SITE SELECTION FOR GEOTECHNICAL/GEOLOGICAL BOREHOLES ON SABLE ISLAND BANK

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SABLE ISLAND GEOLOGICAL/GEOTECHNICAL BOREHOLE SITE SELECTION

1) OBJECTIVE:

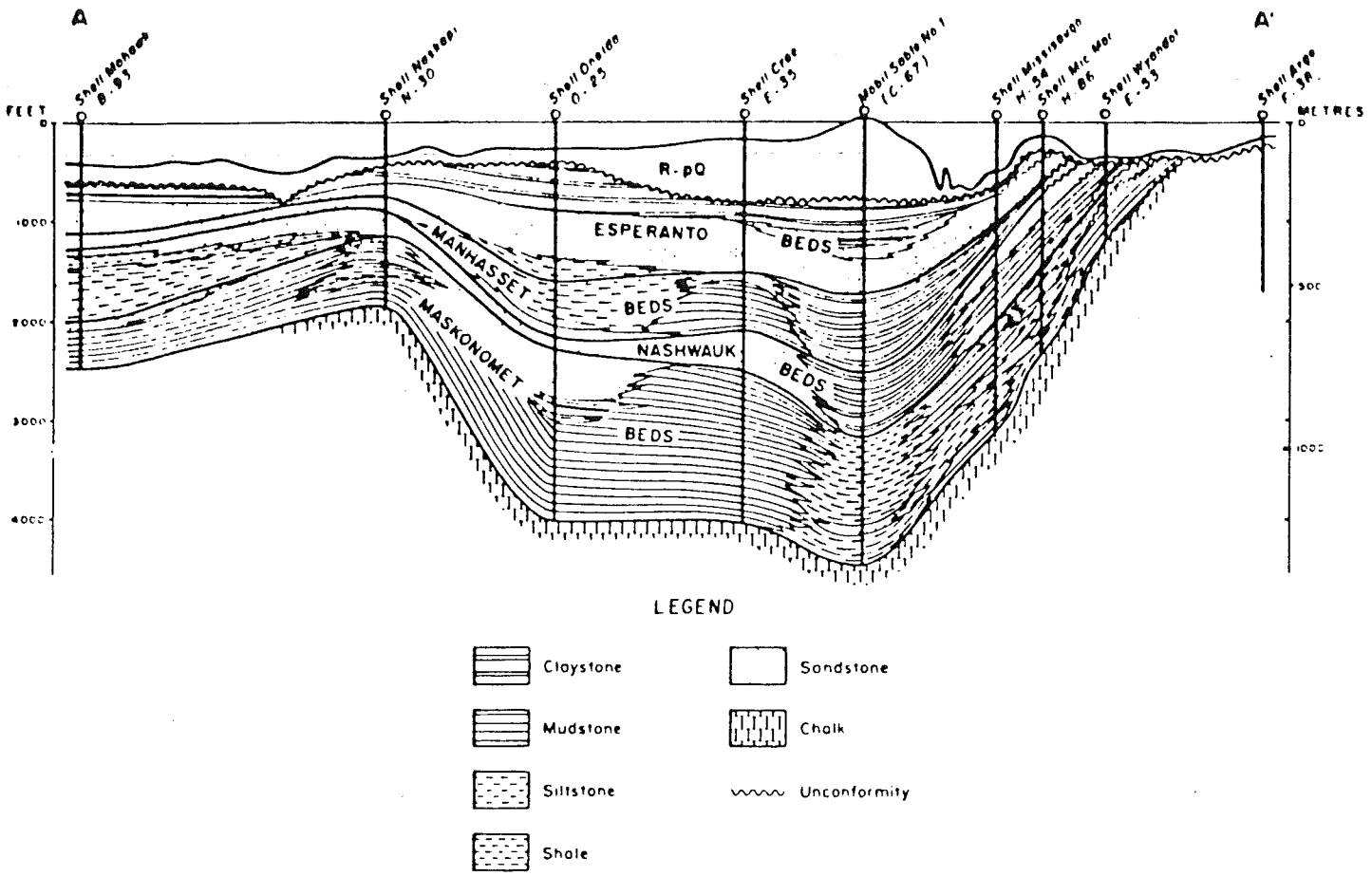
The objective of this report is to identify the most suitable location for a geological/geotechnical borehole to be drilled by the Atlantic Geosciences Centre (AGC) on Sable Island Bank.

2) FORMAT

This report begins with an overview of Sable Island Bank geology. It then identifies the available data sources and provides a synthesis of the interpreted seismostratigraphy of Sable Island Bank. It concludes by listing a suite of potential borehole sites based on the projects scientific objectives. The relevant advantages and disadvantages of each site are discussed.

3) OVERVIEW OF SABLE ISLAND BANK GEOLOGY

The regional geology of the Scotian Shelf consists of a seaward thickening wedge of Tertiary and Cretaceous sediments overlying Paleozoic basement. The Paleozoic Meguma Group outcrops on land and across the inner shelf. Small, isolated Cretaceous exposures are found on the mid shelf but the remainder of the middle and outer Scotian Shelf is covered with either Tertiary or Quaternary sediments (King and Maclean, 1976). Hardy's (1975) study of the Tertiary Banquereau Formation shows a thick Tertiary sequence

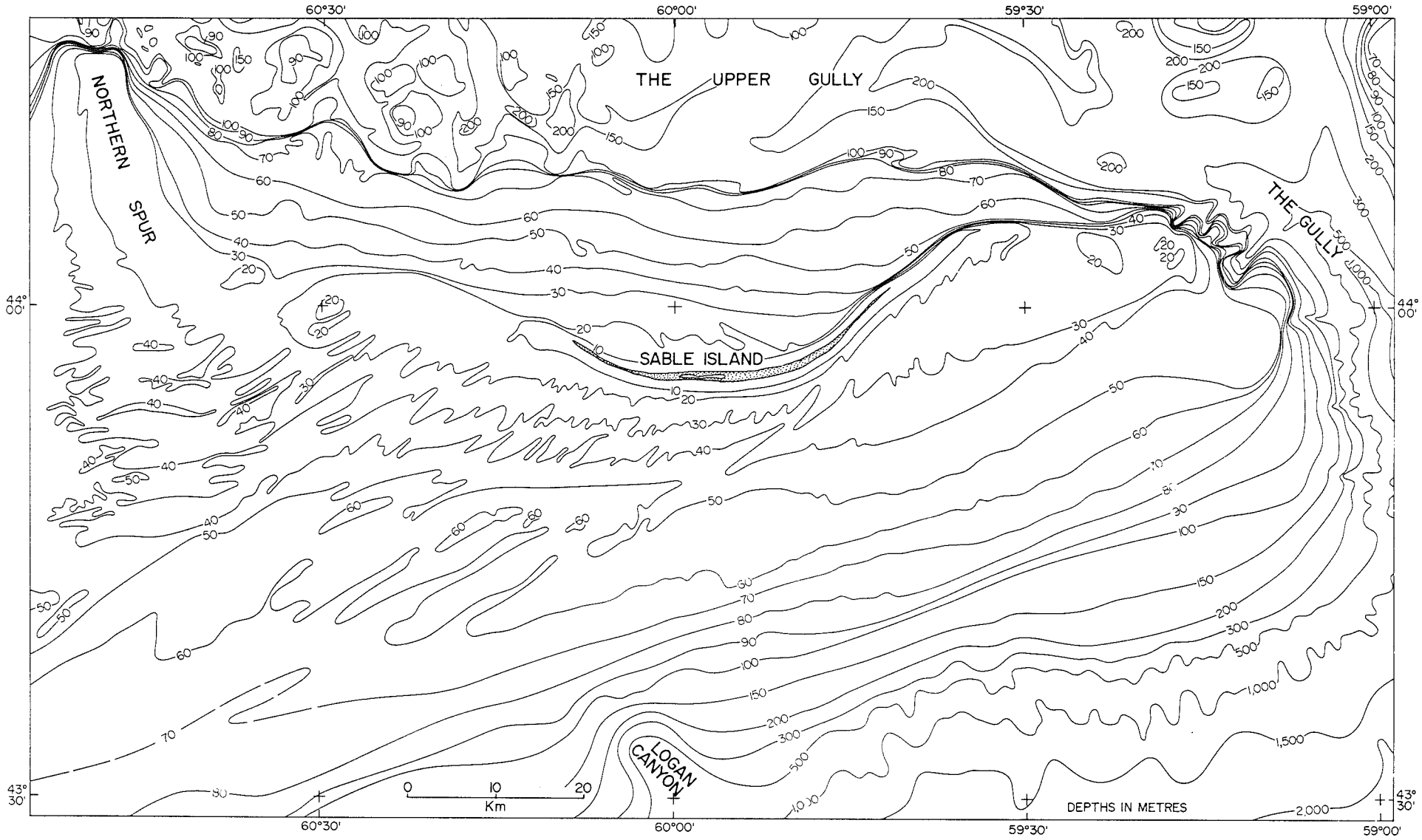


LEGEND

- Claystone
- Mudstone
- Siltstone
- Shale
- Sandstone
- Chalk
- Unconformity

of up to 2km near Sable Island. Marlowe (1965) identified Tertiary rocks exposed at depths of 360m below SL in the walls of The Gully, a submarine canyon 32km NE of Sable Island. Quaternary sediments are shown to occur over Sable Island Bank in Hardy's (1975) study, with thickness varying between 50 and 262m (Figure 1). Quaternary sediments are separated from the underlying Tertiary sediments by a widespread unconformity. However, Hardy's evidence for the boundary between Tertiary and Quaternary sediments appears to be limited to data from the Mobil C-67 well located in the centre of Sable Island where the boundary is considered to be at at 262m below SL. Hardy's evidence for an unconformity between Tertiary and and Quaternary strata was not derived from borehole data but from reference to the work of King et al. (1974) and King and MacLean (1976) elsewhere on the Scotian Shelf.

Relative sea level (RSL) has oscillated throughout Quaternary time. King and Fader (1984) indicate a -110 to -120m low sea level stand occurred on the Scotian shelf around 16000 ybp. Scott et al. (1984) constructed a Holocene sea level history for Sable Island. This curve shows sea level was at -25m 8000 ybp and a steady rise has occurred up to the present time. King (1970) established a classification of surficial sediments on the Scotian shelf. Glaciomarine sediments of the Emerald Silt, marine sediments of the LaHave Clay and sublittoral Sambro Sands are found below the -110m Wisconsinan shoreline. This includes the basins of the middle shelf and also other topographically low areas such as The Gully in the Sable Island area. Above the -110m shoreline the transgressive Sable Island Sand and Gravel is found on the surface of the inner shelf and the banks of the outer Scotian shelf including all of Sable Island Bank.


60°30'
60°00'
59°30'
59°00'
44° 00'
43° 30'
NORTHERN SPUR
THE UPPER GULLY
THE GULLY
SABLE ISLAND
LOGAN CANYON
0 10 20
Km
DEPTHS IN METRES

The topography of Sable Island Bank can be summarised from detailed hydrographic surveys conducted in 1982 by the Canadian Hydrographic Service. The shelf break on the outer Scotian shelf is located at a depth of around -100m south from Sable Island. Further east the shelf break is interrupted by The Gully, a major submarine canyon which cuts into the continental shelf to the north of Sable Island (Figure 2). Sable Island Bank itself can be subdivided into 4 major physiographic regions:

1) A zone of shoreface-detached and shoreface-connected ridges found to the south and southwest of Sable Island between the base of the shoreface and the 70m isobath.

2) A relatively flat region southeast from Sable Island to the shelf break.

3) Sable Island itself and the shallow sandbodies of East Bar Extension and West Bar Extension on to Northern Spur.

4) A relatively flat platform which lies north from region 3 to the edge of the Gully.

4) DATA SOURCES

The data sources that are relevant to choosing potential borehole sites consist primarily of seismic reflection profiles and geotechnical boreholes drilled for engineering purposes at former jackup rig sites. These data consist of: 1) High resolution seismic reflection sub-bottom profiles. These normally originate from 2 sources - Huntec boomer and NSRF sparker. The boomer source has higher potential resolution while the sparker has better penetration. However, the penetration of both sources is usually limited in depth to the arrival of the first water bottom multiple. On Sable Island Bank in the area of interest this means a practical limit of

between 20m and 60m below the seabed.

The principal sources of high resolution seismic data are from AGC and Dalhousie cruises conducted since 1980. These include several cruises with C. Amos chief scientist on board Dawson (82-040, 83-026, 85-037, 84-005) and Baffin (82-039), and Dalhousie's Dawson cruise 85-019.

2) Airgun and watergun profiles. These originate from relatively small 20-40 cu. in. airguns and 60-160 cu.in. waterguns. Airgun and watergun sources have lower resolution than Huntec or NSRF equipment but better penetration. However, in contrast to the normally good to excellent quality of the high resolution sources, airgun and watergun data have suffered from poor quality data from Sable Island Bank including frequent downtime, shallow penetration and strong multiples. Airgun and watergun data also originate from AGC and Dalhousie cruises including most of those listed above (82-039, 84-005, 85-019, 85-037). Earlier AGC cruises of King and Fader's collected airgun data from around Sable Island Bank but their lines end on the bank margins and thus are not directly applicable to borehole site selection.

3) Geotechnical boreholes. Each site drilled by a jackup rig has had a foundation analysis completed before spudding. This foundation analysis typically includes a shallow geotechnical borehole drilled to depths of around 20m-30m. These boreholes are not continuously sampled. Instead, approximately 50cm is sampled in every 3m drilled. All but two geotechnical boreholes on Sable Island Bank have been drilled for Mobil Oil Canada. These include 9 boreholes at the Venture site, 2 at the Thebaud site, and others at Mariner, West Olympia, Olympia, Acadia, Migrant and South Venture. The other 2 borehole sites have been drilled for Shell Resources Canada at Onandaga and Kegeshook. However, the majority of these boreholes are the confidential property of the operators Mobil and Shell and were not

available for this report.

The longest scientific borehole drilled on the Scotian Shelf was completed on Sable Island by Dalhousie University. This borehole was continuously sampled to a depth of 152m and forms the best borehole source of geotechnical and geological information on Sable Island Bank.

4) Industry Site Surveys.

Each wellsite drilled on the Scotian Shelf has a geophysical site survey completed beforehand. This normally consists of 16Kj sparker or equivalent, with multichannel recording and subsequent processing. The objective is to locate and identify any drilling hazards, particularly shallow gas. This data is confidential for 5 years. Since virtually all site surveys relevant to potential AGC borehole sites have been drilled in the last 5 years, wellsite survey results were not available for this report.

SYNTHESIS OF SEISMIC STRATIGRAPHY.

Where airgun and watergun data are of sufficient quality, Tertiary reflectors can be identified underlying most of Sable Island Bank. These are high amplitude, high continuity reflectors which dip consistently toward the SE at low angles. A widespread unconformity occurs near the top of this Tertiary section. The unconformity appears close to the present day seafloor on some parts of the bank such as near the Upper Gully, but in other regions takes the form of a network of major channels up to 550ms below present sea level. It is not clear if this unconformity represents the boundary between Tertiary and Quaternary sediments. Hardy's location of the boundary at -262m has no seismic control but unless the C-67 borehole is situated within a major channel, Hardy's Tertiary/Quaternary boundary would lie below the widespread unconformity.

The Quaternary sequence above the unconformity is complex and contains both locally thick channel-fill sequences and thinner, more regionally extensive sequences. The Quaternary sequence is thinnest over physiographic region 1 (defined above) north of Sable Island and thickest under Sable Island itself and East Bar Extension (region 3). The Quaternary sequence is characterised by multiple unconformities and numerous channel cut and fill structures. The upper part of the Quaternary sequence is best understood because of the abundance of good quality, high resolution seismic profiles, but data quality and interpretation confidence decreases rapidly with depth.

Quaternary Seismic Stratigraphy.

A widespread unconformity occurs over all of Sable Island Bank at a depth of 60-70m below sea level. Correlation of this unconformity with a similar feature on Banquereau (C. Amos personal communication) indicates that it occupies the time period from 8000-16000 years before present (ybp) and therefore probably represents the sea level transgression associated with the Holocene/Pleistocene boundary.

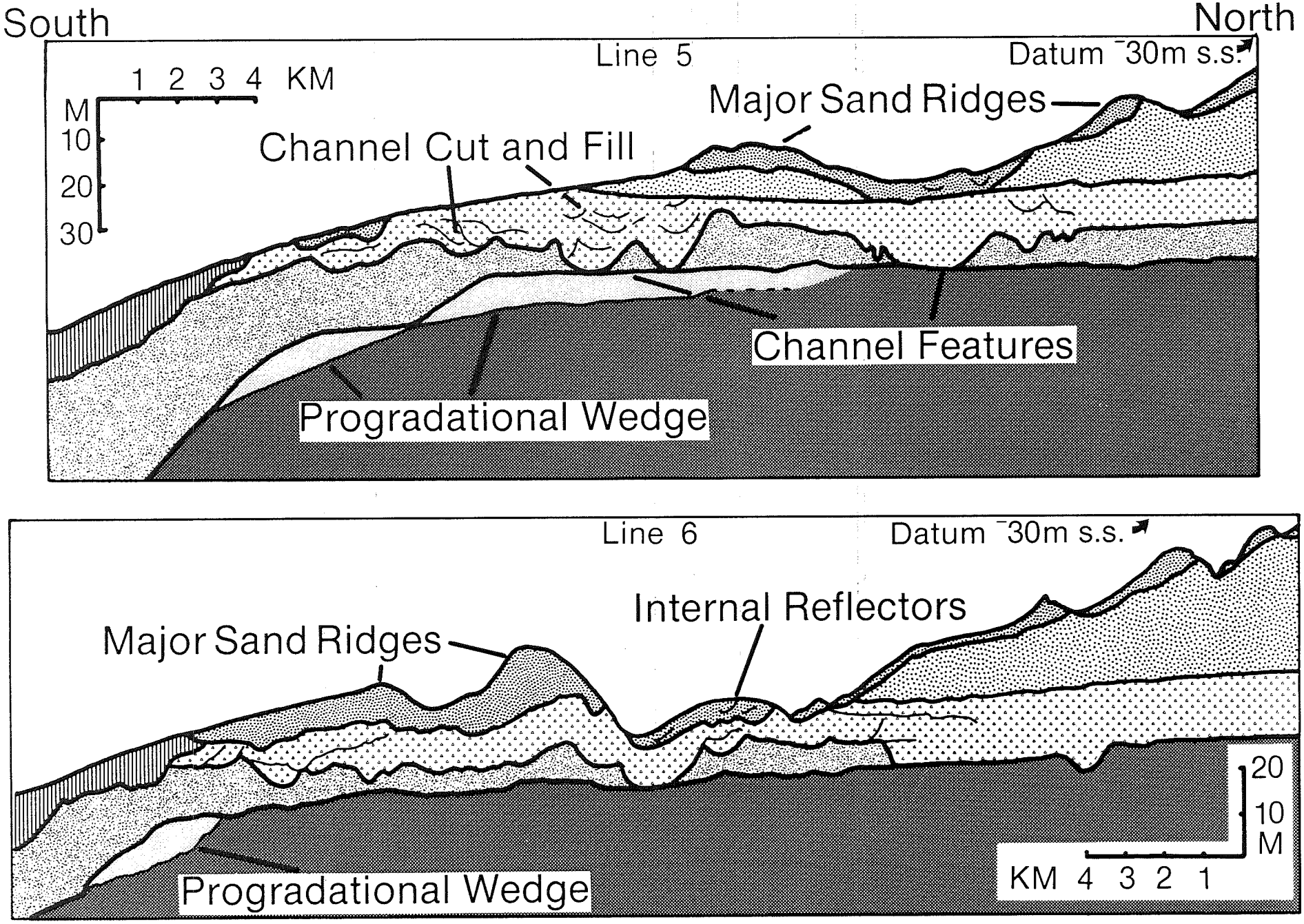
Above the unconformity reflector the Holocene sediments conform to the description of Sable Island Sand and Gravel (King, 1970). They consist of fine to coarse sand and gravel with occasional interbedded silt and clay units. Where these clay units have been dated in boreholes on Sable Island (Scott et al. 1984) they indicate that the upper 25m of Sable Island Sand and gravel accumulated in the last 8kybp. Further out on the shelf south from Sable Island the stratigraphic sequence above the unconformity is

mainly composed of shoreface connected and nearshore ridge systems (figure 3). Seismic stratigraphy in this region shows troughs between individual shoreface ridge systems may scour down to the 60-70m unconformity and may even generate the unconformity in some regions such as near Harcourt-Cameron Ridge in water depths of 50-60m. Migration of the troughs between the shoreface ridges seems likely based on the reflectors observed within the shoreface ridges which show clinoforms prograding towards the South East. Where penetrated by vibrocores the shoreface ridge sequence consists of fine to coarse sand with intervening coarse sand to pebble lags and coarsening-upward grainsize sequences several tens of cm thick (Vaughan, 1982).

East Bar Extension, West Bar Extension and Northern Spur are all accumulations of Sable Island Sand and Gravel which average several tens of meters thick. Through Harky Pass between West Bar Extension and Northern Spur at least one unconformity lies within 10m of the seafloor and the area is characterised by shoreface ridge systems and features which appear to be migrating tidal sand ridges. Both East Bar Extension and Northern Spur appear to be large bar systems with clinoforms which dip to the north and east and indicate migration in those directions.

Sable Island Sand and Gravel thins over the platform between Sable Island and The Gully. Small sand ridges can be seen in many locations but elsewhere the sand is only a veneer and the 60-70m unconformity merges with the seismic bubble pulse at the seafloor.

A variety of seismic stratigraphic facies lie between the top of the Tertiary section and the unconformity at the base of the Holocene. South


South
North
Line 5
Datum -30m s.s.
1 2 3 4 KM
M
10
20
30
Major Sand Ridges
Channel Cut and Fill
Channel Features
Progradational Wedge
Line 6
Datum -30m s.s.
Internal Reflectors
Major Sand Ridges
20
10
M
KM 4 3 2 1
Progradational Wedge

from Sable Island (Figure 2) this part of the seismic stratigraphy contains several widespread low angle reflectors, several of which end in progradational wedges at their seaward ends and the lowermost reflector exhibits oblique toplap. Above the flat lying reflectors are numerous channel cut and fill structures several hundred to several thousand meters wide and up to 15m deep. The channel fills are acoustically transparent to chaotic in nature. To the north of Sable Island only remnants of the flat-lying reflectors can be found where they are not removed by widespread channel erosion. The channels contain a variety of complex channel fills which range from acoustically transparent to units with irregular boundaries and no coherent internal reflectors.

The interpretation of the widespread, low angle reflectors suggests that they are either reflectors within the Tertiary sequence or they are further unconformities within the Pleistocene section which represent earlier sealevel transgressions. Their general conformity with the attitude of Tertiary reflectors suggests the former while the toplap and seaward termination of the reflectors in wedge- shaped reflectors suggests the latter. Where Tertiary material has been interpreted on Huntec or NSRF sources previously, such as in the Upper Gully, little of the acoustic energy penetrates the top of the Tertiary surface. The shallow channels may be interpreted as sub-ice meltwater features (J. Andrews personal communication) or as proglacial glacio-fluvial channels. The transparent reflectors which infill some of the larger channels may be glacial marine clays analagous to those intersected in the Dalhousie Sable Island Borehole . The units with irregular boundaries and no internal reflectors are similar in nature to till units on the inner to middle shelf such as the Country Harbour end moraine.

DRILLING SITE SELECTION

Several major scientific problems need to be addressed by a future AGC borehole: 1) Where is the true Tertiary/Quaternary boundary on Sable Island Bank? This has never been satisfactorily determined. Since the boundary is chronostratigraphic in nature it will need to be determined by biostratigraphy, probably through foraminifera, nannofossils or spores and pollen. Possible candidates for the Tertiary/Quaternary boundary are a) Hardy's (1975) top of the Esperanto beds at -262m in the C-67 borehole, b) the erosional unconformity seen on seismic profiles as the base of a major channel sequence. Hardy's (1975) top of the Esperanto is a tight interbedded claystone and sandstone which is a regional lithologic and well log marker horizon. The seismic unconformity on the other hand is found above the top of the Esperanto beds and could represent any number of lithological or well log boundaries found in the C-67 well (the only well to sample the entire Tetiary and Quaternary section). Possible boundaries are found at 220'(67m) where the base of the dominant sand sequence is located, or at 500'(152m) which is the top of a sequence with a clayey matrix and where clay/anhydrite is interbedded with the sands.

The Tertiary boundary will require establishment by micropaleontological control as the lithological sequence does not appear to be distinctive. The Esperanto beds are greyish-brown to light grey, very fine to coarse grained angular to subrounded poorly consolidated to unconsolidated argillaceous, silty, glauconitic and lignitic quartzose sandstones (Hardy 1975). The

Dalhousie boreholes on Sable Island indicate that this description could also easily fit the Quaternary sequence. 2) It would be an important scientific objective to site a borehole on the crest of a shoreface ridge. Although numerous vibrocores have been dilled on the crests and flanks of ridges no complete sequence through them has been obtained. This objective would allow identifcation of the internal SE-prograding foreset sequence as well as sampling the basal contact.

3) The nature of the sequence below the shoreface ridges needs to resolved. The channels within this sequence may be sub-ice or glaciofluvial in nature. The fill may be diamict-like, it may be glaciomarine clays as in the Dalhousie 1985 borehole, or it may be braided-fluvial sands deposited on an outwash plain.

Therefore the drill site should fulfill the following criteria:

(1) It should be located south of Sable Island to enable the fullest sequence to be sampled.

(2) It should be located on a interchannel high at the unconformity boundary to enable a complete Quaternary sequence to be sampled and the Tertiary surface reached and identified. Such a location would enable the base of the Quaternary to be reached whether it was the unconformity or the top of the Esperanto beds.

(3) It should not be near the shelf edge as deeper units thicken appreciably here and stratigraphy is less well understood.

(4) It should be positioned to enable correlation with both multichannel site survey geophysics and single channel regional coverage. This means any location with a site survey on the south side of Sable Island or its bar extensions would be suitable. Shallow sites have the advantage of sampling a fuller Holocene section but are harder to drill from a drillship. Deeper

sites are more easily correlated with high resolution NSRF or Huntec lines as the seafloor multiple occurs further down in the record. Future economic development appears likely to be concentrated on the Venture and Thebaud sites and along the southern pipeline route which links them to the Nova Scotian mainland. Therefore for maximum future applicability the borehole would be best sited at either the Thebaud or Venture sites.

(5) It should be close to available geotechnical borings to provide correlations and to extend the validity of the results (several boreholes versus just one).

(6)Drilling consideration indicate at least 30m water depth is desirable (S.Yuill personal communication).

(7) The drillhole should be continuously sampled throughout. Without continuous sampling it is difficult to correlate borehole lithology with seismic horizons and to make confident environmental interpretations.

RECOMMENDATIONS FOR DRILLING

a) The borehole should be sited in the central sector of the Thebaud site survey area at 43 degrees 52.7 minutes North and 60 degrees 14.1 minutes West. This area best fits all criteria. This site location is not critical and could be varied 500m in any direction to locate on a sand ridge crest. The nearest major channel as determined from watergun records is 1.5km to the east with a minor channel 1.3km to the southwest. The site appears to be on a high interfluve with around 145m depth below sea level to the base of the major channel unconformity. Water depth at this site which is near the Thebaud K-93 wellsite is 33m. However watergun data quality is not high and final site selection is best done in conjunction with access to multichannel geophysics profiles. These profiles

will need to be requested from Mobil Oil Canada Ltd.

b) An alternative site would be the eastern sector of the Onondaga site survey area. Less total sequence is available here. Other comparable locations are at or near the Migrant J-2 wellsite, or in the Cohasset P-42, D-42 wellsite area (no current site survey is available in Halifax for this site). Available AGC and Dalhousie seismic data for the Cohasset site indicates gently southward-dipping reflectors interpreted as Tertiary in age at depths as shallow as 60m below the seafloor (90m below sea level). These reflectors are incised by large channel systems eroded to depths of at least 150m below sea level. The shallow seismic stratigraphy at the Cohasset site is similar to that shown for the area further east on figure 3.

c) The Venture area is a further possibility but is not recommended due to the extensive drilling already completed, shallow water at the site and the relatively thick Holocene section to be penetrated.

d) A fourth alternative would be on the north side of the island. This would also provide a thinner sequence with little or no Holocene section, bedrock close to the surface and would enable comparison with the south side of the island below the Holocene/Pleistocene boundary. This alternative (d) is recommended as a borehole to be drilled after choices (a) or (b). A likely site would be the West Olympia site. A location on the southern margin of this site survey would enable comparison with geotechnical boreholes and with Dalhousie's recent land boreholes on Sable Island itself.

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