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SYNTHESIS AND INTERPRETATION OF BATHYMETRIC, GEOPHYSICAL AND GEOTECHNICAL DATA FROM ISSIGAK BORROW BLOCK

Submitted to:

INDIAN AND NORTHERN AFFAIRS CANADA
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EXECUTIVE SUMMARY

A review of all available geotechnical, geophysical and bathymetric data for the Issigak granular borrow deposit has been completed by EBA Engineering Consultants Ltd. for Supply and Services Canada and Indian and Northern Affairs Canada. The deposit, located 20 km northwest of Pelly Island in the Beaufort Sea, comprises one of a very few sources of gravel borrow and the only significant borrow source in the western half of the Beaufort-Mackenzie area. The primary objectives of the study were to develop an interpretation of the Issigak geology and to quantify the remaining borrow reserves.

Interpretation of the Issigak site was confounded by apparent inconsistencies between bathymetric data sets and between stratigraphy indicated in adjacent boreholes. Assessing the reliability of various data sets and selecting the most representative for analysis required some subjective judgement. ESSO's 1984 data was selected as the most reliable bathymetric reference and the ESSO's 1983 borehole program was used as a basis for most stratigraphic and borrow thickness interpretation.

The Issigak deposit is interpreted herein to be fluvial-deltaic in nature and correlated with sediments of early Holocene age. Thus it appears that it was emplaced before the latest marine transgression, near the top of a non-marine deltaic sequence. This interpretation relies on the correlation of a section from Tarsuit N-44, through Kadluk O-07 and across the Issigak deposits.

The geologic interpretation leaves unsolved the question of the origin of the granular sediments. The presence of cobbles, comprising up to 10 percent by volume of parts of the deposit, and boulders up to 500 mm in diameter suggest that both fluvial and ice rafting processes were active in the formation of the deposits. Furthermore these large clasts suggest that older granular sediments have been re-worked to provide a source for the Issigak materials. The report speculates that these source sediments were probably located within about 10 km of Issigak to the south or southwest, rather than towards the southeast which the present regional gradient would imply.

Quantity calculations for Issigak are based on borehole data collected in and before July 1983. The quantities were adjusted for dredging programs between 1983 and 1986 which are reported to have removed the equivalent of 52 percent of the Proven Resources. Proven, Probable and Prospective Resources are estimated to be 3.3, 5.1 and 5.8 million cu.m., respectively as of the end of 1986. The gravel and sand fractions are estimated to be 1.2 and 4.6 million cu.m., respectively for all (Prospective) Resources.

1.0 INTRODUCTION

1.1 PROJECT ORGANIZATION

EBA Engineering Consultants Ltd. (EBA) have completed a review and synthesis of data collected by various Beaufort Sea operators relating to the Issigak Borrow Block. This study was contracted from Supply and Services Canada under Contract Serial Number OST85-0041. The project was conducted at the request of the Land Management Division of Indian and Northern Affairs Canada (INAC), under the direction of Mr. R.J. Gowan as the Scientific Authority. It was funded under NOGAP Project A4: Granular Resources Inventory and Management Program (Subproject A4-6).

The Issigak borrow deposit is very important for construction of Beaufort Sea hydrocarbon exploration facilities. It is located in an area where dredgeable borrow is very scarce and is unique because it contains a high proportion of gravel. Most dredgeable borrow in the Beaufort is sand and the nearest quality deposit is located about 60 km to the east in the Isserk block. A general location plan is presented as Figure 1.1.

The project required the compilation and interpretation of geotechnical, geophysical, dredging and bathymetric data that had been acquired between 1974 and 1986 by ESSO Resources Canada Ltd. (ESSO), Dome Petroleum Ltd. (Dome) and Gulf Canada Resources Ltd. (Gulf) (now Gulf Canada Corporation). The Issigak borrow deposit has been referred to as the South Tarsiut borrow in some Dome reports or as the Kadluk borrow site in some ESSO reports. A significant task of the project therefore was to consult with each of the operators to obtain their data and ideas on the nature of the deposit.

EBA's project team for this assignment included Challenger Surveys and Services Ltd. from Edmonton and Mr. Guy Fortin from Hull Quebec, both as subconsultants. Challenger provided the borehole, stratigraphic and bathymetric plotting capabilities. Mr. Fortin provided expertise in the interpretation of seismic data and in developing the geologic model of the deposit.

1.2 WORKSCOPE

The primary objectives of the program included the following.

a) To compile an inventory of bathymetric, geophysical and geotechnical data pertaining to the deposit.
b) To locate, assess the reliability of, and synthesize the various studies into a working data base.
c) To interpret the geologic nature of the borrow deposits.
d) To identify where similar deposits might be found from the geologic model.
e) To determine the remaining exploitable borrow resources.

1.3 INDUSTRY REPRESENTATIVES

As noted above, the data upon which this study is based has been provided by three Beaufort Sea operators. In addition, to coordinating the supply of this data, the following persons contributed their personal observations and interpretations of the Issigak deposit.

a) ESSO Resources Canada Ltd.:
   C.S. Nelson
   R.J. Whyte
   S.B. Shinde

b) Dome Petroleum Ltd.
K.J. Hewitt
H.E. McRae

c) Gulf Canada Corporation
W.R. Livingstone
A.F. Stirbys (no longer with Gulf)

2.0 DATA COMPILATION

2.1 DATA BASE

The first geotechnical work in the area of the Issigak borrow deposit was conducted in 1974 by EBA for ESSO. However, it wasn't until 1980 when Dome became interested in the area as a prospective source of granular borrow for use at its Tarsuit N-44 site (see Figure 2.1) that detailed exploration of the granular resources in the area began. In total, 26 seismic, geotechnical, bathymetric and dredging programs listed on Table 2.1, have been identified for the Issigak block. Many of those programs had bathymetric components that are not separately identified on Table 2.1.

There are 199 borehole logs which were used in the data base for the study. As shown on Figure 2.2, 176 of those holes lie clustered within or very close to the borrow deposit. Only four other holes in the Issigak block have any showings of granular materials. These are identified and discussed in Subsection 5.2.1.

Other direct sampling data was considered including records from grab sampling and drop sampling efforts. This data was most useful for extending the limits of the proven reserves outside the areas with the clusters of boreholes.

The shallow seismic data that was evaluated came mainly from programs conducted by Dome in 1980 and ESSO in 1981 and 1983. Side scan sonograms from ESSO's 1984 program were also used; however, the seismic data from that program could not be located. In general, seismic data was of only limited use, because it seems the operators have been very informal in their handling of this kind of data. Of the seven shallow seismic programs listed on Table 2.1 and summarized below most records could not be found for four of the programs and an interpretative report was not available for any of them.

a) Dome, 1980: This was a regional data gathering program, not specifically oriented to Issigak. Most local records could not be found and there were no lines directly over the deposit. One line, used in Figure 3.4, was examined.

b) ESSO, 1981: A regional line of fair quality was used for the Omat section on Figure 3.5.

c) Gulf, 1981: This was an interpretation of Dome 1980 records purchased by Gulf and does not represent new information. The depth to the first unconformity was mapped, however the interpretation is in disagreement with later data, particularly on the south end of the deposit.

d) Gulf, 1982: The data was not found, however, a map prepared from it shows gravel and sand distribution in the north central part of the deposit. Bathymetry agrees well with later data, but is off datum by approximately 0.5 m.

e) ESSO, 1983: The quality of high resolution seismic generally was very poor because of bad weather conditions. Bathymetry derived from seismic profiles is substantially different from other data sets (up to 3.3 m in places and commonly 1.5 m). The side scan data was used in compilation of Figure 4.9.

f) ESSO, 1984: These seismic records could not be found. Bathymetric data collected by ESSO in 1984 and used in this report was acquired as part of the dredging program (Item 21 on Table 2.1). A map prepared by Johnson (1984) included an interpretation of the area of a hard reflection at seabed that was from this data set. Some of the side scan data was found and incorporated for the preparation of Figure 4.9.

g) Gulf, 1984: A local program to examine similar bathymetric highs to the northeast. This data was not examined because Gulf reported no success in exploring for granular deposits at these other sites.

2.2 DATA RELIABILITY

The quality and thoroughness of the investigation programs have varied greatly. Each operator had slightly different objectives or faced complications with weather, ice and sea-state while on site. Different equipment selections and field procedures also affected the reliability or compatibility of the data.

Water depths measured at boreholes, bathymetric depths interpreted from seismic programs and site specific bathymetric data sets frequently do not match. For example, bathymetric surveys do not appear to be repeatable within 0.5 m to 1.0 m depth range. Relative to the 1.35 m (average) to

3.4 m (maximum)[1] thickness of the deposit, this lack of repeatability causes significant uncertainty in the interpretation of the physical shape, height and volume of the deposit.

Ultimately it was decided to base all bathymetric interpretation on the seabed datum defined by a series of bathymetric surveys prepared by Canadian Engineering Surveys Co. Ltd. (CES) for ESSO in 1984 as part of the dredging program. The toponet presented in Figure 2.3 and bathymetric contours in Figure 2.4 were developed from this data set.

To assess the reliability of the bathymetric data, water depths determined from the borehole logs were compared with those determined from ESSO's 1984 survey (Figure 2.4). The bathymetry of 35 of the 138 boreholes that fall within the area of Figure 2.4 differed from the ESSO survey by one metre or more. In 23 cases the borehole indicated less water than the bathymetric survey, suggesting that dredging which occurred between the two measurements might be a cause of some of the differences; however, not all could be explained this way. Errors in bathymetric measurements,

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1. Only 3 of the 172 boreholes within the limits of the deposit show it to be more than 3.4 m thick. One of those logs (Borehole No. E82(KBI-3))[2] shows 6.5 m; however, it is surrounded by six other holes, within 250 m distance, having an average thickness of 1.54 m of granular material. It is believed that the 6.5 m measurement is in error.

2. Throughout this report, the convention for identifying the boreholes by number is as follows; the operator and year the data was collected are identified first followed by the hole number in parenthesis. For example, E82(KBI-3) is Borehole No. KBI-3 collected by ESSO (E) in 1982. The other operators are Gulf (G) and Dome (D).

interpretation of position and plotting of the bathymetric contours could each be factors.

Substantial differences in stratigraphy were also evident when comparing logs for adjacent boreholes. Table 2.2 illustrates the magnitude of these differences. Errors were suspected when data from one program was inconsistent with another, but it was difficult to decide which, if either, was correct.

Some subjective judgement has been required to interpret the bathymetry and stratigraphy where differences occur in the data. Wherever there is conflicting data, the boreholes collected by EBA for ESSO in 1983 have been relied upon for stratigraphic data and the bathymetry compiled in 1984 by ESSO has been relied upon for bathymetric control.

3.0 SITE DESCRIPTION

3.1 PHYSICAL CHARACTERISTICS

The Beaufort Shelf from Pelly Island to Issigak and Tarsiut is a gently sloping, featureless plain. The only apparent anomaly on this plain is in the area of the Issigak deposit. In profile (Figure 3.1), the Issigak area appears as a feature with 2.5 m of relief above the regional slope. The extreme vertical exaggeration (750x) of the profile on Figure 3.1 distorts the flatness of the region and masks the fact that the average slope from southeast to northwest is only 14 m in 33 km.

The toponet and detailed bathymetric contours (Figures 2.3 and 2.4) show a low ridge linking several small knobs. The ridge stands out well, on Figure 2.3, because of the exaggeration (100x) in the vertical scale. In truth, the deposit is much less spectacular in height and perhaps longer than appreciated. From its northeastern end to its southwestern tip it is almost 11 km long. At the eastern end it is about 1500 m wide but the main prospects are about 500 m to 1000 m wide.

The borrow area rises above the surrounding deltaic plain by about 2.5 m at maximum and 1.0 m to 1.5 m on average. Figure 3.2 presents a detailed section through the part of the deposit with the maximum relief. The upper profile, showing some details of the stratigraphy, is drawn at a vertical exaggeration of 200x. In the lower half of Figure 3.2, the same profile is repeated at 10x exaggeration, for comparison. At this lower exaggeration the true shape of the deposit starts to become evident. The granular deposits are a relatively thin veneer on the seabed. This has suggested to some that the deposit is a lag resulting from the erosion of an outlying barrier island such as Pelly or Garry Island. In comparison the aerial extent of the deposit is approximately 2150 ha (prospective resources, Figure 2.2), whereas, Pelly Island is about 3400 ha.

As noted on Figure 2.2, 176 of 199 boreholes within the Issigak block lie within or immediately adjacent to the granular deposits. In 160 of these boreholes granular material was encountered, however these are highly clustered in the areas showing the greatest relief. The relationship between the relief (bathymetry) and the presence and thickness of the borrow was initially used to identify sites for borrow exploration drilling by the operators.

The bathymetric contours on Figure 2.4 show five centres of maximum relief. Typically these mounds are only 7.0 m to 8.0 m below sealevel (bsl); whereas, the seabed on the inshore side is between 9.0 m and 9.5 m bsl and the outer toe of the deposit appears to be between 10 and 11.5 m bsl.

Figure 3.3 presents a statistical frequency plot of measured borrow thickness from borehole log data. Although 18 of the borehole did not fully penetrate the granular sediments which explains the skewness of the plot, there is clear evidence that most of the Issigak deposit is less than 3.0 m thick. The average thickness of borrow encountered in the boreholes, which were intentionally placed in the thickest parts of the deposits, is less than 1.5 m.

3.2 REGIONAL GEOLOGIC SETTING

3.2.1 Physiographic Region

The Issigak deposit is located at the southern end of the Kringalik Plateau, as shown on Figure 3.4. O'Connor (1982) identified the Kringalik Plateau as "an area of fine-grained, laminated, partially or marginally ice-bonded strata containing at least two unconformities". To the southwest approximately 10 km, is the boundary with the Mackenzie Trough which is infilled with thick fine-grained Holocene sediments. To the northeast and east, approximately 10 km, is the boundary with the Ikit Trough, which is also reported to be infilled with deep fine-grained late Wisconsin or Holocene sediments (O'Connor, 1982).

The southern extension of the Ikit-Kringalik border, towards Pelly Island, is not defined in O'Connor (1982). High resolution seismic studies in the shallow water with deep soft sediments has not been practical. Boreholes at Netserk North (EBA, 1974) show soft sediments (Holocene?) extending to at least 20 m below seabed (bsb). These would appear to be more like the sediments of a trough rather than those of the Kringalik Plateau. Two boreholes (E74(301) and D80(80-72)) located southeast and within 4 km of Issigak appear to show a similar deep accumulation of soft recent sediments.

3.2.2 Regional Stratigraphy

A detailed biostratigraphic study by Burden (1986) of borehole samples from Tarsiut N-44 provide the best available detailed stratigraphic model for the area. Deep borehole data from Tarsuit A-25 and two Kadluk sites have been correlated with the Tarsiut N-44 log on Table 3.1. Four cycles of marine transgression have been identified for Tarsuit N-44 as follows:

a) From -166 m to -125 m below seabed (bsb), the depositional environment was one of a rapidly prograding delta. It was topped off by non-marine sediments that have been dated (Hill et al. 1985) to be around 27000 years old (Middle Wisconsin).

b) From -125 m to -60 m bsb, a progression from shallow deltaic to prodelta or marine conditions is evident. Burden (1986) believes this cycle ended about 18000 years ago (Late Wisconsin).

c) From -60 m to -15 m bsb, there is again evidence of a prograding delta which was topped off by non-marine facies. Burden interpreted that this period ended about 14600 years ago.

d) From -15 m to -6 m bsb, are early Holocene sediments, interpreted to be between 9500 and 6800 years old. These provide evidence of a shallow deltaic environment.

e) Burden (1986) reports an unconformity separated the Holocene sediments into deltaic and prodeltiac facies more recently than 6800 years ago. Late Holocene sediments are interpreted from -6 m bsb to the seabed.

Three unconformities which were identified in the preceeding section (Burden, 1986) have been used to help identify the geology of the Issigak deposit. Specifically these are:

a) Unconformity U/C_1 - near the level of non-marine sediments dated by Hill et. al. (1985) to be about 27,000 years old.

b) Unconformity U/C_2 - above the level of non-marine deposits that Burden (1986) interprets to be 14,600 years or older and below early Holocene sediments that are 9500 to 6800 years old.

c) Unconformity U/C_3 - between early and late Holocene sediments, probably related to the last marine transgression.

3.2.3 Regional Seismic Interpretation

a) Tarsiut - Issigak Correlation

Figure 3.5 features a north-south cross-section which displays the shallow geology to a depth of about 500 metres from the Tarsiut A-25 wellsite to an area situated some 12 km west of the Issigak deposit. The section was constructed from a high resolution multichannel seismic line (DHR 80-530) which was collected in 1980 by Dome. The data quality is good along the northern half of the line but degrades substantially in the southern part due to the presence of shallow gas. The Two Way Transit Time (in seconds) has been translated into depth (in metres) using a constant velocity of 1735 m/sec. for the materials encountered between the sealevel and the Late-Miocene Unconformity. This regional marker occurs at 0.85 second or 737 metres below sealevel at Tarsiut A-25 wellsite (Plate III in Fortin and Torrens, 1986).

The lithology at Tarsiut A-25 has been derived from a deep geotechnical borehole (McClelland, 1978). Although most of the core is fine-grained silt and clay, two sand layers are located between 16 m to 21.5 m below seabottom (bsb) and between 121 m to 122.5 m (bsb), respectively. An ice-bearing clayey silt layer was also logged between 85.5 m and 94 m (bsb).

The deepest sand layer (121 m to 122.5 m bsb) was correlated by Fortin and Torrens (1986) with sand interbeds intercepted between 87.5 m and 136 m (bsb) at Tarsiut N-44 wellsite. Hill et al. (1985) have dated at 27380 years BP a sample of fibrous peat material encountered at 129 m (bsb) and compressed between black clayey mud with sand stringers at Tarsiut N-44. Thus the sand layer logged between 121 m and 122.5 m (bsb) at Tarsiut A-25 is probably on the order of 25000 to 30000 years old.

The ice-bearing clayey silt layer shown on Figure 3.5 gives rise to a high amplitude and continuous reflection which can be traced from Tarsiut A-25 to the Issigak area. This reflector possesses the characteristics of an erosional unconformity and has been labelled U/C_1 on Figure 3.5. Unconformity U/C_1 occurs at a depth of about 90 m (bsb) in the Issigak area, which indicates that the sediments lying above this unconformity are likely not older than 25000 to 30000 years. Therefore, on the basis of seismic evidence and a radiocarbon-dated sample, it appears that the Issigak deposit cannot be related to the Buckland Glaciation which was prevailing over the Beaufort-Mackenzie area during the early Wisconsin.

A more recent unconformity, labelled U/C_2, is apparent at shallow depth on the seismic profile (Figure 3.5). This unconformity occurs near the base of shallowest sand (16 m to 21.5 m bsb) encountered at Tarsiut A-25 and displays little variation in depth along the cross-section. Near the Issigak area, this erosional surface may be present at about 10 m to 15 m (bsb). A number of site-specific geophysical data sets and industry regional lines (eg; Plate V in Fortin and Torrens, 1986) suggest that this seismic horizon may be equivalent to the Unit 'C' unconformity of O'Connor (1980 and 1982) which is thought to be late Wisconsin in age.

b) Omat - Kadluk Correlation

The interpretation of a high resolution analogue Boomer record collected in 1981 along Line 81E10-84405 by ESSO is presented as a cross-section on Figure 3.6. This seismic line begins 5 km northeast of the Omat wellsite, and runs for 18 km in a southwesterly direction, passing some 2300 m north of the Issigak area, about 1250 m south of Kadluk O-07, to terminate about 6 km west of the Issigak deposit (see Figure 2.2). The quality of the Boomer record is reasonably good along most of the line; however, shallow gas and strong multiples have made interpretation difficult along some segments of this shallow acoustic profile. Furthermore, the relatively wide signal of the Boomer system has prevented the resolution of fine stratification and small scale features, thus increasing interpretation difficulties especially near the Issigak area where both shallow gas and a strong water bottom multiple are present.

The lithology in the eastern part of Line 81E10-84405 is derived from a borehole drilled at Omat to a depth of 125 m below sealevel (bsl). For the central part of the line the lithology has been correlated to ESSO's Kadluk O-07 borehole (summarized on Table 3.1). For the remainder of the line, the shallow lithology has been inferred from the various acoustic signatures on the Boomer record as well as from extrapolations of the proposed stratigraphy for the Kadluk borehole and the Issigak borrow area.

Of interest in the Omat borehole, is a sequence of sand and silt layers, 13 m in thickness, which is located between two clay units (18 to 31 m bsb). This coarse-grained sequence has been interpreted (Geoterrex 1985 and 1986) as directly overlying unconformity U/C_2. Evidence of this interpretation was obtained from industry regional seismic data (Geoterrex 1985 and 1986) which was based on wellsite geophysical data from ESSO's Nipterk, Kaubvik and Kadluk sites. The seismic correlations on Figure 3.6

suggest that the sand and silt unit in the Ikit Trough is laterally equivalent to the stiff silty clay between 3 and 13 m bsb at Kadluk O-07.

ESSO's C. Nelson (personal communications) has interpreted two shallow unconformities that can be traced on the Omat line (Figure 3.6) and on ESSO's 1984 seismic lines, from the sand and silt layers of the Ikit Trough across to the Issigak area. The upper one (U/C_3) relates to the latest marine transgression and to O'Connor's (1982) Recent Unconformity and the lower one (U/C_2) presumably relates to the top of late Wisconsin (Unit C) sediments. On the western flank of the Ikit Trough, these two unconformities are very close together but both remain traceable although with difficulty because of gas in the section. Nelson has worked with both ESSO's 1983 and 1984 seismic data. Her interpretation that the Issigak borrow deposits pre-date the most recent Holocene deposition (post transgression) is based on tie-ins of the deposit to the Omat line on missing geophysical lines.

Although the position of the unconformity U/C_2 can only be inferred (dashed line on Figure 3.6) in some places along Line 81E10-84405 because of interference from shallow gas and signal attenuation with depth, the available seismic evidence indicates that this erosional boundary occurs 2300 m north of Issigak at a depth of about 10 m bsb, or at approximately 23 m below present sealevel.

3.2.4 Geologic Model

Rampton (1982 and 1986) interpreted the glacial limit of early Wisconsin (Buckland) ice to be near the Issigak area but a little to the south and west. Late Wisconsin glaciation is believed to have extended no further than the Shallow Bay area approximately 80 km south of Issigak. These limits are shown on Figure 3.7. The early Wisconsin glaciation had apparently receded from the area prior to 30,000 years ago (Hill et. al. 1985). Therefore it is below the base of the Tarsiut N-44 data reported above.

Figure 3.5 traces an unconformity (U/C_1) that lies slightly above the 27000 year old layer dated by Hill et al. (1985) from the Tarsiut area to the Issigak area. This interpretation by G. Fortin found that unconformity U/C_1 occurred about 90 m (bsb) at Tarsuit and about 90 m (bsb) where the Dome 1980 seismic line passes 12 km west of Issigak. If glacial material of Buckland age exists at Issigak, it should be at least 90 m below seabed.

Two unconformities are shown on Figure 3.8 from O'Connor (1982), extending from the shelf edge to Issigak along the Kringalik Plateau. The "Recent Unconformity" occurs at about 4 m (bsb) at Tarsuit and is interpreted to surface just north of Issigak. The "Ancient Unconformity" occurs at about 19 m (bsb) at Tarsuit and appears to be at about 15 m (bsb) in the Issigak area. The latter would appear to agree with Burden's (1986) late Wisconsin unconformity separating sediments of 14600 and 9500 years. The "Recent Unconformity" would likely be related to the unconformity Burden (1986) identified to be younger than 6800 years old. These are therefore unconformities U/C_2 and U/C_3, respectively.

Fortin also identified a shallower unconformity (U/C_2) on Figure 3.6 that occurs at about 20 m (bsb) at Tarsuit A-25 and 15 m (bsb) at a point 12 km west of Issigak. This one would appear to correlate with O'Connor's (1982) "Ancient Unconformity" and can be associated with Burden's (1986) late Wisconsin (14600 year old) unconformity.

The basic geologic framework that must be used to interpret the Issigak deposits is therefore constrained by three widely traceable unconformities. The evidence from the Tarsiut section (Figure 3.5) clearly indicates that late Wisconsin sediments which extend from 15 to 125 m bsb at Tarsiut N-44 are probably just as thick at Issigak. Above that, early Holocene sediments (about 9500 to 6800 years) which appear as 9 m of clay at Tarsiut and as 13 m of sand and silt layers at Omat can be traced to Kadluk where they appear as 10 m of stiff silty clay. This section is only 4500 m north of Issigak. Overlying the early Holocene sediments and separated from it by unconformity (U/C_3) that is attributable to the marine transgression, are late Holocene silty clays. There is evidence (O'Connor, 1982) that this strata pinches out in the Issigak area, but it can be clearly traced from Tarsiut to Kadluk and to Omat.

4.0 GEOLOGY OF THE ISSIGAK BORROW DEPOSITS

4.1 STRATIGRAPHY OF THE DEPOSITS

4.1.1 Identification of the Subunits

A detailed examination of borehole and grain size data has been conducted to identify the facies characteristics of the deposit. A general stratigraphic model for the granular strata that appears to fit a significant number of the logs has been developed, although none of the borehole logs show the full stratigraphic section. The following is considered characteristic of the deposit.

a) Overburden Clay (Unit 1a) - soft silty clay of Holocene age. It has been noted in only one borehole (E82 (KBI-2)) within the area of prospective resources. It appears to exist as an irregular veneer on the surrounding areas. Typical gradation characteristics are shown on Figure 4.1.

b) Interbedded Clay and Gravel (Unit 1b) - stratified interbedded clay and gravel has been noted in the area immediately east of the southern end of the deposits. (Boreholes E83 (IBS-S23, S24 and S25). It appears to be a product of secondary deposition when gravel washed down from the main Issigak deposit into an adjacent quiet water environment.

c) Upper Sand (Unit 2a) - a thin, widespread, clean to silty sand occurs on the flanks and the swales of the main deposits. It blankets much of the are of probable to prospective resources and perhaps occurs in three isolated pockets north of main deposits (Boreholes E74(306), E82 (K-3-1) and E74 (314)).

d) Main Gravelly Zone (Unit 2b) - ranging from gravel and sand ($2b_1$) to sandy gravel to gravelly sand ($2b_2$). There seems to be an upward increase in the average particle size. Cobbles have been noted throughout the section and a surface lag of cobbles has been observed in some areas. Figure 4.2 provides gradation envelopes for these subunits.

e) Underlying Sand (Unit 2c) - ranging from a clean, uniformly graded sand ($2c_1$) to a silty fine sand ($2c_2$). It is clearly stratified, occasionally contains shell fragments, and organic rich zones or laminae have been noted (see Figure 4.8). The eastern end of the Issigak deposit shows these features more commonly. Figure 4.1 provides typical gradation envelopes.

f) Clay Interbed (Unit 2d) - in at least three areas of the deposit (see Figure 4.3) an interbed of silty clay, from 0.2 to 1.2 m thick, separates the granular deposits into an upper and lower section. It is texturally very similar to the underlying clay and in cases where there has been minimal penetration of the basal clay, it might be that only this unit that has been encountered.

g) Second Gravel and Sand Zone (Unit 2c) - below the clay interbed is a granular zone, commonly comprised of a gravel Subunit ($2e_1$) overlying a sandy Subunit ($2e_2$). The gravel subunit is very similar in appearance to the Main Gravelly Zone (2b) and the sand subunit is very much like the siltier facies of the Underlying Sand Unit ($2e_2$). On Figure 4.2 the gradation characteristics of Subunit $2e_1$ are compared with Subunit 2b.

h) Underlying Clay (Unit 3) - below the granular materials, the dark grey to black clay appears to range from a thinly laminated silty clay with sand partings (Subunit 3a) to an organic rich silt or clay (Subunit 3b) to a more massive silty clay (included with Subunit 3a). In quite a few boreholes, occasional pebbles have been noted in the clay underlying the granular deposits. The pebbly strata are identified as Subunit 3c. The contact with the overlying granular unit is generally sharp and conformable but interstratification has been observed in some areas, particularly in the organic silt/clay regions and to the eastern end of the deposit.

4.1.2 Assessment of Granular Subunits

The Upper Sand (Unit 2a) is probably a secondary deposit, developed by reworking during the marine transgression. It therefore could be more properly identified as Subunit 1c but has been grouped with the granular units because its gradation. The upper part of Unit 2b may be the source of the sand for Unit 2a. If so, the lower gravelly sand part of Unit 2b may be more typical of the original deposit (ie. not as extensively reworked).

Unit 2c is variable and the distribution of the two subunits: a clean uniform sand and a lower silty portion, is not well understood. Sampling procedures may have mixed a thinly laminated silty sand and clean, uniform sand so that the distribution of separate units cannot be reliably identified.

The three areas where Units 2d and 2e occur are shown on Figure 4.3. There is some reason to question whether two of the eight boreholes in the areas shown actually encountered these subunits. One of the areas is identified by the troublesome Borehole E82 (KB1-3) which has been noted previously to be strangely anomalous. The second is identified by Borehole D80(80-73) for which granular sediments of Unit 2e have been conjectured on the basis of "No Sample Recovery" in a zone that is stratigraphically similar to a granular one on the adjacent borehole D80(80-70). If this zone had contained non-granular (cohesive) sediments, sample recovery would be expected.

A generalized interpretation of the stratigraphy of the Issigak granular deposits is shown schematically on Figure 4.4. In addition, three detailed cross-sections compiled from the borehole logs, adjusted to the datum defined by the ESSO (1984) survey are presented as Figures 4.5 to 4.7. The average thickness of the deposit is shown in Figure 3.3 to be less than 1.5 m. Therefore it is somewhat meaningless to try to indicate typical or average thickness of the seven identified subunits.

The sampling equipment that has been used at Issigak does not accommodate cobbles or boulders. They have been observed during dredging activities and can be seen on side scan sonograms and seabed camera pictures. Some boreholes have also encountered cobbles in sandy facies (Subunits $2b_2$, 2c), as well as in the upper gravelly facies. Boreholes in which cobbles were noted on the logs are indicated on Figure 2.2.

Figure 4.8 presents an interpretation of ESSO's 1983 and 1984 side-scan records made by G. Fortin. It appears to show areas of relatively coarse surface materials (gravel and cobbles) and areas of sand (Unit 2a?). A cobble lag may be present on the surface of parts of the deposit, although not enough data has been acquired to map it.

The amount and topsize of cobbles has not been accurately measured. EBA personnel who provided quality control monitoring on dredges (EBA, 1983) report that 500 mm (20 inches) boulders have been observed and cobbles up to about 130 mm were most common. The cobbles and boulders in some dredge loads comprised an estimated 5 to 10 percent of the total by weight. Loads that were picked-up at the south end of the deposit generally had a higher ratio of gravel to sand and contained more cobbles, than loads from the northern and eastern parts of the deposit.

Further evidence that the eastern end of the main deposit is finer than the western end and two southern zones was obtained by analysis of the borehole logs. The relative proportions of sand and gravel were determined on the basis of the portion of each log that was identified as being gravel (Units $2b_1$ and $2e_1$) compared to the portion that was sand (Units 2a, $2b_2$, 2c and $2e_2$). The gravel/sand ratio (in 1983) for nine zones which are identified on Figure 4.9 was as follows.

ZONE	% GRAVEL	% SAND
1	90	10
2	69	31
3	69	31
4	34	66
5	20	80
6	61	39
7	38	62
8	24	76
9 (Probable Resources)	0	100
1 - 8 (Proven Resources)	53	47

4.1.3 Overburden

A significant feature of the Issigak deposit is the lack of overlying Holocene sediments. The soft, ice-scoured seabed clays which are absent over the borrow area are much thicker all around. Figure 4.8 prepared by G. Fortin from partial side scan coveraged collected by ESSO in 1983 and 1984, shows a wide area of granular sediments exposed on the seabed. This is in sharp contrast to the surrounding area. For example at:

- Kadluk O-07 (5 km to the north) there appears to be 2.5 to 4 m of Holocene clay (ESSO, 1982).
- Netserk F-40 (15 km to the southeast) logs by EBA (1974) show 11 m of Holocene clay.
- Omat (14 km to the northeast) there are 18 m of Holocene clay.
- Tarsiut N-44 (19 km to the northwest) there are 15 m of Holocene clay (McClelland, 1978).

4.1.4 Underlying Sediments

A key consideration in the interpretation of a deposit's geologic origin is its relationship to the strata it overlies. At Issigak the nature of this contact could not be reliably ascertained nor could the distribution of most underburden subunits be mapped. The general lack of detailed sedimentological data on the borehole logs and the relatively shallow penetration of the clay by many of the boreholes make it impossible.

The most widespread sub-borrow strata appears to be thinly laminated silty clay that is described to contains partings of silt and/or sand on about 50% of the logs (Subunit 3a). The clayey sediments frequently contain organic debris and some shell fragments as well as an occasional gravel sized pebble in the upper zone. Those sediments containing the pebbles which are believed to be dropstones have been grouped into Subunit 3c.

A localized subunit that directly underlies the gravel in some areas is an organic rich, probably stratified clay or silt (Subunit 3b). It is commonly described as odoriferous and black. Although most of the previously described thinly laminated or stratified clay contains some organic material including organic laminae, this subunit is distinctly organic rich. Figure 4.3 shows the distribution of boreholes encountering Subunit 3b. It appears to be common along the northern edge and in the eastern part of the deposit. The continuous nature of it suggests some form of lagoon or lacustrine basin. Its occurrence along the northern perimeter suggests that it has been truncated by subsequent erosion.

Commonly where this organic rich subunit occurs, the overlying sand strata has been observed to contain some thin layers of organics. It appears that the sand and organics were being deposited contemporaneously because in some boreholes (for example E83(IBS-S110)) shell fragments, organic debris and clay lenses are noted in the sand (Unit 2c) which is overlain by gravel and cobbles (Unit 2b) in a predominantly sand matrix. The overlying gravel and cobbles suggests that these sediments were not reworked during the marine transgression. Figure 4.7 shows a section where both Subunit 3b and organic zones in the sand were encountered.

4.1.5 Adjacent Sediments

Strata that are similar to the silty clay with pebbles underburden (Subunit 3c) appear as a more widespread deposit in most boreholes located between Issigak and Kadluk. It is generally described as containing a few (commonly less than 5 percent) of 10 mm to 20 mm pebbles (gravel). The distribution of this strata seems to be limited. It has not been identified at Tarsiut, Omat or Netserk North; however, it was encountered at Kadluk and in eight boreholes between there and Issigak. Figure 4.10 correlates the strata between Kadluk to Issigak on the basis of pebbles.

Several interpretations have been considered for the pebbly unit including:

a) that it is a glaciomarine deposit that pre-dates the Issigak deposit, in which case it could be a source for the gravel which was formed as a lag deposit during the Holocene marine transgression.

b) that it is an early Holocene, delta lobe that was topped off with the Issigak deposits in which case the pebbles were derived from the same source as the Issigak gravels.

c) that it is a marine delta sequence that post-dates the gravel emplacement and the pebbles are dropstones that have been picked up by ice freezing to the Issigak gravels.

Based on geologic age data presented by Burden (1986) and discussed in Section 3.2.4, the second case is believed to be the correct one. The explanation for this interpretation is presented in the next subsection. Regardless it does not seem reasonable that the erosion of these strata could be a source for the borrow as a lag deposit. They are generally thin (less than 10 m) with too little gravel which is generally smaller than observed at Issigak. Furthermore there is no evidence of larger clasts (cobbles or boulders) in these sediments. The third alternate has been similarly ruled out because of borehole evidence that pebbly silty clay sediments underlie the Issigak gravels as Subunit 3c.

4.2 GEOLOGIC INTERPRETATION

4.2.1 Assessment of Age

In Section 3.2.4 the geologic framework for this area was described. Unconformity U/C_2 which separates late Wisconsin from early Holocene sediments was traced to Kadluk at a depth of 13 m bsb. On Figure 4.10, pebbly sediments which can be correlated to be early Holocene sediments at Kadluk (Table 3.1), were traced the short distance between Kadluk and Issigak and under the granular deposits.

A moderately well defined horizon marking somewhat unique geologic conditions is recorded on five boreholes on Figure 4.10. It comprises an identifiable zone of blocky to crumbly soil with occasionally slickensided joints and noticeable evaporation salt accumulations on the joints or fissures. It coincides with the bottom of the pebbly zone in four of those five holes. The blocky zone is interpreted to be evidence of a subareally exposed horizon and a related erosional surface which is Unconformity U/C_2.

Unfortunately very few of the boreholes penetrating the Issigak granular deposits have been continued deep enough to encounter the suggested unconformity, and several of those that have are into permafrost at that level making correlation somewhat difficult. One hole, however, (Borehole Number E83(S25)) does identify blocky soil at an elevation of -17.1 m. Although is is quite a ways off the section presented on Figure 4.10 it suggests that the base of the early Holocene sediments might be about -17 m under the granular deposits.

Another borehole (Number D80(80-76)) encountered a substantial peat and organic silt layer (>1.2 m thick) at an elevation of -17.5 m near the northeastern end of the Issigak deposits. This is further evidence of a pre-Holocene surface (U/C_2) which is continuous under the deposit at this level.

The one moderately deep hole located inshore of Issigak that penetrates to a lower strata is Borehole Number D80(80-72). It encountered a silty sand at -16.2 m (see Figure 4.10). It is believed that this horizon also defines the top of the late Wisconsin sediments.

The ability to trace unconformity U/C_2 below the granular deposits is clear evidence that the Issigak deposits are early Holocene or younger.

Overlying the early Holocene sediments at Tarsiut and at Kadluk, by the correlation presented in Table 3.1, are Holocene sediments that post-date the marine transgression. The relative sealevel curve presented as Figure 4.11 (Hill et al., 1985) indicates that this transgression occurred approximately 2500 years ago at Issigak. Late Holocene sediments of this age appear to pinch out between Kadluk and Issigak as shown on Figure 3.8 and 4.10. Thus it appears that the Issigak deposits date from before the transgression or from the early Holocene.

Evidence demonstrating that the Issigak granular deposits pre-date the late Holocene transgression includes the following:

a) O'Connor (1982) interpreted that the late Holocene sediments pinch out a few kilometres north of Issigak (Figure 3.6).

b) Borehole data from the Kadluk-Issigak section (Figure 4.10) shows that the soft silty clay late Holocene sediments are absent for about one kilometre north of the deposit and intermittent for the next two kilometres.

c) Sections through the granular deposits (Figures 3.2, 4.5, 4.6 and 4.7) shows that the underlying clay which has been correlated in Figure 4.10 to early Holocene sediments stands higher than the offshore plain. This would suggest that erosion of the coastline during the late Holocene transgression cut a low coastal bank accounting for the relief. Once submerged, however, the overlying gravels prevented further levelling of the fine grained sediments. Therefore, the granular deposits must have been in place before the transgression occurred.

To conclusively demonstrate that the Issigak deposits are continuous with early Holocene sediments is somewhat more difficult. The following evidence is presented in support of that argument.

a) The clay interbed (Unit 2d) and Second Granular Zone (Unit 2e) are clear evidence of cyclic deposition and that the granular deposits were not deposited under different conditions.

b) The lower part of the granular deposits, particularly Subunit 2c at the eastern end of the deposit, is interstratified with the organic rich parts of Subunit 3b. The organic rich sediments also appear to be gradationally conformable with underlying Subunit 3a.

On the basis of the foregoing, it is concluded that the Issigak granular deposits are from the later stages of the early Holocene. The sediments they overlie are likely from a deltaic lobe which is locally characterized by the inclusion of disseminated pebbles. The extent of the deltaic lobe southeast of the deposit is not obvious because the pebbly strata do not seem continuous in that direction, however, the data base is very sparse for this area.

4.2.2 Origin of the Granular Deposits

Significantly there is no direct evidence of a source for the coarse deposits. A river distributary system capable of transporting approximately nine million cubic metres of sand and gravel, with cobbles and boulders up to 500 mm should be very easy to detect. However, in the few scattered boreholes between Issigak and the present delta, no evidence of such a channel has been recorded.

Furthermore, there is no evidence of material of similar gradation being located closer than Ya Ya Lakes on Richlands Island (85 km to the southeast). Nor is there evidence of older sediments that could be eroded to produce gravelly sediments closer than Pelly Island. The fluvial gradient between Pelly Island and Issigak would not be sufficient to support a channel carrying clasts of this size either (see Figure 3.1).

The surface on which the early Holocene sediments were deposited was well above sealevel. At the beginning of the depositional sequence, say 9500 years ago, sealevel was at an elevation of -55 to -60 m (see Figure 4.11, from Hill et al., 1985) and the land surface between Kadluk and Issigak was apparently at an elevation of -20 to -24 m. By the end of that sequence, say 7500 years ago (based on Tarsiut N-44 data presented in Table 3.1), sealevel had risen to -40 to -45 m and the level of sediments had risen to at least -9 m at Issigak. The shell fragments, organic rich strata and finely laminated clays therefore must be indicative of a lacustrine deltaic environment. An examination of the shells to determine their marine, estuarine or lacustrine affinity would provide conclusive proof of this. O'Connor (1982) made a similar observation about the sediments infilling the large depressions at the base of the Ikit Trough perhaps being lacustrine in origin.

On a coastal plain, above sealevel, fluvial action is required to explain the movement and accumulation of stratified sands and gravels. Gradation data presented in Section 4.1.2 indicates that the southwest end of the known deposits is coarser and must be nearer the source. The northeast end seems to be finer (more sand) and more clearly stratified. It may be fluvial-deltaic whereas the southwestern, upstream end is likely fluvial.

The profile presented on Figure 4.12 shows that there is a modest downward gradient from the southwest part of the deposit to the northeast end. The elevation of the troughs in the base of the deposit evident on Figures 3.2, 4.5, 4.6 and 4.7 have also been plotted. It is believed that these troughs are possibly infilled channels indicating that distributary flow and local gradient was from the southwest to the northeast.

As noted in Subsection 4.1.4 the northeastern or deltaic portion may have been deposited into a lacustrine or lagoonal water body that had an organic rich bottom. That this environment and perhaps the granular deposits at one time extended further northward and were partially eroded during the transgression is suggested by the profile on Figures 3.2, 4.5 and 4.6. Lowering of the land surface, immediately north of Issigak by 2.5 to 4.5 m during the transgression is indicated.

The distribution of cobbles and boulders in a predominantly gravel and sand deposit strongly suggests that ice floe transport was an active process during the formation of the Issigak deposit. The occurrence of dropstone pebbles in the underlying and adjacent sediments of the early Holocene delta requires that this process was active for a relatively long period. The limited distribution of the dropstones, as discussed in Subsection 4.1.5, and the apparently very restricted distribution of a substantial volume of larger clasts to the area of the Issigak deposit indicate that the ice carrying the dropstones, cobbles and boulders was likely to have originated in the river area rather than further offshore.

A major question that remains is where was the source of the gravel. The presence of cobbles and boulders suggests that the source is likely late Wisconsin or older glacially derived sediments. The coarseness also suggests that the distance to the source may not be more than about 10 km. That is in conflict with late Wisconsin glacial ice limits shown on Figure 3.7. Alternately there may be an undetected remnant of a barrier island, like Pelly or Garry Island, which are believed to be products of Buckland Glaciation, south of Issigak. The former explanation is considered more likely because late Wisconsin a sediment would have been exposed when the first early Holocene sediments were being deposited, whereas Figure 3.5 suggests older glacial sediments were buried under a considerable thickness of late Wisconsin deltaic sediments.

5.0 BORROW RESOURCE QUANTITIES

5.1 QUANTITY INTERPRETATION

The initial (pre-1974) quantity of material at the Issigak pit cannot be determined. The lack of a detailed predevelopment survey and detailed dredging records for the period prior to 1983 preclude it. Furthermore, the inconsistencies between borehole and bathymetric data, discussed in Subsection 2.1, prevent reconstruction of the original bathymetry.

As previously noted, it was necessary to adopt ESSO's 1984 bathymetry as a basis of evaluating topographic features because it was the most complete survey of the entire study area. The most detailed borrow thickness information, comprising 125 boreholes of the 176 available in the area, were obtained by ESSO in July 1983. Between these two events ESSO removed 1.5 million cubic metres from the deposit (approximately 52 percent of the 1983 'proven' reserves). Therefore the distribution and thickness of the borrow could not be extrapolated on the basis of bathymetry.

Figure 4.9 shows the outline of the proven, probable and prospective resource areas as discussed below. It also shows the boundaries for nine zones, defined on the basis of the isopachs, which exhibit varying gravel and sand content. A west to east change in the gravel to sand ratio is reported in Subsection 4.1.2.

Quantities of borrow have been calculated from borrow isopachs for each zone and resource area. The isopachs, shown on Figure 5.1, were prepared on the basis of the data available in July 1983. The quantities have been subsequently adjusted for dredging that occurred in 1983 through 1986, inclusive. This data is summarized on Table 5.1.

There is a conflict between the quantities calculated for some zones and the volume of material reportedly dredged therefrom. ESSO dredging records, which relate the quantity removed to the source area, indicate that more material has been removed since 1983 from each of Zones 2, 3 and 4 than the isopachs indicate was available. Whether this difference is a result of ESSO's method of quantity calculation, their notes on where the material was dredged, or on the reliability of the isopach based calculations is not clear.

5.2 RESOURCE QUANTITIES

5.2.1 Prospective Resources[1]

The area shown in Figure 4.9 for prospective resources is based primarily on side scan sonar data (Figure 4.8) with some adjustments along the northern edge for seismically mapped continuations of the sharp reflector associated with the deposit. This area is, therefore, primarily bounded by the exposure of sand and gravel except on the north side.

Only three widely scattered boreholes show direct evidence to support speculation of any economic borrow material outside this area. North of Issigak, littoral silty sand sediments occur at the marine transgression boundary. The sand and silt at 0 to 3.0 m depth (bsb) in Borehole Number E74(306) and the silty sand at 1.0 to 1.8 m depth (bsb) in Borehole Number E82(K-3-1) occur on this horizon (see Figure 4.10). They are texturally and stratigraphically similar to the sands in the Probable Resource area, around the main body of the deposit, and are interpreted to have washed out of gravelly sediments (ie. Subunit 2a).

It is not clear whether the 0.2 m thick veneer of sand and gravel logged in Borehole E74(314) is evidence of littoral (trangression) deposits or is an outlying remnant of the main body of the deposit.

1. Prospective resources are defined as 'granular resources that are speculated on the basis of only one type of indirect evidence', such as side scan traces or seismic data.

Other nearby boreholes did not confirm the presence of economic borrow in any of these areas. Therefore, they have not been included in the calculation of prospective resources.

In that regard the following should be noted.

a) The east end of the borrow area is not well defined, although there is borehole and sidescan evidence that the deposit doesn't extend as far as UTM 467000 mE.
b) No work of any significance has been conducted south of Zone 1.
c) ESSO's 1984 seismic data is reported (Nelson, Pers. Comm) to show that the early Holocene reflector extends northeastward towards E74(314) under thin clayey sediments. The extent of this reflector and whether it is related to granular sediments or only to the early/late Holocene unconformity cannot be confirmed because that data is missing.

South of Zone 1 it is too shallow for the dredges currently available in the Beaufort Sea. Therefore the operators have had little incentive to look in that direction. The shallow water also makes seismic surveys difficult to interpret. The lack of data, however, doesn't preclude the possibility that granular borrow could extend in that direction. The gradation of the deposits (see Section 4.2.2) indicates that the origin of the Issigak borrow is in that direction and that if further reserves do exist they will be predominantly gravel.

The area outlined on Figure 4.9 for prospective resources is approximately 2150 hectares and the area of probable resources is approximately 1450 hectares. For purposes of volume calculation, it has been assumed that an average thickness of borrow in the prospective zone is 0.1 m. On this basis the volume of respective resources (as of 1983) has been calculated to be 702,800 cubic metres. Large parts of this area may have only a thin veneer of sand and quite possibly other areas have up to 1.0 m

5.2.3 Proven Resources[2]

Geotechnical drilling programs, sampling by drop-samplers and dredging have delineated approximately 3,274,700 cu.m. of granular sediments were in the area of the proven resources prior to 1983. It is known (S. Fitzmorris, personal communications) that ESSO have been dredging primarily in the area of Zones 1 to 5. The quantities reportedly removed from each zone between 1983 and 1986 are indicated on Table 5.1. The quantity of granular material remaining in total is not thought to be misleading; however, there is doubt about the quantity remaining in each zone, because of the disagreement with ESSO's dredging data.

Overburden is not a concern in the main pit area. Only one borehole, that encountered potentially economic granular materials, penetrated any overburden. All of the others in this area (159 of 160) encountered no overburden.

5.2.4 Total Resources

From Table 5.1 the calculated volumes of granular deposits at Issigak at the end of the 1986 dredging season were:

Proven Resources - 3,274,700 cu.m.
Probable Resources - 5,074,800 cu.m. (including Proven Resources)
Prospective Resources - 5,777,600 cu.m. (including Probable and Proven Resources)

2. Proven resources are defined as 'granular resources for which the thickness, distribution and quality are known through direct sampling methods'.

As noted previously, there is some conflict between volumes calculated for each zone from isopachs based on borehole data and quantities determined by ESSO's dredging data. The most convenient explanation for this is that ESSO has dredged some of the probable and prospective resources bordering these areas. With the data available, no other explanation can be incorporated into calculations of gravel and sand quantities.

A previous quantity assessment by O'Connor (1983) speculated that the Issigak deposits contained as much as 15 million cubic metres of which 70 percent (10.5 million) could be considered proven reserves. The area to which O'Connor referred was noted to be 1500 to 2000 hectares. In this present study, 9.0 million cubic metres of granular borrow has been calculated for the Prospective Resources area in early 1983. The Prospective Resources cover an area of about 2150 ha. Thus these two estimates appear to agree in number, although the present study utilizes a much narrower definition of proven resources.

O'Connor (1983) also noted that "it is possible that additional borehole information at both the south and northeast ends of the deposit may ultimately establish reserves in the 35,000,000 to 40,000,000 cubic metre range". This comment was not supported by any evidence and must be termed speculative. The relatively small volume of probable and prospective resources presented herein reflects the fact that the area of the deposit has been well defined and most of the surrounding area has been evaluated and found to be without evidence of economic reserves.

It is possible that the speculation was based on interpretation of shallow seismic data that could not be found for this present study. The older seismic data probably shows a near surface, moderate to high amplitude reflector extending over an area of several square kilometres to the northeast of Issigak. ESSO's 1984 seismic data is reported to show this also (C. Nelson, personal communications). The reflector could be linked to the Issigak deposits and therefore could have been interpreted to be evidence of similar deposits.

More likely, the reflector is the unconformable boundary between the early and late Holocene sediments. In areas where the marine transgression was most active, a sharp reflector would have been produced. There is also some evidence of thin sand pockets and local littoral deposits occurring on this horizon (Boreholes E74(306 and 314) and E82(K-3-1) on Figure 4.10). There is not enough evidence to extrapolate the data from any of these three holes into economically viable deposits; however, one cannot eliminate that possibility either.

5.3 GRAVEL: SAND RATIO

In Subsection 4.1.2 and on Table 5.2 the ratio of gravel/sand is shown for proven resources in each zone, based on borehole log data. Overall, the ratio was approximately 53 percent gravel to 47 percent sand in 1983. Between 1983 and 1986 almost 52 percent of the proven resources were dredged, including substantially all of the proven material from Zones 2, 3 and 4. The calculated post-1986 gravel/sand ratio is 37 percent gravel to 63 percent sand for the proven resources.

For the area lying outside of the Proven Resources, four of nine boreholes, shown on Figure 4.9, show granular sediments and none encountered gravel facies. The geological interpretation of this part of the deposit is that most of this matrial will be re-mobilized sand (Unit 2a) that was washed out of the main deposit during the marine transgression. Not much gravel should therefore be expected in the Probable and Prospective Resource areas.

On this basis the relative proportion of gravel and sand remaining have been interpreted to be:

ZONE	% GRAVEL	% SAND	QUANTITY
Proven Resources	37	63	3,274,700
Probable Resources	0	100	1,800,100
Prospective Resources	0	100	702,800
TOTAL	21	79	5,777,600

6.0 RECOMMENDATIONS FOR FUTURE WORK

6.1 CONFIRMATION OF THE GEOLOGIC MODEL

The purpose for including a detailed geologic study with an assessment of Issigak borrow quantities, which is INAC's more usual mandate, was to develop a framework for further borrow exploration in the western part of the Beaufort Sea. A geologic model has been presented herein which seems to explain the stratigraphic age and depositional environment of the deposit, for the first time. Before the model is fully accepted some of the speculative aspects of it should be confirmed. The first of these is the correlation of the early Holocene zone at Tarsiut to the pebbly zone between Kadluk and Issigak. The following data are required to confirm this.

a) A high resolution shallow seismic line or series of closely spaced parallel lines should be acquired along the section defined in Figure 4.10 and extended to the northwest to Tarsiut N-44.

b) Two or three intermediate boreholes to a depth of about 40 m (bsb) are required between Tarsiut N-44 and Kadluk H-08.

c) Two boreholes to a depth of about 20 m (bsb) are required on the same line in the area where they would penetrate the Issigak deposits.

d) One or two boreholes to a depth of about 15 m (bsb) are required on the same line between Borehole Numbers D81(Tar22) and D80(80-72) (see Figure 4.10).

e) One borehole between Kadluk and Issigak were the section crosses the Omat line (Figure 4.10) would be very useful.

These holes should be logged with careful attention to subtle geologic detail which will be crucial to confirming the model. Some effort to obtain and date organic material from this section would also be valuable. Other datable material should be obtained from the organic rich sediments directly underlying the granular deposits in the areas shown on Figure 4.3 and from the deeper, late Wisconsin-early Holocene boundary believed to be identified at a depth of 8 m (bsb) in Borehole D80(80-76) on Figure 4.10.

6.2 IDENTIFICATION OF SOURCE AREA

One of the most perplexing issues that remains unsolved is to identify the source area for the Issigak granular materals. Although the gradation trend suggests that the source area is off the southwest end of the mapped deposits, the source area and deltaic channel leading into Issigak could be anywhere shoreward of the deposits. Some east-west high resolution seismic profiles would be very valuable if they can be obtained in the shallow waters (5.0 to 9.5 m) south and southwest of Issigak. From these profiles one may be able to orient on the source area where other gravel deposits are thought to exist.

6.3 ADDITIONAL BORROW EXPLORATION

There is weak evidence to indicate that some pockets of granular material exist on the early-late Holocene boundary north and northeast of the main deposits (Boreholes E74(306, 314) and E82(K-3-1) on Figure 4.9). These three isolated sites do not define an economic borrow area be themselves; however, they do offer a hint of other prospects. There is no reason to believe that major deposits of granular material will exist in these areas; however, there may be small pockets that can be economically dredged.

ESSO's missing 1984 seismic program is reported to show (C. Nelson, personal communications) some suggestion of granular sediments under about 2 m of soft (late Holocene) clays in an area 2 to 4 km northeast of Issigak. If ESSO's 1984 seismic data is ever found, several key issues could be resolved with that data. If it is not found further seismic and perhaps borehole data should be acquired in this area.

6.4 MISCELLANEOUS STUDIES

6.4.1 Petrologic Comparison

It may be useful for developing an understanding of the granular deposits in the Beaufort-Delta region to collect petrologic data on the known gravel deposits. The petrology of the deposit is a product of its source area and the method of transport can be inferred from physical characteristics of the particles. For example, with this information one might be able to link the Issigak deposits to similar deposits on the Yukon coast and show that it is different than Ya Ya Lakes deposits.

6.4.2 Sediment Erosion

As reported in Subsection 4.1.3 the absence of late Holocene sediments is evidence that submarine erosion of recent sediments has been occurring in this region. This conclusion has implications for the design of island production structures for future Beaufort Sea development. Further investigation of the engineering significance of this observation may be warranted by the Beaufort operators.

6.5 DATA MANAGEMENT

The availability of data from the six seismic programs listed in Table 2.1, was inadequate for this archival study. Some records have been lost and others dismissed as being of too poor quality without full interpretation. Recently the operator's have established a common storage depot for some of this data, but that contains only some of the original seismic traces. Furthermore, field notes and interpretations of some traces have never been incorporated into a report. That data remains uncompiled, and in the memories of industry staff who are no longer involved in the Beaufort.

Formal reports including shot point maps, geologic interpretations and typical or critical seismic sections should be provided for each seismic program. The cost of this reporting relative to the cost of acquiring the data is not likely to be an issue. For most programs the cost of the interpretive report would be less than a few hours sailing time.

In a related vein, it would be valuable to establish a core or sample depository to keep selected samples or photos of samples from each area. Not only samples of granular materials, but permafrost core and undisturbed core for geological interpretation should be catalogued and preserved for type sections in each deposit or region. For the study presented herein, it would have been very informative to be able to examine a sample of the Issigak gravel or to compare photos or x-rays of the stratigraphic features in the Tarsiut N-44 and Kadluk H-08 boreholes.

7.0 CLOSURE

The Beaufort Sea operator's and their staff have been most helpful and supportive of this project, not only by providing data but also by contributing their ideas and technical assistance throughout. In considering the long history of exploration and development at the site and the progression of staff who have had something to do with the development of the data base, it is fortunate that so much of the data was accessible.

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LICENSEE
N.W.T.

THE ASSOCIATION OF PROFESSIONAL ENGINEERS, GEOLOGISTS and GEOPHYSICISTS OF THE NORTHWEST TERRITORIES
P 018
EBA ENGINEERING CONSULTANTS LTD.

N.R. MacLeod, P.Eng.,
Project Director

NRM:jms:dmc

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TABLE 2.1

HISTORY OF ACTIVITIES IN THE ISSIGAK BORROW BLOCK

EVENT	OPERATOR	YEAR/MONTH	PROJECT DESCRIPTION	DATA	REFERENCES OR DATA EXAMINED
1	Esso	1974/March	Site Investigation, Coring Program	11 B.H. (Boreholes)	EBA, 1974
2	Esso	1975/March	Site Investigation, Coring Program	4 B.H.	EBA, 1975
3	Dome	1980/August	Regional Shallow Seismic Program	40 km	No Report
4	Dome	1980/August	Borrow Investigation, Drilling	18 B.H.	EBA, 1980
5	Dome	1980/Sept.	Dredging	Quantity Unknown	No Report
6	Dome	1981/March	Borrow Investigation, Drilling	6 B.H.	EBA, 1981
7	Dome	1981/July	Borrow Investigation Program	25 B.H., 20 Surface Samples	EBA et al., 1981
8	Esso	1981/	Seismic Program	Omat Line	No Report
9	Dome	1981/Summer	Dredging for Tarsuit Island	Quantity Unknown	No Report
10	Gulf	1981/	Shallow Seismic Data Interpretation	10 km	Map/No Report
11	Gulf	1982/	Dredging	Quantity Unknown	No Report
12	Esso	1982/Sept.	Borrow Investigation Program, Kadluk Site Inv	7 B.H. In Borrow Area	Hardy, 1982
13	Esso	1982/	Detailed Bathymetric Profiling	Unknown	Not Seen
14	Esso	1982/Oct.	Grab Sampling Program	37 G.S. (Grab Samples)	No Report
15	Gulf	1982/Oct.	Bathymetric & Sub-Bottom Profiling	Unknown	Maps, No Reports
16	Esso	1983/	Extensive Shallow Seismic Program	300 km	Data/No Reports
17	Esso	1983/July	Borrow Investigation Program	125 B.H., 273 G.S.	EBA, 1983a
18	Esso	1983/Summer	Dredging for Nipterk	302,600 cu.m.	EBA, 1984
19	Esso	1984/July	Side Scan & Uniboom	? km	S.S. Only
20	Esso	1984/July	Drop Sampler Program	? G.S.	Johnson, 1984
21	Esso	1984/Summer	Dredging for Nipterk, Minuk, Amerk & Kaubvik	1,555,000 cu.m.	Pers. Comm.
22	Gulf	1984/Sept.	Shallow Seismic Program	17 km	No Report
23	Gulf	1984/Summer	Dredging	Quantity Unknown	No Report
24	Esso	1985/Summer	Dredging for Minuk & Kaubvik	1,487,000 cu.m.	Map & Pers. Comm.
25	Esso	1985/Sept.	Bathymetric Survey		Map & Pers. Comm.
26	Esso	1986/Summer	Dredging for Kaubvik	145,000 cu.m.	Map & Pers. Comm.

TABLE 2.2

COMPARISON OF DATA FROM ADJACENT BOREHOLES

BOREHOLE NUMBER	BOREHOLE SPACING (m)	WATER DEPTH (m)	GRAVEL THICKNESS (m)	SAND THICKNESS (m)	BORROW THICKNESS (m)	DEPTH TO CLAY (m)
D81 (Tar 10)		8.4	N/E	1.2+	1.2+	N/E
D81 (Tar 11)		9.2	N/E	1.1+	1.1+	N/E
Difference	16	0.8	N/A	N/A	N/A	N/A
E83 (IBS-04)		10.9	N/E	1.3	1.3	12.2
E83 (IBS-05)		10.9	0.5	N/E	0.5	11.4
Difference	25	0.0	0.5	1.3	0.8	0.8
E82 (KBI-1)		8.0	N/E	2.6	2.6	10.6
E83 (IBS-110)		7.8	0.3	2.2	2.5	10.4
Difference	24	0.2	0.3	0.4	0.1	0.2
E83 (IBS-S1)		8.3	0.8	0.6	1.4	9.7
E83 (IBS-112)		7.8	N/E	1.8	1.8	9.6
Difference	32	0.5	0.8	1.2	0.4	0.1
D81 (Tar 24)		8.5	1.4+	0.4	1.8+	10.3+
E83 (IBS-108)		8.1	N/E	1.2	1.2	9.3
Difference	40	0.4	1.4+	0.8	0.6+	1.0+
D81 (Tar 23)		8.8	0.2+	1.3	1.5+	10.3+
E83 (IBS-58)		8.8	N/E	1.2	1.2	10.0
Difference	11	0.0	0.2+	0.1	0.3+	0.3+

TABLE 2.2 (continued)

COMPARISON OF DATA FROM ADJACENT BOREHOLES

BOREHOLE NUMBER	BOREHOLE SPACING (m)	WATER DEPTH (m)	GRAVEL THICKNESS (m)	SAND THICKNESS (m)	BORROW THICKNESS (m)	DEPTH TO CLAY (m)
D81 (Tar 19)		8.5	N/E	0.7+	0.7+	9.2+
E83 (IBS-58)		9.2	0.2	0.8	1.0	10.2
Difference	31	0.7	0.2	N/A	N/A	N/A
D81 (80-82)		7.6	N/E	1.8	1.8	9.4
E83 (IBS-41)		8.1	0.7	0.8+	1.5+	9.6+
Difference	31	0.5	0.7	N/A	N/A	0.2+
D80 (80-74)		7.6	1.8	N/E	1.8	9.4
E83 (IBS-52)		8.0	0.8	0.7	1.5	9.5
Difference	37	0.4	1.0	0.7	0.3	0.1
Maximum Difference	40	0.8	1.4+	1.2	0.8	1.0
Minimum Difference	11	0.0	0.2	0.1	0.1	0.1
Average Difference	27	0.4	0.6+	0.8	0.4+	0.4+

Notes: 1. Where thickness or depth exceeds the total B.H. penetration the measured maximum is given with a + symbol (e.g. 0.4+).
2. N/E - not encountered.
3. N/A - not applicable.

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TABLE 3.1

REGIONAL STRATIGRAPHIC COMPARISON

TARSIUT A-25 (from McClelland, 1978)		TARSIUT N-44 (by P. Hill in Burden 1986)		BURDEN'S (1986) TARSIUT N-44 INTERPRETATION			KADLUK H-08 (FROM HARDY, 1983)		KADLUK O-07 (FROM HARDY, 1983)	
7 756 500 m N 448 200 m E 24 500 m SE 23 m		7 755 000 m N 454 000 m E 18 800 m SSE 23 m		UTM CO-ORDINATES DISTANCE TO ISSIGAK DEPOSITS (m) WATER DEPTH (m)			7 742 360 m N 461 300 m E 5 200 m SSE 14 m		7 741 500 m N 400 600 m E 4 400 m SSE 14 m	
DEPTH (m) (bsb)	DESCRIPTION	DEPTH (m) (bsb)	DESCRIPTION	UNIT	DEPOSITIONAL ENVIRONMENT	INTERPRETED AGE	DEPTH (m) (bsb)	DESCRIPTION	DEPTH (m) (bsb)	DESCRIPTION
0 - 3	Olive grey soft to firm clay with shell fragments.	0 - 6	Grey bioturbated clay with shell fragments.	A	Prodelta Becoming Marine	Present	0 - 3	Soft silty clay.	0-2.5	Soft silty clay, trace of gravel.
					Unconformity (U/C_3)	< 6 800 / 7 500				
3 -16	Dark grey silty clay with silt partings to lenses stiff to very stiff	6 -15	Dark grey bioturbated silty clay with silt lenses and dessicated horizons.	B	Delta		3 -13	Stiff silty clay.	2.5-13	Stiff silty clay, laminated, some sand layers near top, trace of gravel.
					Unconformity (U/C_2)	9 500 / 14 600				
16-22	Dark grey silty fine sand with some gravel.	15-21	Laminated/lenticular graded silty clay (top) to graded sand and clay (bottom).	C	Becoming Non-Marine	17 000	13-26	Compact silt.	13-17	Silt sandy to trace of sand.
22-34	Olive grey silty clay with silt partings grading down to clayey silt with clay partings.	21-36	Laminated dark grey silty clay. (gradational transition)	D	Prograding Delta				17-34	Interbedded silty clay and clayey to sandy silt

TABLE 3.1 (continued)

REGIONAL STRATIGRAPHIC COMPARISON

TARSIUT A-25 (from McClelland, 1978)	TARSIUT N-44 (by P. Hill in Burden 1986)	BURDEN'S (1986) TARSIUT N-44 INTERPRETATION	KADLUK H-08 (FROM HARDY, 1983)	KADLUK O-07 (FROM HARDY, 1983)
34-60 Olive grey clay with silty partings and silty layers.	(gradational transition) 36-56 Laminated silty clay.	E Prograding Delta	26-70 Very stiff silty clay	34-61 Very stiff laminated silty clay with occasional silt pockets.
	56-66 Homogeneous, bioturbated silty clay with forams.	F 18 000		
60-86 Olive grey clay with organic and sandy pockets and some shell fragments. 86-94 Olive grey clayey silt with some wood fragments. 94-121 Grey clay with silt lenses and partings some wood fragments 121-122 Silty fine sand. End of Borehole	66-129 Thick bedded, laminated clay with some sand beds and organic debris.	Prodelta to Marine G Marine Transgression	70-76 Dense fine sand. 76-100 Stiff clay. 100-113 Stiff silty clay. 113-131 Stiff silty clay. End of Borehole	61-93 Dense fine sand, occasional shell fragments and thin silt and clay layers. End of Borehole
	129 Dated Peat Horizon 130-166 Laminated silt and clay. End of Borehole	Non-Marine 27,000 H Rapidly Prograding Delta		

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TABLE 5.1

BORROW RESOURCE QUANTITIES

ZONE	1983 RESOURCE QUANTITIES PROVEN RESOURCES (m^3)	1983 RESOURCE QUANTITIES PROBABLE RESOURCES (m^3)	1983 to 1986 DREDGING (m^3)	CALCULATED POST-1986 QUANTITIES PROVEN RESOURCES (m^3)	CALCULATED POST-1986 QUANTITIES PROBABLE RESOURCES (m^3)
1	742,100	1,081,300	377,200	364,900	704,100
2	263,000	431,700	525,800*	Apparently Depleted (Zones 2–4)	653,000 (Zones 2–4)
3	529,200	899,000	1,550,700* (Zones 3–4)		
4	998,000	1,398,800			
5	1,660,700	2,022,300	726,900	933,800	1,295,400
6	109,900	-	-	109,900	-
7	1,184,700	1,552,300	-	1,184,700	1,552,300
8	681,400	870,000	-	681,400	870,000
TOTALS	6,169,000	8,255,400	3,180,600	3,274,700	5,074,800
PROSPECTIVE RESOURCES		8,958,200			5,777,600

* Quantities dredged between 1983 and 1986 exceed calculated quantities for 1983. A subjective proportioning of the difference from the Probable Resources and from Zone 5 has been necessary.

TABLE 5.2

CALCULATED GRAVEL AND SAND RESOURCES

ZONE	PROVEN RESOURCES (GRAVEL:SAND) (m^3)	PROBABLE RESOURCES (GRAVEL:SAND) (m^3)	PROVEN GRAVEL RESOURCES (m^3)	PROVEN SAND RESOURCES (m^3)
1	364,900 (90:10)	704,100 (0:100)	328,400	36,500
2	Apparently Depleted (Zones 2–4)	653,000 (0:100) (Zones 2–4)	-	-
3			-	-
4			-	-
5	933,800 (20:80)	1,295,400 (0:100)	186,800	747,000
6	109,900 (61:39)	-	67,000	42,900
7	1,184,700 (38:62)	1,552,300 (0:100)	450,200	734,500
8	681,400 (24:76)	870,000 (0:100)	163,500	517,900
TOTALS	3,274,700 (37:63)	5,074,800 (0:100)	1,195,800 37%	2,078,800 63%
PROSPECTIVE RESOURCES		5,777,600 (0:100)	1,195,800 21%	4,581,800 79%

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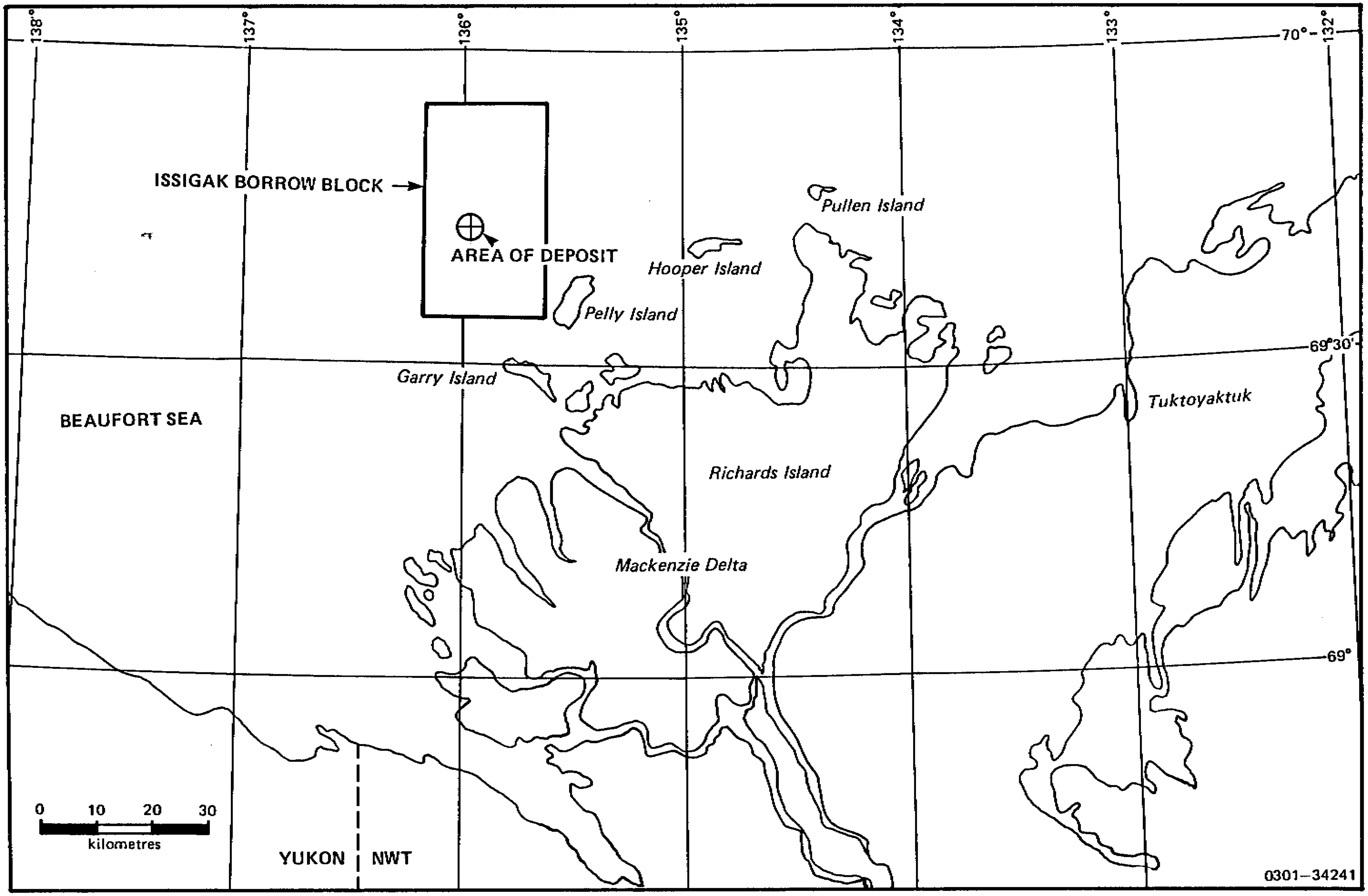

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FIGURE 1.1 GENERAL LOCATION MAP

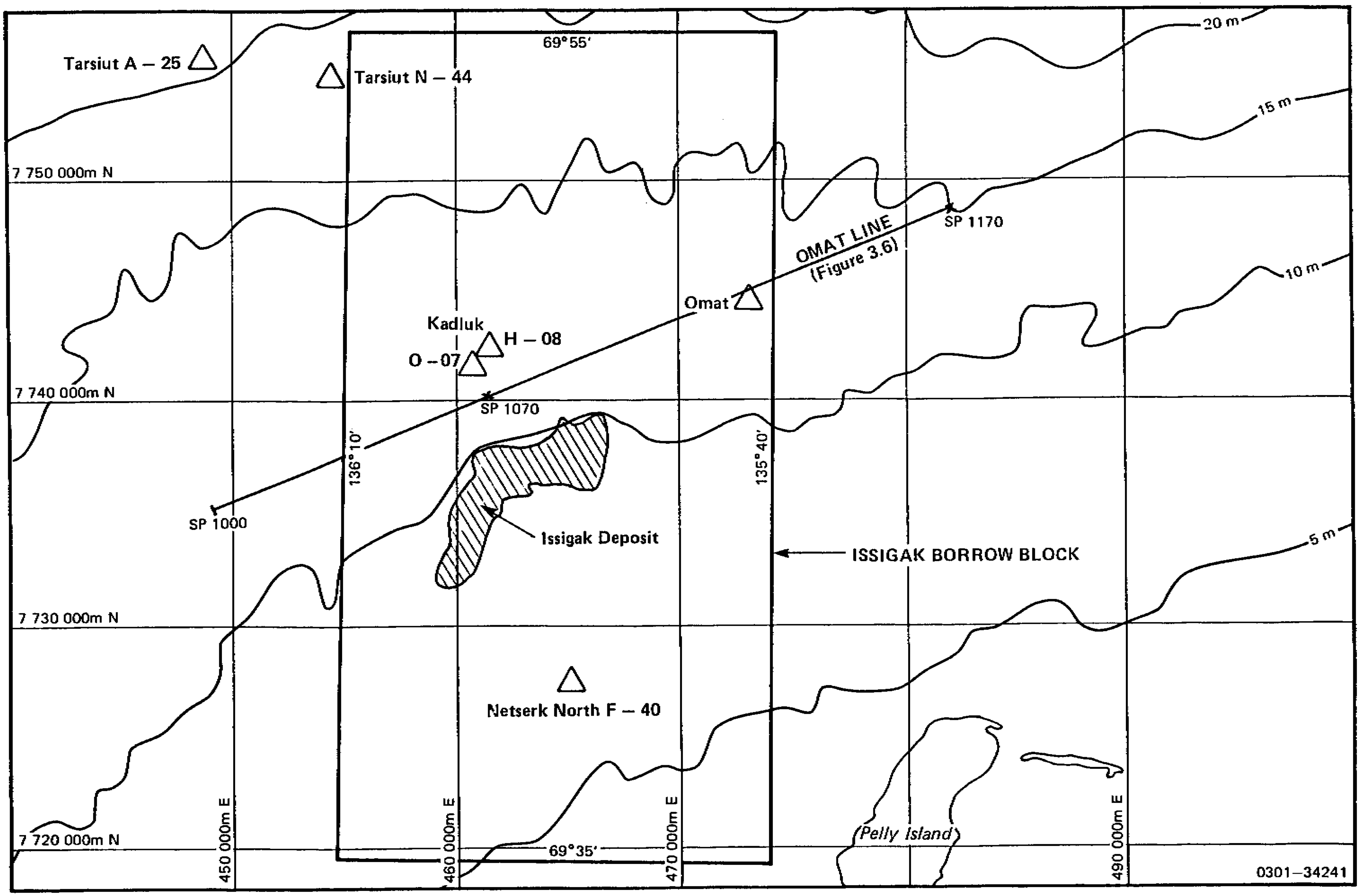

FIGURE 2.1 REGIONAL BATHYMETRY AND REFERENCED WELLSITES

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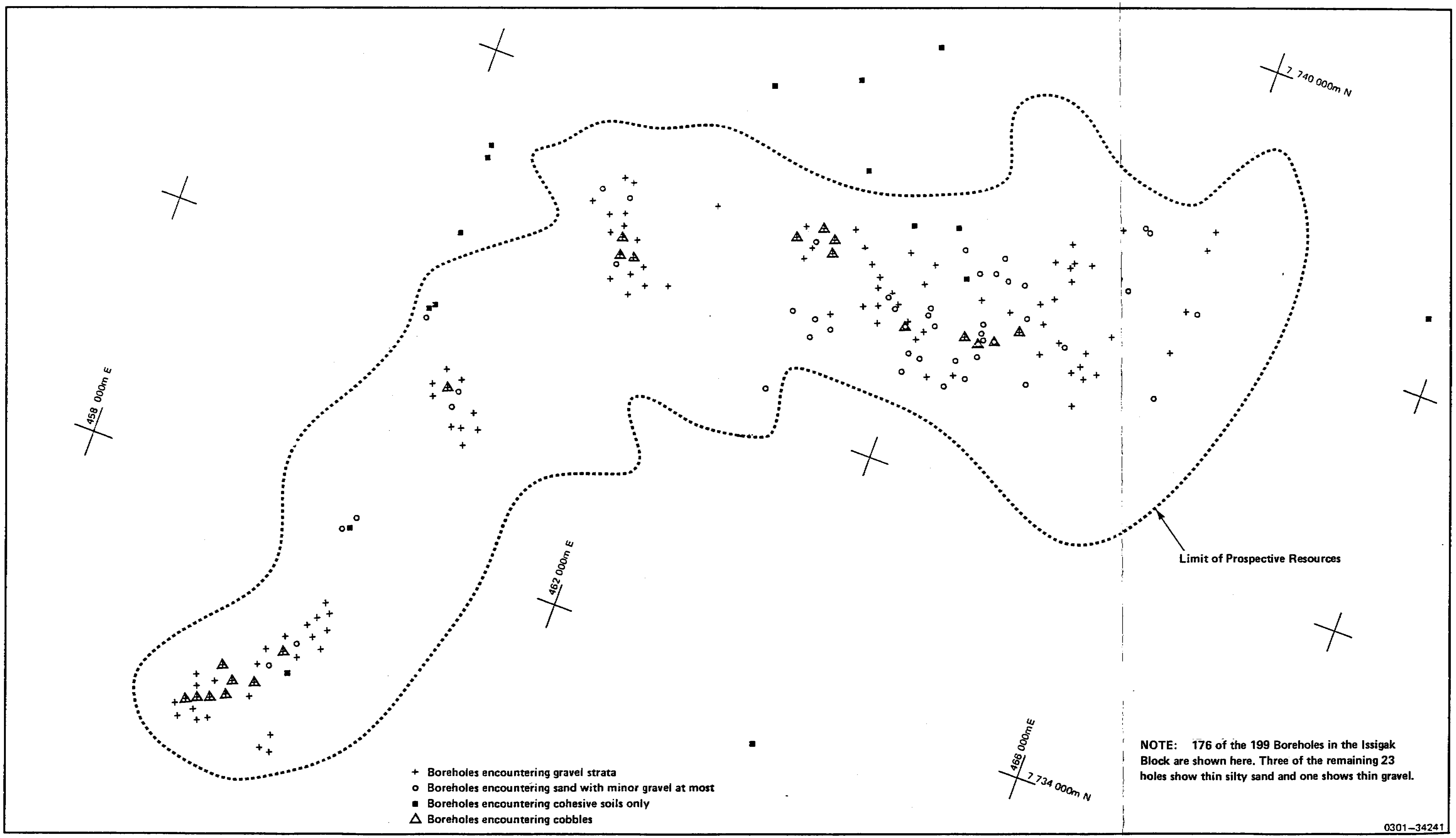

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FIGURE 2.2 LOCATION OF BOREHOLES IN THE BORROW PIT AREA

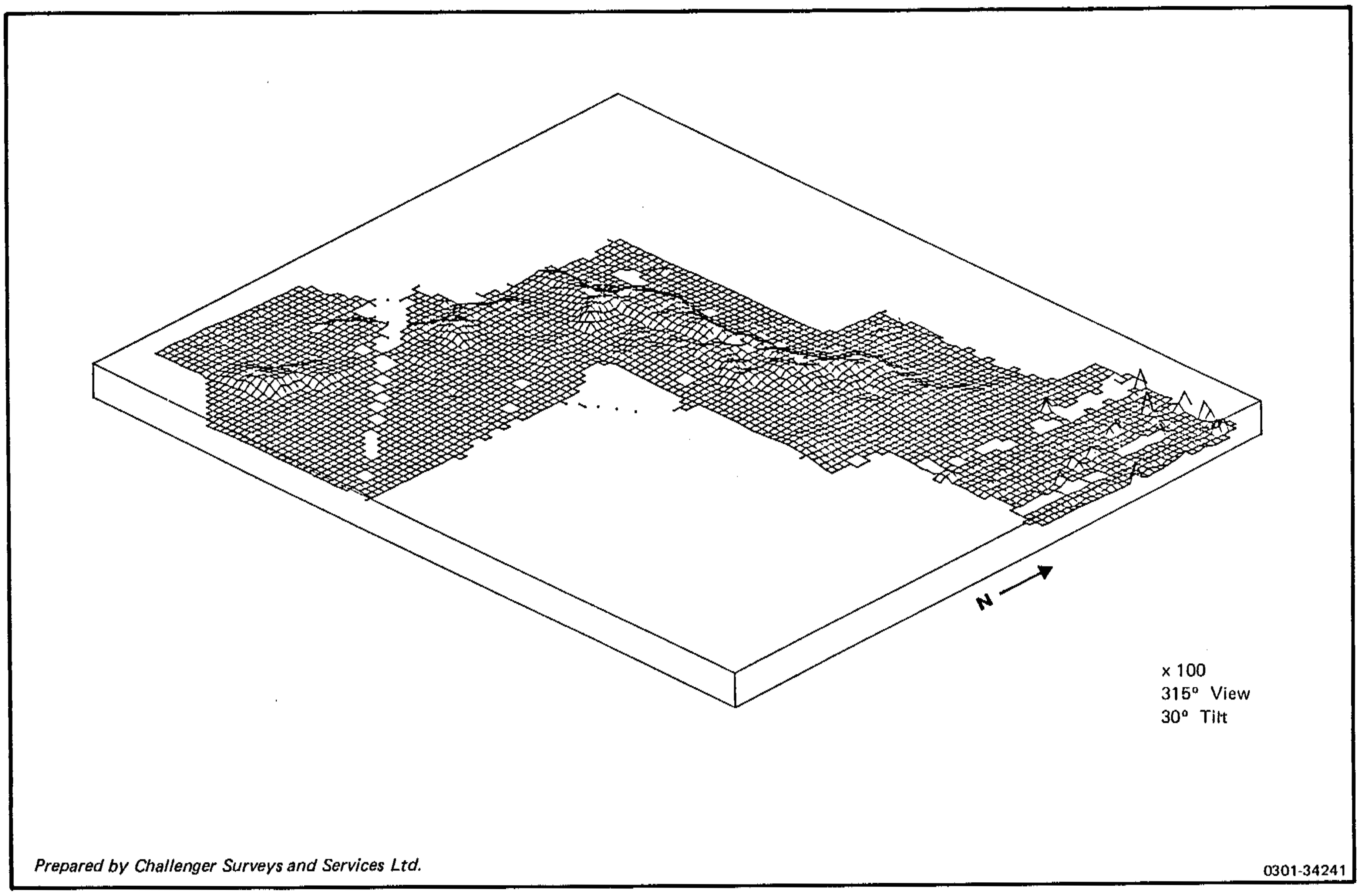

FIGURE 2.3 TOPONET PROJECTION OF ISSIGAK DEPOSIT VIEWED TOWARDS NORTHWEST

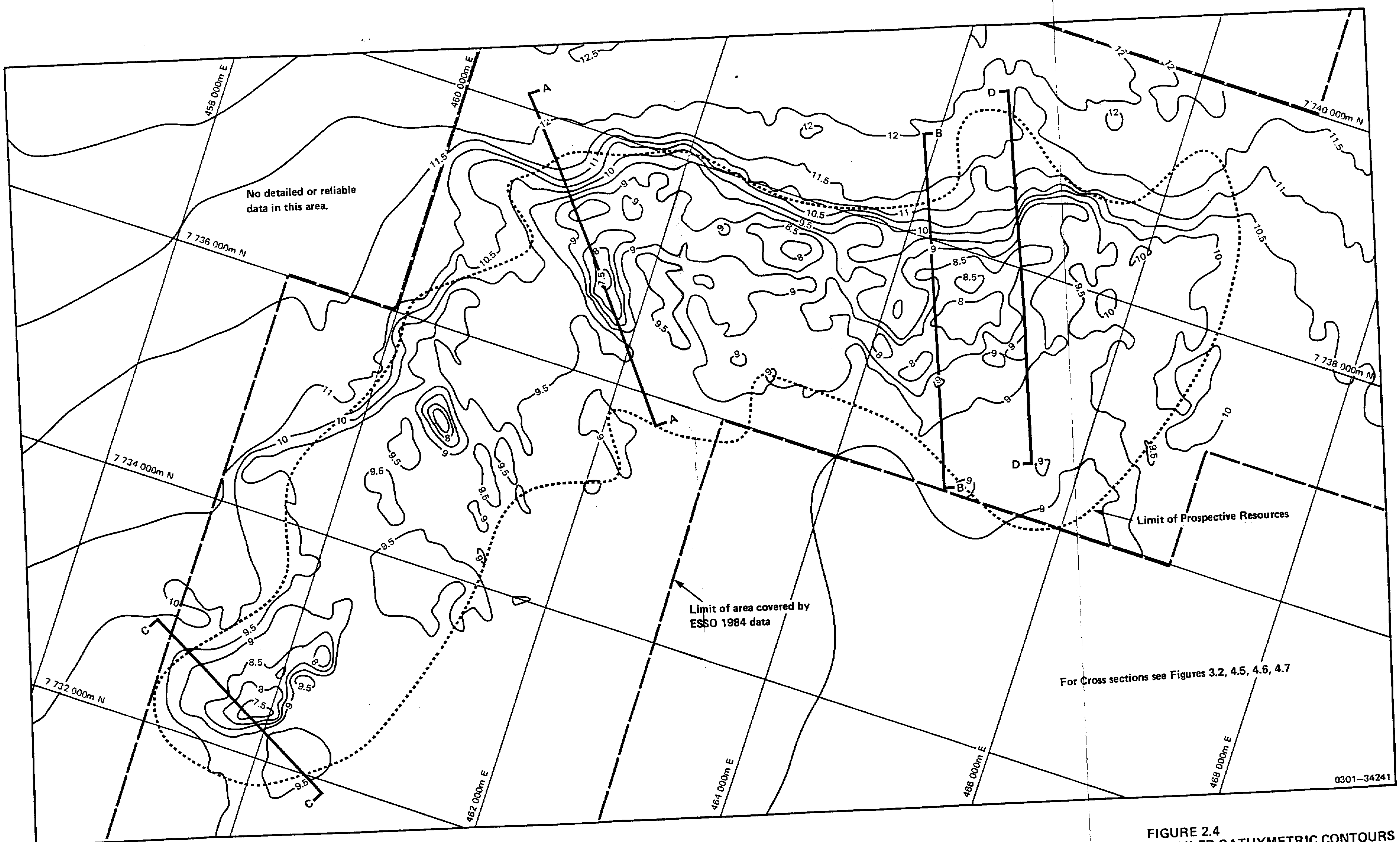

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FIGURE 2.4
DETAILED BATHYMETRIC CONTOURS
FOR THE ISSIGAK DEPOSIT

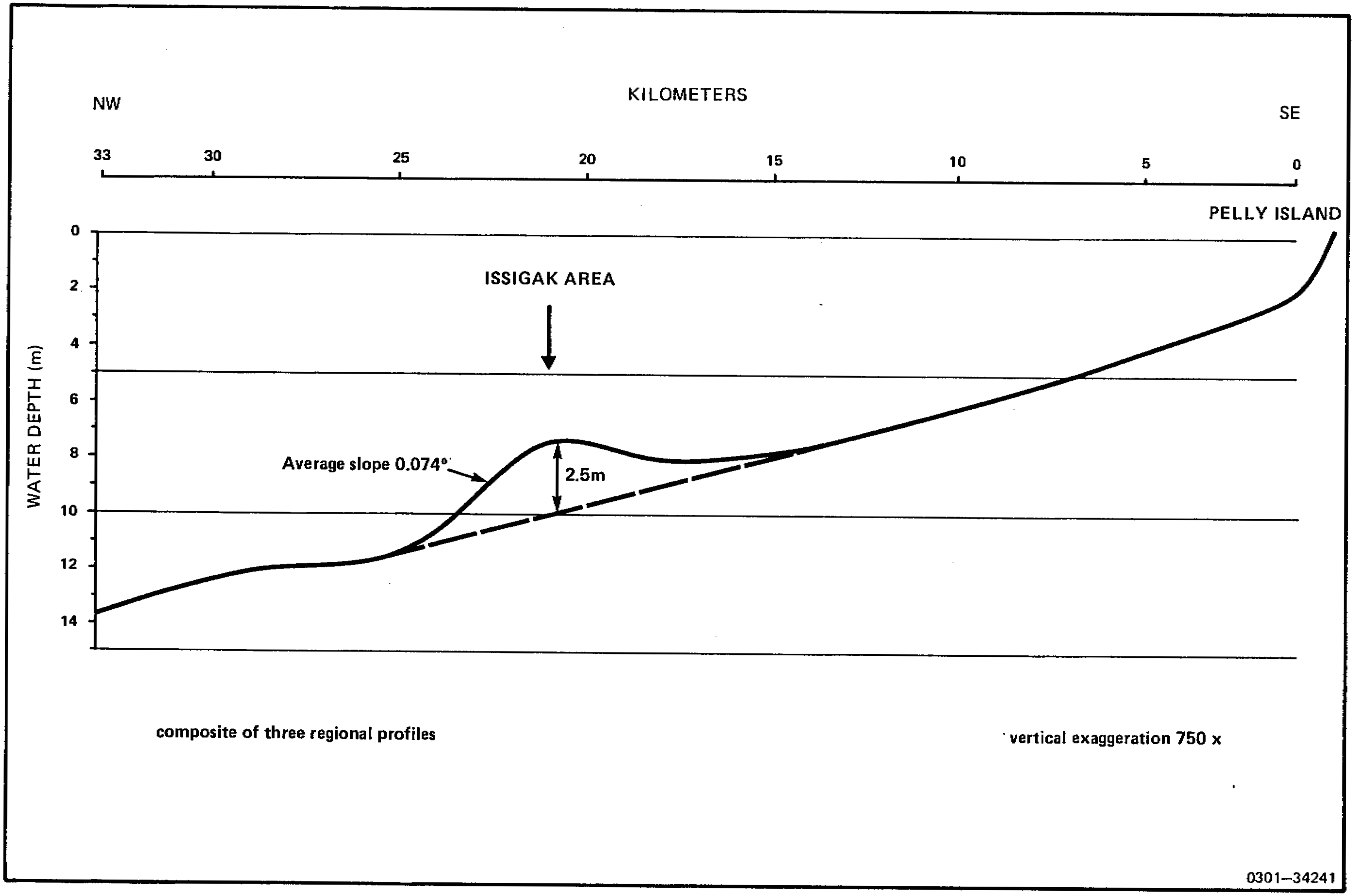

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FIGURE 3.1 COMPOSITE REGIONAL BATHYMETRIC PROFILE FROM PELLY ISLAND THROUGH THE ISSIGAK AREA

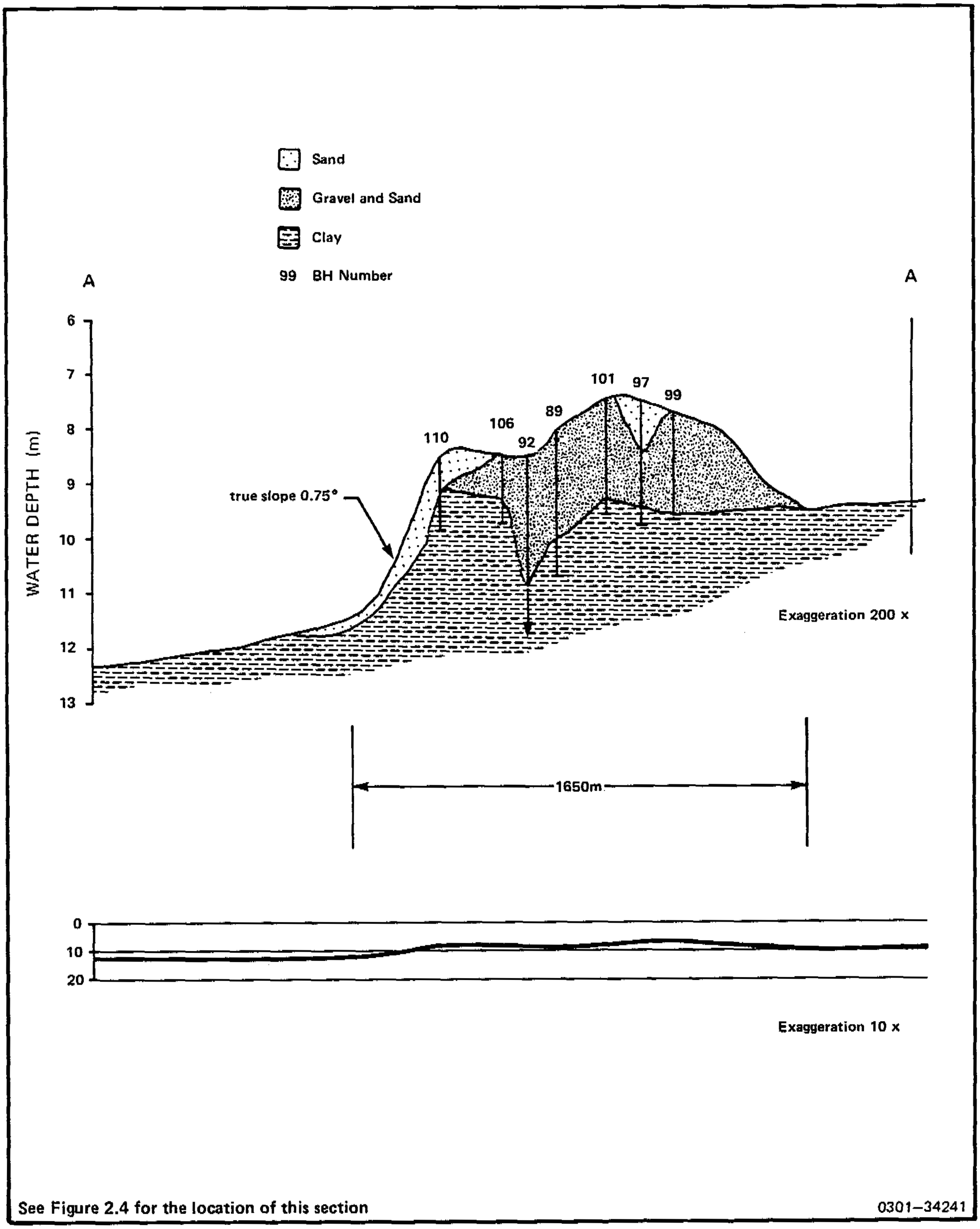

FIGURE 3.2 SECTION A–A THROUGH ISSIGAK DEPOSIT

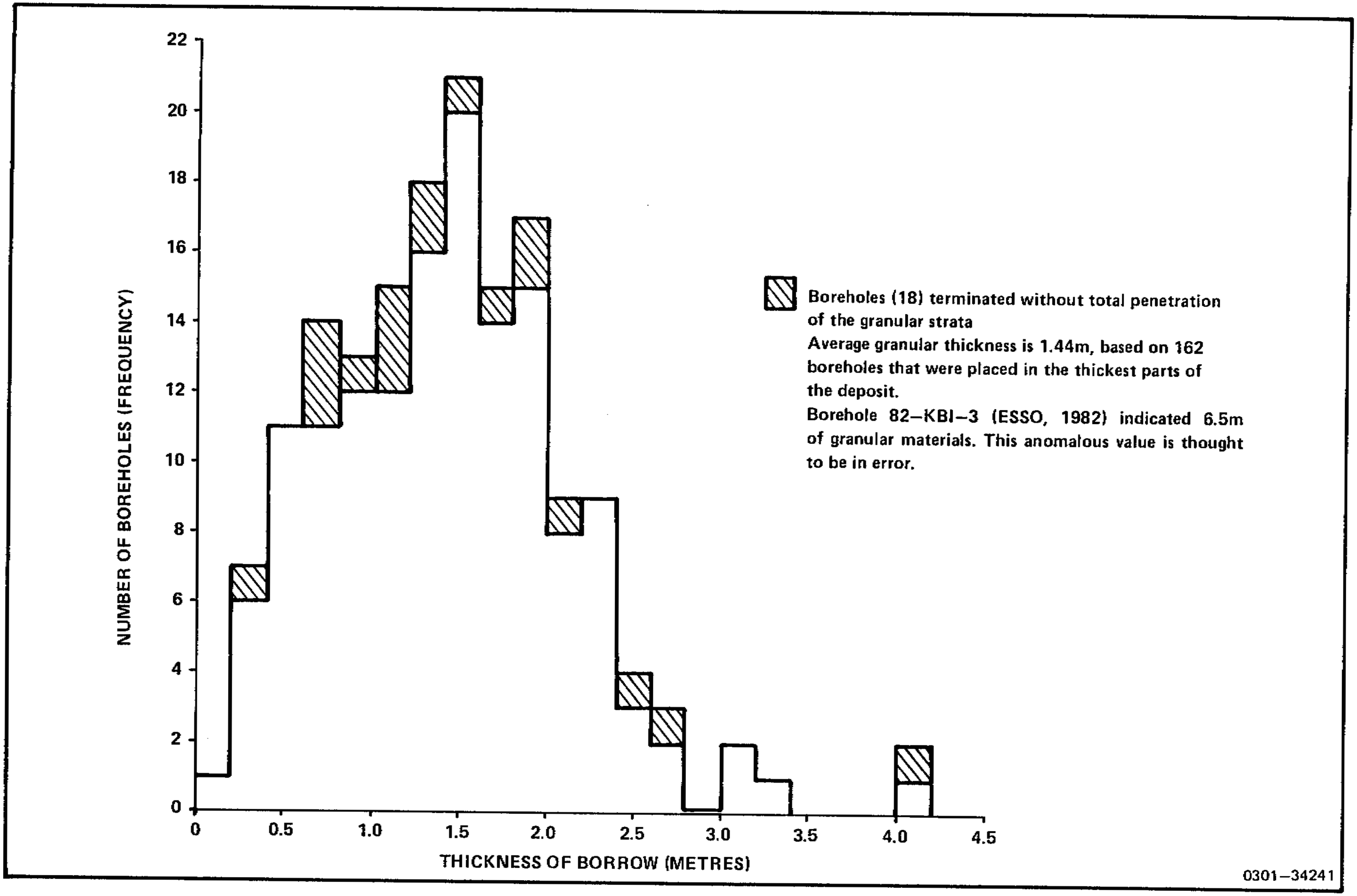

FIGURE 3.3 BORROW THICKNESS FREQUENCY PLOT FROM BOREHOLE DATA

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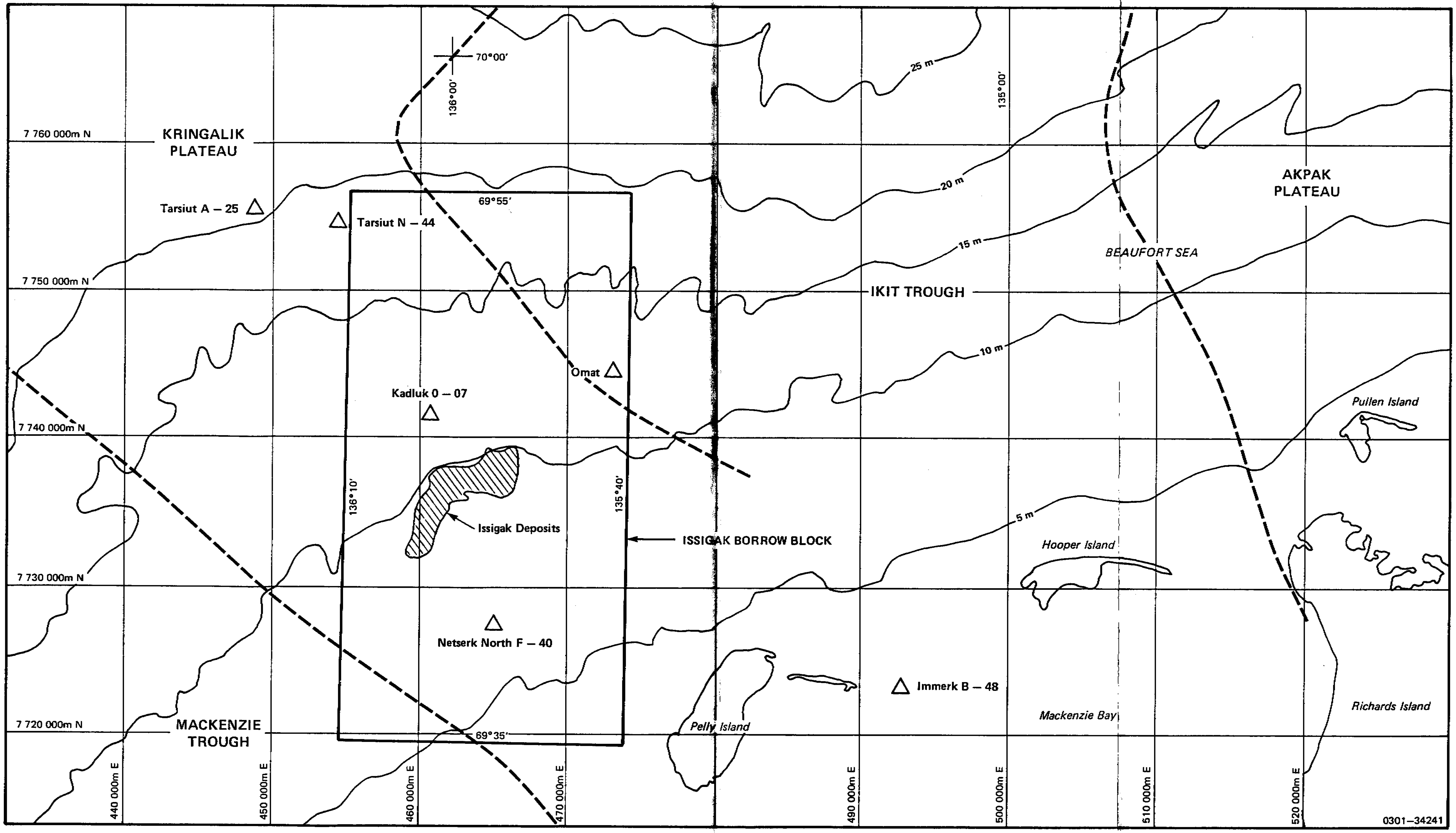

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FIGURE 3.4 PHYSIOGRAPHIC REGIONS
(after O'Conner, 1982)

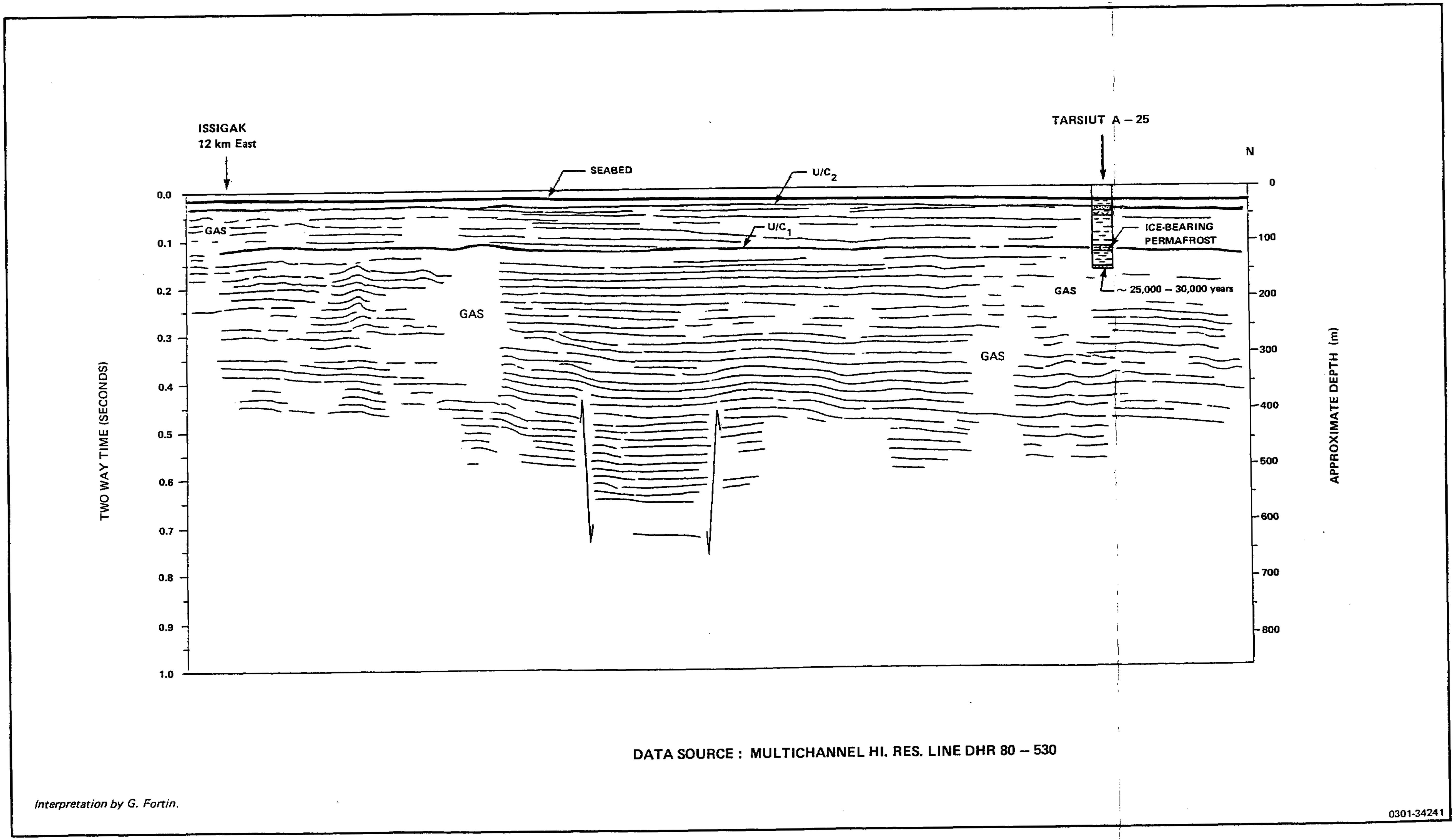

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FIGURE 3.5 SHALLOW STRATIGRAPHY FROM TARSIUT A–25 TO ISSIGAK AREA

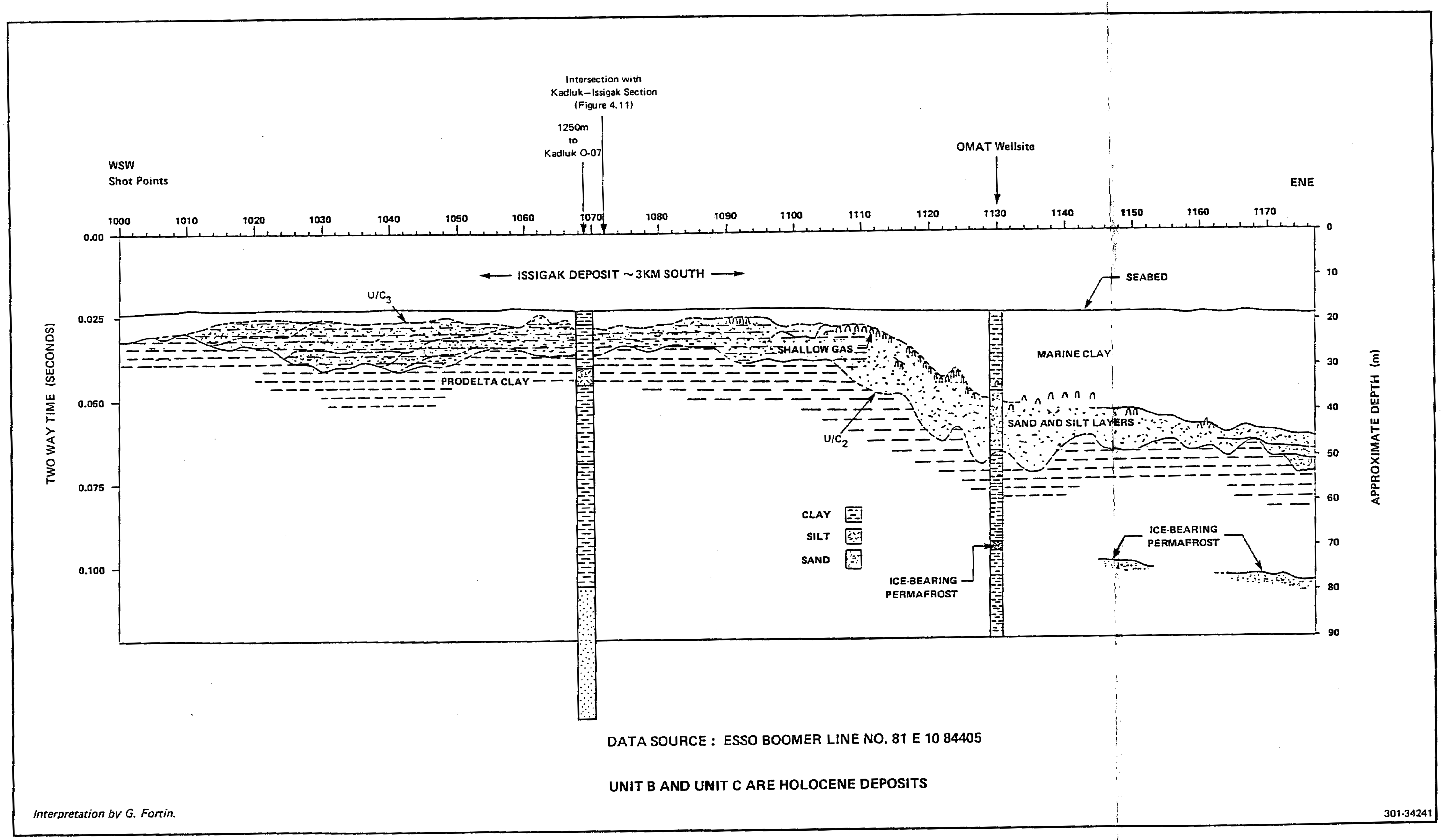

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FIGURE 3.6 SURFICIAL GEOLOGY FROM OMAT WELLSITE TO AN AREA NEAR THE ISSIGAK DEPOSIT

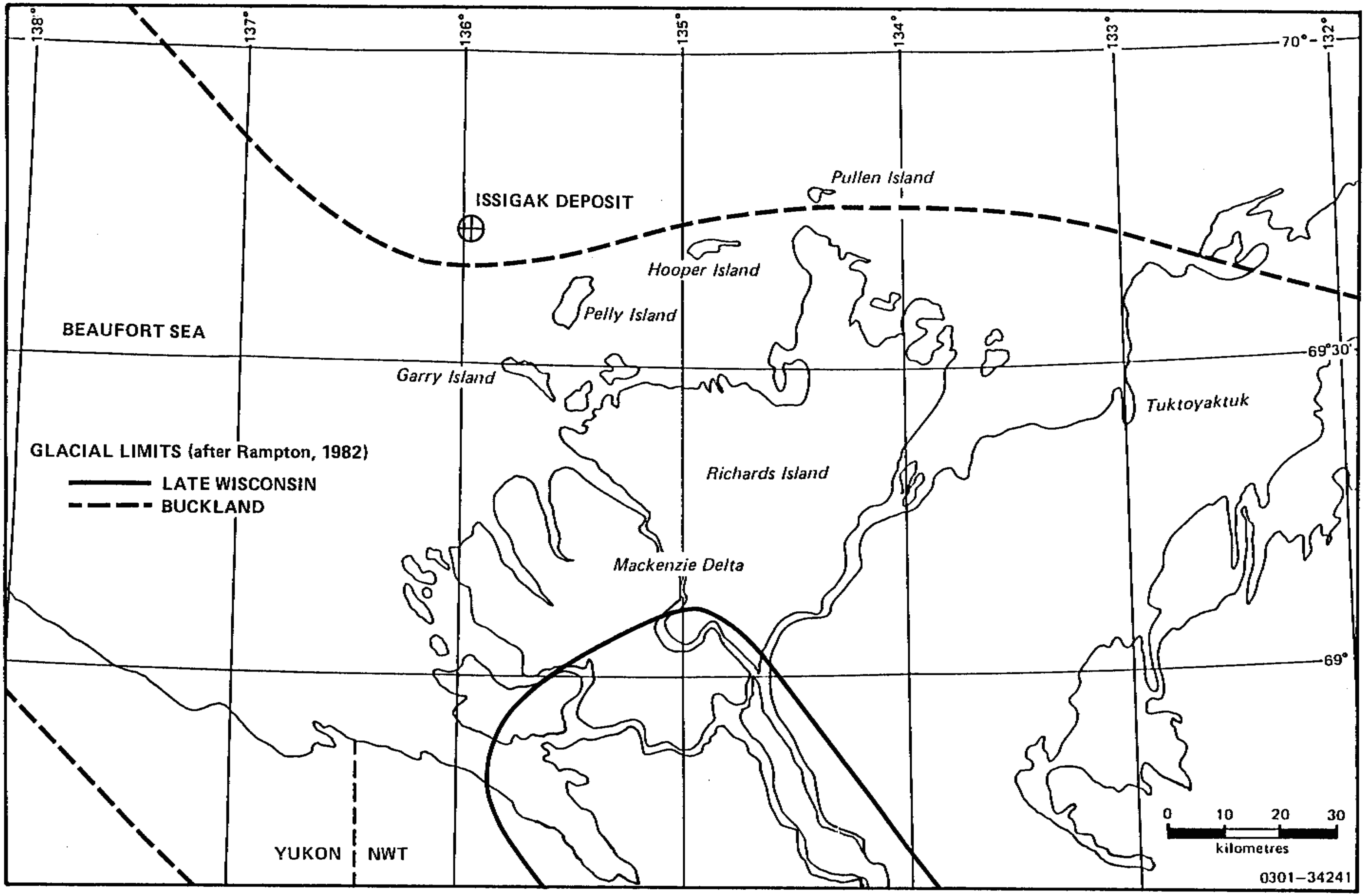

FIGURE 3.7 LIMITS OF LATE WISCONSIN AND BUCKLAND GLACIATION

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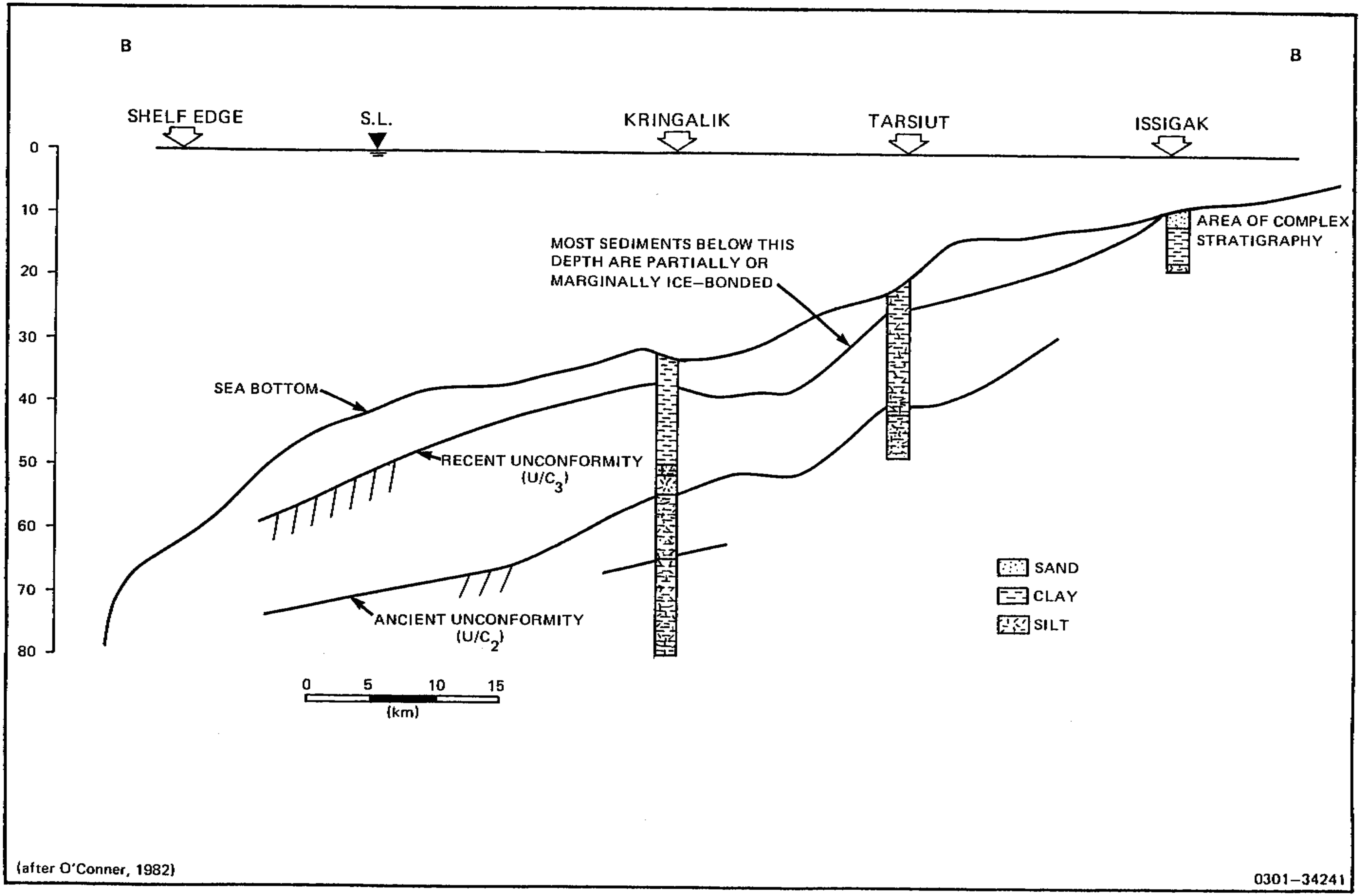


FIGURE 3.8 PROFILE ALONG THE KRINGALIK PLATEAU

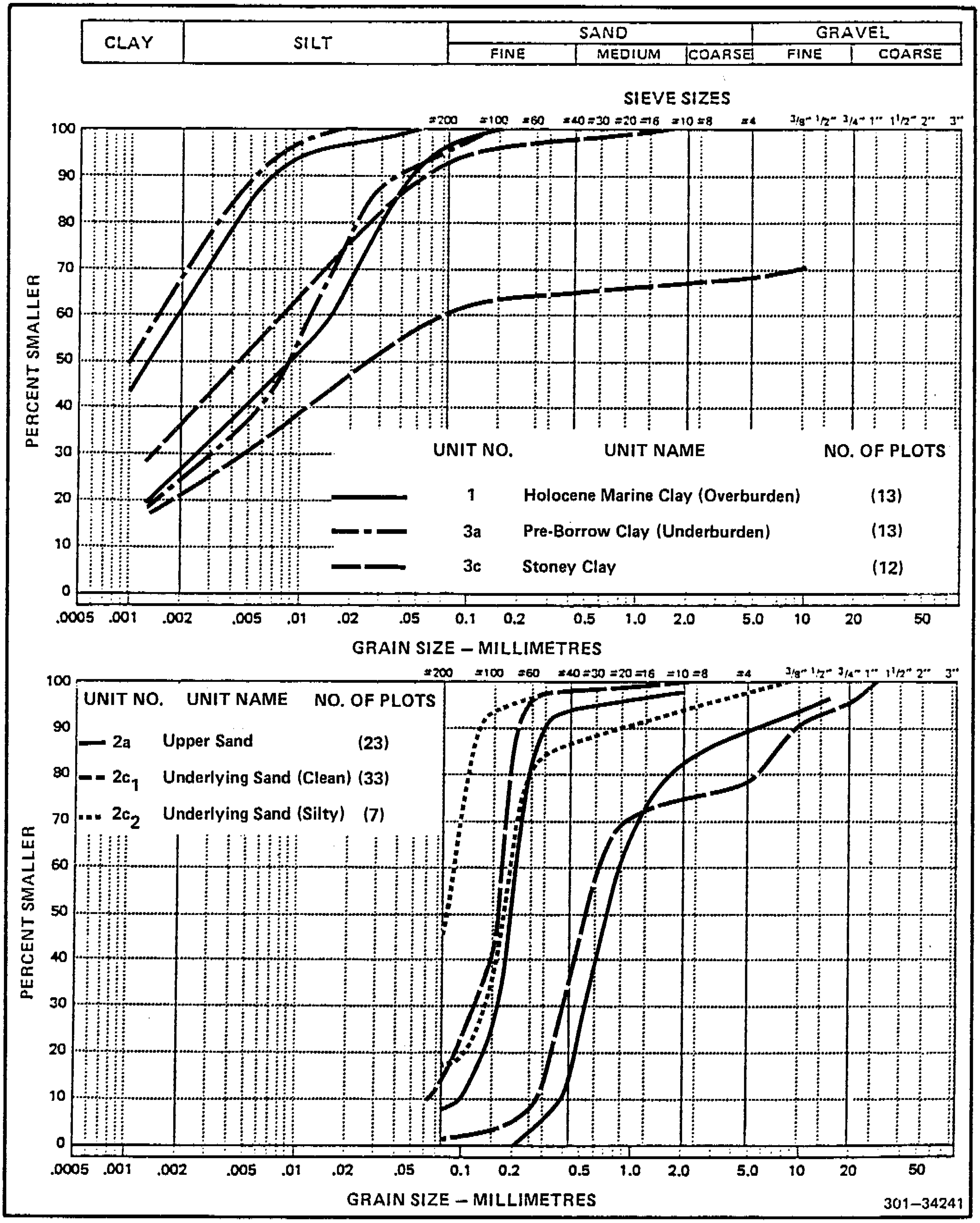


FIGURE 4.1 GRADATION ENVELOPES FOR CLAY AND SAND UNITS

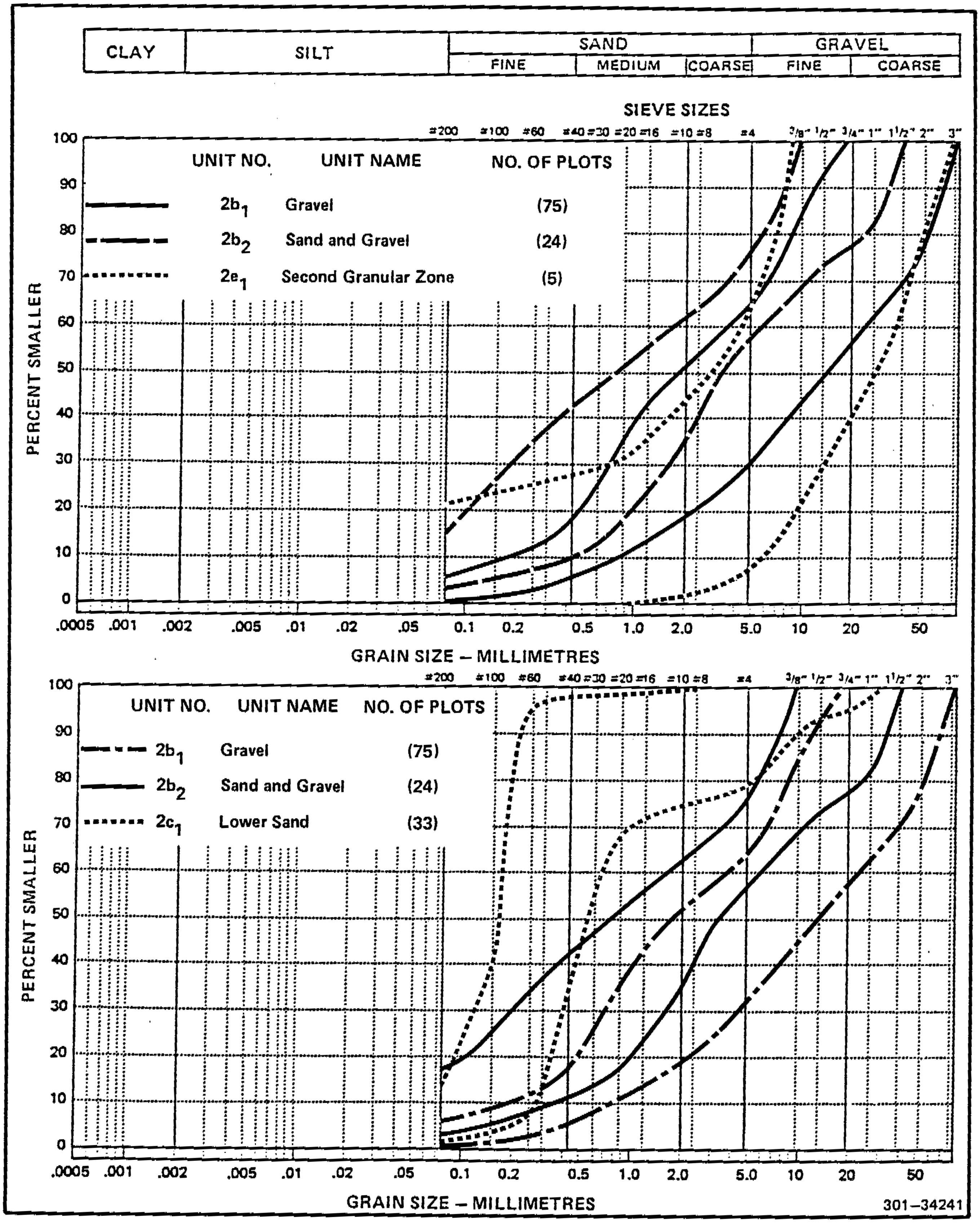
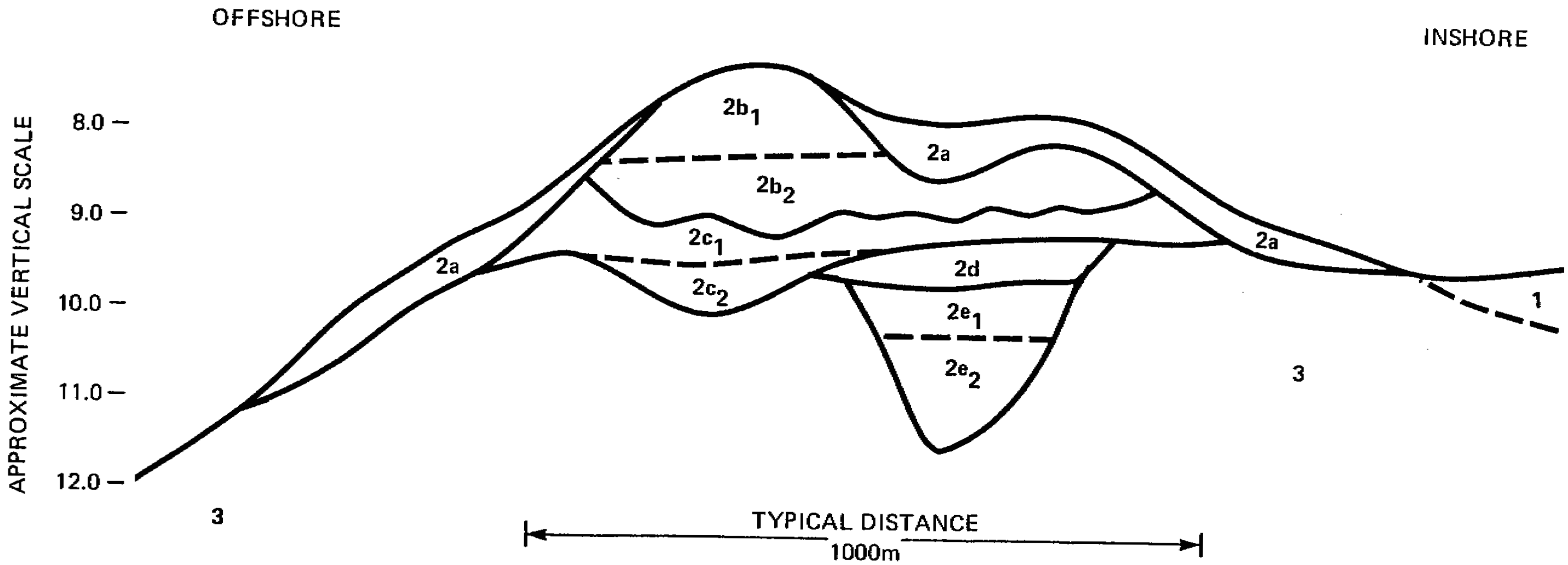


FIGURE 4.2 GRADATION ENVELOPES FOR GRANULAR UNITS



UNIT	DESCRIPTION	UNIT	DESCRIPTION
1	Silty Clay	$2c_2$	Silty Sand
2a	Clean Sand	2d	Silty Clay
$2b_1$	Sandy Gravel to Sand & Gravel	$2e_1$	Sandy Gravel
$2b_2$	Gravelly Sand	$2e_2$	Silty Sand
$2c_1$	Clean Sand	3	Silty Clay

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FIGURE 4.4 **GENERALIZED STRATIGRAPHY OF THE ISSIGAK DEPOSIT**

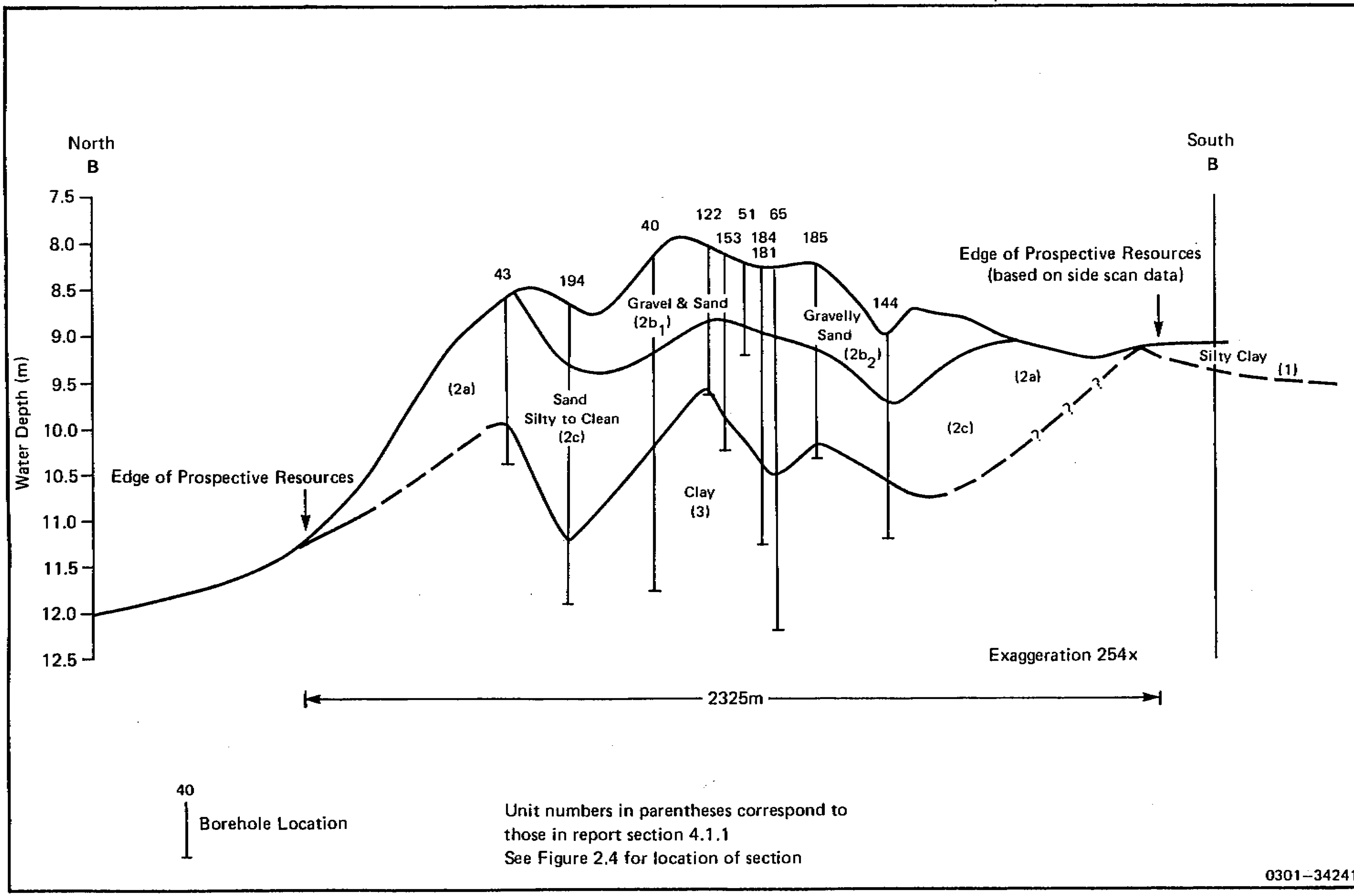

FIGURE 4.5 CROSS SECTION B – B

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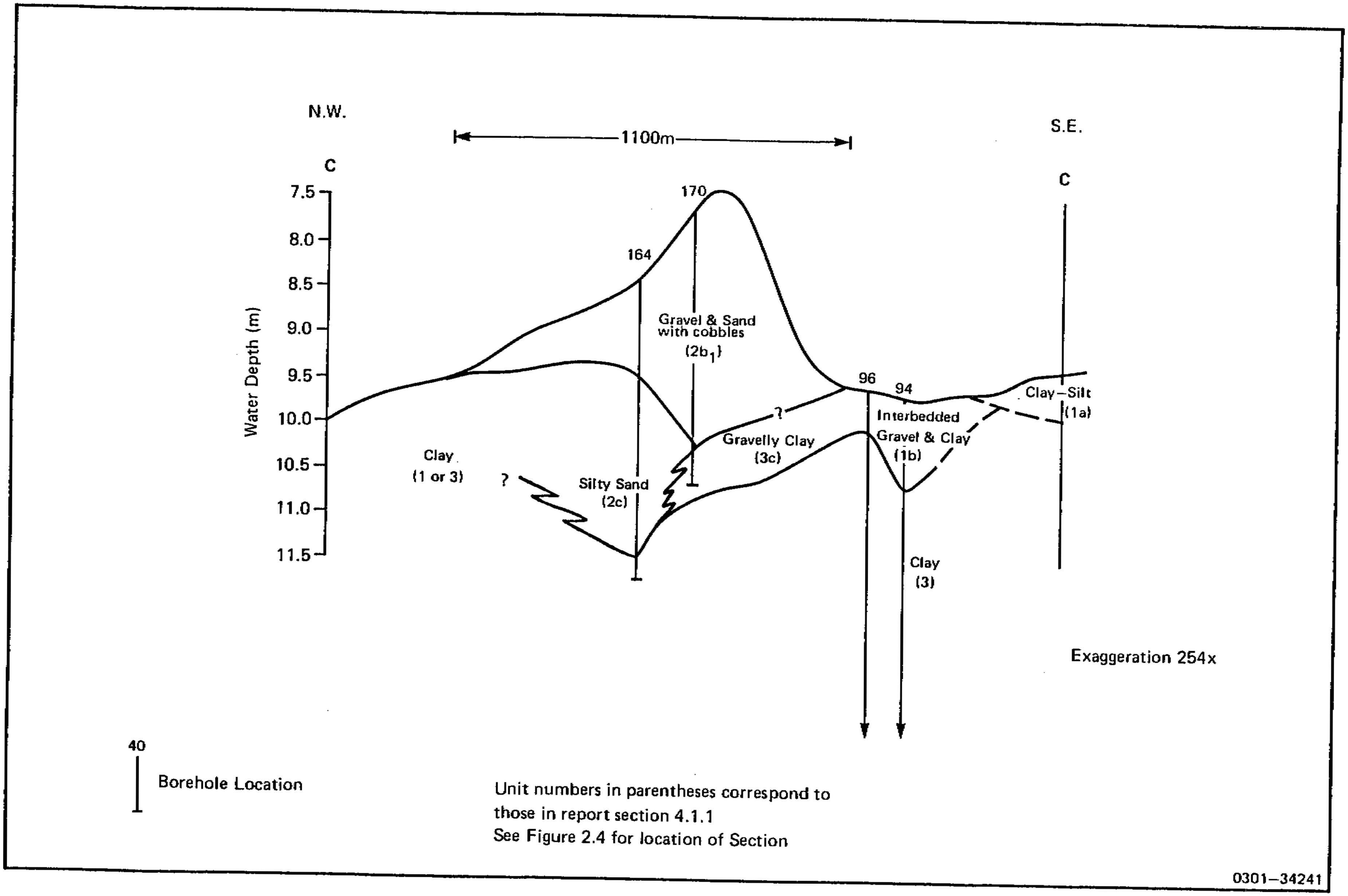

FIGURE 4.6 CROSS SECTION C – C

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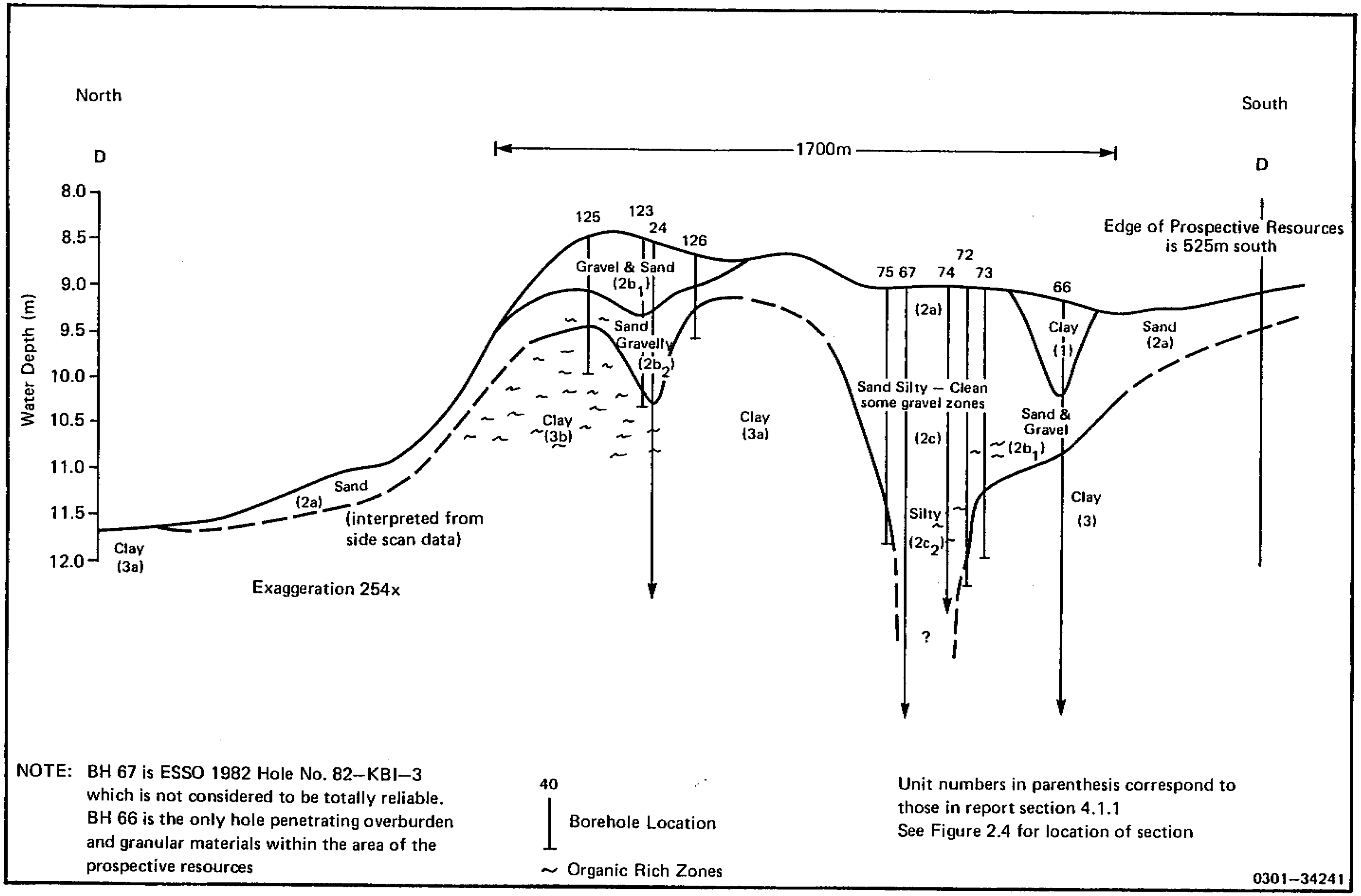

FIGURE 4.7 CROSS SECTION D – D

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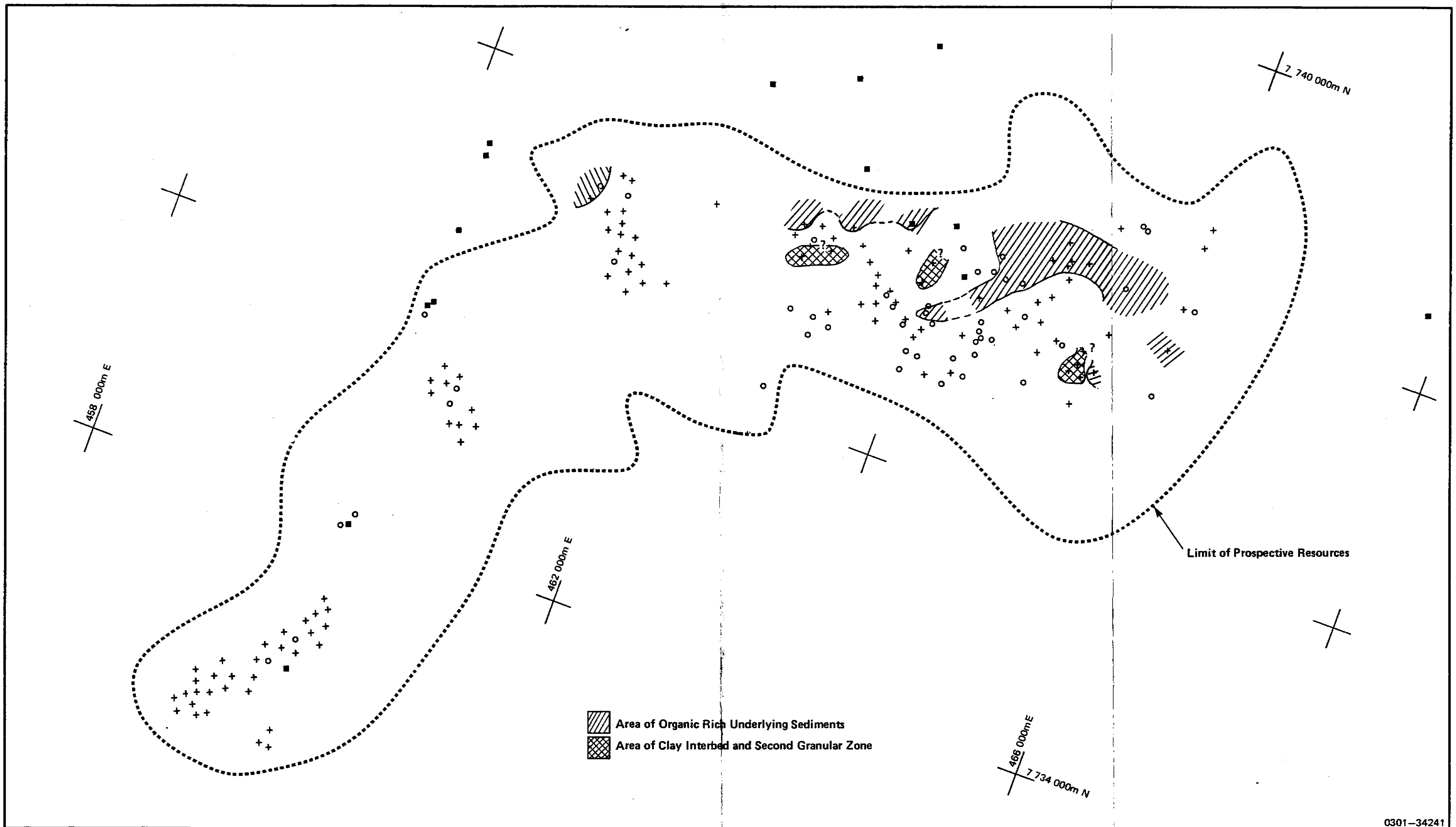

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FIGURE 4.3
DISTRIBUTION OF AREAS OF ORGANIC RICH SEDIMENTS UNDERLYING THE BORROW AND OF THE SECOND GRANULAR ZONE

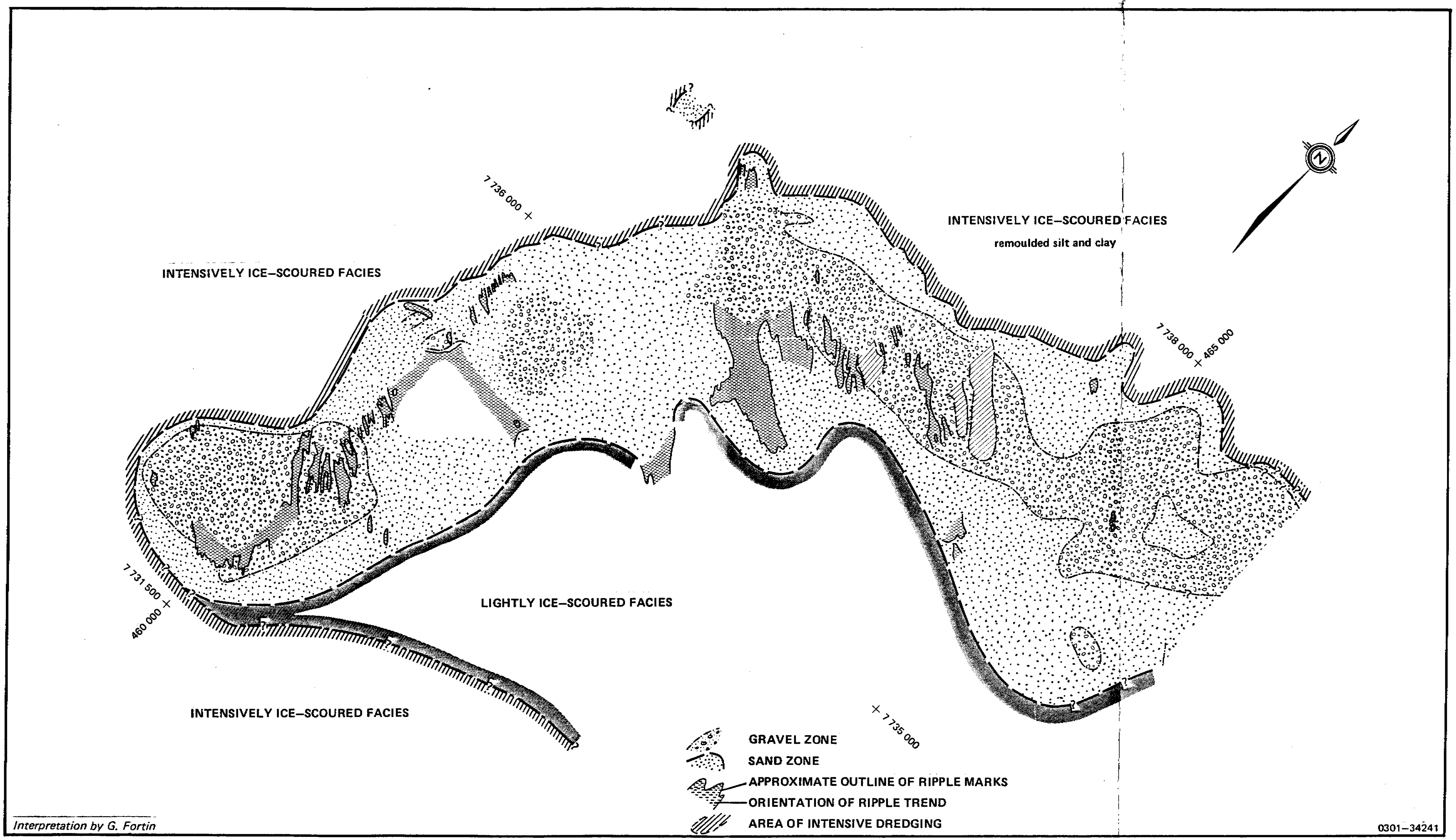

FIGURE 4.8 SIDESCAN INTERPRETATION OF SEABED CONDITIONS

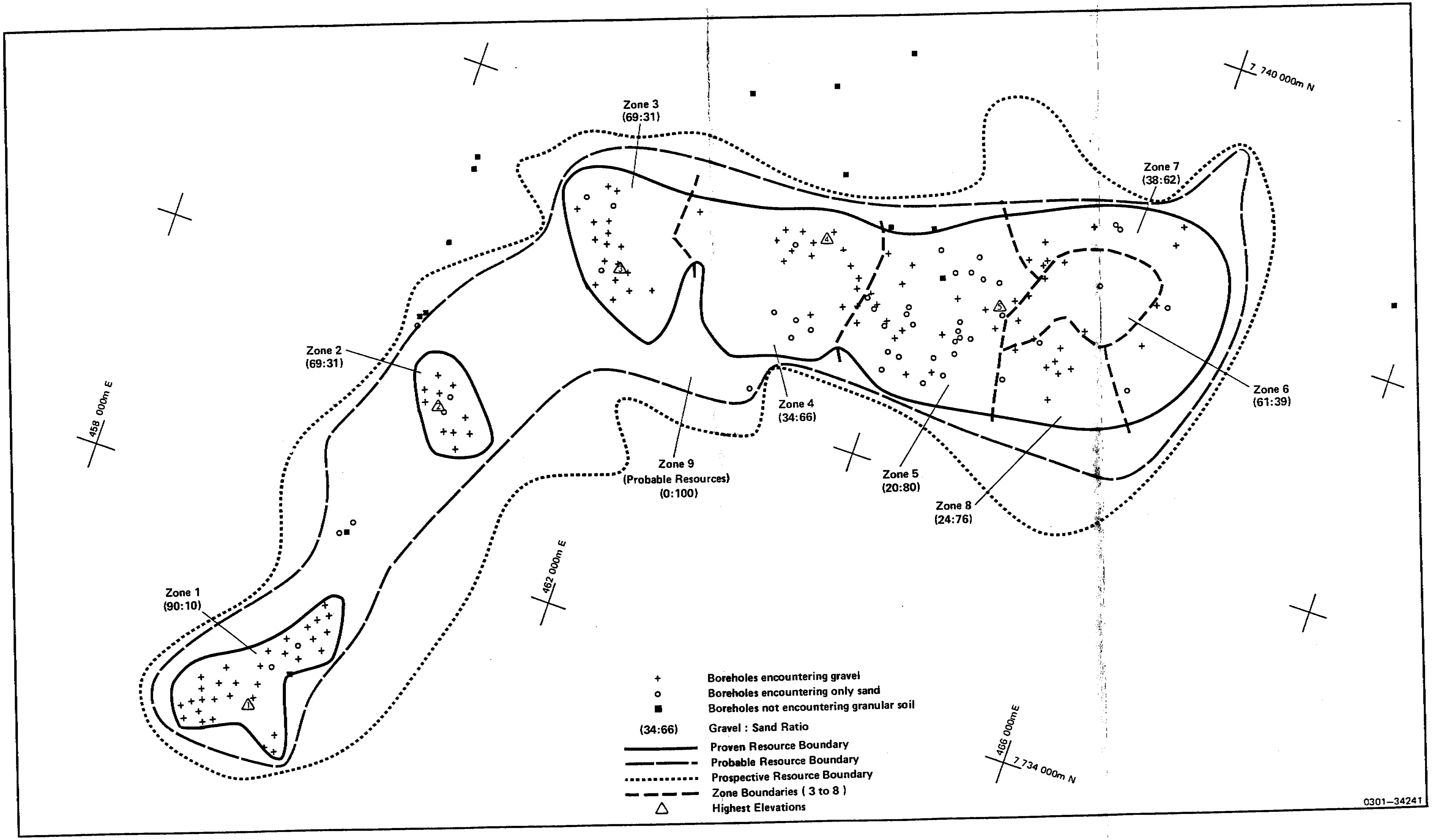

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FIGURE 4.9 RESOURCE & ZONE BOUNDARIES

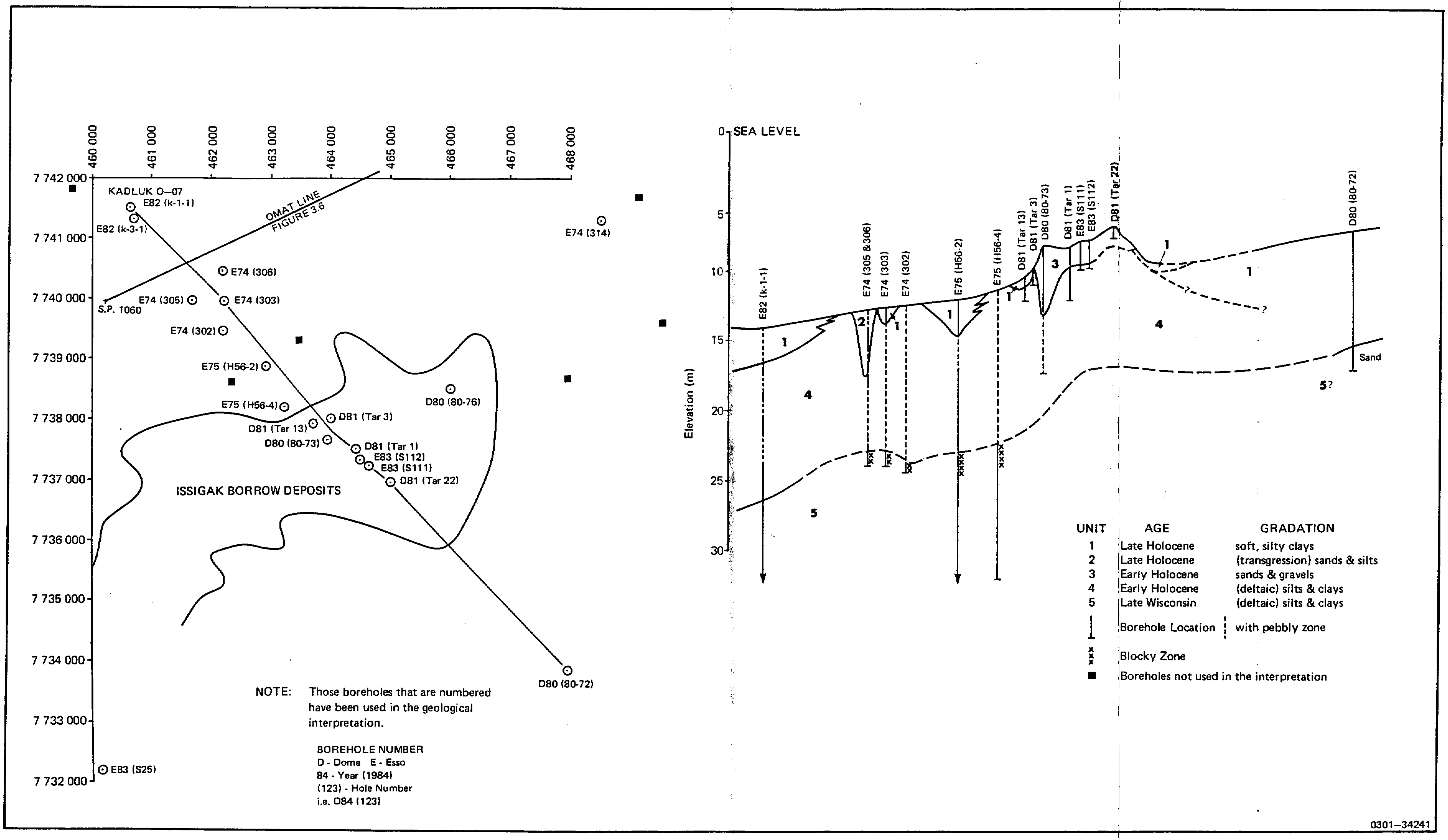

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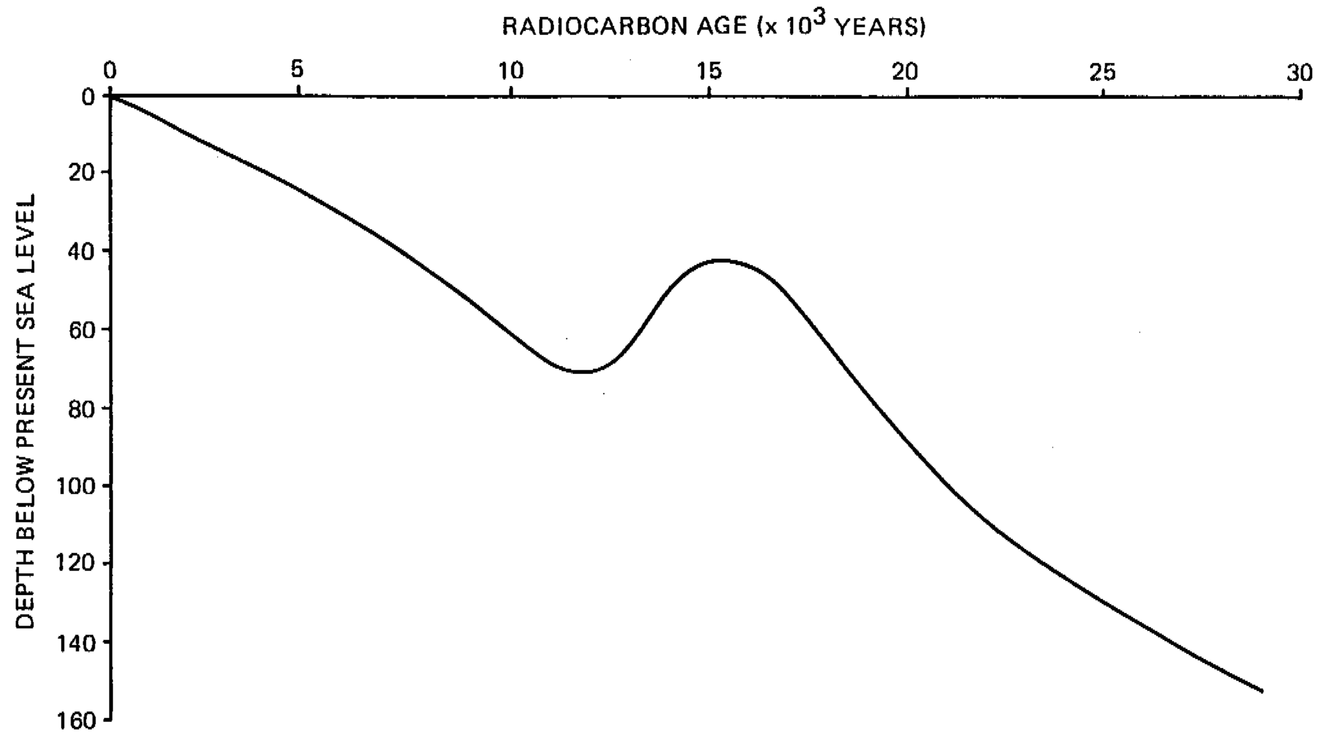
FIGURE 4.10 INTERPRETATION OF THE KADLUK–ISSIGAK REGIONAL STRATIGRAPHY



(from Hill et al, 1985)

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FIGURE 4.11 BEAUFORT SEA LEVEL CHANGES SINCE THE MID WISCONSIN

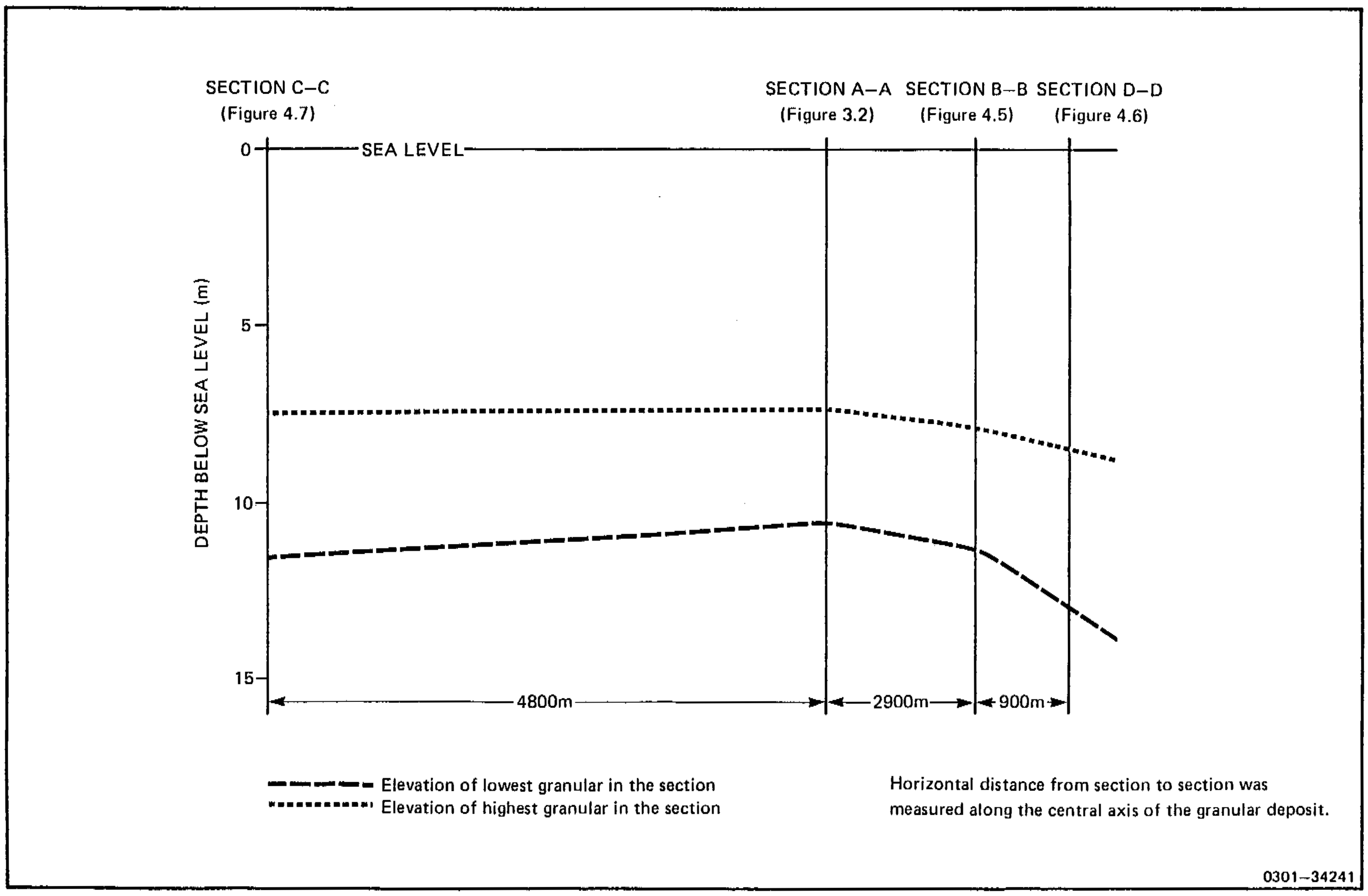

FIGURE 4.12 SOUTHWEST TO NORTHEAST SLOPE OF THE ISSIGAK DEPOSIT

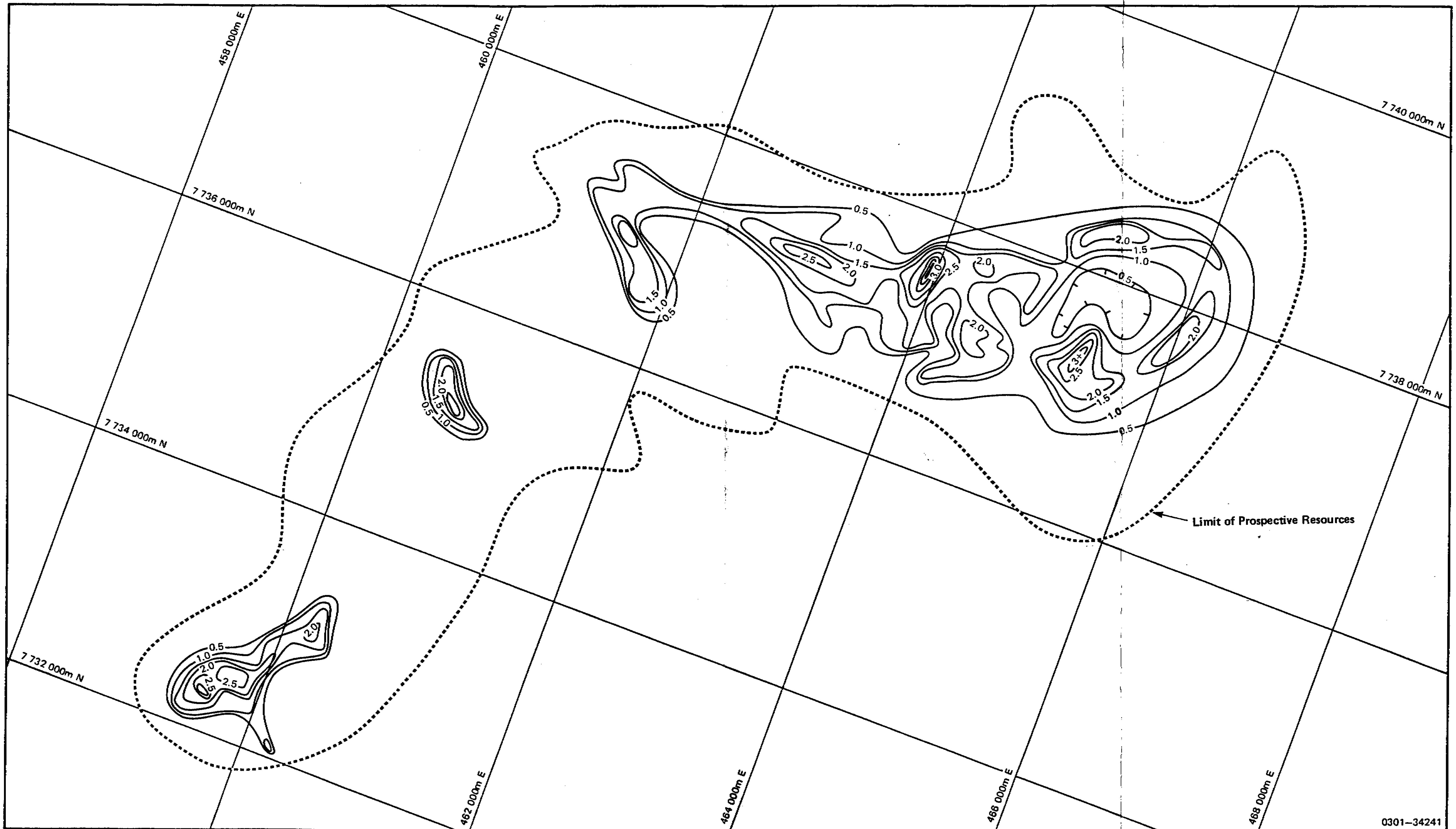

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FIGURE 5.1 BORROW THICKNESS ISOPACH