GEOLOGICAL SURVEY OF CANADA

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MAPPING THE SHALLOWEST SURFACE OF MORE COMPACT SEDIMENTS PREDATING FRASER RIVER DELTAIC DEPOSITS

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ABSTRACT

On the basis of data from different sources, published and unpublished, elevation contours have been drawn to define the surface of more compacted sediments that underlie Fraser River deltaic sediments. The data sources fall within two main categories; onshore investigations of various kinds and offshore seismic reflection profiling. Compilation of data is representative of existing data types but not exhaustive in that many data in private files are not included. The compilation is sufficient to broadly reconcile variations in terminology and to produce two maps, each corresponding to an alternative interpretation of the offshore seismic profiles.

The maps depict regional approximations of the pre-delta topography and are intended to contribute to the understanding of the response of the delta surface to earthquake shaking. Also, they will be useful for planning additional work because they reveal where more information is needed.

INTRODUCTION

To obtain a regional overview of the thickness of Fraser River deltaic sediments and the depths to significantly more compacted material, the topography defined by that more compacted material has been mapped by contouring elevations of its surface compiled from different types of data from a number of sources. The contoured surface, herein called the "pre-delta surface", has not been correlated to any particular geologic sequence but does lie near the Holocene-Pleistocene boundary in many places. The present surficial topography of the area mapped, as well as names of prominent features and geographic locations are shown in fig.1.

The data fall into two main categories; those resulting from onshore borehole studies and refraction surveys and those resulting from offshore seismic reflection profiling. Due to a lack of data beneath Sturgeon Bank, Roberts Bank, Boundary Bay and intertidal areas of the delta, the elevation data sets associated with these categories are practically disjoint and it has been necessary to treat them more-or-less independently.

A fairly large, but spatially sparse, body of information exists describing the internal structure of the Fraser River delta; some of it in the literature (see Luternauer and Hunter, 1996, and references therein) and some in private files. The compilation of information used here is representative of the different types of data available but is not exhaustive in regard to data held privately. Rather, the compilation is sufficient to broadly reconcile various descriptive terms used by geologists, geophysicists and engineers, as well as to produce two maps that constrain possible geoscientific models. One map corresponds to a seismic interpretation of the deepest possible occurrence of the pre-delta surface and the other to an interpretation of its shallowest probable occurrence.

The maps are regional and generalized. They are intended to be first-order approximations of the pre-delta topography and, as such, are expected to promote better understanding of the depositional processes and the potential response of the delta to earthquake shaking. They also will be useful for planning additional work because they indicate areas where more information is needed.

ONSHORE DATA BASE

The set of onshore elevations is compiled from borehole investigations, surface geophysics and stratigraphic sections. Some boreholes were drilled for engineering design purposes and others for a current research program of the Geological Survey of Canada. Elevations from boreholes are derived from both sampling depths and geophysical logging. Some have been published previously (Luternauer and Hunter, 1996) and others not (Appendix A and Hunter, work in progress). In boreholes, the presence of gravel or diamicton* is usually considered to be geologic evidence of Pleistocene deposits because sand is the coarsest naturally occurring grain size found in Fraser River deltaic sediments (Luternauer and Hunter, 1996). Borehole geophysical signatures include relatively low conductivity, relatively high magnetic susceptibility and a rapid increase in the speed of shear-wave propagation (Luternauer and Hunter, 1996). Low conductivity is a consequence of the pore water in the Pleistocene deposits being less saline than that in the deltaic deposits. The high magnetic susceptibility is due to the relatively high magnetite content of Pleistocene deposits in this area. The increase in shear-wave speed is due to the presence of more compacted, coarse-grained and denser material at the surface of Pleistocene deposits.

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*A general term for the nonlithified equivalent of *diamictite* which is a comprehensive, nongenetic term proposed by Flint et al. (1960) for a nonsorted, or poorly sorted, noncalcareous, terrigenous sedimentary rock that contains a wide range of particle sizes, such as a rock with sand and/or larger particles in a muddy matrix (from the Glossary of Geology, Robert L. Bates and Julia A. Jackson, Editors. American Geological Institute, Falls Church, Virginia, 1980).

Depths to the pre-delta surface from surface geophysical measurements, primarily shear-wave refraction profiles, also are both published (Luternauer and Hunter, 1996) and unpublished (Hunter, work in progress). Stratigraphic sections are published by Armstrong (1984).

Elevations from engineering boreholes and stratigraphic sections are usually referred to geodetic datum while others are referred to ground level. Since ground levels on the Fraser Delta are within two or three metres of geodetic datum, any differences are well within the precision of the maps.

Locations for the onshore data are shown in fig.2. A comparison of different terminologies as well as the compatibility of different types of onshore data can be assessed in the vicinity of the Knight Street bridge (fig.3). Engineering cross section s1, which is along the bridge alignment, is divided into five zones (Spence,1968) whose engineering descriptions are given in Table 1. Stratigraphic cross section a40, about 400m west of s1 and parallel to it, is divided into the eight geologic units described in Table 2. Borehole N is 240m west of a40. Refraction profile AA, extending 270m eastward from a point about 100m southeast of borehole N, crosses and is centred about 60m east of a40.

The pre-delta surface is found at a depth of 50m in borehole N and a shear-wave refractor dips easterly across profile AA from a depth of 70m to a depth of 84m. These agree reasonably well with the top of stratigraphic unit C?2,5 on cross section a40, i.e. Capilano sediments considered to be of late Pleistocene age (Armstrong, 1984).

The directions of refractor dip and cross-sectional dips are consistent with a correlation of the top of Capilano with the interface between zone 4 and zone 5 on cross section s1. This would imply that stratigraphic unit F5, the basal unit of Fraser River sediments, corresponds to zone 4 and, in fact, their descriptions in Tables 1 and 2 are somewhat similar. The Capilano sediments would then correlate with zone 5. This correlation is strengthened by the fact that the shallowest observations of gravel on section s1 occur a short distance above the top of zone 5, i.e. either in zone 4 or near the bottom of zone 3. The observation of fresh artesian water and decreases of electrical conductivity provide further evidence that zone 5 represents Pleistocene deposits.

Elevations determined for onshore locations are listed in tabular form: top of Capilano elevations from Armstrong (1984) are in Table 3; elevations of the shallowest gravel, boulders or till-like material in boreholes supplied by R.A. Spence Engineering Ltd. are in Table 4; pre-delta surface elevations according to Luternauer and Hunter (1996) and Hunter (work in progress) are in Tables 5 and 6.

At some onshore locations, the pre-delta surface is too deep to be observed by the method employed. At such places the tables show that elevation of the pre-delta surface is below some highest elevation. This type of information, although rather imprecise, is quite useful for constraining the contouring process.

OFFSHORE DATA BASE

The set of offshore elevations is compiled from single-channel marine reflection profiles. Depths below the water surface were calculated from the time of reflections by assuming the speed of propagation to be a constant 1500 metres per second. Values thus obtained are probably underestimated by about five percent. Tidal corrections were not made because they would have been substantially less than the precision of the calculations.

The profiles are from two sources; Hamilton et al. (1987) and Thalassic Data Limited (previously unpublished). Their locations are shown in fig.2 by dot-dashed and dashed lines, respectively. The profiles of Hamilton et al. (1987) were acquired from large research vessels using two airguns of 1 and 5 in^3 capacity fired simultaneously. The Thalassic Data profiles were acquired in 1982 from a small chartered vessel with compressed air volume sufficient for only a single 1 in^3 airgun. The larger vessels did not acquire data in water depths less than about 25m but the small vessel operated in as little as 4m of water. The result is that the profiles of Hamilton et al. (1987) exhibit greater penetration than, but do not extend into water as shallow as, the Thalassic Data profiles.

It can be seen in fig.2 that onshore and offshore data have no locations in common because they are separated by areas of shallow water and the intertidal zone. It is not possible, therefore, to identify an offshore reflection that coincides with onshore observations. For this reason, two seismic interpretations of the pre-delta surface have been mapped; one below which the pre-delta surface cannot occur and one above which it probably does not occur. These correspond to maximal and minimal pre-delta surface depths, respectively, in the offshore part of the study area.

MAXIMAL OFFSHORE PRE-DELTA SURFACE DEPTHS

The seismic profile in fig.4, profile PGC-83-03-87 (Hamilton et al., 1987), crosses Georgia Strait between Sturgeon Bank and Valdes Island, which lies about 1 km northwest of Galiano Island. The prominent feature covered by deltaic sediments is an extension of Fraser Ridge (fig.1) which is buried beneath Roberts Bank (McGee, 1996). Fraser Ridge must have existed prior to formation of the delta (Mathews and Shepard, 1962), therefore the reflection from the surface of its buried extension is interpreted as corresponding to the deepest possible location of the pre-delta surface wherever the extension is present.

It can be seen in fig.4 that the southwestern flank of Fraser Ridge descends into a basin that is partially filled by a unit of layered sediments with a nearly horizontal surface. The seismic character of this unit is distinctive throughout the Strait of Georgia. The unit is classified as lower post-glacial (Clague, 1975). Its upper layers have been sampled where they outcrop and have been found to be stiff clay devoid of datable material but indicative of a brackish depositional environment, possibly sea water diluted by glacial melt water (B.E.B. Cameron, pers. comm.). The reflection from the base of the unit is interpreted as marking the deepest possible pre-delta topography between Fraser Ridge and the rise to Valdes Island. In the southwestern portion of fig.4, post-glacial sediments are evident locally on that rise as seismically transparent units overlying reflections from older sediments and bedrock.

Northeast of Fraser Ridge, the pre-delta surface can occur no deeper than the surface of Point Grey peninsula (Armstrong, 1984). Relatively deep subbottom reflections not shown in fig.4 but seen on profiles in the vicinity of Point Grey have been interpreted to be from the flank of that promontory. Reflections from the southwestern flank of Point Grey and the northeastern flank of Fraser Ridge are considered to indicate the deepest possible pre-delta topography in their vicinity.

MINIMUM OFFSHORE PRE-DELTA SURFACE DEPTHS

The offshore profile that extends into the shallowest water is TDL-82-14 (Thalassic Data Limited, unpublished), one end of which is in 4m water depth on Sturgeon Bank. This profile (fig.5) shows the delta front between Sturgeon Bank and the southwestern flank of Fraser Ridge whose summit is exposed at this location. A subbottom reflection is seen to dip from 45ms below the sea floor near Sturgeon Bank to 100ms below it near Fraser Ridge. The reflector is not clearly defined, partly because of the presence of gas in the deltaic sediments (Judd, in publication) and partly because the reflected energy is scattered. It must represent a significant impedance contrast, however, because the reflection is strong enough to be seen even in the presence of gas. The onset of reflected energy is scattered over an interval of about 4ms indicating roughness on the order of a few metres. The high reflectivity is what can be expected from coarse sediments and the roughness suggests a hummocky topography. It is reasonable to expect that the pre-delta surface in this vicinity would be marked by ice-rafted drop stones as glaciers retreated from the coast (Armstrong et al., 1965). The scattered reflection can therefore be interpreted as being generated by a hummocky accumulation of coarse material dropped from floating ice. This interpretation is consistent with the observation in fig.5 that the amount of scattering decreases with distance from Sturgeon Bank. Since there is no other strong reflection above the scattered one, it is also interpreted as representing the shallowest probable location of the pre-delta surface.

Nearby profiles of Hamilton et al.(1987) exhibit similar reflections. One is apparent in fig.4 near Sturgeon Bank about 70ms below the sea floor and subparallel to it. It is concave upward and continuous at least as far offshore as the buried crest of Fraser Ridge. Southwest of the ridge crest, it becomes concave downward and extends as far as the reflection from the steep slope of the southwestern ridge flank. A reflector laps onto the steep southwestern flank and appears to "hang" above the horizontal surface of the sediments below. The "hanging" reflection is strong near the ridge flank and becomes progressively weaker with increasing distance from it. The opposite is true of the horizontal reflection below; it being very weak near the ridge flank and progressively stronger until it emerges from beneath the "hanging" reflection. This is due to the amount of energy reaching the horizontal surface below being inversely proportional to the reflectivity of the "hanging" reflector. Near the ridge flank, the reflectivity of the "hanging" reflector is so great that almost no energy is transmitted to reach the surface of the layered unit below.

If, as previously discussed, the horizontally layered unit is lower post-glacial, the sediments above it would be deltaic. It is difficult to explain, however, how a reflection of such strength could be generated by an impedance contrast within purely deltaic sediments, especially so far from shore and apparently without the presence of gas. It seems more likely that the "hanging" reflector consists of coarse material which is distributed less densely with increasing distance offshore. If so, it lies on a surface that, where the coarse material is absent, is seismically transparent, i.e. presents little impedance contrast to overlying sediments. If the coarse material is dropped from floating ice, the layered unit below must be older than post-glacial and the shallowest probable pre-delta surface would be located some distance above its horizontal surface. If the coarse material were put in place during post-glacial time, perhaps by some mechanism such as slope failure on Fraser Ridge, the horizontally layered unit could indeed be post-glacial and its base would comprise the pre-delta surface.

CONSTRUCTION OF THE MAPS

Two maps of possible pre-delta topography have been constructed by combining the onshore elevations in Tables 3-6 with offshore elevations calculated on the basis of the two seismic interpretations described above. The map corresponding to the lowest possible pre-delta surface is shown in fig.6 and that corresponding to the highest probable pre-delta surface is shown in fig.7.

The onshore portions of the two maps are the same. Their western portions, where contours have been adapted from McGee (1979), are also the same.

Contours in the vicinity of the "hanging" reflector (stippled portion of fig.7) are drawn to indicate the horizontal surface of the unit classified as lower post-glacial (Clague, 1975). The "hanging" reflector is situated within a small range of elevations near -400m and the horizontal surface is slightly deeper than -450m. If the "hanging" reflection is generated by coarse material dropped from floating ice, it would represent the pre-delta surface and, outside the stippled area, would occur shallower than -450m but it would not be observable due to seismic transparency. If the "hanging" reflection is generated by material put in place during post-glacial time, contours in its vicinity would be as depicted in fig.6.

DISCUSSION OF RESULTS AND CONCLUSIONS

A pre-delta topographic low separates the uplands of Vancouver-Burnaby-Surrey from the Fraser Ridge and its extension beneath Roberts Bank which rises above sea level to form Point Roberts (figs 1 and 6). This low forms a NW-SE trending valley which once opened into the Strait of Georgia between Point Grey and Fraser Ridge but is now filled by sediments. These sediments could be entirely deltaic if the scattered reflection in fig.5 represents a post-glacial surface.

If it is true that the scattered reflection in fig.5 corresponds to a late-Pleistocene accumulation of drop stones, the mouth of the valley was infilled prior to formation of the delta and most deltaic sediments are confined to an isolated basin.

Additional information is required, especially from beneath the intertidal zone of Sturgeon Bank, to determine which of these interpretations provides more accurate depths to the first more compacted layer beneath the delta. Making that determination is important because the two possibilities could represent significantly different responses to earthquake shaking, i.e. an isolated basin fill would resonate at a more discrete set of frequencies than would a fill that is partially unconfined. Which of the two would produce a more severe ground motion would depend on the frequency of shaking and direction of propagation.

In either case, it is evident that deltaic sediments lap onto adjacent pre-delta topographic highs in wedge-shaped configurations. Detailed information in the vicinity of onlaps should be acquired because, under certain conditions, wedges of unconsolidated sediment can amplify local ground motion (Alverez et al., 1995).

The Fraser Ridge could be providing a stabilizing support for the delta front as well as containment of the looser deltaic deposits in the Pleistocene topographic low along its northeast flank. Such a situation would significantly influence the earthquake response of localities in Richmond and Delta.

If the earthquake response of the Fraser Delta is to be understood in a useful way, computer modelling would probably be the most direct and economical way to proceed. When combined with existing knowledge of speeds of propagation and other pertinent seismic parameters, the maps presented herein provide a basis to begin such modelling.

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APPENDIX A

SUMMARY OF BOREHOLES AND LOGS - R. A. SPENCE ENGINEERING LTD.

s 1: Knight Street Bridge alignment; 12 holes (see Fig.3 and Table 1)

s 2: St. Edwards and Caithcart Roads, Richmond; 2 holes (27m and 79m) sandy over silty-clayey material

s 3: Fentiman Place, Richmond; 2 holes (21m and 30m) sandy-silty-clayey throughout

s 4: Deas Tunnel alignment; 7 holes (deepest 64m), sandy-silty throughout

s 5: Tilbury Island LNG site; 4 holes (deepest 76m), sandy-silty throughout

s 6: 9425 River Road, Delta; 3 holes (deepest 28m), loose gravel near 20m in one

s 7: Grace and River Roads, Surrey; 3 holes (deepest 24m), gravel/cobbles at 20m

s 8: 800 Carlisle Road, Annacis Island; 3 holes (deepest 30m, dense below -20m

s 9: Western Copper site, Annacis Island; 6 holes (deepest 23m), some gravel

s10: Queensborough Bridge alignment; 13 holes (deepest to -45m geodetic)
northernmost hole, artesian water at +3m
north shore of river, boulders at -8m
in river channel, gravel at -16m
south shore of river, gravel at -28m
further south, sandy-silty with peat to as deep as -45m

s11: near base of western slope to Surrey upland; 1 hole to -58m,
clayey-silty-sandy throughout

s12: Port Mann Bridge alignment; 46 holes (deepest 80m),
till-like material at -58m in cental part

No exact location: "Annacis Island crossing"; 1 hole, cobbles and boulders at -22m

Table 1: Description of zones in engineering cross section s1 (Spence, 1968)

Zone 1: Soft organic SILT and loose sandy SILT and silty SAND.

Zone 2: SAND, medium loose becoming dense with depth.

Zone 3: Grey silty CLAY, medium stiff to stiff, sensitive.
Occasional thin layers or partings of silt and sand near top of zone.
Occasional shells and gravel near bottom of zone.

Zone 4: SAND with layers of gravel and some sandy SILT.

Zone 5: Compact SAND and GRAVEL in matrix of SILT and CLAY SILTS.
ARTESIAN WATER at various levels.
In some places the till-like materials directly underlie zone 4,
and in other areas they occur at lower depth in zone 5.

Table 2: Description of units in stratigraphic section a40 (Armstrong, 1984)

Salish sediments:
- SA1 - peat, organic silt loam and silty clay loam

Fraser River sediments:
- F1 - channel and floodplain silty sand to silty clay loam; minor organic sediments
- F4 - deltaic and channel fine to coarse sand; minor silt, silty loam and silty clay loam
- F5 - deltaic fine sand to clayey silt; includes estuarine deposits

Capilano sediments:
- C2 - glaciomarine stony silt to clay loam
- C5 - marine silt loam to clay loam; minor sand and silt; minor glaciomarine (C2)

Vashon drift:
- V1 - sandy, loamy lodgement till
- V2 - glaciofluvial pebble to boulder gravel and sand

Quadra sand:
- Q1 - fine to coarse sand; minor silt and gravel
- Q4 - silt, sand and silty clay, minor gravel; probably of marine origin

Cowichan Head formation:
- CH5 - marine silt, silty clay and sand; lenses of gravel

Semiahmoo drift:
- SE1 - loamy lodgement till, minor lenses of sand and gravel
- SE2 - glaciomarine and marine, stony silt loam, clayey silt and silty clay

Highbury sediments:
- H4 - marine fine sand, silty sand, silt, clay and minor gravel

Table 3: Elevations of the top of Capilano sediments (Armstrong, 1984)

a40: 0m,-50m,-100m from north to south along cross section

a41: -26m

a45: -28m

a49: -43m in central part

a50: below -108m

a51: below -88m

a52: -4m

Note: At all other locations from Armstrong (1984), the top of Capilano coincides with present ground level.

Table 4: Elevations of the top of gravel, boulders or till-like material in boreholes supplied by R. A. Spence Engineering Ltd

s 1: 0m,-50m,-100m from north to south along cross section

s 2: below -79m

s 3: below -30m

s 4: below -64m

s 5: below -76m

s 6: below -28m

s 7: below -28m

s 8: below -27m

s 9: below -19m

s11: below -58m

s10: +3m,-8m,-16m,-28m, below -45m north to south along alignment

s12: -58m in central portion of alignment

Note: Artesian water found throughout s1 and in the northern part of s10.

Table 5: Elevations of shallowest occurrence of gravel or diamicton and/or geophysical anomalies in boreholes, Luternauer and Hunter (1996) and Hunter (work in progress; h1,4)

A : -8m

B : -33m

C : -185m

D : -35m

E : -53m

F : -66m

G : -32m

H : -100m

I : -19m

J : -236m

K : -109m

L : -52m

M : -91m

N : -50m

O : -186m

P : -305m

Q : -78m

h1: -45m*

h4: below -115m

* also the site of a shear-wave refraction profile (see Table 6).

Table 6: Elevations of shear wave refractor (and direction of dip where observed) from Luternauer and Hunter (1996) and Hunter (work in progress; h1,2,3)

R : -86 (N)

S : -78 (N)

T : below -190m

U : below -235m

V : below -246m

W : below -274m

X : below -161m

Y : -69m (NE)

Z : -11m (S)

AA: -77m (E*)

BB: -90m (NW)

CC: -24m (S)

DD: -26m (S)

EE: -72m (NE)

FF: -52m (N)

h1: -45m (S)

h2: -280m +/-30m**

h3: approx. -200m

* misprinted as "NE" in Luternauer and Hunter (1996)

** determined by transient electromagnetic (large loop) method

FIGURE CAPTIONS

Fig.1 - Topography of the map area and names of prominent features and geographic locations.

Fig.2 - Data base location map. Locations of boreholes are indicated by large circles (solid, Luternauer and Hunter, 1996; open, Hunter, work in progress) and solid diamonds (R.A.Spence Engineering Ltd.). Locations of refraction profiles are indicated by triangles (solid, Luternauer and Hunter, 1996; open, Hunter, work in progress). Locations of stratigraphic sections (Armstrong, 1984) are indicated by small open circles. Symbols linked by solid lines indicate cross-sectional profiles. Dash-dotted lines indicate seismic profiles of Hamilton et al. (1987). Dashed lines indicate seismic profiles of Thalassic Data Limited (unpublished).

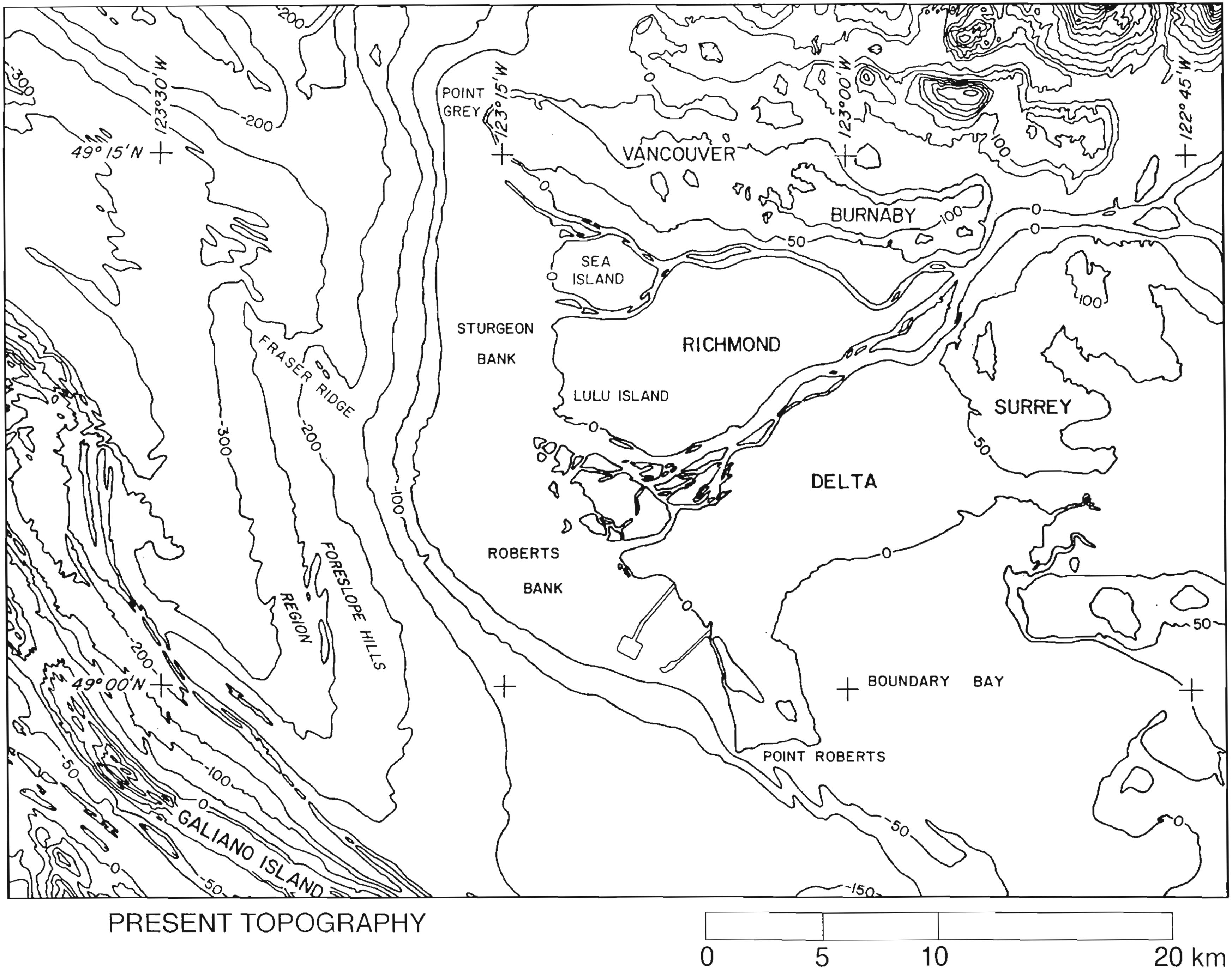
Fig.3 - Illustration of the compatibility of different types of onshore data.

Fig.4 - Seismic profile PGC-83-03-87 (Hamilton et al., 1987) illustrating interpretations of the deepest possible and shallowest probable pre-delta surfaces. Water depths calculated assuming 1500m/s speed of propagation. Note the "hanging" reflector that laps onto the southwestern flank of Fraser Ridge and the relationship between its reflection strength and that of the horizontal reflector below it (see text).

Fig.5 - Seismic profile TDL-82-14 (Thalassic Data Limited, unpublished) illustrating the scattered reflection possibly generated by a hummocky accumulation of ice-dropped stones. It can be seen that the severity of scattering decreases with distance from Sturgeon Bank. Water depths calculated assuming 1500m/s speed of propagation. Note that the shallow part of the depth scale is nonlinear due to the water depth becoming less than the source-receiver offset distance.

Fig.6 - Map corresponding to the seismic interpretation of the deepest possible pre-delta surface.

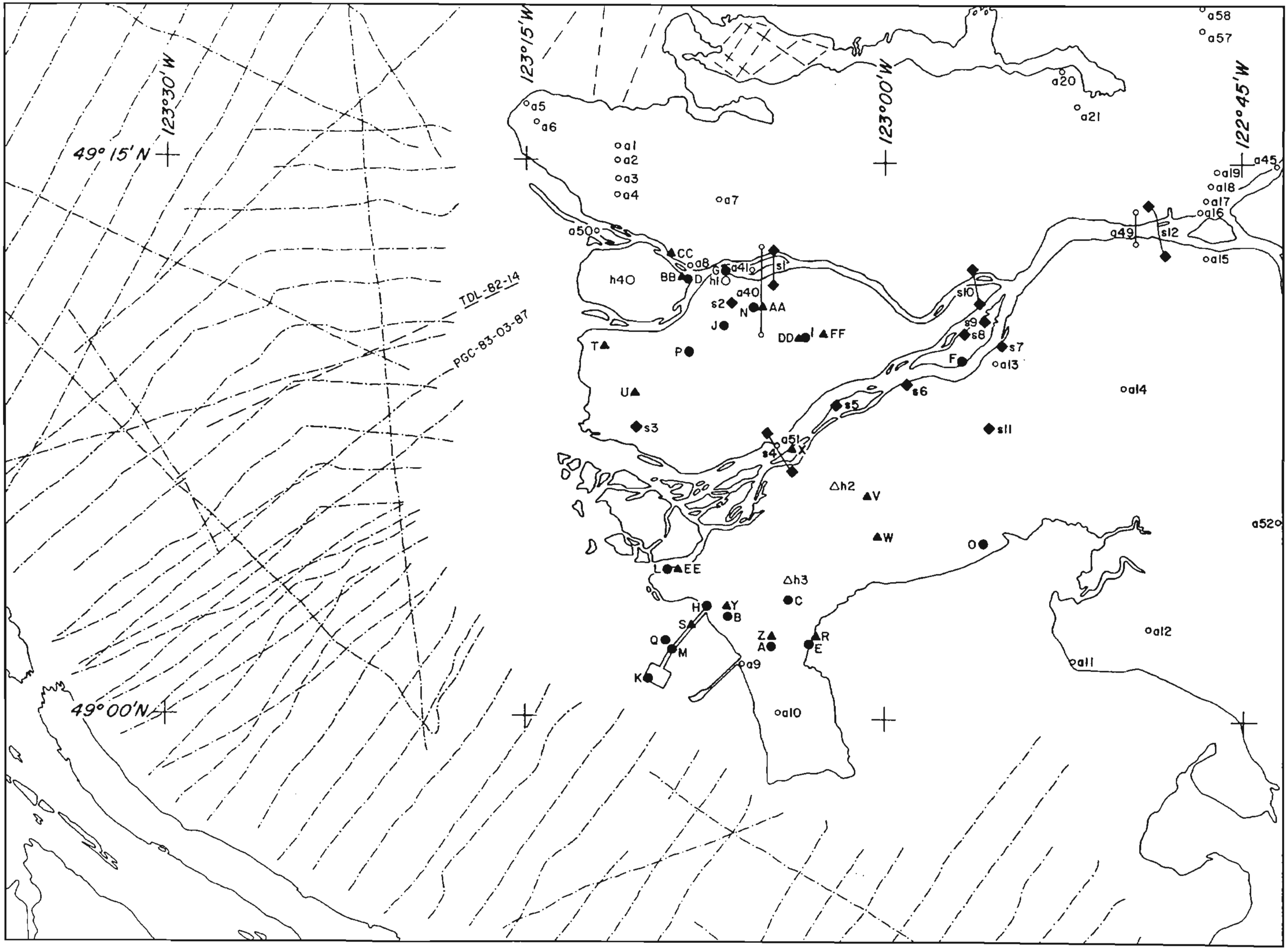
Fig.7 - Map corresponding to the seismic interpretation of the shallowest probable pre-delta surface. Stippled area indicates extent of the "hanging" reflector. The horizontal surface is on the unit classified as lower post-glacial (Clague, 1975).



PRESENT TOPOGRAPHY

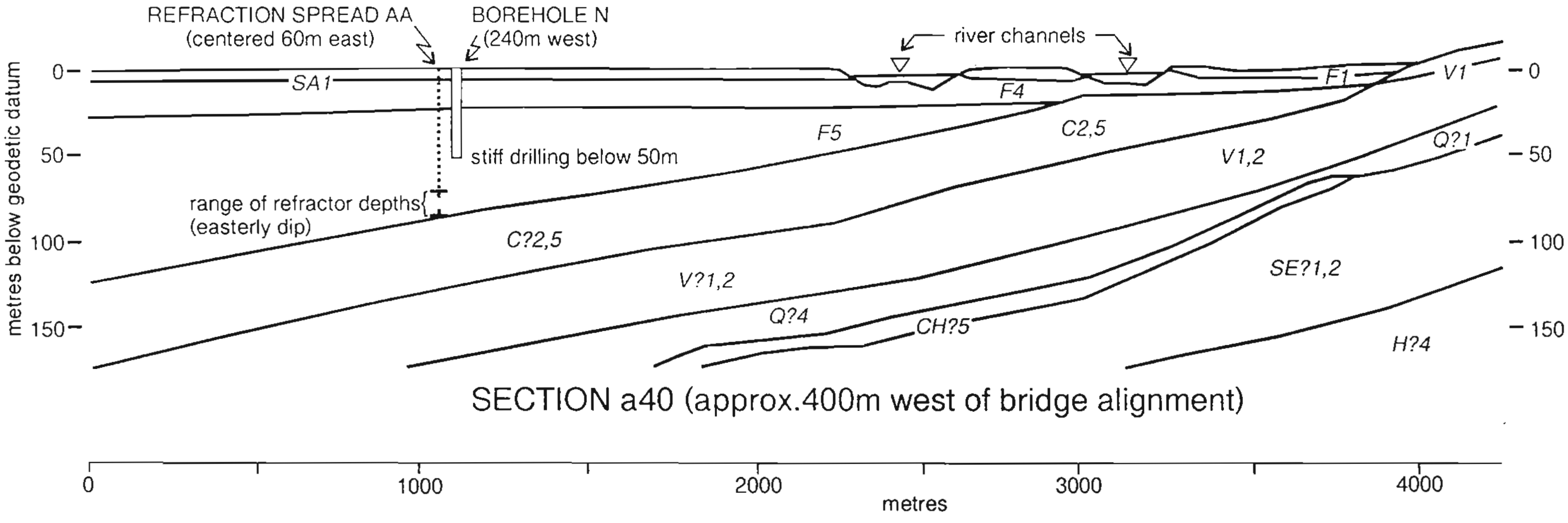
50 M. CONTOURS REFERRED TO PRESENT SEA LEVEL

FIGURE 1



DATA BASE

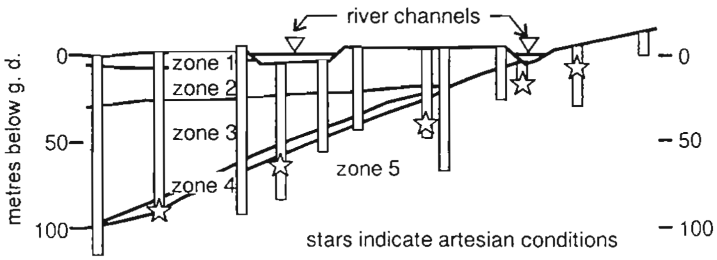
○ STRATIGRAPHIC SECTIONS -Armstrong (1984)
○ ● BOREHOLE GEOLOGY AND GEOPHYSICS
△ ▲ SHEAR WAVE REFRACTION SPREADS
solid, Luternauer andHunter (1996)
open, Hunter (work in progress)
◆ ENGINEERING BOREHOLES - Spence (private files)
SINGLE-CHANNEL SEISMIC PROFILES
—·— Hamilton et al. (1987)
— — Thalassic Data Limited (unpublished)



SECTION a40 (approx.400m west of bridge alignment)

VICINITY OF

KNIGHT STREET BRIDGE



SECTION s1 (along bridge alignment)

FIGURE 3

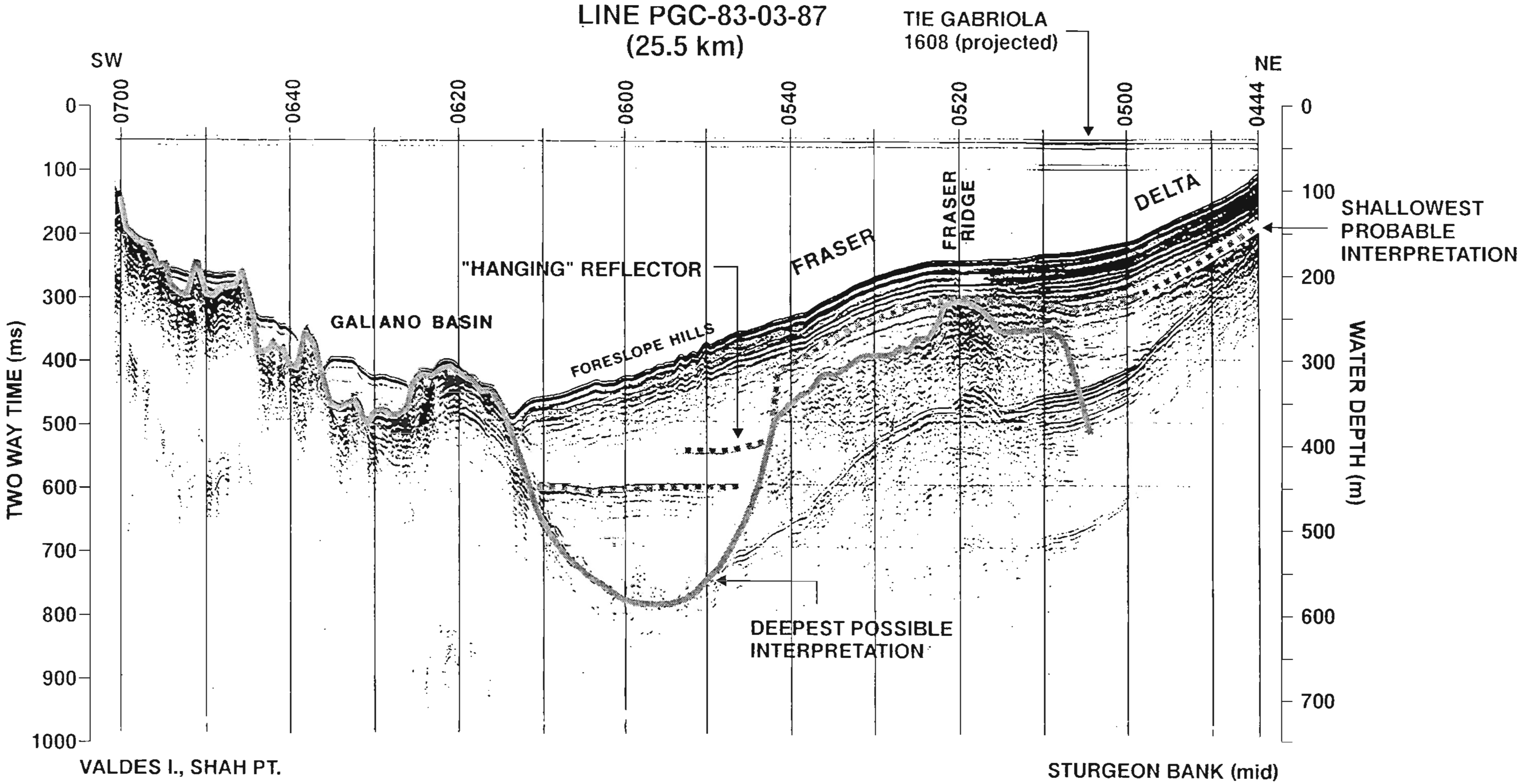

LINE PGC-83-03-87
(25.5 km)
TIE GABRIOLA
1608 (projected)
SW
NE
0700
0640
0620
0600
0540
0520
0500
0444
TWO WAY TIME (ms)
0
100
200
300
400
500
600
700
800
900
1000
WATER DEPTH (m)
0
100
200
300
400
500
600
700
SHALLOWEST
PROBABLE
INTERPRETATION
DELTA
FRASER
RIDGE
FRASER
"HANGING" REFLECTOR
GALIANO BASIN
FORESLOPE HILLS
DEEPEST POSSIBLE
INTERPRETATION
VALDES I., SHAH PT.
STURGEON BANK (mid)

FIGURE 4

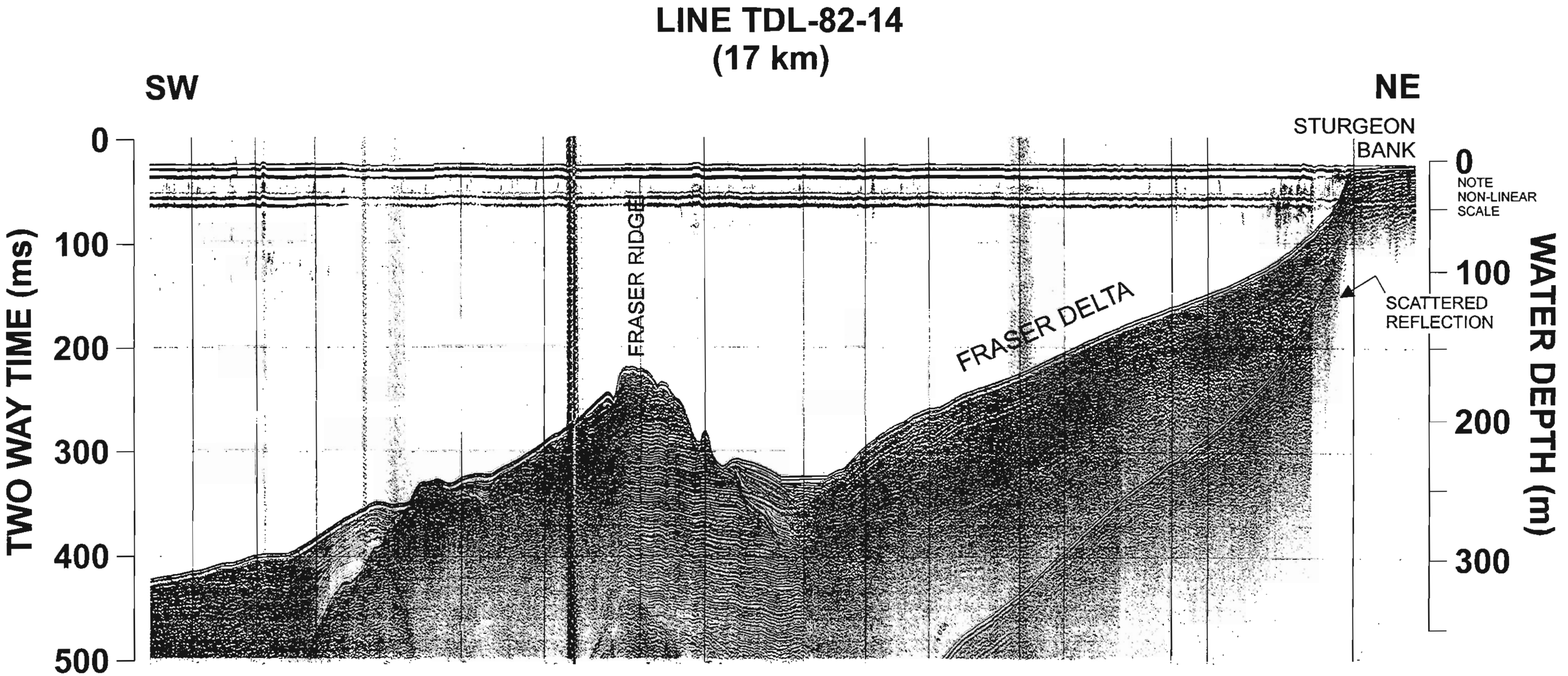
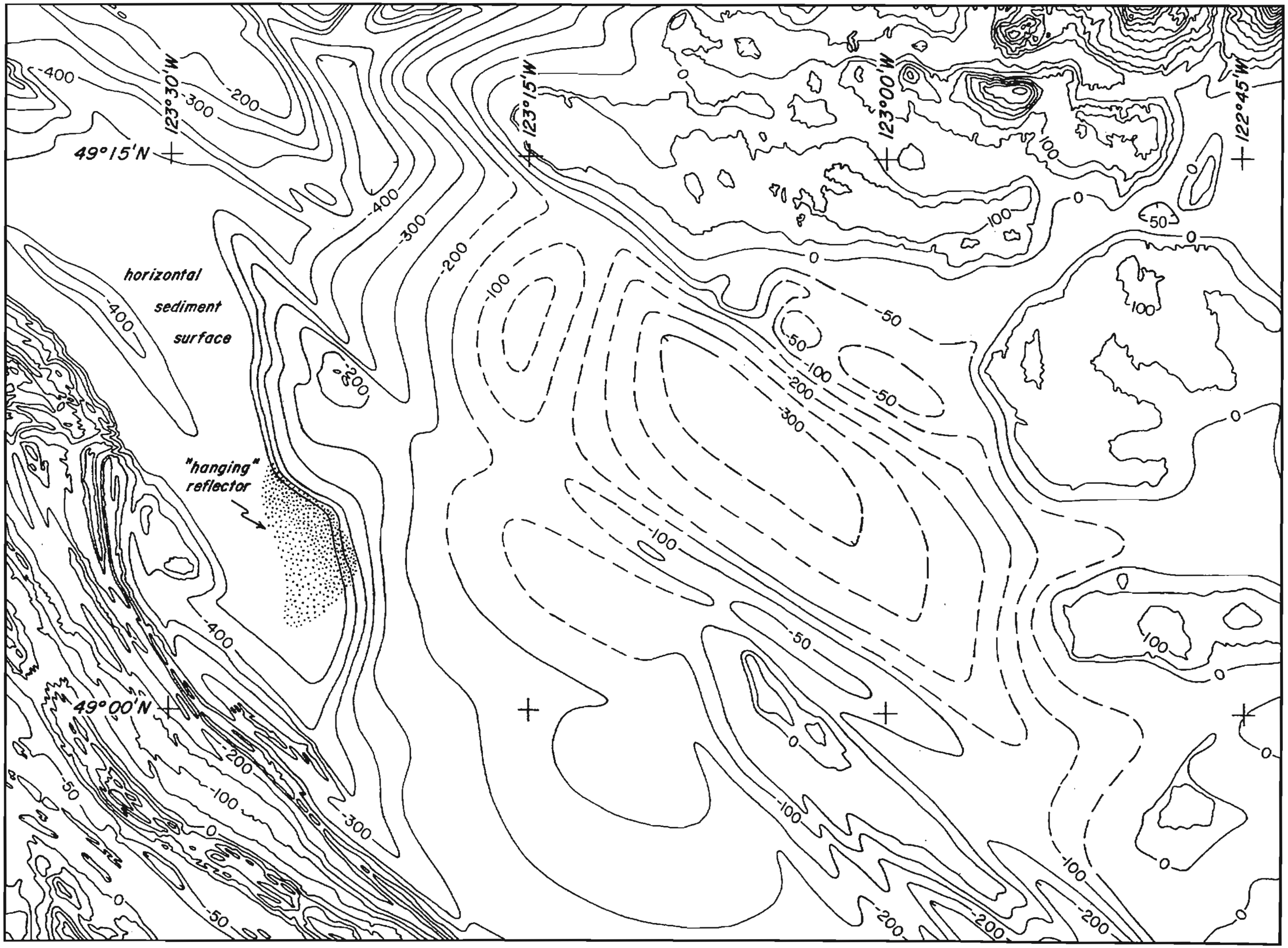

LINE TDL-82-14
(17 km)
SW
NE
STURGEON BANK
TWO WAY TIME (ms)
0
100
200
300
400
500
WATER DEPTH (m)
0
NOTE NON-LINEAR SCALE
100
200
300
SCATTERED REFLECTION
FRASER RIDGE
FRASER DELTA

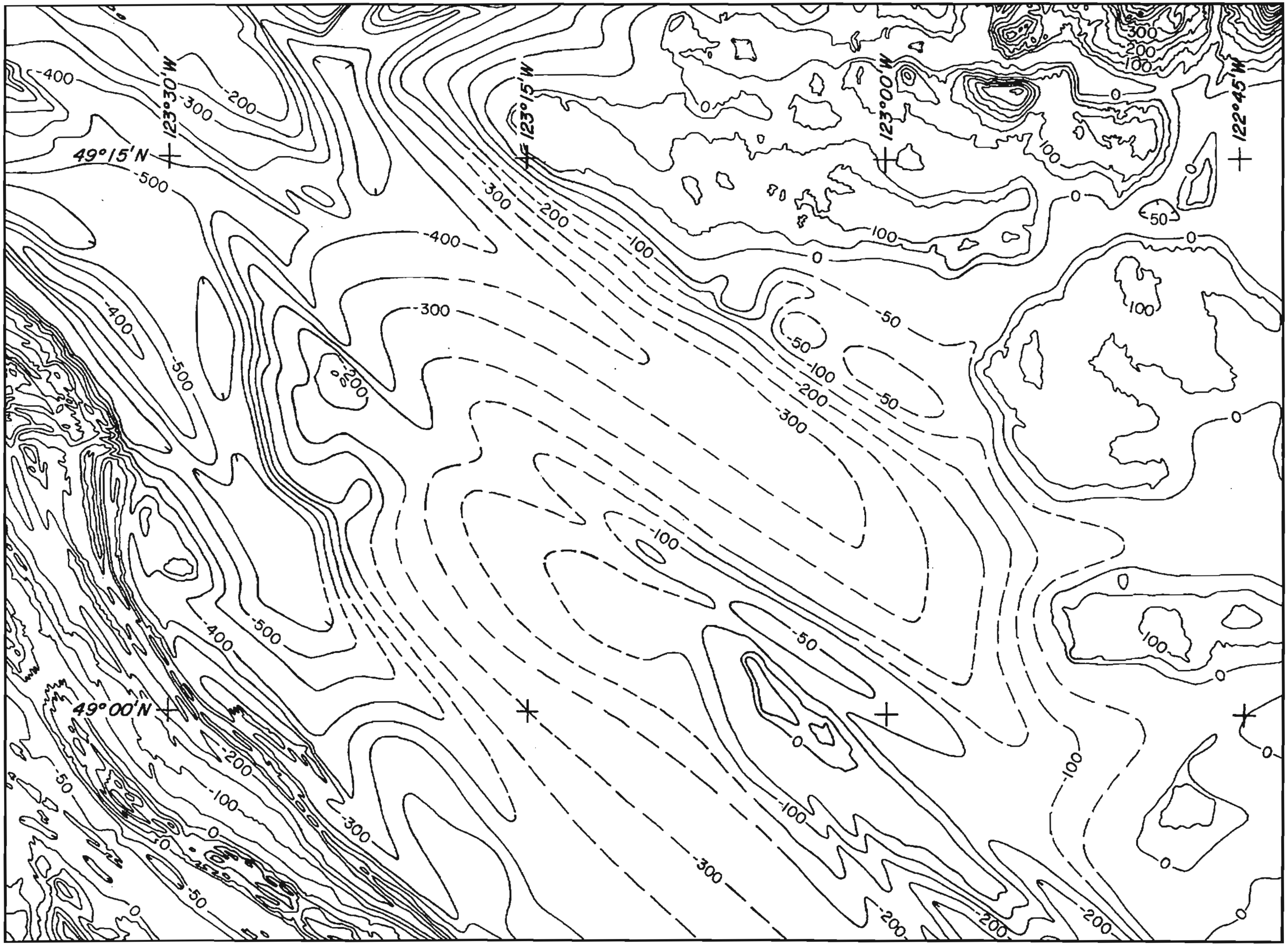
FIGURE 5



APPROXIMATE TOPOGRAPHY
PRIOR TO DELTA EMPLACEMENT
(CORRESPONDING TO MINIMAL DEPTHS)

0 5 10 20 km
50 M. CONTOURS REFERRED TO PRESENT SEA LEVEL

FIGURE 6



APPROXIMATE TOPOGRAPHY
PRIOR TO DELTA EMPLACEMENT
(CORRESPONDING TO MAXIMAL DEPTHS)

FIGURE 7