. Figure 13). However, it is difficult to judge whether the lesser amplitude events occurring above the APF reflectors are caused by lithological contrasts, unconformities, shallow gas, etc., or beds having a marginal ice-content. A meticulous analysis of high resolution refraction seismograms of good quality allows the seismic interpreter to obtain velocity measurements from the shallow layering and possibly, to trace thin and marginally frozen beds whose amplitude on the acoustic profiles is similar to that of the background reflections. In such cases, the amplitude of these weak reflectors cannot be used as a diagnostic reflection characteristic for permafrost detection. Therfore, it may be concluded that the P-wave velocity observations provide direct evidence of the presence of ice-bearing permafrost at depths shallower than the hummocky APF features visible on the reflection records. The occurrence of thin frozen beds above the shallow permafrost table may be explained by ice-bearing, coarser-grained layers that would have degraded less extensively than the finer-grained host sediments in response to the sub-seabottom warming during marine submergence.

New glacial model versus O'Connor's model

The interpretation offered herein differs significantly from the model proposed by O'Connor (1980) for the surficial geology of the Southern Beaufort Sea (see Sect. 2.1). In the present report, the O'Connor Unit B is not recognized as a purely transgressive deposit in this sector of the Akpak Plateau, but it is believed that this unit includes rather a number of sequences which would have deposited following the inferred glacial maximum (Cf. Figure 7). In our model, Unit B would have accumulated during the course of at least three major depositional environments that existed during the deglaciation and the subsequent marine transgression over the area.

Firstly, a **proglacial environment** that was prevailing between the glacial maximum, which event was accompanied by an important sea-level lowering to about -140m and the resulting subaerial exposure **(U/C1** in Figure 16) of this sector of the Plateau to arctic climate, and a second relative sea-level lowering and minimum to about -70m (Cf. Figure 3). Early in the deglaciation, subglacial and periglacial meltwater channels were incised into the glacial (morainal) and older (Unit C of O'Connor) deposits. These channels carried out meltwater and fine outwash directly to the sea while coarser-grained outwash deposited on the channel bottoms (**VT** in Figure 16). During the deglaciation, a standstill and/or a sea-level lowering from -40m to -70m on the sea-leavel curve (Cf. Figure 3) resulted in a temporary quiescence in the glacial outwash influx during a probable glacial readvance. This non-depositional environment corresponds to an hiatal unconformity (**U/C2** in Figure 16) that can be traced within the major meltwater channels.

Secondly, glacier retreat may have occurred again to the south of the area depositing large volumes of fine glaciofluvial deposits (**GF** in Figure 16) over U/C2 in a **outwash fan**



VT: Valley Train deposits   GF: GlacioFluvial deposits   RS: Reworked Sediments

Fig. 16 SEISMO-STRATIGRAPHY AND INFERRED LITHOFACIES, SOUTHERN AKPAK PLATEAU.

environment. This environment was interrupted by the approach of a transgressive shoreline in this region of the Plateau.

Thirdly, a **transitional environment** resulted in shoreface erosion and reworking of the underlying fine outwash. The fine rerworked materials (**RS** in Figure 16, or Unit B of O'Connor), with locally concentrations of sand in areas where most underlying outwash deposits are sandy, redeposited over a shallow regional unconformity (**U/C3** in Figure 16). In the deep water areas, a variable fraction of recent marine sediment (Unit A of O'Connor) may have been incorporated into the reworked zone as a result of ice-scouring processes.

SECTION 8 - CONCLUSION

In 1988, the recording of reflection records by means of an airgun system has provided both increase subbottom penetration and improve acoustic picture of the permafrost-affected zone. This set of airgun profiles brings additional information that helps to better understand the advantages and limitations inherent to both reflection and refraction surveying. For instance, the reflection systems record continuous profiles of the subbottom that are very useful in delineating shallow stratigraphy and features. On the basis of anomalously high amplitude reflections, often of discordant nature, APF features can be traced easily on these records providing indirect evidence of significant ice-bonding wthin a relatively thick zone. In boudary conditions, i.e. thin beds having a marginal ice-content, the otherwise diagnostic amplitude of the APF reflections intermingles with the background resulting in serious interpretation uncertainties. On the other hand, although the current deep-towed refraction system has the capability of exploring a continuous section of the seabottom, the uncorrected depth points are posted at their apparent spatial position (centre of the spread) providing ponctual, but conclusive evidence of thin beds or large hummocks of ice-bearing permafrost.

Notwithstanding the cost, the deployment of both reflection and refraction systems along the course of a seismic transect, allows the geophysicist to enhance its capability of interpretation on the grounds of correlations or disappointing mis-correlations (often to the detriment of the geophysical methods) between the borehole data and the shallow seismic data.

The glacial deposits recognized south of the inferred glacial maximum and delineated between the reworked zone and the former land surface are not transgressive in origin, and thence they cannot be classified as Unit B sediment of the O'Connor model. In this sector of the Akpak Plateau, the O'Connor model may not be adequate for describing the various sequences that deposited following the late Wisconsinan glaciation(s). In most places, a variable thickness (few metres to few tens of metres) of fine glaciofluvial deposits, chiefly valley trains and outwash plains, cover the former land surface. Shoreface erosion, reworking and redistribution of these deposits by generally transgressive coastlines have resulted in a fine-grained transgressive sequence, essentially the O'Connor Unit B, with locally concentrations of sand (e.g. Isserk Borrow Pit).

SECTION 9 - RECOMMENDATIONS

The author developed the following recommendation based on its evaluation of the 1988 refraction/reflection data. Further documentation and case analysis of selected seismic line segments of high quality is needed to determine exactly how both refraction and reflection waves and ice-bearing permafrost interact in different terrain conditions, as well as to evaluate the accuracy that can be achieved on the computation of the refractor depths. It may be particularly instructive for the seismic interpreter to learn how such interactions can be recognized and should be interpreted on the reflection seismic profiles and refraction seismograms. This should focus on cases where there is strong evidence that thin layers of ice-bearing sediments occur above prominent APF reflectors. The Isserk Borrow area could be utilized as a ground-truth site if access to the information from the boreholes (e.g. Dome 1980 and Gulf 1982) drilled in this location, can be arranged with the petroleum operators.

Although some operational difficulties were experienced during the sea trials conducted in the hostile Beaufort Sea environment, the deep-towed refraction arrays remain a promising technique for the detection of ice-bearing permafrost. Therefore, it is recommended to develop opportunities for deploying the system in the Beaufort Sea, as well as in other areas and for different applications (bedrock investigations, borrow searchs, etc.).

Whereas seismo-stratigraphic evidence indicates a probable glacial advance on the southern Akpak Plateau and the associated glacial deposits that cannot be easily linked to the O'Connor model posing a major correlation problem with other regions of the Beaufort Sea, there is a need for a geological model to account for the whole glacial and post-glacial stratigraphy of this sector of the Plateau. Towards this end, it is recommended to review the existing shallow seismic data and other geoscience information in order to refine the model proposed in the present study (Cf. Figure 16).

The recommendation that follows is concerned with promoting a synthesis (GSC paper, scientific and technical publications) of the 1985 through 1988 experimentations with the new refraction technique in order to improve the diffusion of the results throughout the industry and scientific community in terms of engineering applications, geo-acoustic modelling and regional studies.

Respectfully submitted:

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APPENDIX "A"

GEOPHYSICAL OPERATIONS REPORT

GEOPHYSICAL OPERATIONS REPORT
C.C.G.S. NAHIDIK, SEPTEMBER 1988
BEAUFORT SEA

Submitted to:

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Bedford Institute of Oceanography
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Submitted by:

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Scientific Authority:	Mr. Steve Blasco
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Chief Scientist - Phase 1	John Lewis
Chief Scientist - Phase 2	Jim Hunter
D.S.S. Contract Officer:	Mary MacLellan Koches
EOR Project Manager:	John Lewis
EOR Project No.:	88-27
Submission Date	January 1989

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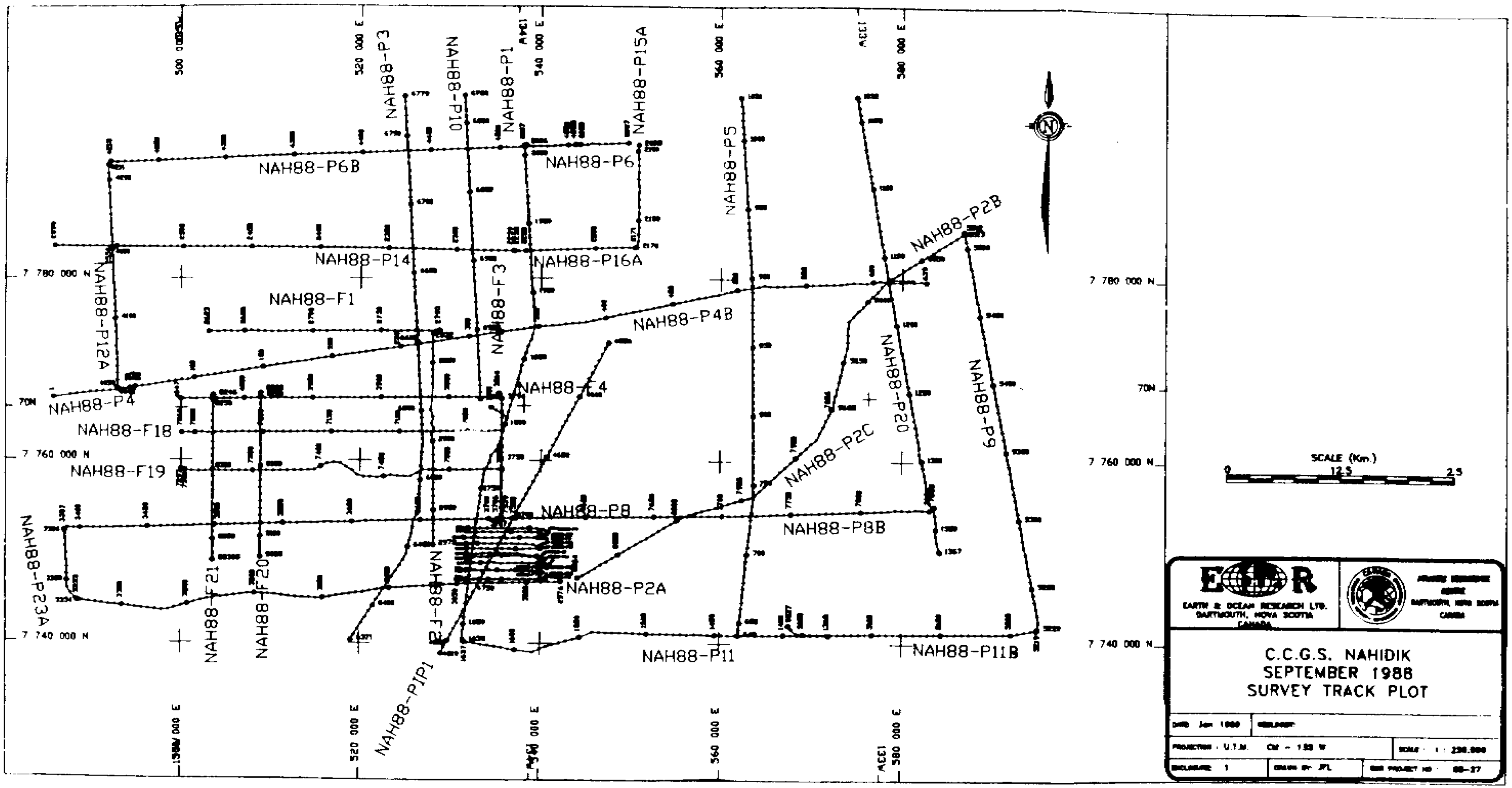
1 INTRODUCTION

During the period of August 30 to September 18 of 1988, Earth & Ocean Research Limited provided geophysical support personnel for the G.S.C. survey operations on board the CCGS NAHIDIK in the central Beaufort Sea. This service was provided under D.S.S. Contract No. 23420-8-M478/01-OSC with Mr. Steve Blasco as the scientific authority. EOR's responsibilities included providing Mr John Lewis as second chief scientist, to represent Mr. Blasco on board the NAHIDIK since he was concurrently chief scientist aboard the CSS TULLY working in the area. Also EOR was instrumental in selecting the survey grid to be completed during this program as a supplement to a regional geology interpretation contract that is currently underway for Mr Blasco. EOR also provided experienced personnel for the setup and operation of the seismic reflection geophysical equipment utilized for the program. This report details the field operations conducted.

The cruise was a joint effort between AGC from Dartmouth Nova Scotia and the Terrain Sciences Group of the GSC in Ottawa. The chief scientist for the program was Dr. Jim Hunter of the Terrain Sciences Group though he did not join the vessel until Sept 8. The program involved an attempted recovery of a bottom mounted monitoring package belonging to the USGS, the collection of regional reflection profiles and the collection of regional refraction profiles. Reflection profiles were carried out on a 24 hour per day basis under the direction of Mr John Lewis of EOR, and refraction data collection was conducted on a 12 hour per day basis under the direction of Dr. Hunter. Figure 1 indicates the line coverage completed during this program with a total of 1216.2 km of seismic reflection data collected and of this total 311.4 km of the coverage included seismic refraction data collection.

Mobilization of the seismic reflection equipment commenced on Aug 30 and was not fully complete until Sept 3 after a rendezvous and equipment transfer from the CSS Tully in the lee of Herschel Island. On Sept 3 an attempt was made to reach the northwestern Yukon Shelf for recovery of the bottom tripod unit installed by USGS, however this area was blocked by ice and the recovery was abandoned at this time. Reflection survey began on the morning of the 4th and refraction and reflection survey combined did not commence until Sept 9 after a delayed arrival of the winch unit for the deep tow system. The field program continued until the 17th of September when the vessel steamed up river to Inuvik for demobilization. Appendix 1 gives the a detailed log summary of the events of the survey program.

The following sections describe the operational activities of the cruise with particular emphasis on the seismic reflection program. The report outlines operational problems and recommendations for future programs.



NAH88-P6B
NAH88-P6
NAH88-P3
NAH88-P10
NAH88-P1
NAH88-P15A
NAH88-P14
NAH88-P16A
NAH88-P12A
NAH88-F1
NAH88-F3
NAH88-P4B
NAH88-P4
NAH88-F4
NAH88-F18
NAH88-F19
NAH88-P8
NAH88-P8B
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NAH88-P2A
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NAH88-P11
NAH88-P11B
NAH88-P5
NAH88-P2B
NAH88-P2C
NAH88-P20
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580 000 E
7 780 000 N
7 760 000 N
7 740 000 N
70N
SCALE (Km.)
0
12.5
25
EARTH & OCEAN RESEARCH LTD.
DARTMOUTH, NOVA SCOTIA
CANADA
C.C.G.S. NAHIDIK
SEPTEMBER 1988
SURVEY TRACK PLOT

2 SURVEY PROGRAM - AUG 31 TO SEPT 18

The 1988 NAHIDIK geophysical cruise program ran from Aug 31 to Sept 18. The program was a joint survey combining a regional seismic reflection program on the central Beaufort shelf for Steve Blasco of AGC and a more site specific refraction (permafrost detection) program in the area of the Akpak Plateau for Jim Hunter of the GSC in Ottawa. The seismic reflection program was designed to enhance the understanding of the surficial geology in the region from 69° 45' N to 70° 20' N and from 131° 45' W to 135° 30' W. In general the seismic reflection program consisted of a high resolution profiler system, a boomer high resolution system and a single channel medium resolution airgun system. The refraction system consisted of a GSC Terrain Sciences custom system using an airgun source on a deep towed delta wing and a 24 channel deep towed streamer. During this program additional survey lines were completed in the vicinity of the proposed Amauligak to North Point pipeline corridor to aid in the understanding of this region as well.

During operation of the deep tow refraction systems the reflections systems were operated as well to enhance the understanding of the combined systems.

During the initial stages of the program an attempt was made to reach and recover a bottom mounted sensor package located on the northwestern portion of the Yukon shelf. This package belongs to the USGS and was jointly deployed by the GSC and USGS during the 1987 survey year to monitor current and ice conditions throughout the winter seasons. The package has completed it's monitoring program and this was the first attempt at recovery. Because of heavy ice conditions in the western Beaufort during this time period we were unable to get within 70 km of the deployment location and the recovery attempt had to be aborted. The acoustic release batteries are designed to accommodate a full two year deployment and therefore another attempt will have to be made during the 1989 season unless a method of recovery under the winter ice is used.

2.1 PERSONNEL

The following personnel were involved in the scientific program with the grateful assistance and excellent cooperation of Captain Fayez Ali and the officers and crew of the C.C.G.S. NAHIDIK.

Dr. Jim Hunter	Sept 7 to Sept 18	GSC	Chief Scientist
John Lewis	Aug 29 to Sept 18	EOR	2nd Scientist
Martin Douma	Aug 29 to Sept 18	EOR	Reflection
Ed Mayzes	Aug 29 to Sept 18	EOR	Refl Airguns
Ron Good	Aug 29 to Sept 1 Sept 7 to Sept 18	GSC	Refrac Mech
Robbie Burns	Aug 29 to Sept 18	GSC	Refrac Electr
Bob Gagne	Sept 7 to Sept 18	GSC	Refrac Comp.
Mike Huges	Aug 29 to Sept 5	GSC	Reflec Tech
Rene Grand	Aug 29 to Sept 18	CES	Navigation
John	Aug 29 to Sept 18	CES	Navigation
George Tate	Sept 1 to Sept 6	USGS	Instr. Recovery

Note: GSC refers to Geological Survey of Canada
USGS refers to United States Geological Survey
EOR refers to Earth & Ocean Research Ltd of Dartmouth
CES refers to Canadian Engineering Surveys of Edmonton

2.2 SURVEY VESSEL

The C.C.G.S. NAHIDIK is a purpose built shallow draft vessel of approximately 55 m length with 5000 horsepower engines and follows the design of the large river tugs used on the Mackenzie River. The vessel was under the command of Captain Fayez Ali and carries a compliment of 16 Coast Guard officers and crew. She is based out of Haye River and her primary task is that of a buoy tender and policing/rescue vessel for the western arctic coastal regions.

During the late summer time period of this survey, the vessel is in a slow period having laid her navigational aids after breakup and has been kindly made available for scientific research work in the region prior to starting buoy recovery operations after the short arctic navigational season.

2.3 EQUIPMENT SUMMARY

The seismic profiling and refraction equipment used on this program consisted of a Raytheon PTR 3.5/7.0 kHz profiler, a uniboom seismic profiler, a small array airgun seismic profiler and a custom GSC designed refraction system. These systems consisted of the following equipment.

3.5/7.0 kHz Profiler

Raytheon PTR Transceiver Unit
Pipe mounted fixed position 3.5 kHz Transducer
Note: this transducer functioned poorly when set on the 3.5 kHz position of the Transceiver but produced very good results when set on the position labelled 7.0 kHz. There may be a miss-labelling of the transceiver or the transducer and this problem should be checked out prior to future use.
EPC 3200 graphic recorder - normally run on split display with the boomer signal recorded on the second channel.

Boomer System

EG&G Model 230 Uniboom sound source - catamaran mounted
EG&G Model 234 Power Supply and trigger capacitor bank operated at 300 Joule setting
Prototype IKB SEISTECH line and cone receiver system
EG&G Model 260 single element hydrophone (spare - not used)
NSRFC tapered Hydrophone array (10m) (spare - not used)
EPC 3200 graphic recorder (half sweep display combined with PTR and airgun on two separate recorders)
TSS time varied gain amplifier
Krohn Hite variable band pass filter

Airgun System

7 cfm compressor - 50 hp electric motor
75 kva diesel generator
surfboard mounted dual 10 cu in Bolt 600B airguns and towing bridle
Bolt dual gun airgun firing system controller
NSRFC tapered Hydrophone array (10m)
EPC 3200 graphic recorder (half sweep display combined with boomer record)
TSS time varied gain amplifier
Krohn Hite variable band pass filter

Refraction System

Bauer 2.5 cfm diesel powered compressor
300 m umbilical cable
Hawbolt winch
Endeco delta wing depressor
Bolt 600B 40 cu in airgun

Custom built 100 m - 24 channel streamer cable
GSC custom built airgun firing system
Prototype Scintrex 24 channel digital acquisition system
Data General microcomputer data logging system
Custom software for acquisition and display
Dual Geometrix 1210F 12 channel acquisition systems (backup - not used)
Dual Apple IIE microcomputer logging systems (backup - not used)

Other

EOR dual source trigger system
TSS graphic recorder Annotator
Tektronixs Model 454A delay time base oscilloscope
Tektronixs Model 465 storage oscilloscope
spare EPC 3200 graphic recorder

Navigation

During this survey program Canadian Engineering Survey of Edmonton Alberta provided a complete Syledis navigational system with computer software and logging system. The details of the navigation system and shore control for this survey are covered under separate report by CES.

2.4 OPERATIONAL SUMMARY

Figure 2 indicates the in water towing and equipment configurations used throughout this survey program. Operationally the seismic refraction survey program was conducted on a nominal 12 hour per day basis but did not commence until Sept 9th because of problems related to the late arrival of the deep tow main winch to Inuvik in time for the Sept 1 sailing of the vessel. Also the reflection program did not commence until Sept 3 due to transfer of necessary equipment from the CSS TULLEY though with the exception of weather or equipment problems or transits the reflection survey ran continuously throughout the program. Appendix 1 gives a log summary of the operations while Appendix 2 is a table of the survey lines completed through the program.

Operationally the cruise was divided into three planned tasks throughout the 2 week period. The first task was the attempted recovery of the USGS bottom mounted instrument package on the Northwestern Yukon shelf. The initial plan was to transfer equipment from the CSS TULLEY at Tuktoyaktuk and then proceed to this area for the recovery. Because of rough weather conditions off Tuk the transfer had to take place in the lee of Herschel island on the 2nd of Sept. After this an attempt was made to reach the instrument deployment area however heavy pack ice in the area prevented access to the area and this portion of the program was aborted. The second task was a regional reflection survey program in the regions of the Akpak Plateau and the Tingmiark Plain and the Kugmallit Channel. This program was designed to supplement the present regional industry and government data bases by specifically tying boreholes together and also cover areas of no data coverage along with regions of poor quality older data. The third goal of this survey program involved supplementing the high resolution refraction seismic data base over the Akpak Plateau as part of Jim Hunter's ongoing study of the shallow permafrost in this area.

The reflection and refraction programs involved a shared resource activity of the vessel time. Operationally personnel limitations of the refraction crew resulted in a nominal 12 hour refraction survey day during which the reflection equipment was also run over the Akpak region. During the off 12 hour periods reflection lines were completed in other areas and both groups attempted to optimize their survey programs while minimizing transit times. In general these procedure worked well though only limited coverage was obtained in the eastern portion of the regional reflection grid because of this cooperative effort combined with unfortunate weather conditions during the early survey period when the refraction system was not functional.

The following sub sections outline operational problems encountered with the survey equipment.

NAHIDIK 1988 — GSC SURVEY CONFIGURATION

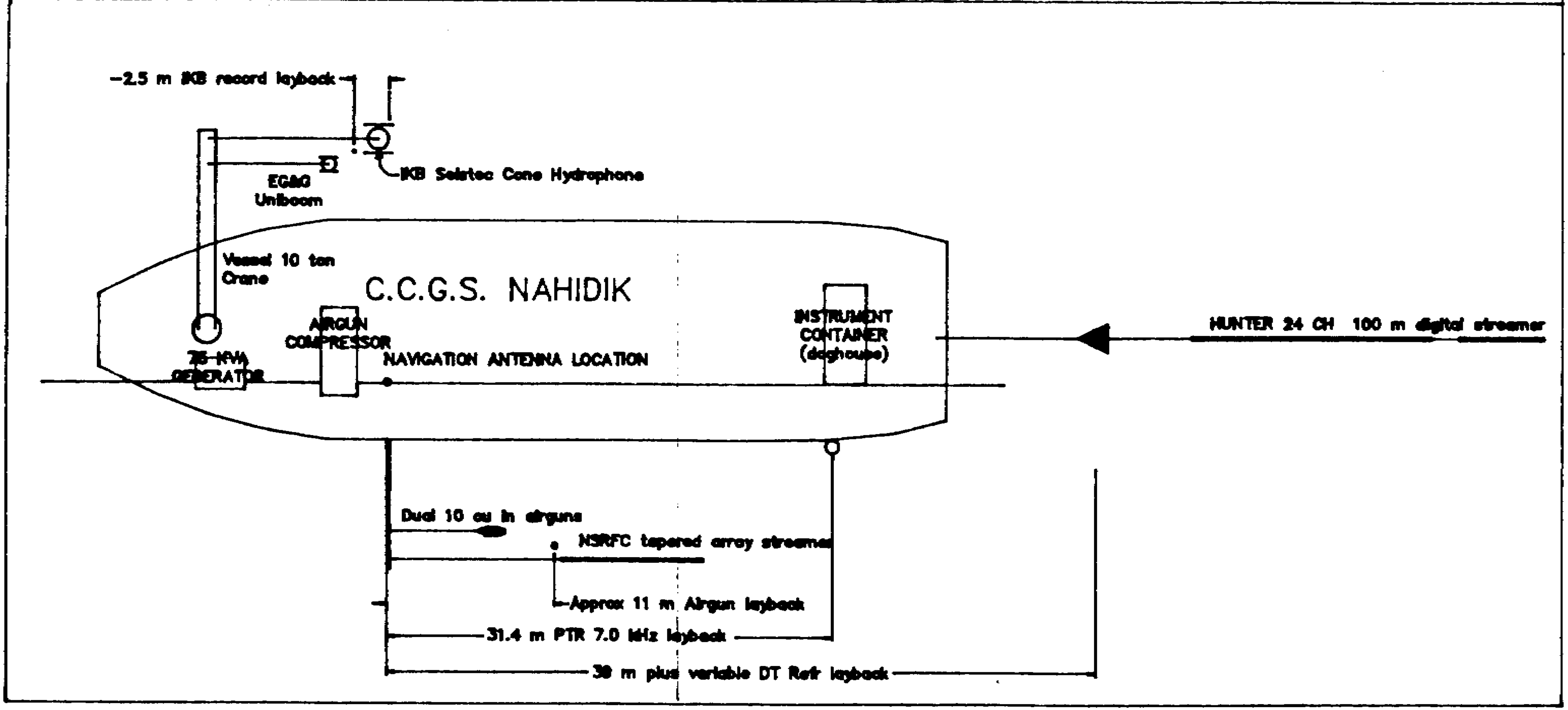

FIGURE 2

2-4-1 3.5/7.0 kHz Profiler

The only problem encountered with the profiler system was that it was our understanding that the transducer provided by AGC was a 3.5 kHz unit and when the system was deploy it provided very poor results. These results were identical to those obtained during the 1987 NAHDIK survey but were considered of very poor quality. After considerable attempts at tuning the system the transceiver was switched to the 7.0 kHz mode and the results improved by approximately 200 to 300%. As time was limited with other operational problems the system was operated in this mode throughout the remainder of the survey with no further problems and good quality records. This problem should be resolved during the winter maintenance period as it may be that the labelling on the transceiver units or the transducer is simply incorrect.

2-4-1 Boomer Seismic System

No problems were encountered with the sound source system throughout the program. The IKB line and cone hydrophone system functioned well through the first week of the survey and particularly well during good weather conditions. In the latter part of the survey a significant high frequency and high energy glitching appeared on the records which was particulary bad as the weather deteriorated. This glitching was not believed to be an electrical fault and on inspection of the unit it was found that the canvas dead zone shield stretched over the bottom of the cone had torn and was in generally a weak or almost rotted condition. It is assumed that this canvas was flapping in the towing wash and actually striking the hydrophone line array to create the glitching noise. As there was no replacement available for this shield it was mended as far as possible using twine on two occasions with the noise being somewhat reduced but not eliminated entirely. The other minor problem with this unit was that during the initial assembly at the beginning of the cruise two of the hydrophone retaining bolts in the wooden collar on top of the unit were seized up and the collar had to be split apart in order to jury rig the assembly for operation.

These problems are simply maintenance items and the unit should be repaired prior to a future use. It is the authors understanding that Peter Simpkin has redesigned the canvas cover part of the system to a plastic shield which works quite well. It is advised that the AGC unit should be modified to this new design.

2-4-3 Airgun Seismic System

Operation of the airgun systems created the most continuous problems throughout the survey. This resulted in a number of broken segments of survey lines throughout the program with the survey continuing with the other systems and the lost line segments were not recovered. The electronics within the doghouse functioned well throughout the survey and when the compressor and in water airguns were functioning properly good quality records were obtained.

The compressor had been rebuilt prior to this cruise by personnel at PGC and in the process many of the spares that had been left in the container in 1986 had been used up and not replaced. Also the new blow down system that had been installed had not been thoroughly tested nor had spares been provided for it. Operationally the 50 hp electric motor functioned well through the cruise. Problems such as a sheared pipe leading from the second to third stages of the compressor created some consternation. As no spares were available on board for this pipe it was lucky that the pipe could be shortened and refitted into position after the break, otherwise the airgun operations would have been halted at that point in the survey. The other compressor problem that was encountered was that the new blowdown system would stick in the open position occasionally and overall pressure would drop to 800 or 900 psi until the guns and compressor were shut down and restarted. This was somewhat of an annoyance though it was not crucial to the operation.

The airguns created a significant problem from Sept 4th through to the 14th. During this period one gun in the array would continually fail after 1 to 3 hours of operation. Of the 3 airguns available to us two of them showed this problem and the third gun (always the same one) would continue to work. On the 14th it was finally discovered that the new replacement upper shuttle sleeves purchased through Hamco Supply were manufactured incorrectly and were oversized by about 2-3 mm. This allowed the shuttle to hit the spring retainers crooked and resulted in the seat springs breaking after a very short time. It was found that the one working gun had been put together with an old sleeve (from 1986 survey) and it had functioned correctly with the springs lasting 2 to 4 days. When this was discovered the bad sleeves were replaced with old parts that were of the correct size and the guns functioned with minimal down-time after this.

3-4-4 Graphic Recorders

On this survey there were three EPC 3200 graphic recorders available. Of these three one (S/N 512) would not run continuously on a 125 or 250 msec sweep rate. After attempting all adjustments reasonably available this recorder was abandoned as non functional. It was assumed that the recorder possibly has a weak transistor or poor components somewhere in the drive components or drivers and there was insufficient time to properly trouble shoot this recorder. Recorder S/N 496 arrived at the vessel with a smashed Analog/Digital switch on the left panel of the unit. After this was replaced it was found that the calibration check signal was not functioning correctly. After further trouble shooting the channel A DAC chip was replaced and the recorder functioned properly throughout the remainder of the cruise. Recorder S/N 446 arrived functional, however on day 2 when power to the lab was coming from the cold start generator the recorder received a large (>> 150 V) transient surge which damaged the main 5 volt power supply of the recorder. The power supply was replaced by the spare and the recorder functioned well through the remainder of the survey.

Some or all of these problems may be related to the AC power available to the lab container. The power to the lab was supplied by extension cords to available sockets within the accommodation containers and or from outlets on the lower deck. In general the voltage was in the range of 108 to 112 volts which represents the lower operational range for the EPC recorders. This problem should be addressed for future surveys on the NAHIDIK.

2-4-5 Refraction System

Operation of the Deep Tow Refraction system was entirely under the control of the Terrain Sciences personnel from Ottawa. In this report only a very general comment can be made regarding its operation.

Within the doghouse the system primarily utilized the new Scintrex 24 channel recording system which had been partially funded by the GSC for it's development. In a broad overview this part of the system functioned well though there were some software glitches that would hang the system up from time to time causing missed shots. These should be resolvable as refinements are made on the software. Operationally, approximately one in ten refraction shots would be severely contaminated by interference from the non synchronized airgun reflection systems output shot. This could easily be resolved with a simple synchronization of the shots or a reflection shot lockout system with an appropriate window before the refraction shot.

There were significant problems with the in water portion of the deep tow system. During its first deployment the system appeared to snag something on the bottom which dragged the unit into the mud and damaged the airgun firing line in the umbilical cable. After unsuccessful attempts to repair the break a modified towing arrangement was used which kept the system very near the surface and significantly reduced its usefulness in deeper water situations. The other problem with the system related to ballasting of the streamer which as not yet been fully resolved.

At this time the author cannot comment on the data quality as this will have to await analysis in Ottawa.

2-4-6 Other System Comments

The EOR built dual system controller functioned well throughout the survey with the exception of the trigger shuttle sensor circuitry from the airguns. This portion of the system was designed to condition the shuttle sensor return signals when the airgun fired and use this signal as the asynchronous trigger input to the EPC graphic recorders. During this survey the return signals from the airguns were of low amplitude with a considerable amount of AC noise on the lines. This resulted in the conditioning circuitry miss triggering on a regular basis which seriously degraded the analog records. The noise was apparently related to the very long signal lines to the airgun container and possibly some leakage on the sensor signal lines in the water. In order to rectify this problem the circuitry would require redesign and possibly line amplifiers would be required in the airgun container. Through this survey there was not sufficient time or personnel or materials to rectify this problem and therefore the airgun records are not compensated for this trigger delay.

The TSS Annotator functioned well through the survey though it would occasionally miss a fix from the navigation or gain a spurious fix or two. The problem was very sporadic and could not be located though grounds etc. were checked as much as possible. It was suspected that the problem is related to the long cable runs out on deck and spurious noise that was picked up through these lines. During the survey a close watch was kept on the annotator fix number and when jumps were observed the numbers were updated to match the navigation monitor that was in the doghouse. This annoying problem was not serious through the survey though raises potential data problems when matching to the navigation. No immediate solution is recommended though careful cable layouts and possibly line drivers and conditioners between the navigation and the annotator might be used in the future.

The only other operational difficulties that were encountered related to the doghouse container. The electrical supply to the container is poor and consists only of various extension cords to the accommodation containers and outside deck plugs. Voltage as measured in the container was low (107-112 volts) which is considered marginal for survey operations. It is believed that at least some of the EPC problems were related to this, and it is suggested that some form of AC line conditioning or a proper 440V hookup and transformer distribution panel be organized for future surveys. The other difficulty with the container was it's poor ventilation. With two EPC's running at high sweep speeds the air was virtually un-breathable. During this survey a small fan was jury rigged with some ventilation hoses attached to each recorder though there was not sufficient suction on that fan to alleviate the problem. During the latter stages of the survey a larger ventilation fan was borrowed from the ship which helped the problem but tended to freeze out the occupants. In future a better system is required unless some other type of recorder is utilized.

2.5 FUTURE RECOMMENDATIONS

The following is a summary list of recommendations for future operations as a result of this survey.

1. Check out the Raytheon PTR system before it's next use to resolve the 3.5 kHz - 7.0 kHz question.

2. A full maintenance and upgrade of the IKB Seistech receiver system is required before it is sent out again.

3. Ensure an adequate level of spares is obtained for the airgun compressor container.

4. In future either buy airgun replacement parts directly from Bolt or at least thoroughly check out and verify the parts if they are obtained from another manufacturer.

5. Upgrade or replace the doghouse container that is currently used on the NAHIDIK if similar operations are planned, with particular attention to power and ventilation.

6. Investigate the sensor trigger conditioning problem with the airgun system and either add line drivers into the compressor shack or modify the threshold tracking system in the trigger controller to handle this problem (possibly both).

7. From experiments on this survey (and in 1987) with pseudo bottom track heave compensation, the moderate weather condition data quality can be enhanced by a factor of two or three times. This technique is only valid in areas of smooth seabed (< about 8 m of water in the Beaufort) and therefore an active (accelerometer type) heave compensation system should be investigated for the Boomer and PTR data records in particular. This improvement will allow more subtle geological features to be recognized on the data which are presently only seen when weather conditions are ideal (approx 10-15% of any survey duration) and should significantly enhance the record interpretability.

8. Joint operations are functional as seen in this survey but an earlier effort of joint planning would allow an even more optimum choice of survey plan for both parties and would overall result in less transit times throughout the survey program.

3 CONCLUSIONS

In conclusion this joint survey was extremely successful with a total of some 1216 km of moderate to high quality reflection and refraction survey data being collected. The cooperation of the Canadian Coast Guard and the officers and crew of the C.C.G.S NAHIDIK are gratefully recognized as being a very important contribution to the success of this program.

The data quality is generally very good and with the few exceptions noted above the survey equipment functioned well and with minimal down-time throughout the program.

APPENDIX 1

OPERATIONS LOG SUMMARY

TIME	REMARKS
Aug 29, 1988	
	B Harmes and M Hughes depart Halifax for Inuvik to commence mobilization.
Aug 30, 1988	
0645L	J. Lewis and M. Douma depart Halifax enroute Inuvik E. Mayzes departs Calgary enroute Inuvik
1400L	E. Mayzes arrives Inuvik
1730L	J.L. & M.D. arrive Inuvik - meet Steve Blasco at airport arriving from Tuk
1900L	To NAHIDIK for slide show with crew
2100L	to apartment in Inuvik
Aug 31, 1988	
0900L	Begin loading gear aboard NAHIDIK
1200L	Ron Good is informed his deep tow winch has just left Edmonton by road and will not be in Inuvik until Saturday or Sunday.
1600L	Virtually all gear on board - begin sorting out Doghouse - still have to transfer remaining gear from TULLEY on 1st or 2nd - sailing time set for 0500 on 1st
1800L	move aboard NAHIDIK - some evening mob work on doghouse
Sept 1, 1988	
0430L	Ron Good and R Burns to airport to pick up their compressor
0600L	back to ship with unit and off to park vehicle
0615L	Depart Inuvik in transit to Tuk winds 15-20 northerly
1300L	Contact TULLEY
1400L	S. Blasco agrees is too rough to attempt transfer - continue heading for Tuk
1635	alongside C.C.G. dock in Tuk - work still continues on sorting out doghouse
2 SEPT., 1988	
0705	Away from CCG Base Tuk.
0930	Near Tulley. Transfer our gear to Tulley via launch.
1030	Decide to come alongside and attempt to lift off compressor container. Too much heave. Abort on container and transfer other boxes.
1120	Away from Tulley - Head for Herschel - Will meet Tulley in morning to transfer container. Pack away gear and continue mobilization of what we have.

TIME	REMARKS
1445	Stop off Pullen Island to repair Raycon Beacon.
1645	Underway for Herschel Island.
2400	In transit to Herschel - Winds L & V - Calm. Some ice.

3 SEPT., 1988

0130	Anchor in Pauline Cove - Herschel Island.
0800	Tulløy alongside. Transfer container and get Al, electrician from Tulløy, to help hook up.
1005	Underway to Tripod site - Heavy ice - Rigging gear.
1630	Have made approx 20 km toward tripod site area. 7/10 ice covered and worse ahead - Reported 9/10 at tripod site. Abort attempt after discussion with George Tate, Capt, Don Sweeney and radio call to Steve - Head east toward survey area.
1900	Rig and deploy boomer system for test.
1950	Attempt run-up of boomer. No signal return from IKB.
2005	Recover gear. Work on IKB - Extension connector was partially disconnected. System okay.
2200	Approximately 10 km from SOL P-4. Stop to deploy boomer/IKB and PTR. - Test run in to set up gear.
2330	Coming up on start of line.
0530 GMT	

4 SEPT., 1988

***	***ALL TIMES GMT HENCEFORTH
0600	SOL NAH88-P4 HDG 082 SPD 3.6 kts. Boomer & PTR only. FSP 1
0700	Send airgun crew for sleep. Cannot rig towing in dark.
0718	Terminate line - 3rd EPC failed - no stylus drive & no 5V power. Abort line circle back. Try other bad EPC with boomer on channel A.
0818	SOL NAH88-P4B FSP 55 HDG 081. Pick up line NAH88 P4 at fix 55. Boomer record washing out a bit due to bow wave.
1037	EPC backup. Annotator dropped fix 161, renumbered by hand. Splice previous NAH88 P4B record to working EPC.
1126	Waypoint 87KA1
1130	Reprogrammed TSS Annotator to 1 ms print delay and data moved back to proper position.
1220	Annotator failed on fix 235, fixed by hand.
1420	Lower boom on crane. Attempt to lower boomer & IKB into water to reduce blanking - seas on starboard bow.
1456	New Paper - Roll #3. Line NAH-P4B
1511	SP 340.5 Waypoint AWBH5.
1640	SP 386 Waypoint AM85501/02

TIME	REMARKS
1813	Try 250 msec Swp - No additional data.
1818	Back to 125 msec Swp.
1910	Airgun in water - Problem with stays on the boom - won't allow full deployment - adjustments being made.
1925	Port boom bent by surfboard heaving. Guy wires slightly off position.
2010	Guns in water and firing.
2020	Forward guy on A/G boom let go. Stop ship for repair - drift on line.
2030	Underway. Stay on line.
2037	Waypoint #7 KY82S02/03. - Adjusting airguns.
2100	Marginal Records - Winds 15-25 easterly. 3-5 ft seas.
2057	Change paper on boomer records.
2242	Winds 25-30, may be dropping seas 4-5 ft. All equipment functioning okay but records suffer from weather.
2354	Replaced stylus airgun and boomer EPC

5 SEPT., 1988

0021	One airgun down.
0030	Both guns turned off. Records poor anyway. 7kHz boomer working okay.
0115	Suspending line due to weather. EOL.
0130	PTR, airguns, boomer & IKB aboard.
0135	Turn to starboard, head for Tuk.
0700	Alongside CCG Base in Tuk.
1300	Winds L & V in Tuk. Working on repair of starboard rudder which was bent in the ice two days ago.
1400	Radio Sched with Polar Shelf - winch will not be in until 2200 and Bob Gagne and the Power Pack for winch will not be in until 2400.
1500	Jim Hunter aboard. Discuss Plan. George Tate will stay in Tuk to monitor ice and possibly try recovery from Tulley on departure. Working on rudder est 1700 complete.
1800	Work on rudder complete. Reload workboats, etc.
1834	Pull away from CCG Base Tuk. Head for line P5. G. Tate still aboard.
2124	Gear deployed and ready to fire.
2130	All systems firing.
2145	SOL NAH 88-P5. FSP 640
2150	Trouble with one airgun - erratic firing every other pulse.
2211	Guns shut down, free flow in airline.
2225	Guns aboard.
2244	New paper roll Boomer & PTR
2245	Increase speed from 3 to 3.2 knots.
2319	Airguns back on line.
2330	Replace stylus PTR & boomer EPC.

TIME	REMARKS
6 SEPT., 1988	
0201	Shallow gas show on boomer and PTR.
0213	Replace stylus - Airgun and boomer EPC
0214	Airgun down, air leak, back up without taking in.
0241	Black gun down again.
0247	Surfboard aboard.
0314	Airgun back in water, firing okay. Failure due to broken springs in black gun.
0318	Waypoint KY82502/03 course 357 degrees, speed 4.1
0417	Change paper PTR & Boomer EPC. Fix 939 - change from program 1 of 4 at 3/8 to 1 of 6 at 1/4.
0445	Increase speed to 4.3 - 4.5 knots.
0449	Speed 4.7, course 357 degrees.
0556	EOL NAH88 P-5 install new stylus Boomer & PTR.
0721	SOL NAH88 P-20 Fix 1022, Speed 4.5
0755	Black airgun firing erratically, misses every 4th to 6th.
0758	Ed reports pressure way down, turns guns off to build pressure.
0805	Reduce speed to 4.1, restart guns, still missing.
0818	Guns off to bring aboard.
0833	Ed diagnoses a rigging problem, est 30 min. to fix.
0940	Watch Change. J.L. on.
0953	Pass waypoint NT82301
0958	Guns back in water and working. Sp 1174.
1057	Black gun down again.
1115	Guns on board. Winds northeast 15-18 kts. Seas building and record quality deteriorating.
1130	Winds increasing 20 gusting to 25
1137	Airguns back on line SP 1272. Broken spring retaining ring and damaged seats.
1236	SP1328 Diversion to Port to avoid artificial island (Ammerk).
1300	IKB starting to take a beating. Data still okay.
1310	One airgun intermittent.
1318	EOL NAH88-P20 SP 1367. Terminate to preserve gear.
1338	Gear on board. Head slowly toward Tuk. Forecast NE 30 today and NE gales Wed (tomorrow).
1730	Arrive Coast Guard Base Tuk - Standby on weather and await arrival Jim Hunter's winch and remaining crew.
2400	Tuk Coast Guard Base Standby for weather.
7 SEPT., 1988	
0000	Standby for weather.
1200	Standby for weather - winds dropping. Waiting for deeptow winch.
1800	Deeptow winch has arrived by Twin Otter aircraft

TIME	REMARKS
2000	Problem with main engine. Oil cooler water leak. Estimate 4-8 hours to repair - Winds moderating and conditions improving.
2400	Standby Tuk. Engine repair & install deeptow.

8 SEPT., 1988

0000	Standby in Tuk - Work on main engines.
0800	Still working on Main Engines (Replace contaminated oil - 300 gal).
0930	Depart Tuk. Head for line P-11 WP #3
1145	Begin to deploy gear.
1205	Surfboard and PTR in water.
1215	IKB and boomer in water.
1224	SOL NAH88-P11 at WP #3 (ERK78-1) SP #1368 HDG 090 SPD 4 kts.
1316	Ed reports airgun running at 1700 psi, records good.
1335	Guns off to build pressure.
1341	Compressor quit.
1342	WP ERK78-2 Line P11
1348	Airgun filters from 255 - 1500 to 500 to 3000 level on TVG +3 turns.
1400	Broken electrical lug on compressor fixed, TVG & KH filter back to normal.
1446	New paper - boomer, PTR EPC
1624	Dropped 2 fixes somewhere, now on 1564
1645	Black gun down.
1653	Both guns turned off.
1700	Surfboard on board.
1719	Guns back in water. Fix 1610
1754	EOL NAH88-P11 Fix 1638
1755	SOL NAH88-P1 Fix 1638
1816	Increased speed to 4 kts to try to cure wave interference.
1855	Black airgun misfiring.
1856	Prepare to bring in gun, circle to regain. Fix 1880 in 1/2 hour.
1745	Guns back in water ready to test, returning to line P1 Fixes will begin at 1680, Line P1B
1940	SOL NAH88-P1B FSP 1680 BRG 7 degrees at WP #5
2039	Slowing to dead slow to deploy Hunter's fish.
2055	Airgun down again.
2103	Surfboard aboard.
2120	New paper. PTR and Boomer EPC
2211	Gun intermittent again, goes down, comes back.
2222	Turn off black air, run one gun only.

TIME	REMARKS
9 SEPT., 1988	
0152	EOL P1B turn to line P6 east
0200	Red gun off to replace black gun
0207	Surfboard aboard.
0300	Surfboard in water. Changed out forward gun.
0333	All okay. New paper PTR and boomer EPC
0340	Deep tow system snagged something and was dragged into bottom damaging airgun firing line.
0350	EOL P6A SP 2088. Slow down to recover deep tow. Also work on fixes from bridge. Some spurious fixes.
0414	SOL NAH88-P15A. FSP 2095 HDG 180 degrees.
0424	SP 2101 - increased speed to 4 kts. Wind and swell on Port Bow - Boomer records poor.
0521	SP 2142 - Black gun down again. - Free flow. Run on one gun.
0557	EOL NAH88-P15A. LSP 2169 - Turn off line for swell affecting records. - Poor data.
0558	SOL NAH88-P16A/14 FSP 2170, HDG 270 deg. Spd 4.6 kts.
	Comment: Have tried replacing all black gun parts with new. Even Total Gun on more than one occasion but springs still keep breaking. Suggestion is that towing con- figuration holds a vortex trapped air bubble in the chamber and is effectively like firing the gun on deck at full pressure and breaking springs. Working well on one gun at present. Keep shooting and when opportunity arises, will pull and repair gun and also rotate towing bridle by 90 degrees to attempt to change physical towing situation.
0732	SP 2258 - End of P16 - Continue on extension of P14 which is a repeat of line GHR81-022 and 22B.
0940	Compressor check - belt surging - fed bulldog tape - okay winds SE at 20 knots.
1250	Compressor check - more bulldog - wind SE 20 - Seas 4-6 ft
1345	SP 2583.4 - 8-9 metre deep scour on gassy edge ? ice scour or pock mark?
1359	EOL NAH88-14/15A LSP 2596 Break survey to service generator/compressor & guns.
1605	Rearranged guns to have perpendicular - rebuilt both guns - broken springs in black - tightened comp belt - service generator. Head for Line P23.
1630	Boomer, airgun and PTR in water. On line direction PTR and boomer useless. Decide to recover boomer and IKB.
1645	Boomer and IKB recovered - Jim deploying deep tow and wants airgun after has tested his equipment.

TIME	REMARKS
1650	EST 27 km to start of Jim's line.
1655	Decide to recover airguns as being thrashed and cannot run line from this corner of grid.
1705	Airgun on deck - working on deep tow and slow transit toward beginning of Jim's line.
2117	Begin shooting on Jim's line FHR-1 SOL Fix 2623
2210	Shut down red gun to conserve parts. Sea still rough, records poor.
2300	Lost the capability to fire black gun.

10 SEPT., 1988

0053	EOL FHR88-1 Fix 2793
0109	Deep tow depth transducer problems. SP 2813 - Drift in circle to recover and repair.
0128	Deep tow in water and working.
0130	Deployed boomer and IKB, airgun at 1/sec, Boomer 3/sec
0148	SOL FHR88-2 Fix 2832
0240	Power interruption on bridge, Syledis down.
0248	Fixes re-acquired starting at 2872.
0308	Serious helm error, 90 degrees off course.
0458	EOL FHR88-2 SP 2975
0520	Surfboard aboard, make for SOL P2 at WP 5.
0600	Replace one wire strap on airgun and black gun had 2 broken springs. Steaming toward SOL at Arnak (1976).
0740	Airguns back in water 2.2 k to SOL.
0805	SOL NAH88-P2A FSP 2976 - HDG 269 deg. SPD 4.4 kts.
1028	SP 3111 change sweep on boomer & PTR. Records to 62.5 ms.
1043	SP 3124 - Try PTR in 3.5 kHz switch position - Bad record, switch back to 7.0 kHz.
1103	SP 3144 Compressor down - blew compression fitting on 1st stage of compressor - (no spares - try engine room)
1110	SP 3152 Divert off survey line for Western Polaris coming from other direction along same survey line.
1300	Compressor functional
1303	SP 3250 - Airguns working.
1308	SP 3253 - Black gun down. Run on red gun.
1446	EOL NAH88-P2A - LSP 3333
1446	SOL NAH88-P23A FSP 3334 HDG 000
1539	EOL P23A LSP 3386
1925	Hunter's fish deployed.
2110	Gen Set off to check lube oil. Gun at 1.5 sec rate.
2112	Gen set back on line
2200	EOL NAH88-P8; Fix 2706 A/C to north

TIME	REMARKS
0500	Black gun down - IKB and boomer cables fouled - haul gear and winch cable on crane fouled - gear on deck - weather building.
0530	SOL NAH88 FHR 6; Fix 4925 Grid - Refraction survey
0650	EOL NAH88 FHR 6; LGSP 4977 Line turn
0706	SOL NAH88 FHR88-7 FGSP 4984
0810	EOL FHR88-7 LGSP 5035
0830	All gear on board - winds NW 30 - Seas building - wrapped deep tow tail buoy in rudder guard - slowed recovery. Steam for Tuk. Will repair crane and compressor blow by leak in Tuk in morning. Standby for weather.
1230	Arrive Tuk - Tie up at CCG Dock.
1400	Crane repaired and operational - Standby for weather.
2230	Depart Tuk.

13 SEPT., 1988

TIME	REMARKS
0100	SOL NAH88 P11B
0140	switch to black gun only to conserve parts.
0143	Back to 2 guns - 1.75 sec rate.
0145	Black gun down again
0146	Black gun up again.
0220	Black gun up and down like a yo-yo.
0418	WP 4 Line P11 proceed north 3 km then turn N to P 9
0440	EOL NAH88P11B; Fix 5219 - SOL P9 North of WP4; Fix 5220
0440	SOL NAH88-P9' FSP 5220
0600	SP 5296 - J.L. on watch
0950	SP 5494 - Try running airgun with no Krohn Hite filter at all. Record slightly sharper - higher resolution - suspect NSRF pre-amps may have filters built in??
1010	EOL NAH88-P9: LSP 5512 - During turn raise boomer and IKB to untangle IKB cable which was caught underneath the boomer.
1039	SOL NAH88-P2B; FSP 5513
1200	SP 5597; Black gun down - free flow - run on one gun.
1210	SP 5604; Put filters back and adjust gains and TVG of airgun.
1219	SP 5613; Pass waypoint # 10 - borehole SU83 502
1226	Check compressor - holding 1000 psi - Shut down & get Ed.
1235	Restart Compressor - Gauges come up and building pressure.
1236	SP 5633; 2 guns now operational
1338	EOL NAH88-P2B; LSP 5685
1352	All gear on board - head for refraction grid.
1536	SOL NAH88-FHR8; FSP 5686
1545	5691 - Turn on other EPC with bottom track heave comp
1600	SP 5702; Airgun on line.
1658	EOL FHR8 LSP 5744
1659	Circle to FHR 9 - Continue fixing in turn

TIME	REMARKS
1716	SOL NAH88-FHR 9; FSP 5759
	SP 5787 - Black gun quit. Free Flow
	SP 5790 - 2 guns on
	SP 5792.5 - Black gun - free flow
	SP 5795.5 - 2 guns
	SP 5797-5800 - intermittent free flow.
1809	SP 5798-5806 - Good Example Kugmallit Trough base angular unconformity - suggest troughs is a recent erosion feature.
1818	EOL NAH88 FHR9; Fix 5813 **
1845	SOL NAH88 FHR10; Fix 5833
1941	Black gun down again
2000	Black gun up again
2015	EOL NAH88 FHR10; Fix 5885
2026	SOL NAH88 FHR11; Fix 5899
2137	EOL NAH88 FHR11; Fix 5962
2203	SOL NAH88 FHR12; Fix 5970
2321	EOL NAH88 FHR12; Fix 6022
2337	SOL NAH88 FHR13; Fix 6034

14 SEPT., 1988

TIME	REMARKS
0049	EOL NAH88 FHR13; Fix 6087 **
	** Too many extra people in doghouse. All these lines have boomer depth comp at 62.5 msec. Must amend rolls.
0055	Guns out for service.
0115	Guns back in water, Fixes on TSS went astray - repaired.
0125	SOL NAH88 FHR14; Fix 6107
0218	Black gun intermittent.
0224	Back up.
0234	EOL NAH88 FHR14; Fix 6160 - one gun.
0304	SOL NAH88 FHR15; Fix 6178 - one gun.
0305	Restarted TSS clock.
0409	EOL NAH88 FHR15; Fix 6231 - one gun.
0451	SOL NAH88 FHR16; Fix 6255 - one gun.
0603	EOL NAH88 FHR16; Fix 6308 - one gun.
0617	SOL NAH88 FHR17; SP 6318 - one gun.
0725	EOL NAH88 FHR17; SP 6370
	Complete detailed permafrost grid.
0740	Pull in all gear and steam for Line P3 west of Pullen. Gear on Board.
	Note: Ed found defective upper shuttle sleeves in black gun - (All "new" parts from Hamco) replaced with one of the old upper sleeves from 1986 which is correct size and hope.
0928	Gear in water and operational.
0931	SOL NAH88-P3; FSP 6371 HDG 033 deg. SPD 4.4 kts.
1058	SP 6443; Waypoint #5

TIME	REMARKS
9 SEPT., 1988	
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0200	Red gun off to replace black gun
0207	Surfboard aboard.
0300	Surfboard in water. Changed out forward gun.
0333	All okay. New paper PTR and boomer EPC
0340	Deep tow system snagged something and was dragged into bottom damaging airgun firing line.
0350	EOL P6A SP 2088. Slow down to recover deep tow. Also work on fixes from bridge. Some spurious fixes.
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1359	EOL NAH88-14/15A LSP 2596 Break survey to service generator/compressor & guns.
1605	Rearranged guns to have perpendicular - rebuilt both guns - broken springs in black - tightened comp belt - service generator. Head for Line P23.
1630	Boomer, airgun and PTR in water. On line direction PTR and boomer useless. Decide to recover boomer and IKB.
1645	Boomer and IKB recovered - Jim deploying deep tow and wants airgun after has tested his equipment.

TIME	REMARKS
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2210	Shut down red gun to conserve parts. Sea still rough, records poor.
2300	Lost the capability to fire black gun.

10 SEPT., 1988

0053	EOL FHR88-1 Fix 2793
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0128	Deep tow in water and working.
0130	Deployed boomer and IKB, airgun at 1/sec, Boomer 3/sec
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0248	Fixes re-acquired starting at 2872.
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0520	Surfboard aboard, make for SOL P2 at WP 5.
0600	Replace one wire strap on airgun and black gun had 2 broken springs. Steaming toward SOL at Arnak (1976).
0740	Airguns back in water 2.2 k to SOL.
0805	SOL NAH88-P2A FSP 2976 - HDG 269 deg. SPD 4.4 kts.
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1043	SP 3124 - Try PTR in 3.5 kHz switch position - Bad record, switch back to 7.0 kHz.
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1110	SP 3152 Divert off survey line for Western Polaris coming from other direction along same survey line.
1300	Compressor functional
1303	SP 3250 - Airguns working.
1308	SP 3253 - Black gun down. Run on red gun.
1446	EOL NAH88-P2A - LSP 3333
1446	SOL NAH88-P23A FSP 3334 HDG 000
1539	EOL P23A LSP 3386
1925	Hunter's fish deployed.
2110	Gen Set off to check lube oil. Gun at 1.5 sec rate.
2112	Gen set back on line
2200	EOL NAH88-P8; Fix 2706 A/C to north

TIME	REMARKS
2200	SOL NAH88-FHR3; Fix 3707
2210	Surfboard aboard for preventative maintenance.
2348	New stylus boomer, PTR EPC
2355	Airgun in water, firing black gun only - Fix 3756.

11 SEPT., 1988

TIME	REMARKS
0015	Changed to red gun only, black free flowing, then seated.
0039	EOL NAH88-FHR-3; Fix 3795,
0105	SOL NAH88-FHR-4; Fix 3814
0433	Checked gen set - OK
0541	EOL NAH88-FHR-4; SP 4047
0548	Surfboard aboard for gun maintenance
0642	Guns back in water
0646	SOL NAH88-P12A; FSP 4048; HDG 357 degrees
0815	SP 4115; Black gun starting to no-fire.
0832	SP 4120; Run on red gun only - black gun leaking and pressure was down to 1100 lbs.
0900	Try firing rate 1 sec; lose some signal and change firing to 1.25 sec.
1016	EOL NAH88-P12A LSP 4212
1017	SOL NAH88-P6B; HDG 88 degrees; FSP 4215
1355	SP 4416 - No problems
1645	EOL NAH88-P6B LSP 4555
1700	Boomer and IKB and airguns on deck for maintenance. IKB has glitch noises from towing. - Discover Canvas bottom cone cover is torn - weave rope through it to secure it back in place (should be replaced) - Black gun down (springs) - Re-configure towing arrangement to that of 1986 - last desperation try - possibly other configuration has some kind of interaction that causes spring failures.
1900	At BOL Gulf pipeline run - still working on guns & circling.
2048	SOL NAH88-PIPE 1; FSP 4556; HDG 208 degrees; SPD 3.9 kts.
2124	Stylus PTR boomer EPC; Compressor leak, change rate to 1 3/4 sec - A.G. set back to 1 1/2.

12 SEPT., 1988

TIME	REMARKS
0105	Compressor can't keep up; change back to 1 3/4 sec
0159	Still losing air; shut off black gun. Leak in relief valve piping. Plugged but no safety release - monitor pressure very carefully.
0217	EOL NAH88 Pipe 1; Fix 4811

TIME	REMARKS
1150	SP 6490 Change airgun to 1.5 sec. Firing from 1.75 sec - 3rd stage of comp. blowing down regularly and guns running at 1900 lbs.
1230	Back to 1.75 firing = 3rd stage gauge stuck. Not blowing down.
1240	SP 6528 - Waypoint #3
1309	SP 6554 - End bottom trigger heave comp on AG/Boomer Record - Too much ice scour. IKB records glitching. Canvas cover likely hitting hydrophone.
1322	SP 6566 - Waypoint #2
1715	Glitching very bad on boomer records - will attempt repair at end of line.
1730	EOL NAH88-P3; LSP 6779 - Recover boomer/IKB - Tighten canvas cover on cone.
1820	Gear back in water and operational - Still glitching.
1824	SOL NAH88-P10; Fix 6780
2000	Change stylus
2256	EOL NAH88-P10; Fix 7000
2311	Begin fixing prior to starting refraction line 18.
2344	SOL NAH88 FHR 18; Fix 7025

15 SEPT., 1988

0512	EOL FHR 18; Fix 7260, turn off guns for refraction interference
0540	Airguns back on line.
0602	SOL FHR19; Fix 7297
0619	Sp 7310 Guns off. Compressor blowdown stuck on 900 psi.
0629	SP 7314 Guns back on - problem fixed.
0815	SP 7394 - alter course to avoid GSI ship.
0920	SP 7441 - Fewer ice scours - Switch AG/Boomer record (boomer) to bottom track heave compensation and 62.5 msec sweep spd. Now 200 m south of track around Isserk artificial island.
1124	EOL FHR19; LSP 7538 - Recover deep tow. Recover airguns to check rigging - in bad shape. Almost lost guns. Steam for line P8B.
1244	SOL NAH88-P8B; FSP 7539 - Start at intersection of line P1 HDG 090.
1258	SP 7552. Incr firing rate to 1.5 sec to reduce pressure to 1600. Adequate penetration and reduce hammering on ship and gear. Still have glitching on IKB?? Winds on Stbd side.
1400	SP 7606. Remove bottom track heave comp on AG/boomer record. Too much ice scouring.
1513	SP 7672 WP #4
1525	Reduce AG firing rate to 1.75 sec to build pressure.
1609	SP 7722 - Compressor blowdown stuck on guns to 900 psi - shut down.
1615	SP 7728 - guns back on.
1834	EOL NAH88 P8B; Fix 7850
2024	SOL NAH88 P2C; Fix 7856, attempted repair IKB to pinpoint glitching noise source, only partially successful.

TIME	REMARKS
2057	Fix 7879; Waypoint UB 80-41
2337	Fix 7994; WP NA81-2

16 SEPT., 1988

TIME	REMARKS
0136	Fix 8085; EOL NAG88 P-2C
0352	SOL NAH88 FHR 20; Fix 8085
0415	Trouble with trigger level on AG EPC Fixed
0638	EOL NAH88 - FHR 20 - LSP 8203 - Transit West to FHR 20 with survey on.
0748	SOL NAH88 FHR 21; FSP 8246 in rain and wind squall - winds W 15-20 - winds swinging to NW.
0805	Compressor blow down stuck. Guns off SP 8261
0816	SP 8269. Guns on - compressor on manual. Increase firing rate to 1.5 sec. SP 8284 - back to 1.25 sec firing rate.
0900	SP 8307 Back to 1.5 firing - drop pressure to reduce hull hammering so crew can sleep.
0915	Winds WNW at 15 knots - swells building and records deteriorating.
	Note: SP's 8323 to 833. Good example of delta front sediments - forset beds indicating source toward the north???
1006	EOL FHR 21; LSP 8365 - Pull in refraction system. Airguns and boomer - steam at 6 kts to beginning of P7 - winds 20, seas building.
1025	Gear on board - boomer and IKB tangled.
1200	Near BOL - Winds 20-30 from NW - conditions look bad. Try steaming line direction - decide to continue offshore to deeper water to see if swell conditions improve.
1330	10 km down line in 10 m water. Winds 25 kts NW - seas 1-2 m and breaking - considered too rough to get decent data and will likely just damage gear. Wake Jim Hunter for discussions on plan of action.
1415	Pull in PTR transducer and head for Tuk Fairway Buoy (Captains choice).
1600	At anchor waiting on weather.
2000	Steam to line P15; waypoint 5
2100	Airgun gear in water for test - winds 20-25 NW. Seas 1-2 m
2200	Record quality very poor with swell & sea noise. Far too rough for boomer - decide to recover airguns. Captain and Jim Hunter decide to call this end of survey.
2230	Transit to river mouth.
2400	Transit.

TIME	REMARKS
17 SEPT., 1988	
0000	Transit to river mouth.
0330	Nose into Creek to take on fresh water and park for the night.
1300	Pull away from shore and head up river toward Inuvik. Demobilize gear.
2000	(1400 local) Arrive Inuvik
2200	Demob and packing.
18 SEPT., 1988	
0000	(Local) In Inuvik for demob
0700-1200	Demob and packing.
1530	J.Lewis, M.Douma and E. Mayzes catch flight to Edmonton. Ed Mayzes on to Calgary.
2000	Arrive Edmonton - overnight in Nisku Inn.
19 SEPT., 1988	
0730	JL & MD fly Edmonton to Halifax.
1910	Arrive Halifax.
	20 SEPT., 1988
1000	Deliver data to Bob Harmes at B.I.O.

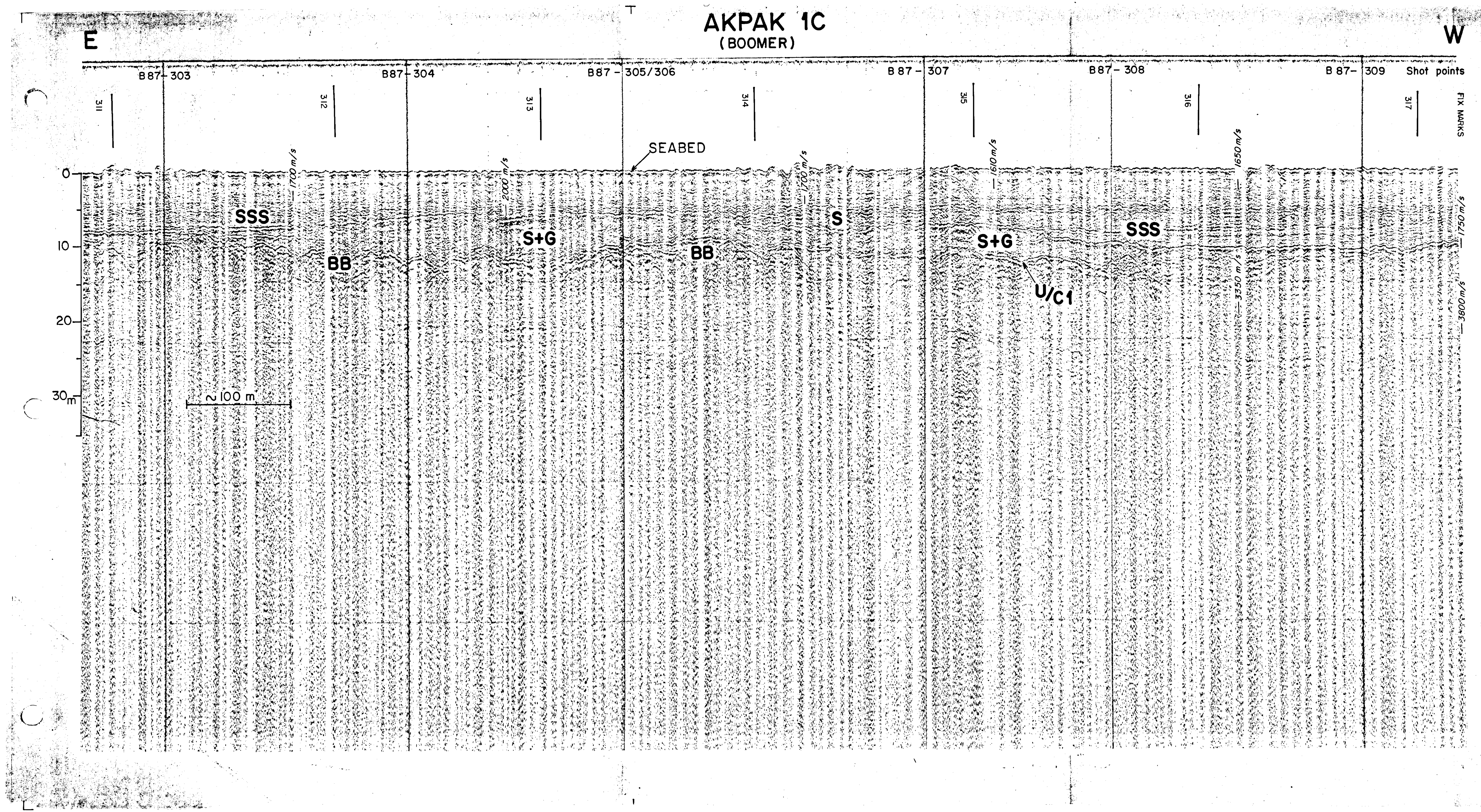
APPENDIX 2

RECORD AND LINE SUMMARY

LINE	DAY	SOR TIME	EOR TIME	FSSP	LSP	SWP SPD	SYSTEMS	ROLL #
NAH88-P4	04 Sept	0600	0718	1	56	125	PTR	1
						125	Boomer	
P48	"	0818	1456	55	331	125	"	2
"	"	1456	2057	332	519	"	"	3
"	"	2057	0115	520	639	"	"	4
"	05 Sept		0057	492	632	250	Airgun	1
						250	Boomer	
P5	"	2130	556	640	1031	250	Airgun	2
						125	Boomer	
"	"	2130	556	640	1031	125	Boomer	5
						125	PTR	
P20	06 Sept	0721	1318	1032	1367	250	Airgun	3
						125	Boomer	
"	"	0721	1318	1032	1367	125	Boomer	6
						125	PTR	
P11	08 Sept	1224	1854	1338	1637	125	Boomer	7
						125	PTR	
"	"	1224	1854	1338	1637	250	Airgun	4
						62.5	Boomer	
P1 + P1B	"	1855	0150	1638	2006	125	Boomer	8
						125	PTR	
P1 + P1B	"	1855	0150	1638	2006	250	Airgun	5
						62.5	Boomer	
P6	09 Sept	0150	0350	2007	2088	250	Airgun	6
						125	Boomer	
"	"	0150	0350	2007	2088	125	Boomer	9
						125	PTR	
P15A	"	0414	0557	2095	2169	250	Airgun	7
						125	Boomer	
P15A	"	0414	0557	2095	2169	125	Boomer	10
						125	PTR	
P16A/14	"	0558	1359	2170	2596	250	Airgun	8
						125	Boomer	
"	"	0558	1359	2170	2596	125	Boomer	11
						125	PTR	
FHR-1,2	9,10/Sept	2117	0458	2623	2975	125	Boomer	12
						125	PTR	
"	"	2117	0458	2623	2975	250	Airgun	9
						125,62.5	Boomer	
P2A	10 Sept	0805	1446	2976	3333	125,62.5	Boomer	13
						125,62.5	PTR	
P2A	"	0805	1446	2976	3333	250	Airgun	10
						62.5	Boomer	
P23A	"	1446	1539	3334	3386	125/62.5	Boomer	14
						125/62.5	PTR	
P23A	"	1446	1539	3334	3386	250.62.5	Airgun	11
						125	Boomer	
NAH88-P8A	"	1539	2200	3387	3706	125	Boomer	15
						125	PTR	

LINE	DAY	SOR TIME	EOR TIME	FSSP	LSP	SWP SPD	SYSTEMS	ROLL #
P8A	"	1539	2200	3387	3706	250	Airgun	12
						125	Boomer	
FHR 3	"	2200	0038	3707	3795	125	Boomer	16
						125	PTR	
"	11 Sept	2200	0038	3707	3795	125	Boomer	13
						250	Airgun	
FHR 4	"	0105	541	3814	4047	125	Boomer	17
						125	PTR	
"	"	0105	541	3814	4047	250	Airgun	14
						125	Boomer	
NAH88-P12A	"	0646	1016	4048	4212	125	Boomer	18
						125	PTR	
"	"	0646	1016	4048	4212	250	Airgun	15
						125	Boomer	
NAH88-P6B	"	1017	1645	4215	4555	125	Boomer	19
						125	PTR	
"	"	1017	1645	4215	4555	250	Airgun	16
						125	Boomer	
NAH88-PIPE-1	"	2045	0217	4556	4811	125	Boomer	20
						125	PTR	
"	"	2045	0217	4556	4811	250	Airgun	17
						125	Boomer	
NAH88-FHR6	12 Sept	0530	0650	4925	4977	250	Airgun	18
NAH88-FHR7	"	0706	0810	4984	5035	250	Airgun	18
NAH88 P11B	13 Sept	0100	0434	5036	5219	250	Airgun	19
						125	Boomer	
"	"	0100	0439	5036	5219	62.5	Boomer	21
						125	PTR	
NAH88 P9	"	0440	1010	5220	5512	250	Airgun	20
						125	Boomer	
NAH88 P9	13 Sept	0440	1010	5220	5512	62.5	Boomer	22
						125	PTR	
NAH88 P28	"	1039	1338	5513	5685	250	Airgun	21
						125	Boomer	
"	"	1039	1338	5513	5685	62.5	Boomer	23
						125	PTR	
NAH88 FHR 8	"	1536	1658	5686	5744	250	Airgun	22
						62.5 BT	Boomer	
"	"	1536	1658	5686	5744	125,62.5	Boomer	24
						125,62.5	PTR	
NAH88 FHR 9	"	1716	1818	5759	5813	250	Airgun	22
						62.5 BT	Boomer	
"	"	1716	1818	5759	5813	62.5	Boomer	24
						62.5	PTR	
NAH88 FHR 10	"	1845	2015	5831	5892	250	Airgun	23
						62.5 BT	Boomer	
"	"	1845		5831		125	PTR	25
						62.5	Boomer	

LINE	DAY	SOR TIME	EOR TIME	FSSP	LSP	SWP SPD	SYSTEMS	ROLL #
WAH88 FHR 11	"	2016	2137	5893	5952	250	Airgun	24
						62.5 BT	Boomer	
"	"	2016	2137	5893	5952	62.5	Boomer	26
						62.5	PTR	
WAH88 FHR 12	"	2139	2221	5953	6023	250	Airgun	25
						62.5 BT	Boomer	
"	"	2139	2221	5953	6023	62.5	Boomer	27
						62.5	PTR	
WAH88 FHR 13	"	2222	0239	6024	6160	62.5	Boomer	28
						62.5	PTR	
WAH88 FHR 14	"	2222	0239	6024	6160	62.5 BT	Boomer	26
						250	Airgun	
WAH88 FHR 15	14 Sept	0239	0409	6178	6231	250	Airgun	27
						62.5 BT	Boomer BT	
"	"	0241	0409	6178	6231	62.5	Boomer	29
						62.5	PTR	
WAH88 FHR 16	"	0451	0603	6255	6308		Airgun/Boomer BT	27
"	"	0451	0603	6255	6308		Boomer/PTR	29
WAH88 FHR 17	"	0617	0725	6318	6370		Airgun/Boomer BT	27
"	"	0617	0725	6318	6370		Boomer/PTR	29
WAH88 P3	"	0931	1730	6371	6779	250	Airgun	28
						62.5,125	Boomer BT	
WAH88 P3	14 Sept	0931	1730	6371	6779	62.5	Boomer	30
						62.5,125	PTR	
WAH88 P10	"	1824	2256	6780	7000	125	Boomer	29
						250	Airgun	
"	"	1824	2256	6780	7000	125	PTR	31
						62.5	Boomer	
WAH88 FHR 18	"	2311	0514	7001	7260	250	Airgun	32
						125	Boomer	
"	"	2311	0514	7001	7260	125	PTR	30
						62.5	Boomer	
WAH88 FHR 19	15 Sept	0515	1124	7261	7538	250	Airgun	31
						125,62.5	Boomer BT	
"	"	0515	1124	7261	7538	125,62.5	PTR	33
						62.5	Boomer	
WAH88 P8B	"	1244	1838	7539	7855	250	Airgun	32
						62.5	Boomer	
"	"	1244	1838	7539	7855	62.5	Boomer	34
						62.5	PTR	
WAH88 P2C	"	2024	0136	7856	8084	250	Airgun	33
						125	Boomer	
"	"	2024	0136	7856	8084	62.5	Boomer	35
						62.5	PTR	
WAH88 FHR 20	16 Sept	0352	0638	8085	8203	62.5	Boomer	36
						62.5	PTR	
"	"	0352	0538	8108	8203	250	Airgun	34
						125	Boomer	
WAH88 FHR 21	"	0748	1006	8246	8365	62.5	Boomer	37
						62.5	PTR	
"	"	0748	1006	8246	8365	250	Airgun	35
						125,62.5 BT	Boomer	



SSS : Stratified Sand & Silt
S : Sand
S+G: Sand & Gravel
BB , Boulder Beds

FIG. 8 REWORKED TILL ? AND RELATED FACIES.

Fig: 12 **POST-GLACIAL SEISMO-STRATIGRAPHY AND INFERRED LITHOFACIES, SOUTHERN AKPAK PLATEAU.**

LEGEND:

RS: REWORKED SEDIMENTS (post-trangression)
GF: GLACIOFLUVIAL DEPOSITS (at margin of ice)
VT: VALLEY TRAIN OUTWASH (at front of ice)
CD: COLLUVIAL DEPOSITS
RM: ROLLING MORAINE

-2700 ··· P-WAVE VELOCITY
··· COMPUTED REFRACTOR DEPTH

Fig: 13 PERMAFROST CONDITIONS IN THE UPPER SECTION OF SOUTHERN AKPAK PLATEAU.

LEGEND:

R: THIN FROZEN BED

4000 ... P-WAVE VELOCITY

| ... COMPUTED REFRACTOR DEPTH

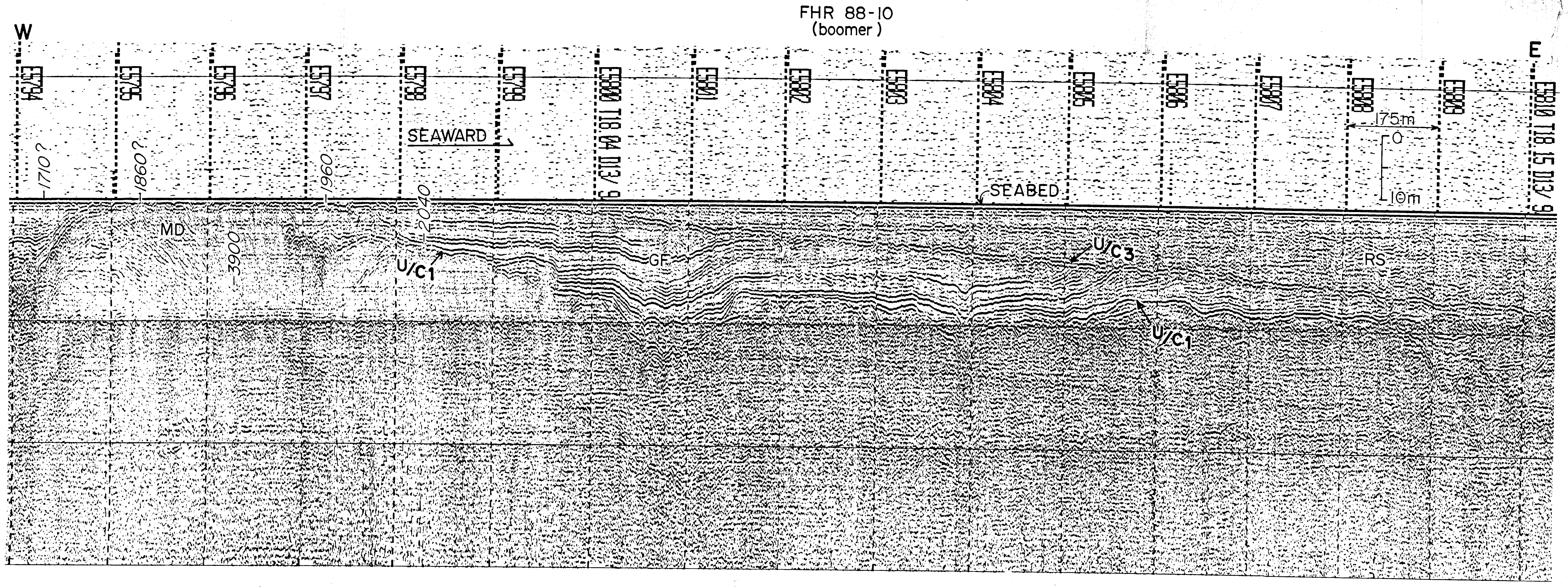


Fig: 14 ELEVATED LAND FEATURES; OFFSHORE ZONE.

LEGEND:

R'S : REWORKED SEDIMENTS

GF : GLACIOFLUVIAL DEPOSITS

MD : MORAINAL DEPOSITS

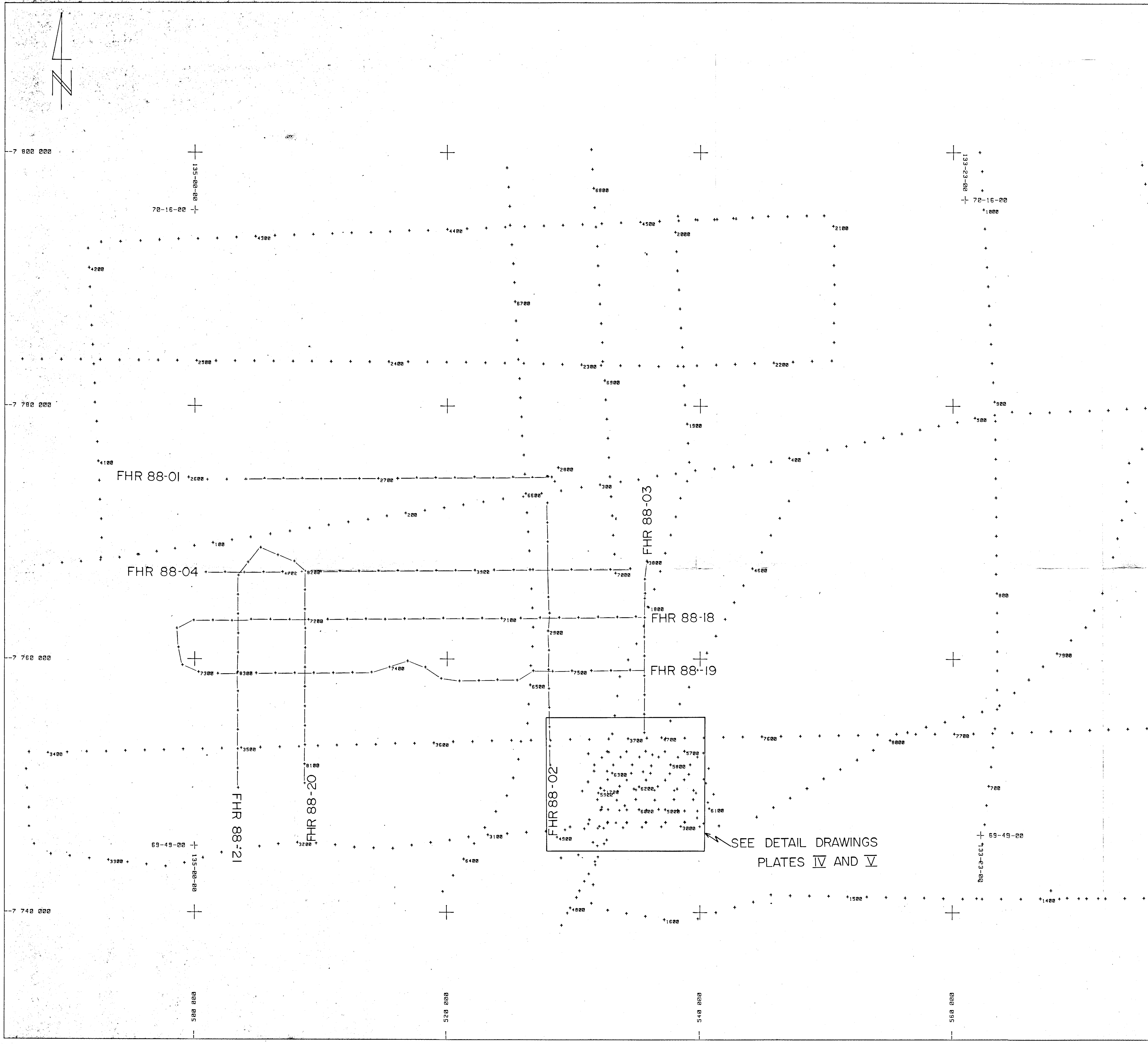
3900 ··· P-WAVE VELOCITY

— ··· COMPUTED REFRACTOR DEPTH

FHR 88-15
(boomer)

Fig: 15 ELEVATED LAND FEATURES; INSHORE ZONE.

LEGEND:
RS: REWORKED SEDIMENTS
GF: GLACIOFLUVIAL DEPOSITS
CO: COARSE OUTWASH
MD: MORAINAL DEPOSITS
4000 ...P-WAVE VELOCITY
...COMPUTED REFRACTOR DEPTH



NOTES:

1. HORIZONTAL POSITIONING : SERCEL SYLEDIS IN PASSIVE MODE. POSITIONING EXCELLENT DRMS 01, LPME 02/03 ENROUTE

LEGEND:

REFRACTION/ REFLECTION SEISMIC LINE

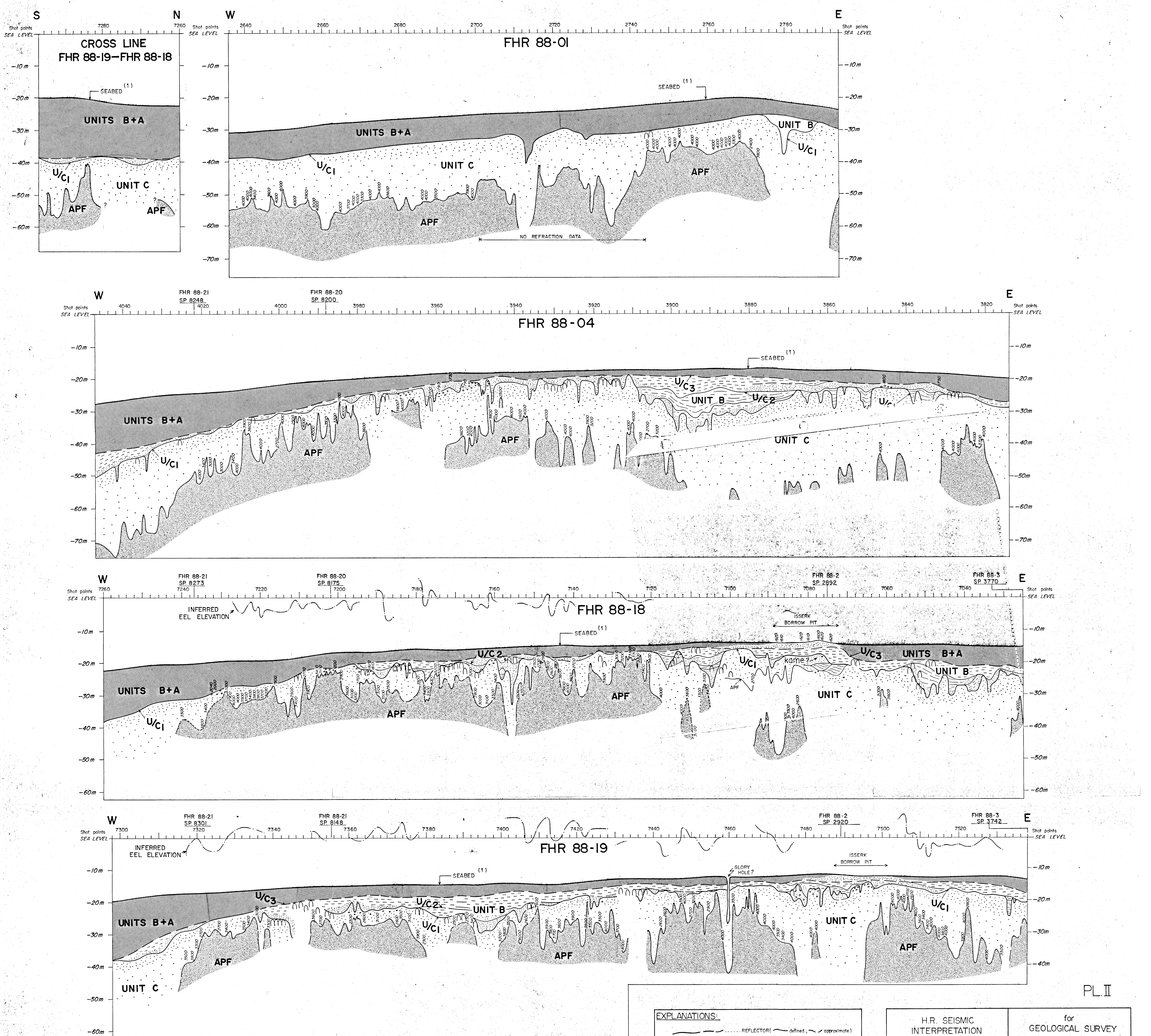
PL. I

GEOLOGICAL SURVEY

NAHIDIK
SEISMIC SHOTPOINT LOCATIONS

BEAUFORT SEA
1988

H.R. SEISMIC INTERPRETATION SERVICES INC.				S. I. S.
SCALE: 1:150000	DATE: MARCH 1989	JOB NO.: 014	DWG. NO.: PL. I	



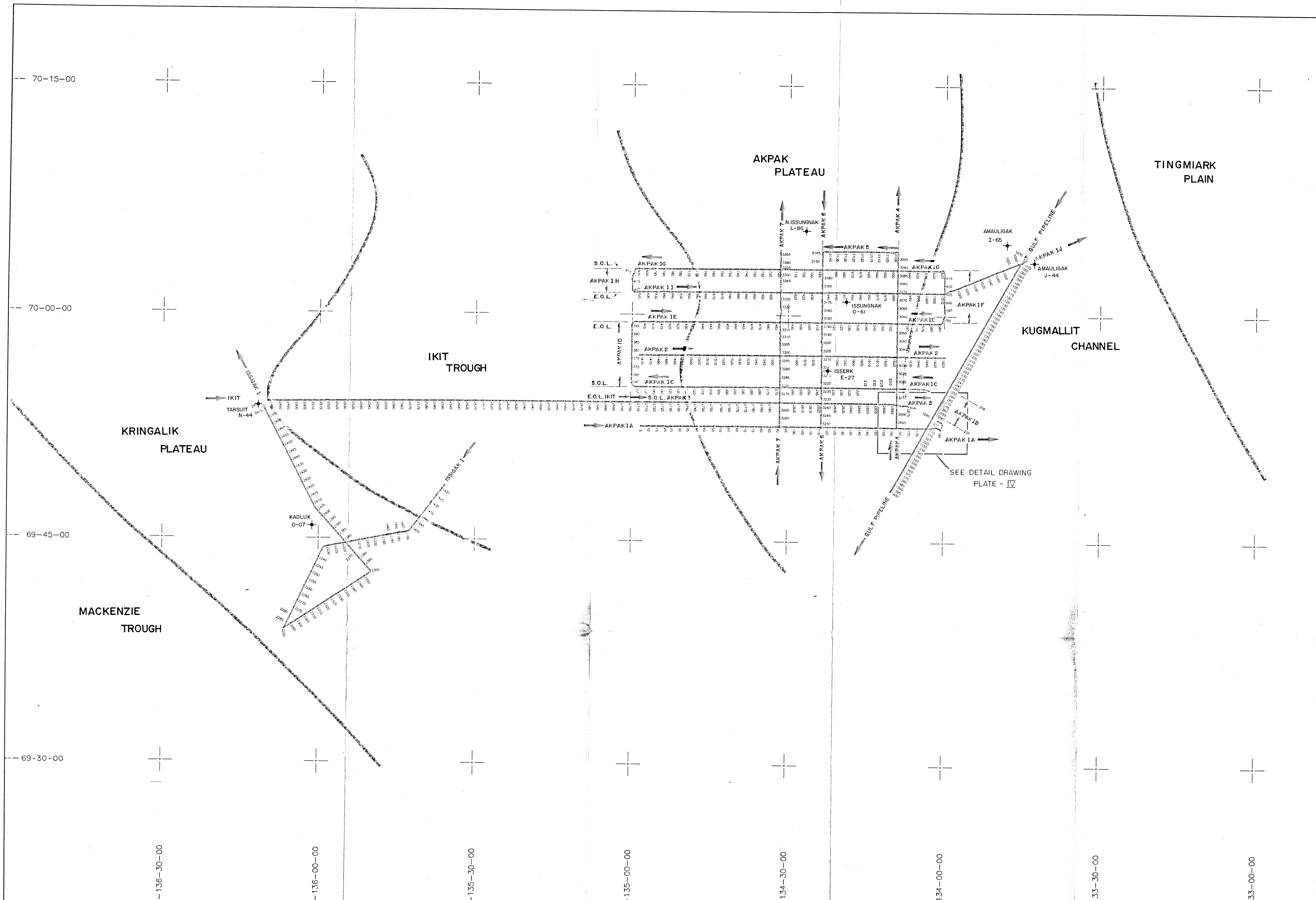
PL. II

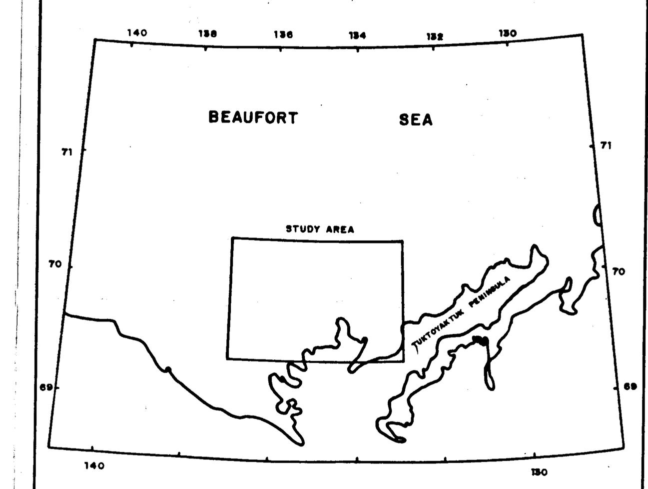
EXPLANATIONS:

- REFLECTOR (defined ; approximate)
- REFRACTOR
- SHALLOW GAS
- 1500 2500 ACOUSTIC VELOCITY IN M/SEC.
- REWORKED, REMOULDED FACIES (clay & silt)
- STRATIFIED FACIES (clay, organics)
- PARTIALLY STRATIFIED FACIES (interbedded clay, silt, sand)
- SAND
- GRAVEL, TILL

NOTE: (1) SEABED SMOOTHED FOR ICE-SCOURING EFFECT

H.R. SEISMIC INTERPRETATION SERVICES INC.	for GEOLOGICAL SURVEY of CANADA
MARINE BOTTOM & SUBBOTTOM SURVEY BY HIGH RESOLUTION SEISMIC METHODS	
AKPAK PLATEAU	EAST-WEST INTERPRETATIVE CROSS SECTIONS
SCALE: HORIZONTAL 1:50,000 VERTICAL 1:400 — INTERPRETED BY: G. FORTIN	PROJECT No. 014 — MARCH 1989





LOCATION DIAGRAM

NOTES

1) PROJECTION – MERCATOR
2) THIS SEISMIC PLAN IS OFFSET APPROXIMATELY 80 KM WEST OF HYDROGRAPHIC SERVICE CHART #7663, KUGMALLIT BAY.
3) POSITIONS ARE DERIVED FROM SYLEDIS MR3 RANGE MEASUREMENTS TO 3 OF 6 SHORE STATIONS LOCATED AT GARRY ISLAND, STOKES POINT, KING POINT, PULLEN ISLAND, TOKER POINT AND ATKINSON POINT.
4) SHORE CONTROL VALUES WERE PROVIDED BY GSI AND WERE DERIVED USING GPS TRANSLOCATED SATELLITE OBSERVATIONS. SHORE CONTROL IS REFERENCED TO THE NAD 1927 DATUM; MAY 1983 RE-ADJUSTMENT.
5) SURVEY VESSEL: CCGS NAHIDIK.
6) SEISMIC DATA WAS COLLECTED BETWEEN 06 SEPT. 1987 AND 11 SEPT. 1987.
7) SEISMIC LINE FIXES INDICATE THE POSITION OF THE SYLEDIS ANTENNA.

LEGEND

° 999 — FIX MARK AND NUMBER
AKPAK 1 → — SEISMIC LINE NAME AND SURVEY DIRECTION
GEOGRAPHIC GRID TIC
LOCATION OF WELLSITE
APPROXIMATE PHYSIOGRAPHIC BOUNDARIES (AFTER O'CONNOR, 1982)

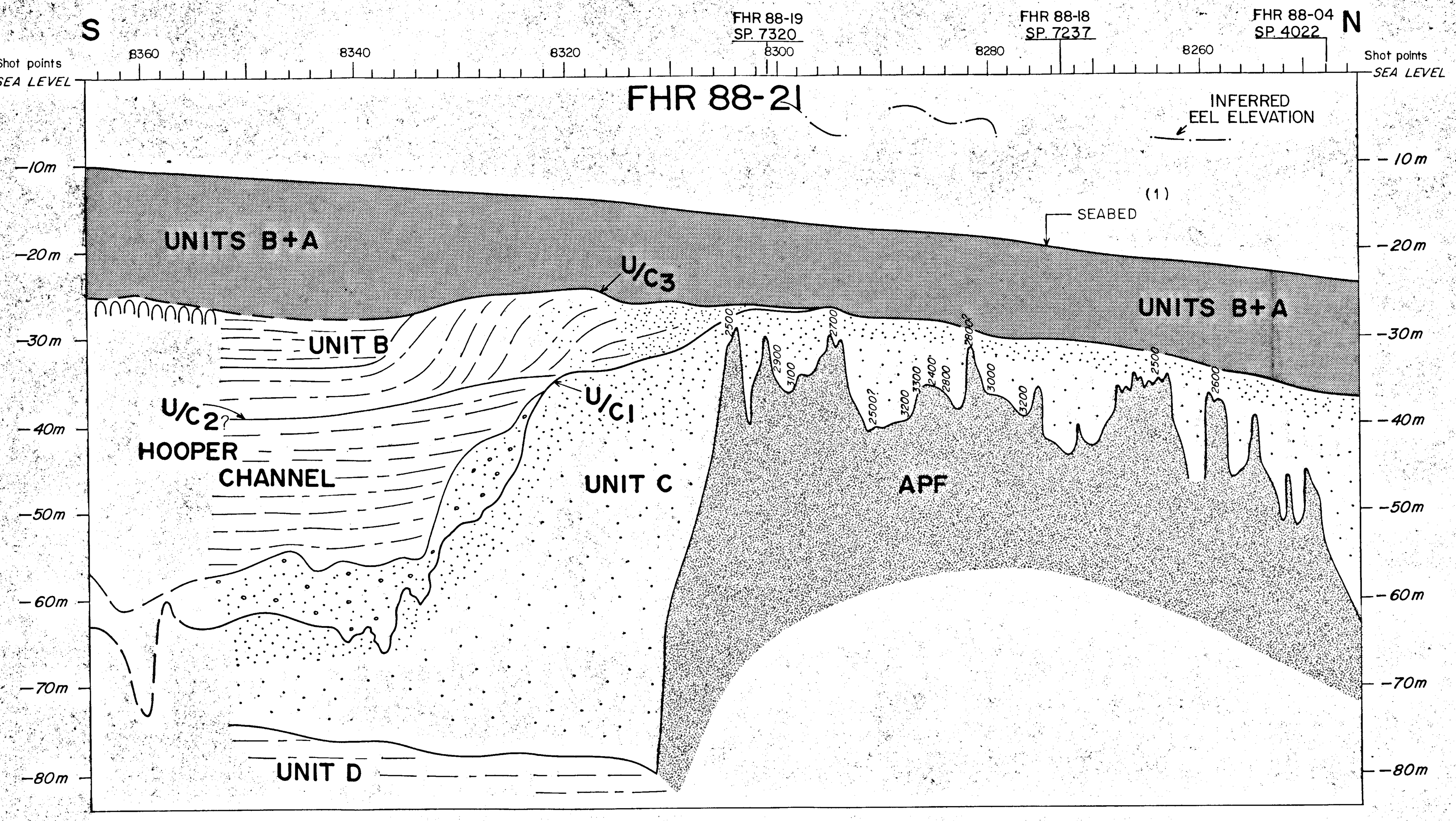
NOTE: SCALE IS 1 : 150 000 AT LATITUDE 69° 36' 00"

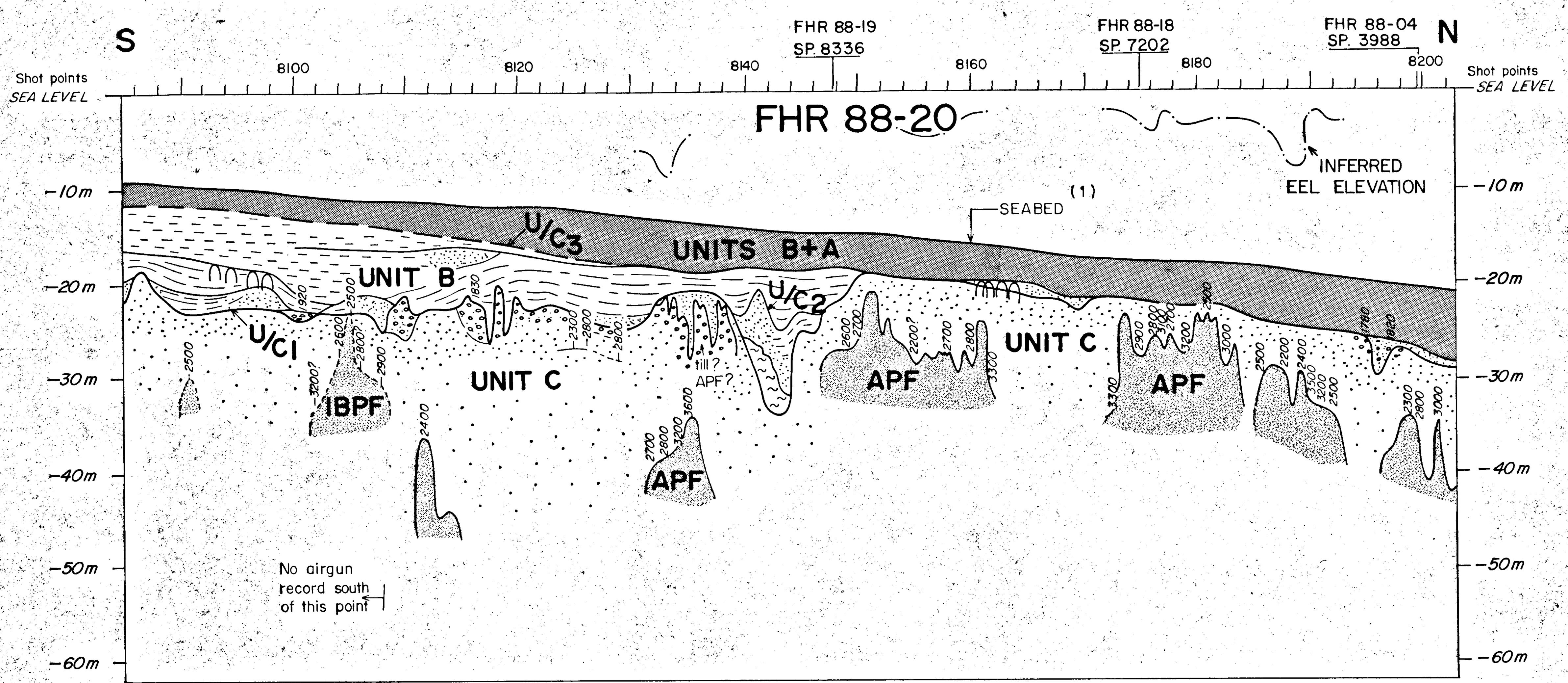
GEOLOGICAL SURVEY OF CANADA

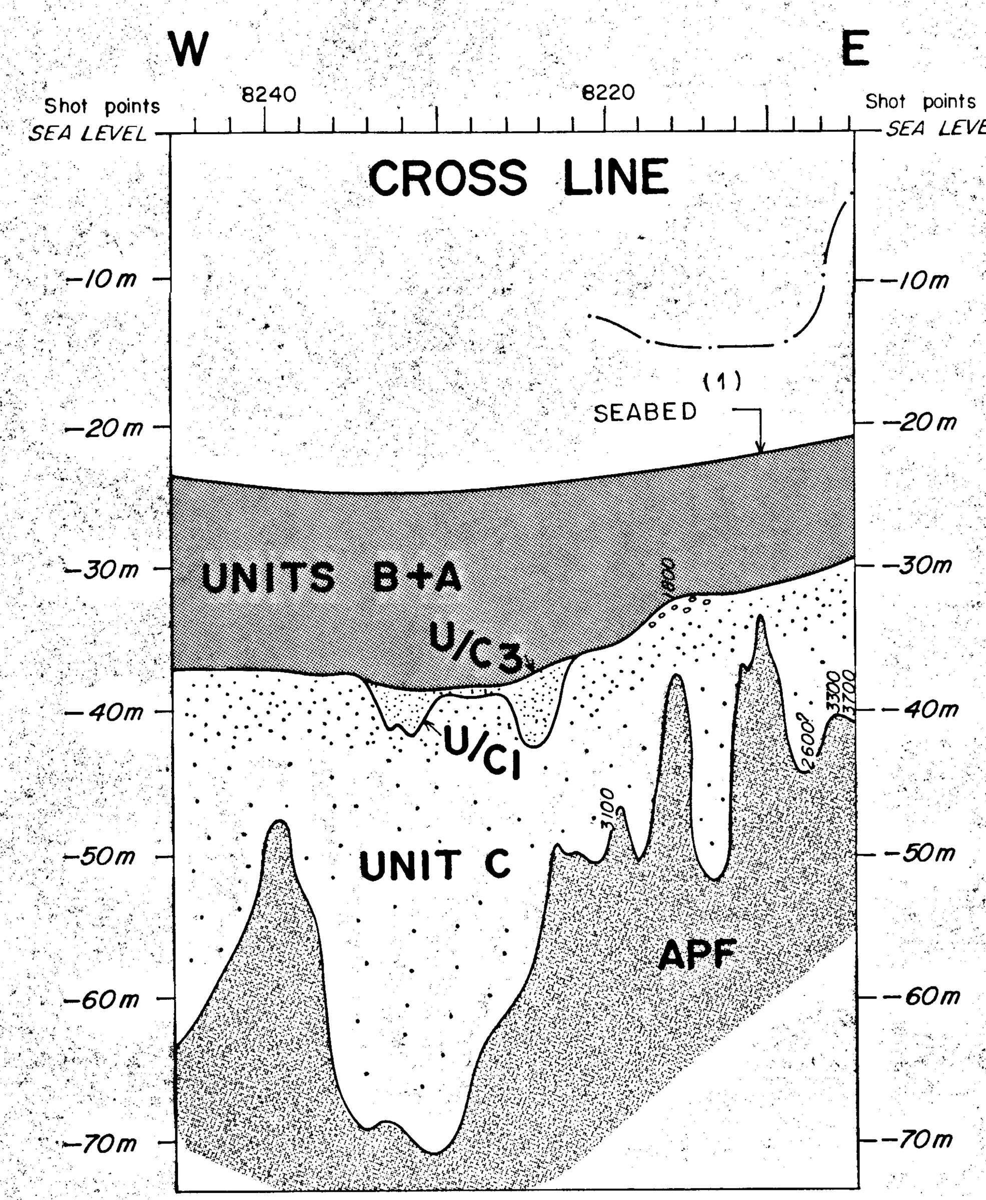
PL. I SEISMIC LINES

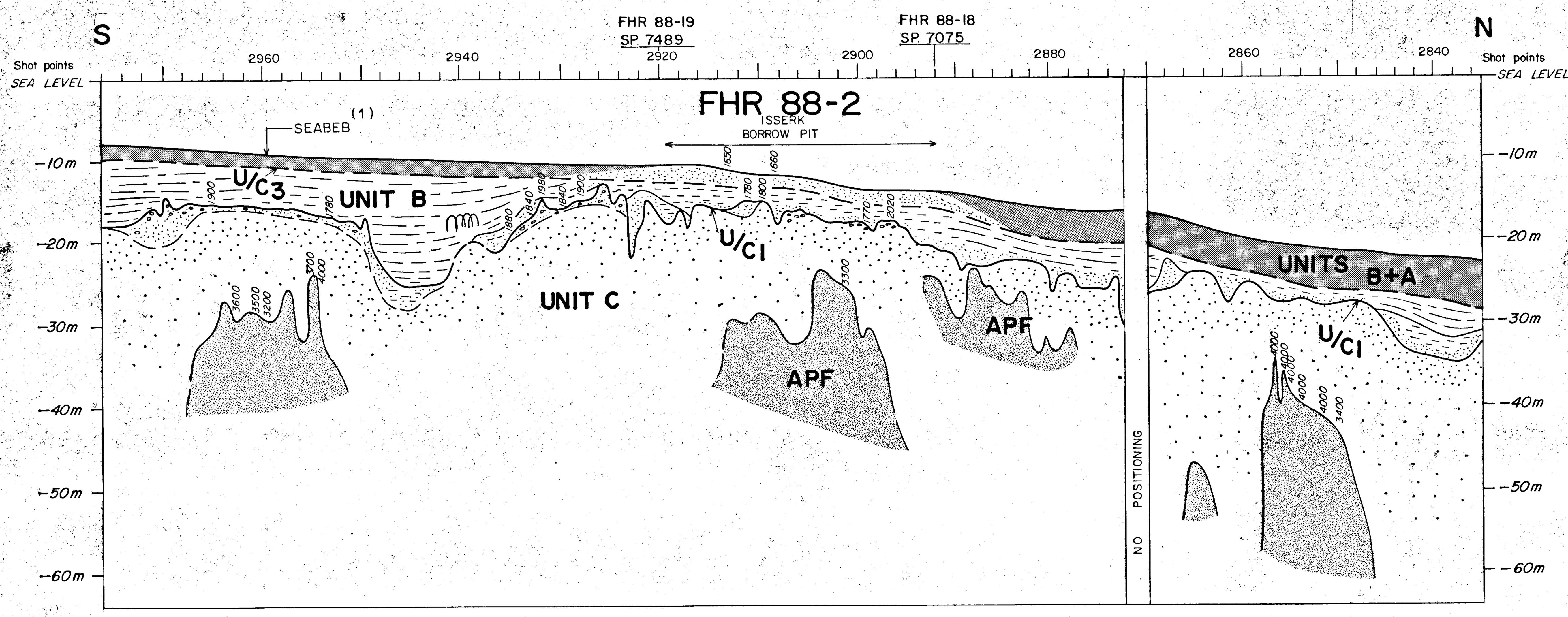
NORTH OF
MACKENZIE BAY
BEAUFORT SEA
NORTHWEST TERRITORIES

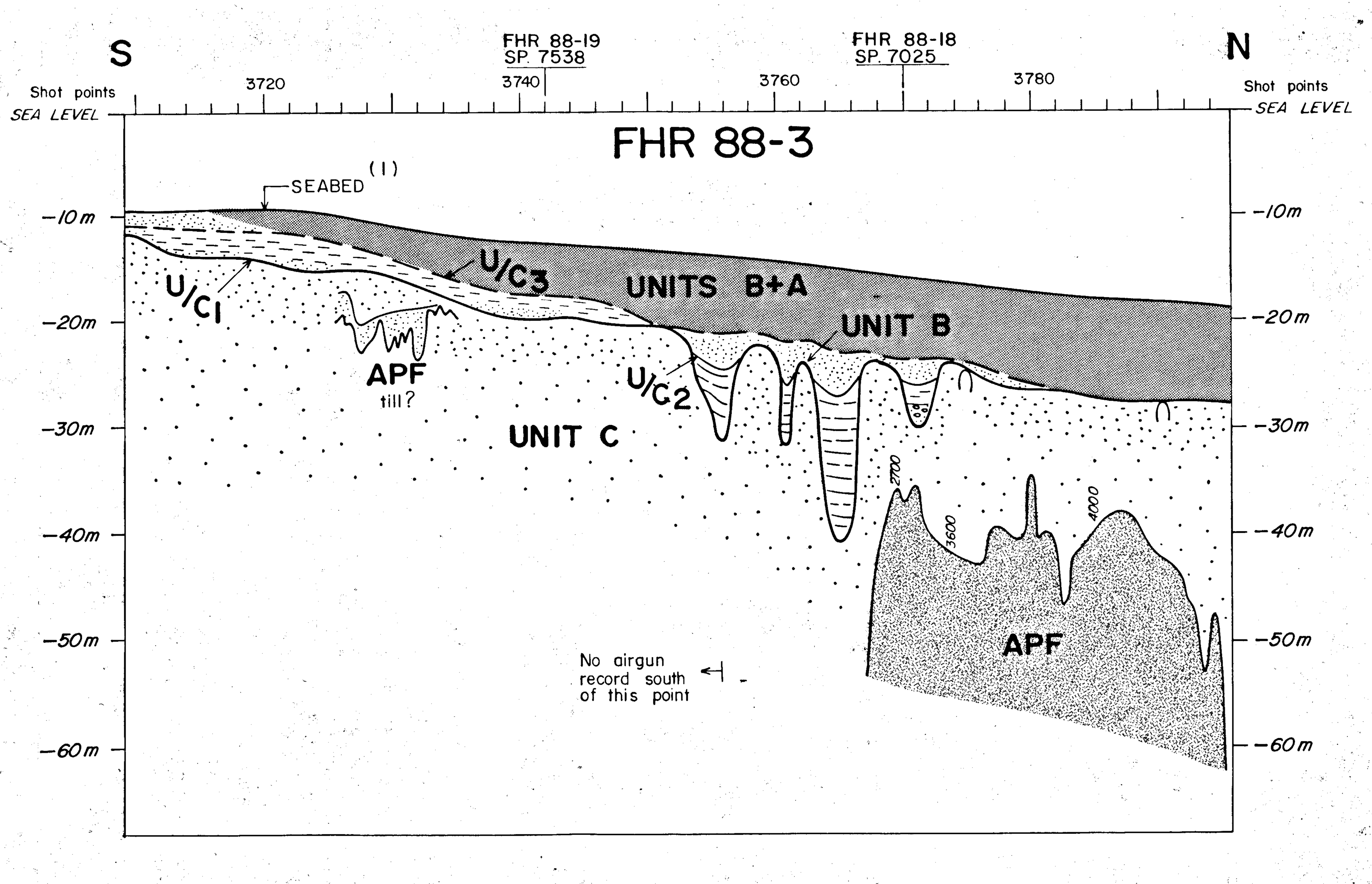
INTERPRETED BY: S.I.S. INC.	SCALE: SEE ABOVE NOTE	JOB No. 010
	DATE: SEPT. 1988	NAVIGATION BY: CHALLENGER

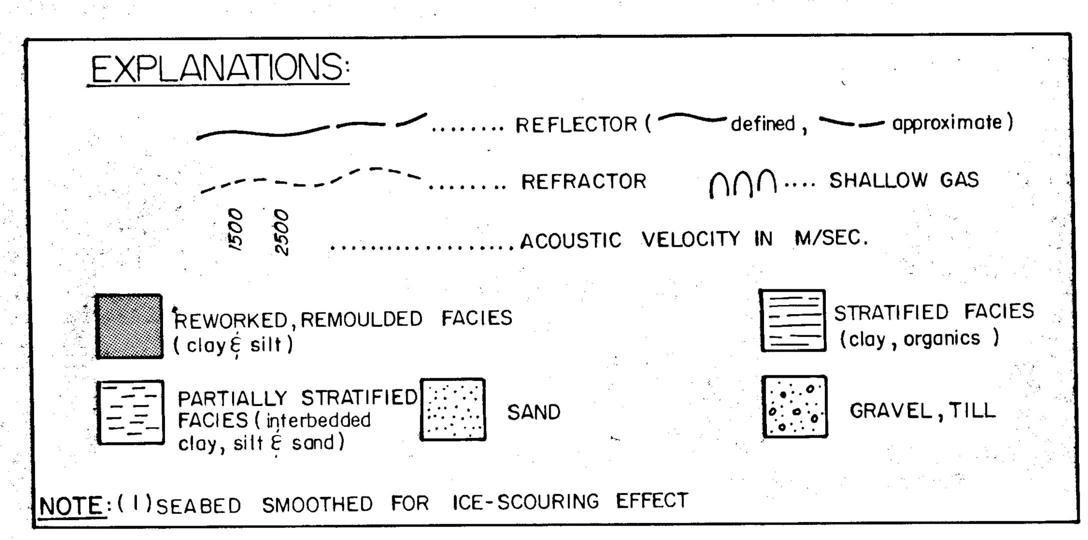






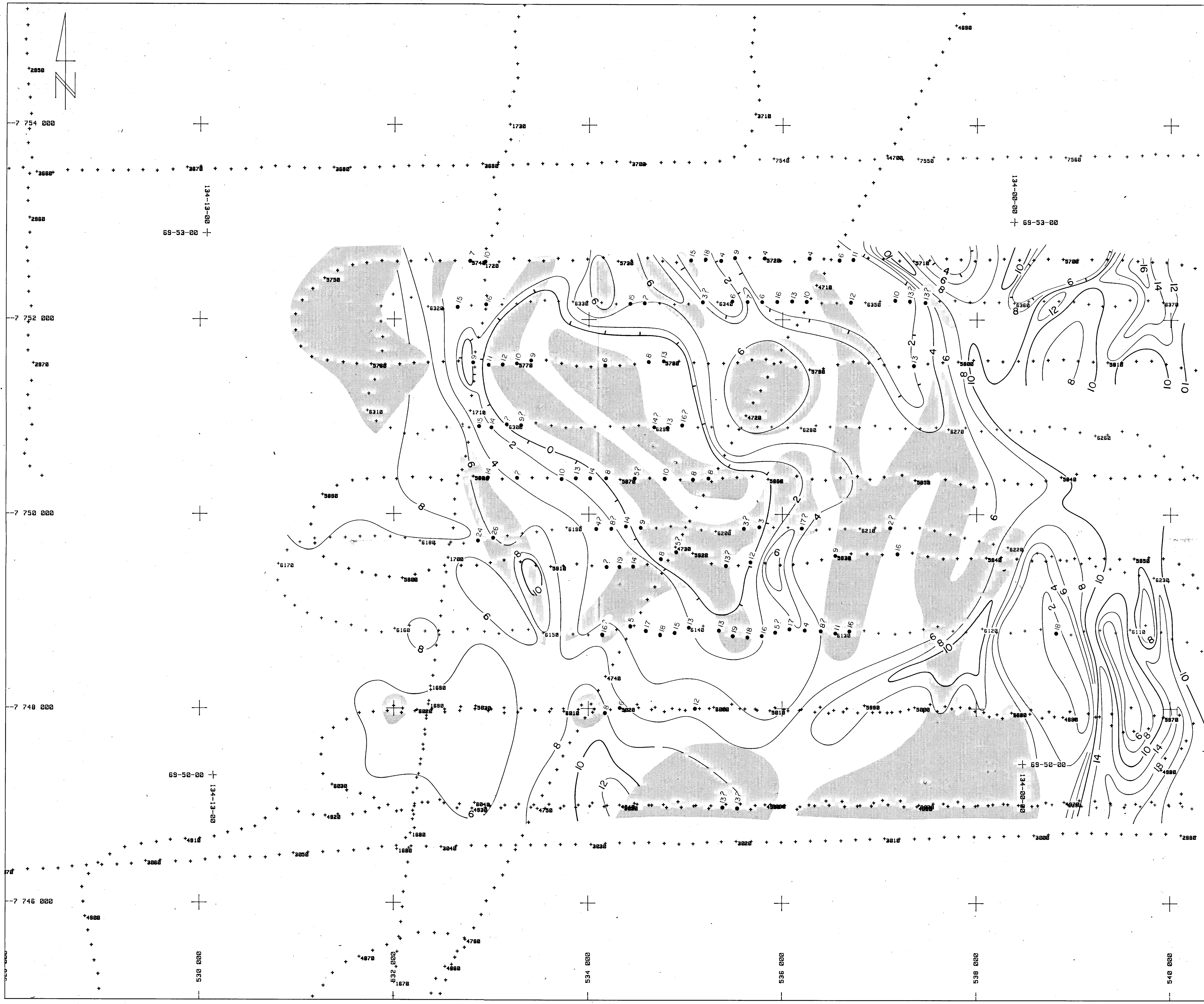






PL. III

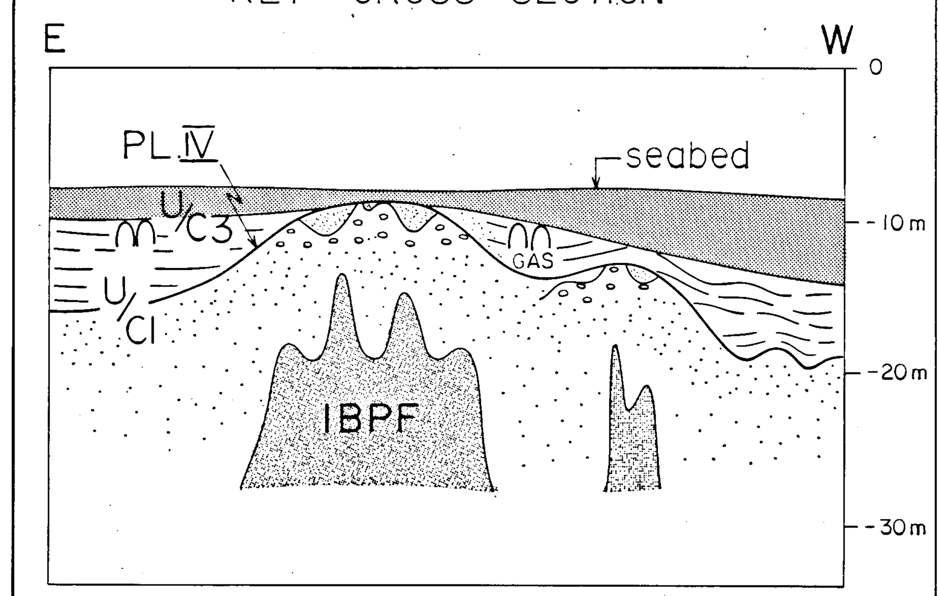
H.R. SEISMIC INTERPRETATION SERVICES INC.	for GEOLOGICAL SURVEY of CANADA
MARINE BOTTOM & SUBBOTTOM SURVEY BY HIGH RESOLUTION SEISMIC METHODS	
AKPAK PLATEAU	NORTH-SOUTH INTERPRETATIVE CROSS SECTIONS
SCALE: HORIZONTAL 1:50,000 VERTICAL 1:400 — INTERPRETED BY: G. FORTIN	PROJECT No. 014 — MARCH 1989



NOTES:

1. HORIZONTAL POSITIONING : SERCEL SYLEDIS IN PASSIVE MODE. POSITIONING EXCELLENT DRMS 01, LPME 02/03 ENROUTE

KEY CROSS SECTION



LEGEND

6 / 8 .... sediment thickness (m) to U/C1

.... U/C1 and U/C3 coincident

.... shallow gas above U/C1

.... depth (m) to layer below seabed

.... high velocity (2,000-4,000 m/s)

PL. IV

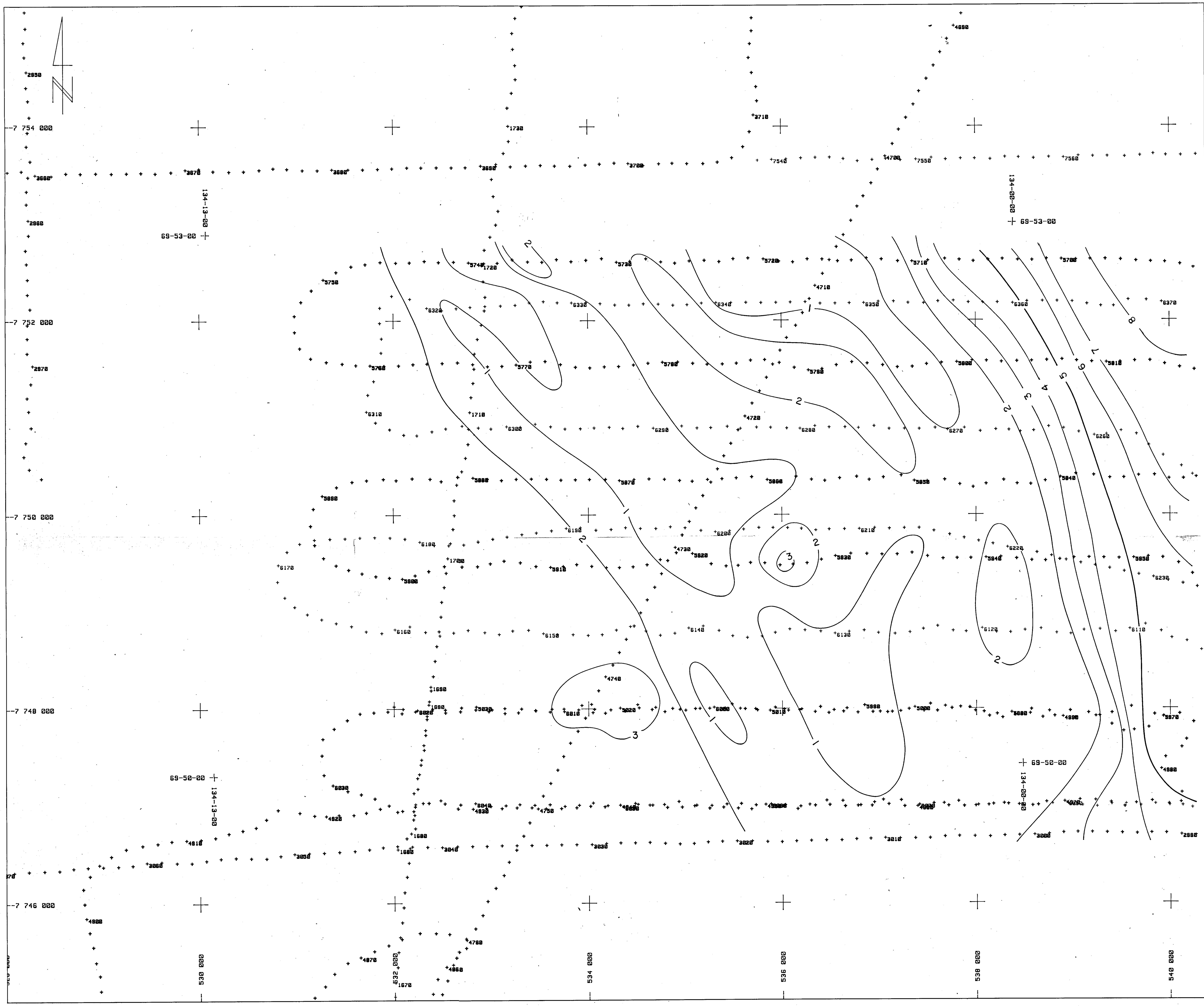
SEDIMENT THICKNESS TO U/C1

GEOLOGICAL SURVEY

NAHIDIK
SEISMIC SHOTPOINT LOCATIONS
ISSERK AREA

BEAUFORT SEA
1988

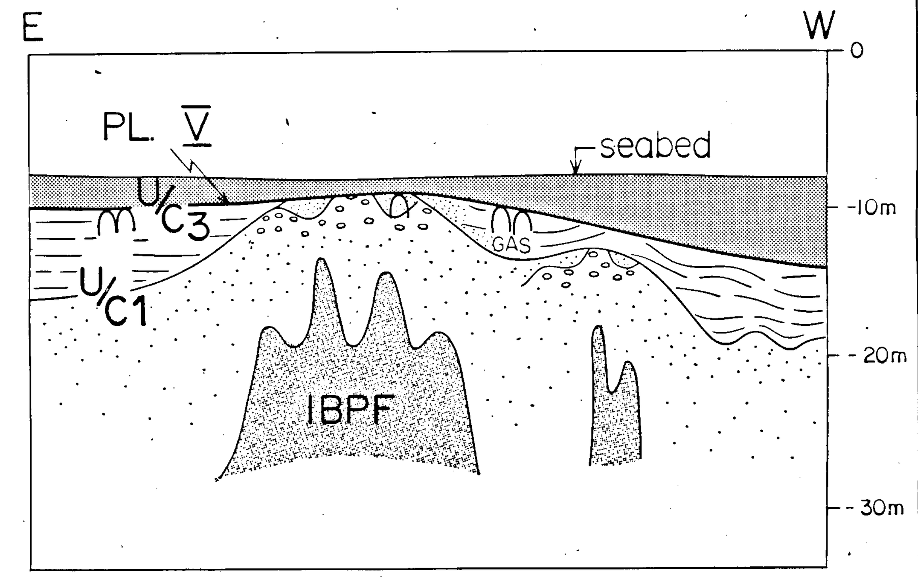
H.R. SEISMIC INTERPRETATION SERVICES INC.				S.I.S.
SCALE: 1:20000	DATE: MARCH 1989	JOB NO.: 014	DWG. NO.: PL. IV	



NOTES:

1. HORIZONTAL POSITIONING : SERCEL SYLEDIS IN PASSIVE MODE. POSITIONING EXCELLENT DRMS 01, LPME 02/03 ENROUTE

KEY CROSS SECTION



LEGEND

3, 2 ....sediment thickness(m) to U/C3

PL. V

SEDIMENT THICKNESS TO U/C3

GEOLOGICAL SURVEY

NAHIDIK
SEISMIC SHOTPOINT LOCATIONS
ISSERK AREA

BEAUFORT SEA
1988

H.R. SEISMIC INTERPRETATION SERVICES INC.				S.I.S.
SCALE: 1:20000	DATE: MARCH 1989	JOB NO.: 014	DWG. NO.: PL. V	