DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2008/45

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Geological description and interpretation of nine vibrocores from the Rigs-3 site, Northern Tails End area, Danish North Sea

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Contents

1. Introduction

Nine vibrocorings were carried out as a part of a site survey by Gardline Geosurvey Ltd. for Dong Efterforskning og Produktion A/S. The objective of the survey was to facilitate a general examination of the Rigs-3 site within the Danish sector 5604/29 (Gardline Geosurvey Ltd. 2006).
The cores were handed over to GEUS by DONG according to law no. 293, § 34, of June 10. 1981 and no. 13 of January 7. 1991.

2. Location and Seabed Features

2.1 Location

The Rigs-3 site is proposed at Latitude 56d 06' 52.25" North and Longitude 004d 11' 44.19" East, at UTM Grid Zone 31 Easting 574 348, Northing 6 219 606 (Enclosure 1).
The vibracores were retrieved from a survey area of 2,8 x 2,2 km. (Enclosure 2, 3, 4).
The Rigs-3 site is located over the Danish Central Graben area in the northern part of the Tail End area on seabed depths of approximately 61 m below sea level (bsl).

2.2 Seabed Features and Geological Setting

According to the Gardline Geosurvey Ltd. (2006) industrial report, water depths within the survey area range from 60.60 to 61.37 m, revealing that the seabed in this area is flat and subdued. The seabed consists mainly of sandy silt and fine-grained, silty sand. The side scan sonar investigation shows several scattered patches of coarser material or shells to a height of 0.3 m above the sea bed, with three debris concentrations suggested from 0.3 to 1.7 m above the sea bed.

According to Gardline Geosurvey Ltd. (2006), Quaternary sedimentary deposits are 352 m thick in the area. Several channels in the Quaternary sequence are recognised on the seismic sections and at least three phases of channelling are inferred (Enclosure 5).
The uppermost channel, located between 2 m and 14 m below the seabed, is oriented in a NW-SE direction filled by layered clay, silt and sand (Enclosures 18). A second channel with steep dipping layers crosscutting the first channel is also evident in the seismic section (Enclosure 19). The vibrocore sections contain ~5 m of channel deposits and other clastic sediment, revealing that the channels incised into older Quaternary deposits consisting of clay with sand layers. For example, three incising channels are evident in the upper 138 m while the lower 124 m of sediment consists of horizontally layered deposits.
Some of these layers contain traces of gas.

3. Geological Description of Vibrocores

A legend of the lithological logs is found in Enclosure 6.

3.1 Sedimentological Core Logs

VC1. DGU Well file no. 560429.22
The geological description of vibrocore VC1 is given in Enclosure 7. The 3.85 m long core mainly contains fine-grained, silty sand in the upper 1.60 m together with shells and shell fragments. From 1.60 – 2.40 m laminated fine-grained sand dominates, interbedded with several thin horizontal beds of slightly sticky clay and few scattered shells. Fine-grained sand with small streaks of clay and few scattered shells is found from 2.40 – 3.75 m. Sand with plant remains and clay streaks occurs at 3.65 – 3.75 m. A sample of the plant material has been radiocarbon dated. Sticky, structureless clay with many shells characterises the bottom of the core between 3.75 – 3.85 m depth. A foraminiferal analysis performed on a sample taken at the bottom is found in Enclosure 17.

VC2. DGU Well file no. 560429.23
The geological description of the vibrocore VC2 is given in Enclosure 8. The 4.80 m long core is made up of fine-grained sand, clay and sand, clay and silt, peat and gyttja layers. The upper part of the core from 0 – 0.36 m consists of very fine-grained sand with shells whereas the interval from 0.36 – 1.7 m is horizontally laminated, containing very fine sand with silty streaks and organic material. The degree of interlayering between clay and sand increases downcore between 1.70 – 3.35 m. A 9 cm thick moss-peat containing silty gyttja occurs between 3.35 – 3.44 m depth. A sample from the latter layer has been radiocarbon dated. Clay and silt with organic material characterises the basal section of the core between 3.44 – 4.80 m depth. Samples for foraminiferal analysis were collected between 3.80 – 4.00 m and 4.70 – 4.80 m (Enclosure 17).

VC3. DGU Well file no. 560429.24
Vibrocore VC3 is described in Enclosure 9. The 5.10 m long core is made up mainly of two sections. The upper section between the seabed and 1.72 m depth consists of structureless, fine-grained sand with shells. In the lower section from 1.72 – 5.10 m silt, sandy-silt, and clay layers with few streaks of organic material are interlayered. A sample for foraminiferal analysis was taken at 5.00 m.

VC4. DGU Well file no. 560429.25
The lithological log for vibrocore VC4 is located in Enclosure 10. The 4.30 m long core consists mainly of fine-grained sand with few clay layers. Structureless fine-grained sand that contains many shells occurs in the upper part of the core from the seabed to 0.98 m depth. In the lower part of the core the sand contains thin layers of organic material and layers of clay.

VC5. DGU Well file no. 560429.26
The description of the vibrocore VC5 is shown in Enclosure 11. The 3.40 m long core is made up of fine-grained and very fine sand. In the upper part of the core between seabed and 0.60 m depth the structureless sand contains many shells. The lower part consists of laminated, very fine-grained, silty sand with relatively few layers of clay, organic material and peat.

VC6. DGU Well file no. 560429.27
The results of the description of the vibrocore VC6 is presented in Enclosure 12. The 4.48 m long core consists mainly of laminated, very fine-grained sand. The upper part of the core between the seabed and 0.65 m depth contains many shells. Between 1.10 – 3.00 m depth, horizontal layers of clay are found in the sand whereas thin horizontal layers of organic material are found in the sand between 3.00 – 4.48 m.

VC7. DGU Well file no. 560429.28
The geological description of the vibrocore VC7 is shown in Enclosure 13. The 4.45 m long core consists mainly of laminated, very fine-grained sand. The upper part between seabed and 0.85 m depth contains many shells. In the middle part between 1.23 – 1.88 m some horizontal clay layers are interlayered with the sand. Between 2.88 – 3.00 m depth, horizontal layers of organic material are found in the sand whereas from 3.80 – 4.10 m depth thin peat layers occur in the sand.

VC8. DGU Well file no. 560429.29
The description of the vibrocore VC8 is given in Enclosure 14. The 4.88 m long core is mainly made up of very fine-grained sand. A variety of shells are found between the seabed and 0.70 m depth. The laminated sand contains thin organic layers and small fragments of bivalves and gastropods from 0.70 to 4.40 m depth. At the bottom of the core between 4.40 – 4.88 m depth, horizontal clay deposits with plant remains are present. A sample for foraminiferal analysis was taken at 4.82 m (Enclosure 17).

VC9. DGU Well file no. 560429.30
Vibrocore VC9 is described in Enclosure 15. This core is 4.40 m long and consists mainly of fine-grained and very fine-grained sand. Structureless, silty, very fine-grained sand with many shells occurs between the seabed and 0.22 m depth while the sand down to 2.4 m has only few shell fragments and scattered organic material. From 2.40 to 4.40 m the sand contains several thin layers of organic material. Thin layers of clay are noted in the lower part of the core between 2.70 – 2.85 m and between 3.70 – 4.40 m depth.

4. Biostratigraphy

4.1 Mollusca and Foraminifera

Molluscs from the cores was identified by Larsen, B. (2006) (Enclosure 16).
Molluscan specimens were picked out from 9 depth intervals from 6 of the vibrocores.
All the identified species are of marine origin and are known from both the Holocene and the Eemian.
According to the overall interpretation of the deposits, all the species are regarded as Holocene or Weichselian (see chapter 6).

Analysis of foraminiferal samples were made by Ebbesen, H. (2006) (Enclosure 17).
Ten foraminiferal samples were taken from 5 vibrocores. However, it was possible to carry out analysis on 3 samples only.

The analysis identified Quaternary foraminifera. The presence of foraminifera confirms that the sedimentary records were deposited in a marine setting. The foraminifera assemblages in vibrocores VC1 (3,75–3,85 m) and VC8 (4,82 m) are similar and likely reflecting the beginning of the Holocene or perhaps from the termination of the Late Weichselian. They belong to a warm boreal climate and shallow marine water.
Vibrocore VC2 (4,70–4,80 m) seems to represent the Late Weichselian Yoldia Clay level deposited in deeper and cooler marine water.
The VC2 foraminifera sample originates from deeper water compared to the samples in VC1 and VC8.

4.2 Plant Macrofossil Analysis

In order to obtain material for 14C dating, two samples from VC1 and VC2 have been analysed for their macrofossil content.

In VC1, the following macrofossils were registered at 3.65 – 3.67 m depth: Rubus sp., seed-fragment (1), Carex sp., tristigmatae seed (2), Cyperaceae undiff., seed-fragment (3), Ranunculaceae undiff., seed (1), Twig-fragment without bark (1), Menyanthes trifoliata, seed (1), Ranunculus sect. Batrachium, seed (3), Charcoal (1).

In VC2, the following macrofossils were registered at 3.35 – 3.44 m depth: Carex sp. tristigmatae seed (34), Eleocharis sp., seed (3), Cyperaceae undiff., seed-fragment (94), Twig-fragment (2), Chara sp., oospore (1), Sphagnum sp., leaves (1), Daphnia, ephippia (2), Charcoal (19), Moss-fragments undiff. (in large numbers).

The sediment matrix and macrofossil content of the two samples clearly indicates that the deposits are of lacustrine origin with a mixture of terrestrial, fen and aquatic plants.

5. Radiocarbon Dates

Two samples from VC2 and VC3 were dated at the AMS 14C dating Centre, Aarhus University.

VC1, 3.65 – 3.67 m depth:
Sample lab no: AAR-11785
Dated material: Rubus sp., seed-fragment (1), Carex sp., tristigmatae seed (2), Cyperaceae undiff., seed-fragment (3), Ranunculaceae undiff., seed (1), Twig-fragment without bark (1).
Dating result: 18620 ± 150 14C yr BP; calibrated age: 22350 – 22070 yr BP (1 sigma).

VC2, 3.35 – 3.44 m depth:
Sample lab no: AAR-11145
Dated material: Carex sp. tristigmatae seed (34), Eleocharis sp., seed (3), Cyperaceae undiff., seed-fragment (94).
Dating result: 11140 ± 70 14C yr BP; calibrated age: 13110 – 12960 yr BP (1 sigma).

6. Stratigraphy and Depositional Environments

A geological cross section was compiled using well logs VC7 – VC1 - VC2 – VC3 – VC4 – VC5, all situated in the central part of the area (Enclosure 20). The section demonstrates the interpreted correlation between the units and is described in the following chapters.

6.1 Stratigraphy

The biostratigraphical data combined with the 14C-dates indicates that the deposits are of Late Weichselian and Holocene age.

Lithostratigraphical units have not been defined in this part of the Danish North Sea sector but so far it has been possible to fit some of the Danish units into units defined in the Dutch sector (Konradi, 2003, 2004). The described deposits from the vibrocores are placed in the following units (from the top):

The youngest lithological unit from the seabed down to approximately 2.4 m depth (0.5–2.4 m thick) is referred to the Terschellingbank Member of the Nieuw Zeland Gronden Formation (Jeffery et al., 1989; Laban et al., 1995). This member is of marine origin and is characterised by fine to very fine-grained sand, often silty, with shells or shell fragments. The formation is found in other wells in the Tail Ends area but sometimes developed as the Western Mud Hole Member of the same formation (Konradi, 2003, 2004; Konradi and Czako, 2002). In these areas the Holocene deposits are thin, with glacial deposits present below the formation. The member forms a unit which can be recognised over large parts of the Danish, Dutch and British North Sea sectors (Cameron et al., 1992; Gatliff et al., 1994).

The next unit consists of heterolithic sediments, fine sand and clay deposits. These deposits are correlated with the Elbow Formation (Oele, 1969). The uppermost layers consist of heterolithic, laminated fine-grained sand, silt and clay above fine-grained sand with few shells. Thin organic layers are abundant throughout the deposit. The presence of few peat layers and shells indicates a near-shore depositional environment such as an upper tidal flat, a delta plain or a lagoon. Post-glacial marine clay and silt at the bottom of the unit suggests that marine conditions dominated for a period of time prior to the more brackish period which also is known from other areas (Cameron et al., 1989). The brackish and marine deposits are regarded as being early Holocene age even though the sediments contain redeposited older material (see remarks on the 14C-datings).
The Elbow Formation forms an often patchy unit recognised over large areas of the North Sea (Cameron et al, 1992; Gatliff et al., 1994).
The next unit consists of freshwater silt, clay and gyttja. A radiocarbon date from the 9 cm thick layer of moss peat with silty gyttja in core VC2 yielded an age result of 11,140 ± 70 yr BP, thus revealing that this sediment was deposited during the Late Weichselian - Allerød period. It is not possible to place the layers in the established lithostratigraphy of the English and Dutch parts of the North Sea, but the Lower Weichselian to Holocene Twente Formation consists of wind blown sand and freshwater sediments that were deposited under

periglacial conditions (Cameron et al., 1989). A thick basal peat layer is placed in the Elbow Formation and is considered to be Holocene age (Oele, 1969).
The lowermost marine layers belong to the Yoldia Clay unit of the Late Weichselian. These deposits are probably related to the Dogger Bank Formation, though the exact age relationship is unclear. The Yoldia clay is distributed in the Northern Danish Kattegat and Skagerrak areas (Gyllencreutz, 2005; Lykke-Andersen et al., 1993). Any potential connection to the Dogger Bank area is not known at this time.

A tentative lithostratigraphical subdivision is presented in the chart below:

Holocene	Nieuw Zeeland Gronden Formation	Terschellingbank Member
Holocene	Elbow Formation	
Late Weichselian	"Freshwater" Formation (Allerød) (Twente Formation ?)	
Late Weichselian	Yoldia Clay Unit (Dogger Bank Formation ?)	

The two radiocarbon dates partly support the lithostratigraphic interpretation that is detailed in the chart above. The section in well VC02 shows that the Late Weichselian Yoldia clay is followed by Allerød deposits (11140 ± 70 14C yr BP). This succession seems to suggest that the deposits are *insitu*. The dating of 18620 ± 150 14C yr BP from VC01 from nearly the same level as the Allerød beds likely reflects the redeposition of Weichselian material at the VC01 site during the Holocene. The redeposited sediment was probably eroded from the land area on the Dogger Bank.

6.2 Interpretation of depositional environment

During the Weichselian interval, the Dogger Bank area was characterized by deep channels and incised tunnel valleys as well as by glaciofluvial erosion and deposition due to large amounts of meltwater from glacial discharge from the numerous channels and lakes that existed in the area. In the Holocene, but before rising sea level submerged Dogger Bank around 7500 yr ago, a system of fluvial, estuarine and intertidal channels existed (Cameron et al., 1989; Fitch et al., 2005). A warm period around 18.000 BP supported plant growth in the Dogger Bank area.
The Yoldia Clay found in the bottom of 2 cores consists of clay and silt that contains marine shells and foraminifera. The clay was deposited in a deep marine environment characterised by cold water. Considering that deposition during the Late Weichselian occurred on the margin of the Dogger Bank, it was probably contemporeous with the glaciofluvial deposition on the bank.
During the Late Weichselian - Allerød period the area was uplifted, with sediment deposition occurring in lakes or near-shore lagoons.
In the Early Holocene the older deposits were cut by channels along the coast and the depressions were filled by lake, nearshore and marine sediments from the Elbow Formation.

Indeed, the heterolithic, interlayered sand, silt, clay and organic material deposited at this time contains occasional shells. Further, peat layers coupled with plant remains are evident as thin layers. These types of sediments are found in other parts of the Tail End area (Konradi, 2004), being especially well developed at the South Pod site on the Dogger Bank, Tails End area (Konradi and Czako, 2002). The high content of plant remains and peat suggests a near-shore environment while the shells could indicate a marine environment close to the coast. Seismic data suggests the existance of a shallow channel structure. The deposition area could have been a channel in upper tidal flat, with a delta plain or coastal lagoon close to the coast. The channels have been filled through different periods of marine and brackish conditions.

During the Late Holocene and the recent past, deposits of fine-grained sand with marine shells are present in all 9 vibrocores. The same type of sand is found in other parts of the Tail End area, e.g. at the HANNE-1 site (Konradi, 2004), the JETTE-1 site (Konradi, 2003), South Pod site (Konradi and Czako, 2002) and KIT-1x site (Fugro Engineers, 2001). This sand blanket is interpreted as being deposited in an open marine environment in the shoreface area on deeper water with low currents. This is also indicated by the molluscs.

7. Conclusion

The sediments of the 9 vibrocores demonstrate the deposition environment and the types of lithostratigraphical units in the central Tails End area in the North Sea. The units can partly be correlated with units in other parts of the western and southern North Sea.

8. References

Behre, K-E, 2007: A new Holocene sea-level curve for the southern North Sea. Boreas, Vol. 36, 82-102.

Cameron,T.D.J., Schüttenhelm, R.T.E. and Laban, C., 1989: Middle and Upper Pleistocene and Holocen stratigraphy in the southern North Sea between 52o and 54o N, 2o to 4oE. In: Henriet, J.P. & Moor De G.(eds.): The Quaternary and Tertiary geology of the Southern Bight, North Sea. Ministry of Economic Affairs Belgian Geological Survey, 119-135.

Cameron, T.D.J., Crosby, A., Balson, P.S., Jeffery, D.H., Lott, G.K., Bulat, J. and Harrison, D.J., 1992: The Geology of the Southern North Sea, United Kingdom Offshore Regional Report, British Geological Survey. 152 pp.

Fitch, S., Thomson, K. and Gaffney, V., 2005: Late Pleistocene and Holocene depositional systems and the palaeogeography of the Dogger Bank, North Sea. Quaternary Research 64, 185-196.

Fugro Engineers B.V., 2001: Soil investigation and spudcan penetration analysis, Kit-1X location, Danish sector, North Sea, februar 2001, GEUS report file no. 18185.

Gardline Geosurvey Ltd., 2006: Dong Efterforskning og production A/S. Danish Block 5604/29. Rigs-3 Site Survey. Survey Report February 2006.

Gatliff, R.W., Richards, P.C., Smith, K., Graham, C.C., McCormac, M., Smith, N.J.P., Long, D., Cameron, T.D.J., Evans, D., Stevenson, A.G., Bulat, J. and Ritchie, J.D., 1994: The geology of the central North Sea. United Kingdom Offshore Regional Report, British Geological Survey, 118 pp.

Gyllencreutz, R., 2005: Late Glacial and Holocene paleoceanography in the Skagerrak from high-resolution grain size records. Palaeogeography, Palaeoclimatology, Palaeoecology 222, 344-369.

Jeffery, D.H., Laban, C., Niessen, A.C.H.M., Schüttenhelm, R.T.E., 1988: Silver Well, Sheet 54^0 N – 02^0 E. Sea bed sediments and Holocene Geology. 1:250.000 series.

Konradi, P., 2003: Description of vibrocores from four well sites in the Danish North Sea. Danmarks and Grønlands Geologiske Undersøgelse Rapport 2003/75, 18 pp + enclosures.

Konradi, P., 2004: Geological description of five vibrocores from the Hanne-1 Site, Danish North Sea. Danmarks og Grønlands Geologiske Undersøgelse Rapport 2004/7, 6 pp. + enclosures.

Konradi, P. and Czako, T. 2002: Geological description of five vibrocores from the South Pod Site, Store fisker Banke Area, Danish North Sea. Danmarks og Grønlands Geologiske Undersøgelse Rapport 2002/41, 7 pp + enclosures.

Laban, C., van der Klugt, P.C.M. and Frantsen, P.J., 1995: Oyster Grounds. Kaartblad/Sheet 54^0 N- 04^0 E. Sea Bed Sediments & Holocene Geology. Rijks Geologische Dienst. 1:250.000 Series.

Lykke-Andersen, H., Knudsen, K.L. & Christiansen, C., 1993: The Quaternary of the Kattegat area, Scandinavia: a review. Boreas, Vol. 22, 269-281.

Oele, E., 1969: The Quaternary geology of the Dutch part of the North Sea, north of the Frisian Isles. Geologie en Mijnbouw, 48,5, 467-480.

9. Enclosures

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8. Sedimentological core log, DGU no.560429,23, Rigs-3, VC2
9. Sedimentological core log, DGU no.560429,24, Rigs-3, VC3
10. Sedimentological core log, DGU no.560429,25, Rigs-3, VC4
11. Sedimentological core log, DGU no.560429,26, Rigs-3, VC5
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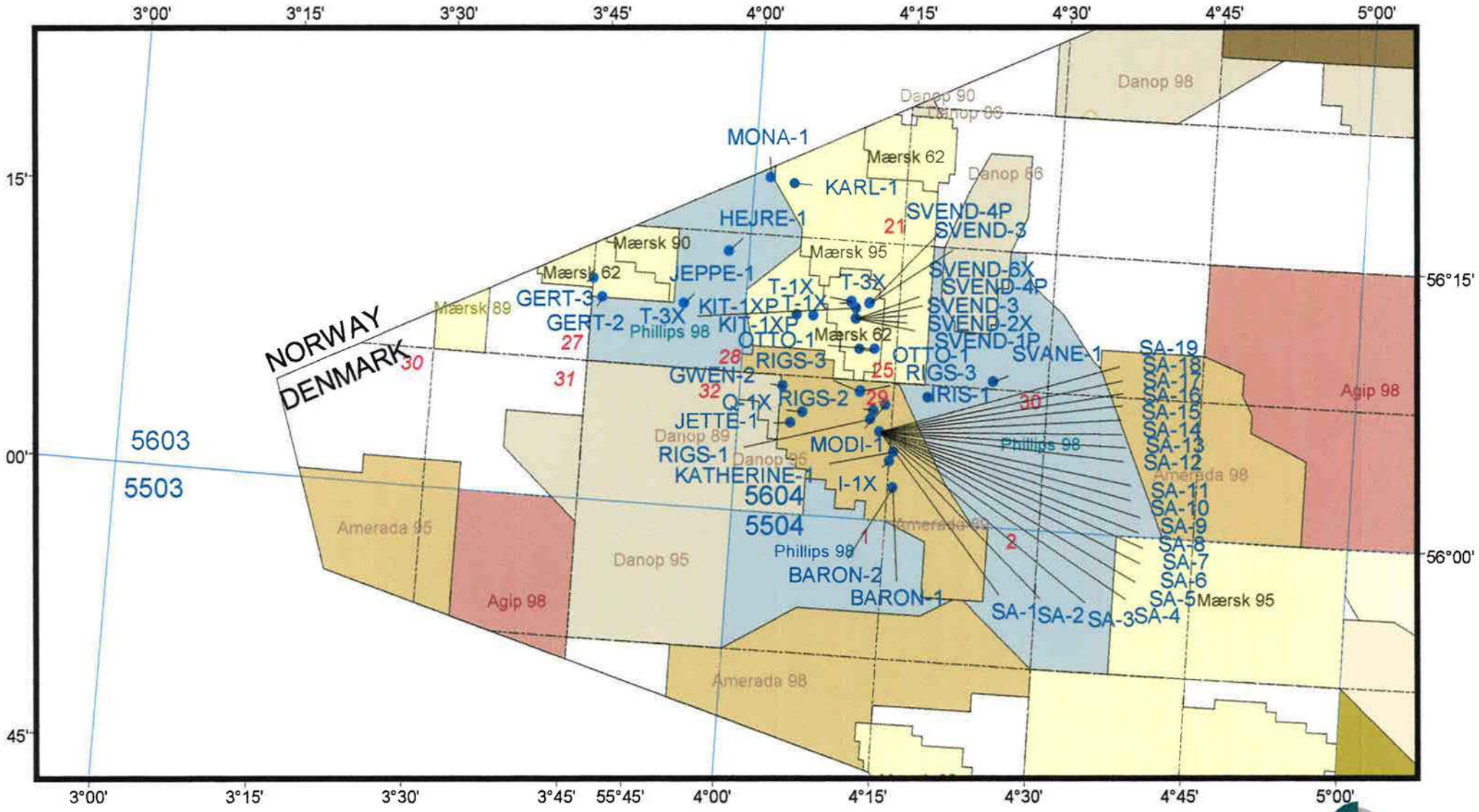
Enclosure 1: Location map of Rigs-3 site, Danish North Sea.



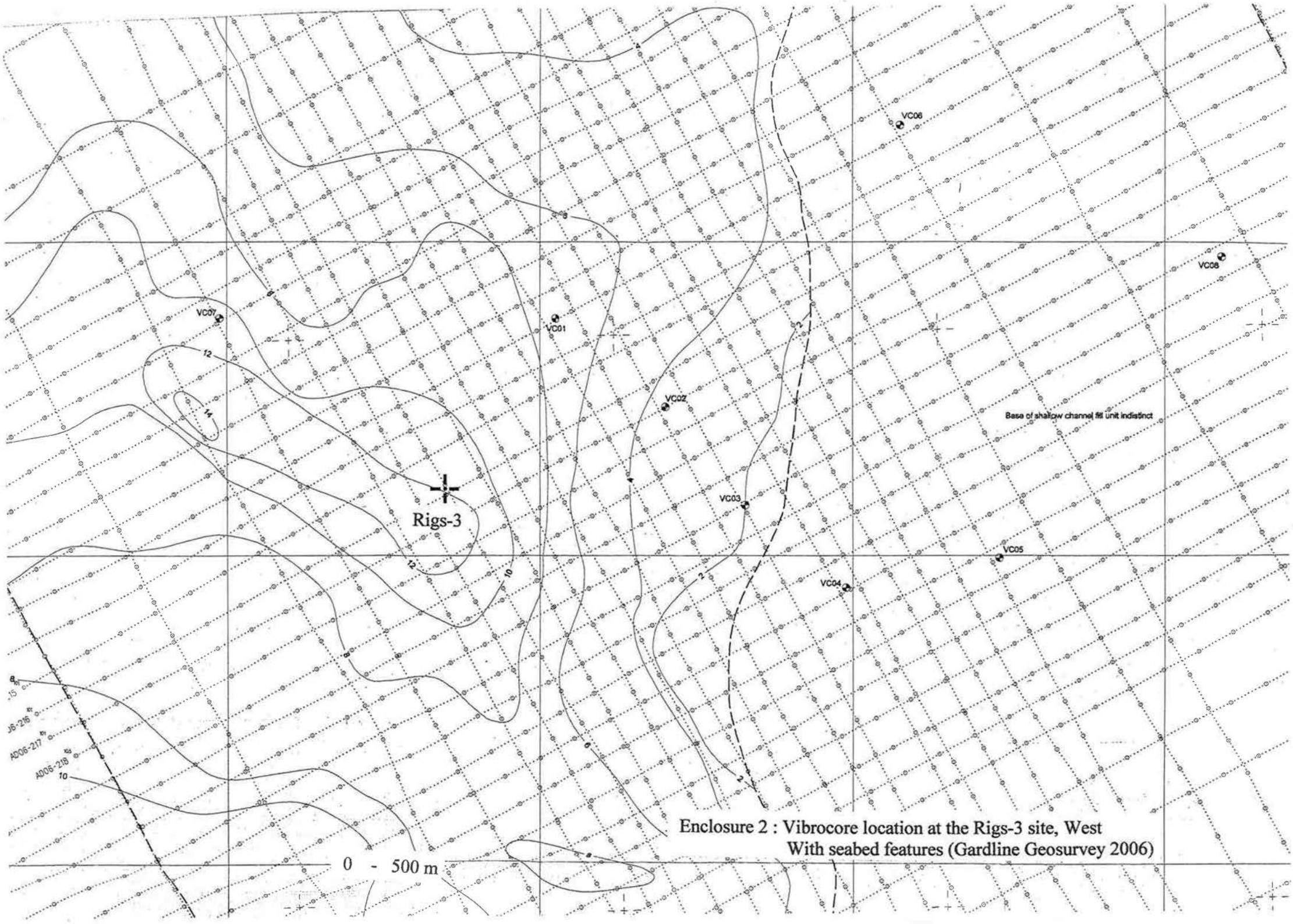
Scale: 1:550000

0 5 10 Kilometers

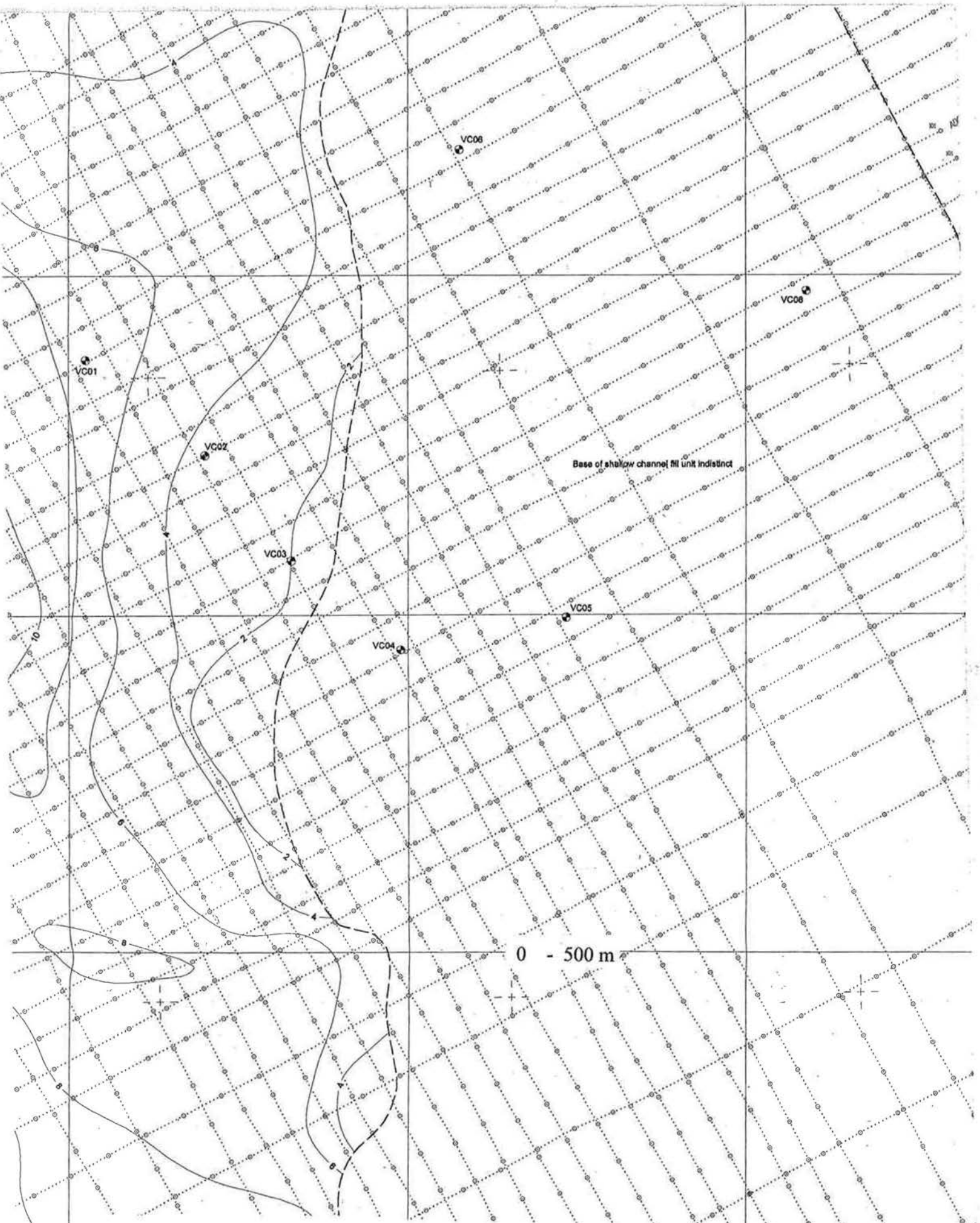
● Hydrocarbon well

GEUS

Map Completed: GEUS/Lotte Møller/Maj 2007



Enclosure 2 : Vibrocore location at the Rigs-3 site, West
With seabed features (Gardline Geosurvey 2006)



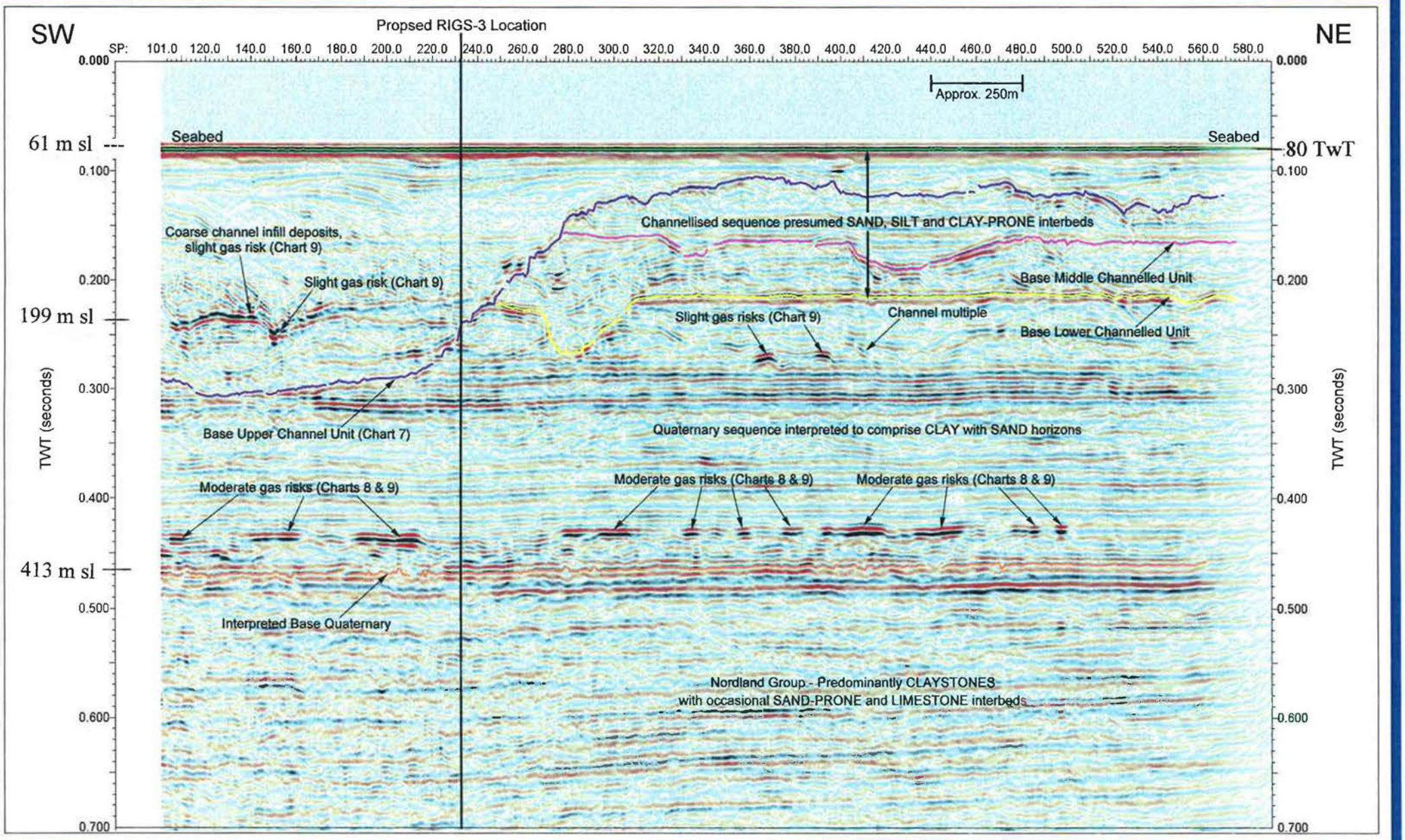
Enclosure 3 : Vibrocore location at the Rigs-3 site, East
With seabed features (Gardline Geosurvey, 2006)

Vibrocores from Rigs-3 site, Danish North Sea **Enclosure 4a**

Gardlines original numbering	Core Recovery depth (m)	Foraminifera sample	Water depth (m)	UTM 3d E Easting	Northing	Geographical position Latitude	Longitude	DGU Well File no in Jupiter database
Station VC1	0.00-1.00		61.21	574 526	6219 877	56d07'00.903" N	4d11'54.738" E	560429.22
	1.00-2.00							
	2.00-3.00							
	3.00-3.85	3.75-3.85						
Station VC2	0.00-0.80		61.37	574 701	6219 736	56d06'56.245" N	4d12'04.725" E	560429.23
	0.80-1.80							
	1.80-2.80							
	2.80-3.80							
	3.80-4.80	3.80-4.00						
		4.70-4.80						
Station VC3	0.00-1.00		61.35	574 828	6219 580	56d06'51.129" N	4d12'11.918" E	560429.24
	1.00-2.00							
	2.00-3.00							
	3.00-4.00							
	4.00-5.10	5.00						
Station VC4	0.00-1.00		61.24	574 989	6219 449	56d06'46.802" N	4d12'21.104" E	560429.25
	1.00-2.00							
	2.00-3.00							
	3.00-4.30							
Station VC5	0.00-1.00		61.13	575 233	6219 496	56d06'48.184" N	4d12'35.273" E	560429.26
	1.00-2.00							
	2.00-3.40							

Vibrocores from Rigs-3 site, Danish North Sea (cont.) **Enclosure 4b**

Gardlines original numbering	Core Recovery depth (m)	Foraminifera sample	Water depth (m)	UTM 3d E Easting	Northing	Geographical position latitude	Longitude	DGU Well in Jupiter	File no database
Station VC6	0.00-1.00		61.14	575 076	6220 187	56d07'10.617"N	4d12'26.887" E	560429.27	
	1.00-2.00								
	2.00-3.00								
	3.00-4.48								
Station VC7	0.00-1.00		61.05	573 988	6219 878	56d07'01.236" N	4d11'23.559" E	560429.28	
	1.00-2.00								
	2.00-3.00								
	3.00-4.45								
Station VC8	0.00-1.00		61.16	575 589	6219 977	56d07'03.535" N	4d12'56.368" E	560429.29	
	1.00-2.00								
	2.00-3.00								
	3.00-4.00								
	4.00-4.88	4.82							
Station VC9	0.00-1.00		61.19	575 542	6218 437	56d06'13.764" N	4d12'52.078" E	560429.30	
	1.00-2.00								
	2.00-3.00								
	3.00-4.40								



Line AD06-216

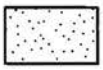
Enclosure 5 : SW – NE Seismic section. Tertiary and Quaternary interpretation
(Gardline Geosurvey, 2006)

Fig. 4.7

Job No. 6602

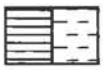
LEGEND FOR SEDIMENTOLOGICAL LOGS

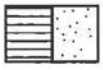
LITHOLOGY

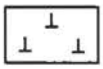

Sand, fine


Silt


Clay

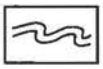

Heterolith
Clay/Silt


Heterolith
Clay/Fine Sand


Gyttja

SEDIMENT STRUCTURES


Parallel lamination


Forstyrret lamination

——— Sharp boundary

– – – – Gradual boundary

PLANT / FOSSILS


Plants

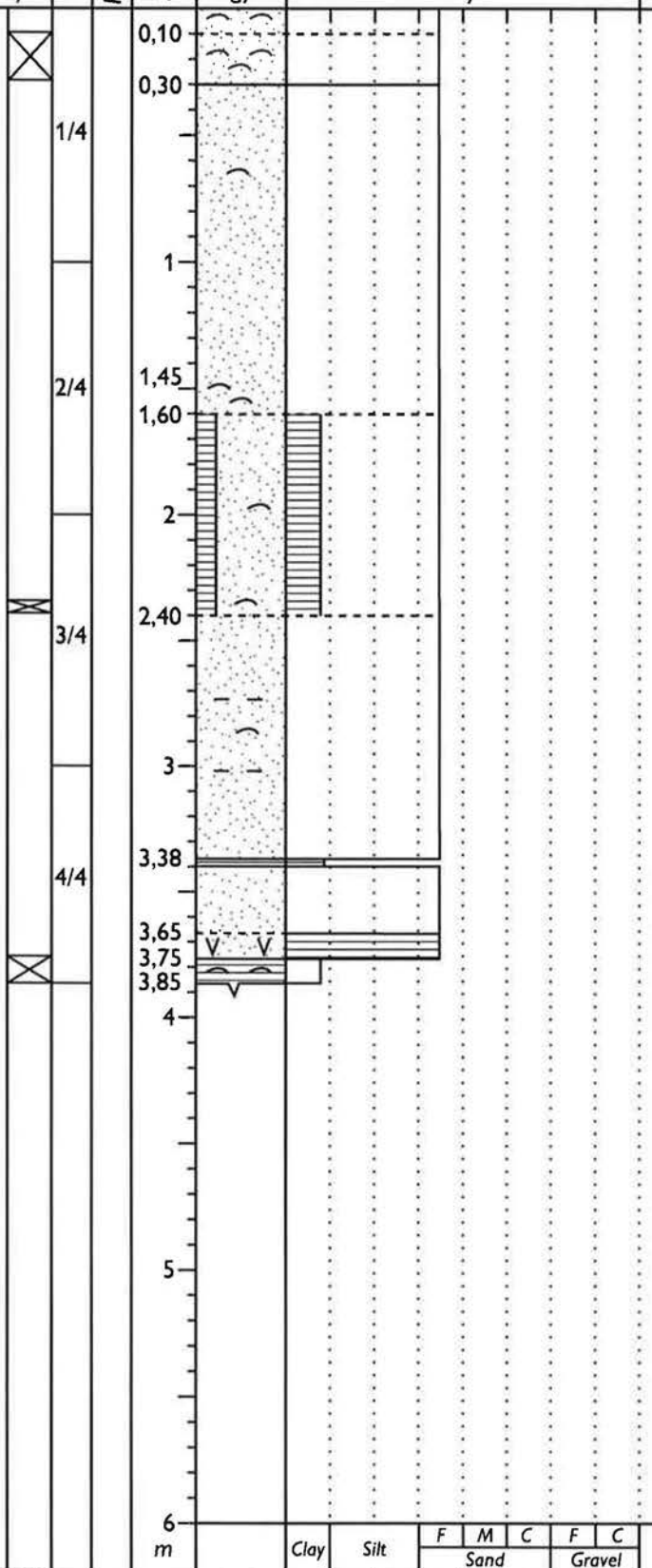

Shells

HL : Holocene marine clay
HS : Holocene marine sand
HV : Holocene marine clay and sand
TP : Late-glacial freshwater gyttja
YL : Late-glacial marine clay (yoldia-clay)

Enclosure 6

SEDIMENTOLOGICAL CORE LOG

CORE NO.: VC 1 (Rigs-3) DGU 560429.22 **POSITION:** 56°07′00.903′′N 4°11′54.738′′E *Water depth:* 61,21 m



	Description	Environment and age
0,00	Sand, fine, silty, few shells, structureless, very dark grayish brown 2,5Y 3/2.	
0,10	Sand, fine, silty, many thick shells, structureless, very dark grayish brown 2,5Y 3/2.	HS
0,30	Sand, fine, structureless, upper 0,20 m few shell fragments, few scattered organic material, at 1,45-1,60 m shell fragments, organic material, gray 2,5Y 5/1.	
1,60	Sand and Clay, Sand, fine, few scattered shells and organic material, horizontal layers of slightly sticky clay (1 cm), sand gray 2,5Y 5/1, clay dark gray 2,5Y 4/1.	HV
2,40	Sand, fine, few small streaks of clay and very fine silty sand, few scattered shells and organic material, gray 2,5Y 5/1.	HS
3,38	Clay, slightly sticky, horizontal bedding, thin streaks of organic material, dark gray 5Y 4/1.	HL
3,40	Sand, fine, structureless, gray 2,5Y 5/1.	HS
3,65	Sand, fine, layers of plant remnants 0,5-3,0 cm, few streaks of clay and silty sand, layers of plant remnants 0,5-3,0 cm, few streaks of clay and silty sand, gray 2,5Y 5/1.	HL
3,75	Clay, slightly sticky, few streaks of fine sand, many shells at the bottom, structureless, gray 5Y 4/1.	
3,85	Bottom.	

Enclosure 7

Master Grafisk

3/7/06 *Date:* TC *Described by:*

Geological Survey of Denmark and Greenland

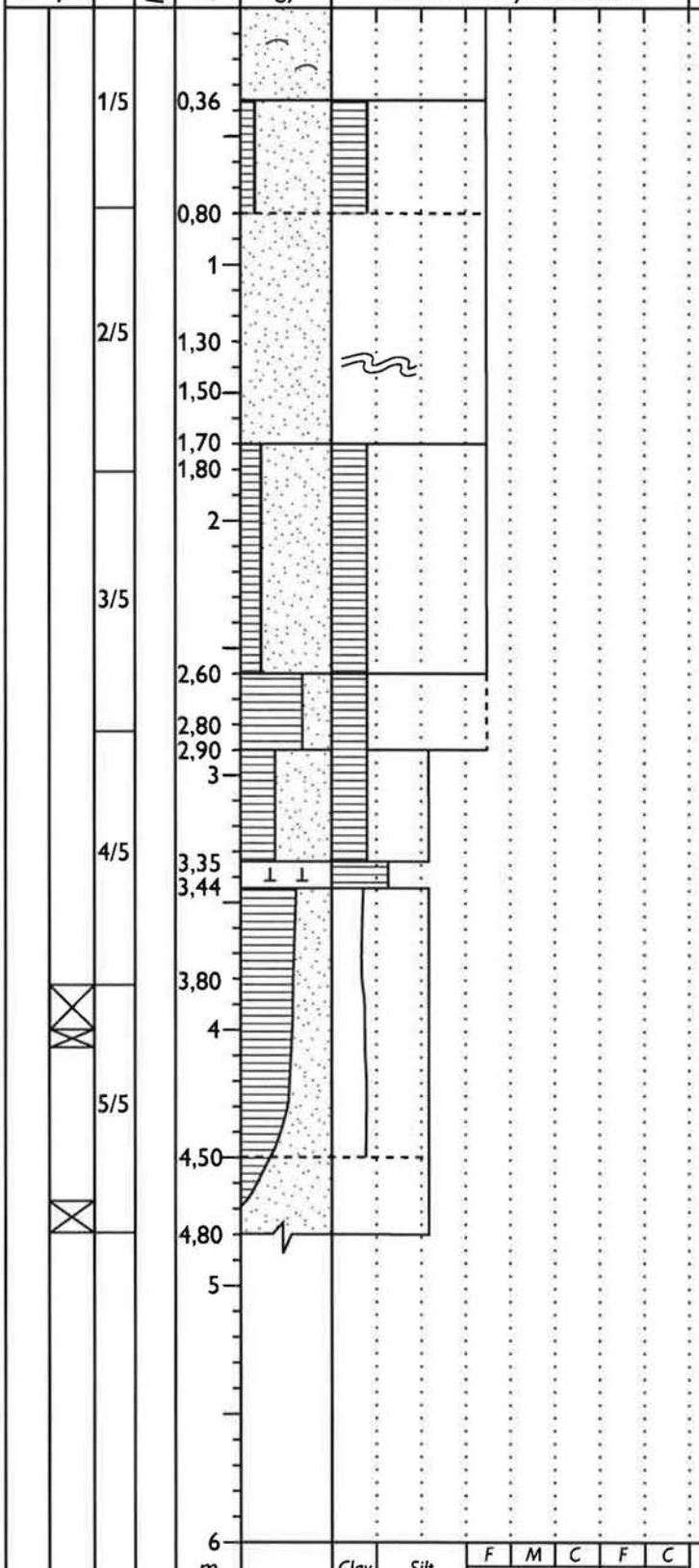
GEUS

SEDIMENTOLOGICAL CORE LOG

CORE NO.: VC 2 (Rigs-3) DGU 560429.23

POSITION: 56°06'56.245''N 4°12'04.725''E

Water depth: 61,37 m



Description	Environment and age
0,00 Sand, very fine, streaks of silty sand, many shells, few gravels, grayish brown 2,5Y 5/2.	HS
0,36 Sand, very fine, streaks of silty sand, thin layers of slightly sticky clay 0,1-2 cm, horizontal bedding, few streaks of organic material, gray 5Y 5/1.	HV
0,80 Sand, very fine, streaks of silty sand, few horizontal streaks of organic material, at 1,30-1,50 disturbed parallel lamination, dark grayish brown 2,5Y 4/2.	HS
1,70 Sand and Clay, Sand very fine, silty, 1-3 cm horizontal layers of clay, sand greenish gray GLEY1 5/1, clay dark greenish gray GLEY1 4/1.	HV
2,60 Clay and Sand, dominant clay horizontal layers, sand very fine, clay dark greenish gray GLEY1 4/1, sand greenish gray GLEY1 5/1.	HV
2,90 Silt and Clay, horizontal bedding, streaks of thin horizontal material, silt greenish gray GLEY1 5/1, clay dark greenish gray GLEY1 4/1.	TP
3,35 Gyttja, silty, horizontal bedding, very dark brown 10YR 2/2.	YL
3,44 Clay and Silt, structureless, clay slightly sticky, greenish gray GLEY1 5/1.	YL
4,50 Silt, sandy, structureless, many streaks of organic material, dark grayish brown 2,5Y 4/2.	YL
4,80 Bottom.	

Enclosure 8

Master Grafisk

4/7/06 Date:

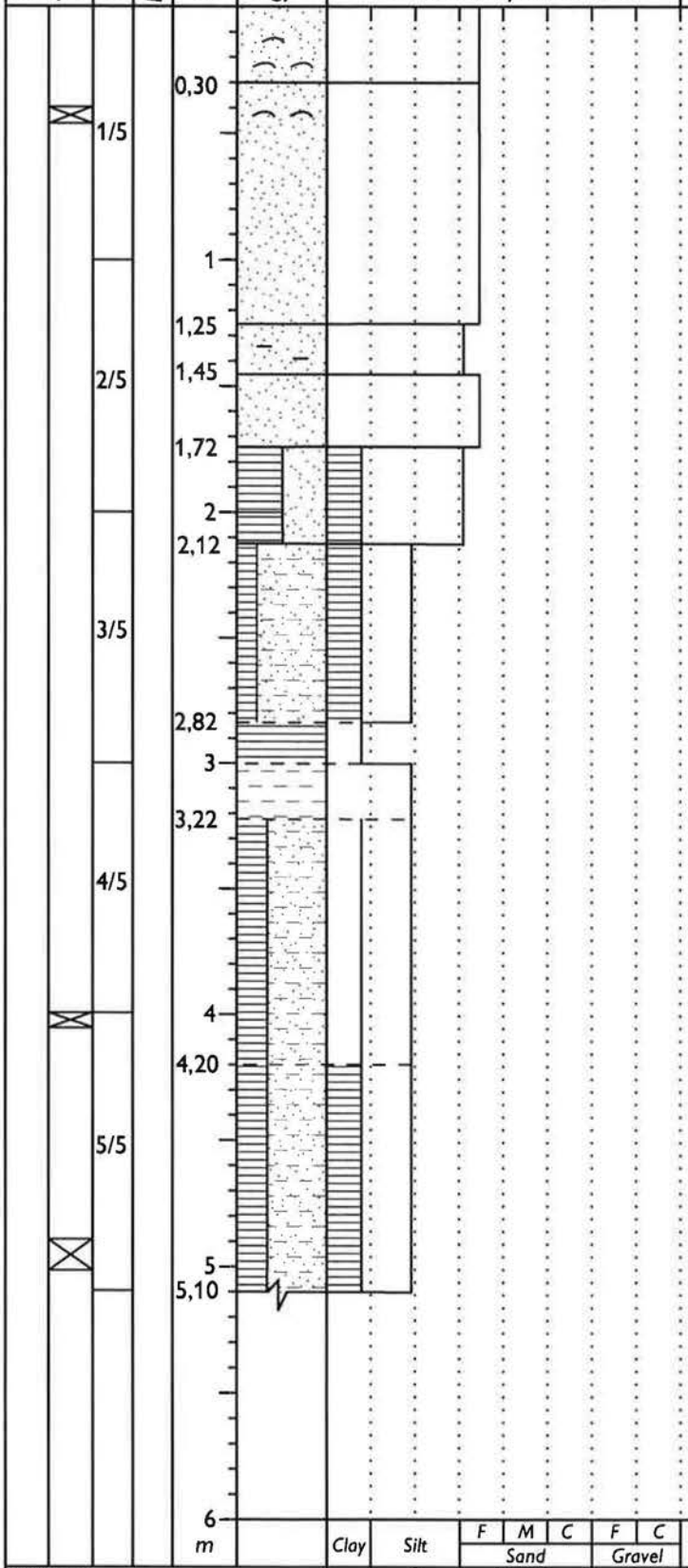
TC Described by:

Geological Survey of Denmark and Greenland

GEUS

SEDIMENTOLOGICAL CORE LOG

CORE NO.: VC 3 (Rigs-3) DGU 560429.24 POSITION: 56°06'51.129''N 4°12'04.725''E Water depth: 61,35 m



	Description	Environment and age
0,00	Sand, fine, structureless, many shells, light olive brown 2,5Y 5/3.	HS
0,30	Sand, fine, structureless, at 0,3-0,5 m many shells, below 0,5 m few shells, gray 2,5Y 5/1.	
1,25	Sand, very fine, silty, structureless, gray 2,5Y 5/1.	
1,45	Sand, fine, structureless, gray 2,5Y 5/1.	
1,72	Sand and Clay, Sand very fine, gray 2,5Y 5/1, 2-5 cm clay layers with horizontal bedding, very dark grayish brown 2,5Y 3/2.	HV
2,12	Silt, content of sand, structureless, many streaks of organic material, layers of clay, olive brown 2,5Y 4/3.	YL
2,82	Clay, silty, structureless, dark gray 2,5Y 4/1.	
3,00	Silt, content of clay, structureless, dark grayish brown 2,5Y 4/2.	
3,22	Silt and Clay, Silt sandy, many small streaks of clay, structureless, few streaks of organic material, dark grayish brown 2,5Y 4/2.	
4,20	Clay and Silt, Clay slightly sticky, 1-3 cm horizontal bedding, silt sandy, clay and silt dark grayish brown 2,5Y 4/2.	
5,10	Bottom.	

Enclosure 9

Master Grafisk

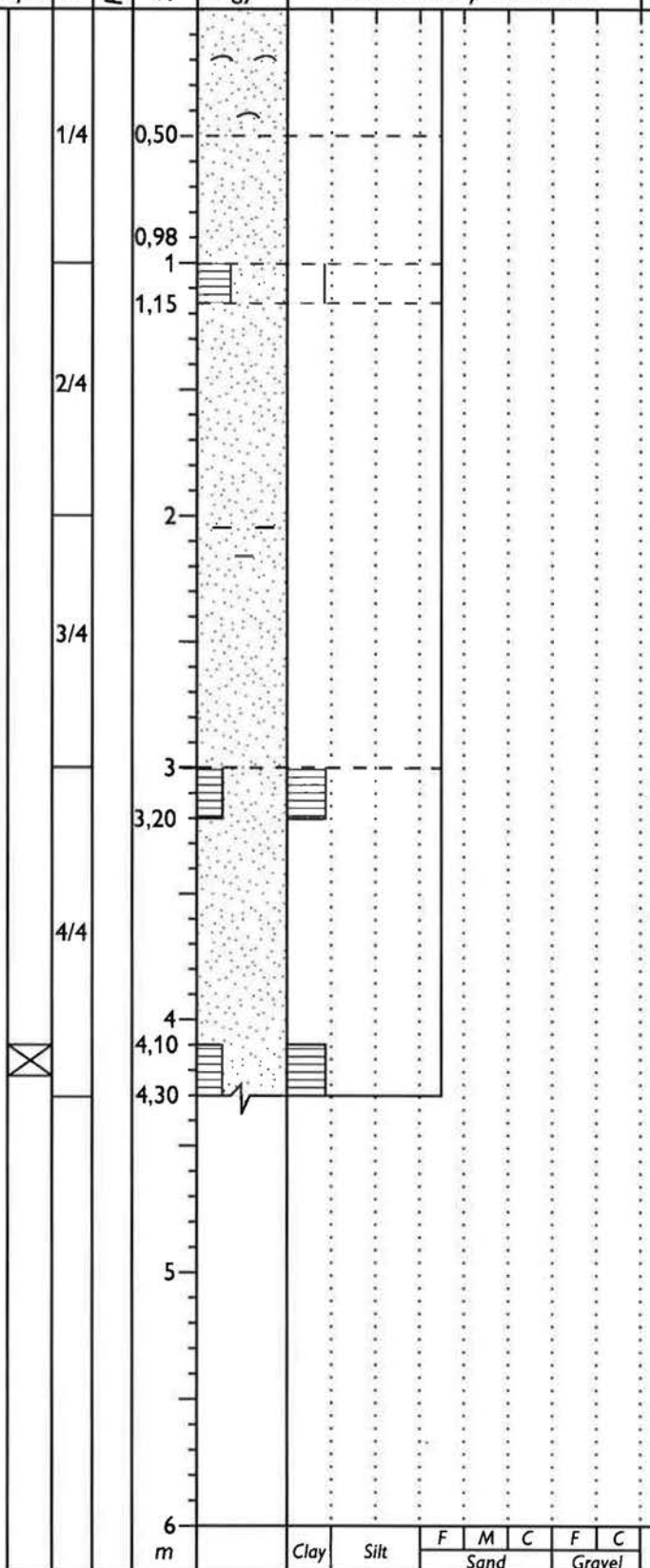
4/7/06 Date: TC Described by:

Geological Survey of Denmark and Greenland

GEUS

SEDIMENTOLOGICAL CORE LOG

CORE NO.: VC 4 (Rigs-3) DGU 560429.25 POSITION: 56°06'46.802''N 4°12'21.104''E Water depth: 61,24 m



0,00	Sand, fine, partly very fine, struc tureless, many shells, olive brown 2,5Y 4/3.
0,50	Sand, fine structureless, few streaks of organic material, gray 5Y 5/1.
0,98	Clay and Sand, Clay layers disturbed by coring, dark gray 5Y 4/1, sand fine, gray 5Y 5/1.
1,15	Sand, very fine, structureless, few layers of clay, at 2,00-2,20 content of silt, gray 5Y 5/1.
3,00	Sand, very fine, few layers of organic material with horizontal bedding, few thin layers of clay 0,5-1,0 cm at 3,00-3,20 and 4,10-4,30, light olive brown 2,5Y 5/3, at 3,20-4,10 gray 5Y 5/1.
4,30	Bottom

Environment and age: HS | HV | HS | HV | HS | HV

Enclosure 10

Master Grafisk

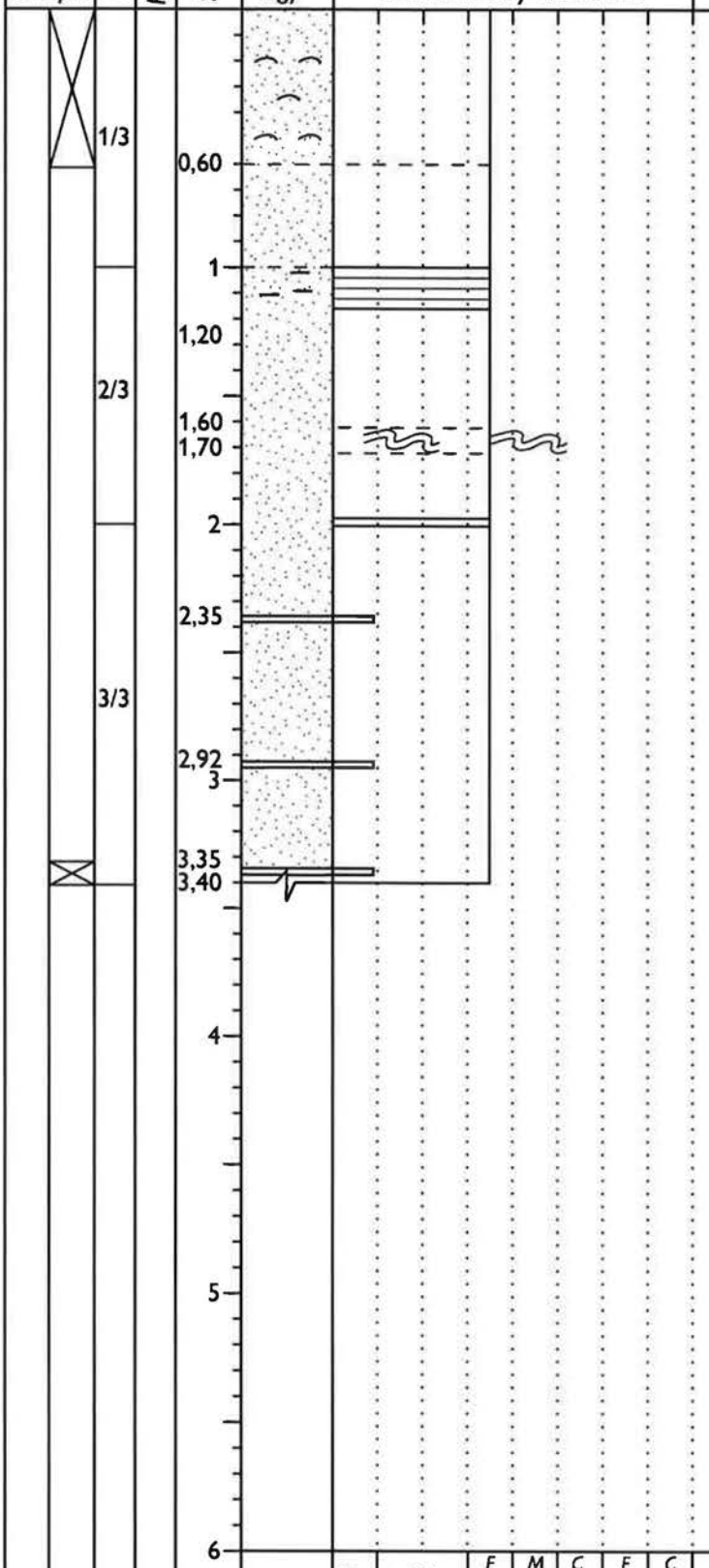
4/7/06 Date: TC Described by:

Geological Survey of Denmark and Greenland

GEUS

SEDIMENTOLOGICAL CORE LOG

CORE NO.: VC 5 (Rigs-3) DGU 560429.26 POSITION: 56°06'48.184''N 4°12'35.273''E Water depth: 61,13 m



Description	Environment and age
0,00 Sand, fine, structureless, many thin and thick shells, dark gray 5Y 4/1.	
0,60 Sand, very fine, structureless, gray 5Y 5/1.	
1,00 Sand, very fine, silty, parallel lamination at 1,00-1,20, disturbed parallel lamination at 1,60-1,70, thin layers af clay and gyttja at 1,95-2,00, at 2,35 and 2,92 and 3,35 thin layers of clay together with organic material with horizontal bedding, sand gray 5Y 5/1.	HS
3,40 Bottom.	

Enclosure 11

Master Grafisk

5/7/06 Date:

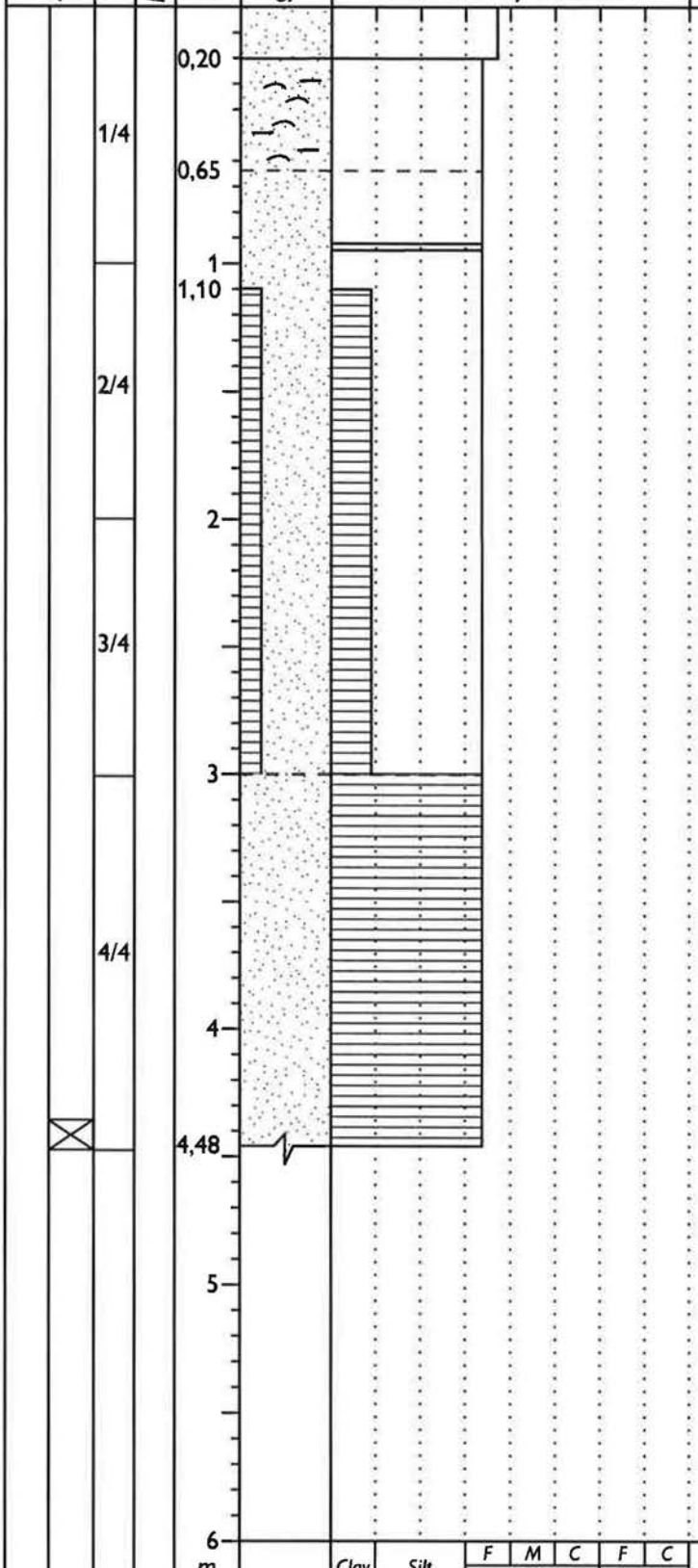
TC Described by:

Geological Survey of Denmark and Greenland

GEUS

SEDIMENTOLOGICAL CORE LOG

CORE NO.: VC 6 (Rigs-3) DGU 560429.27 POSITION: 56°07′10.617′′N 4°12′26.887′′E Water depth: 61,14 m



	Description	Environment and age
0,00	Sand, fine, structureless, olive gray 5Y 5/2.	
0,20	Sand, very fine, silty, structureless, upper part many thick shells, lower part many thin shells, dark gray 5Y 4/1.	HS
0,65	Sand, very fine, horizontal layers of organic material, at 1,10-3,00 horizontal layers of clay 3-5 cm, gray 5Y 5/1.	
3,00	Sand, very fine, horizontal lamination, thin horizontal layers of organic material, light olive brown 2,5Y 5/3 and gray 2,5Y 5/1.	HV
4,48	Bottom.	HS

Enclosure 12

Master Grafisk

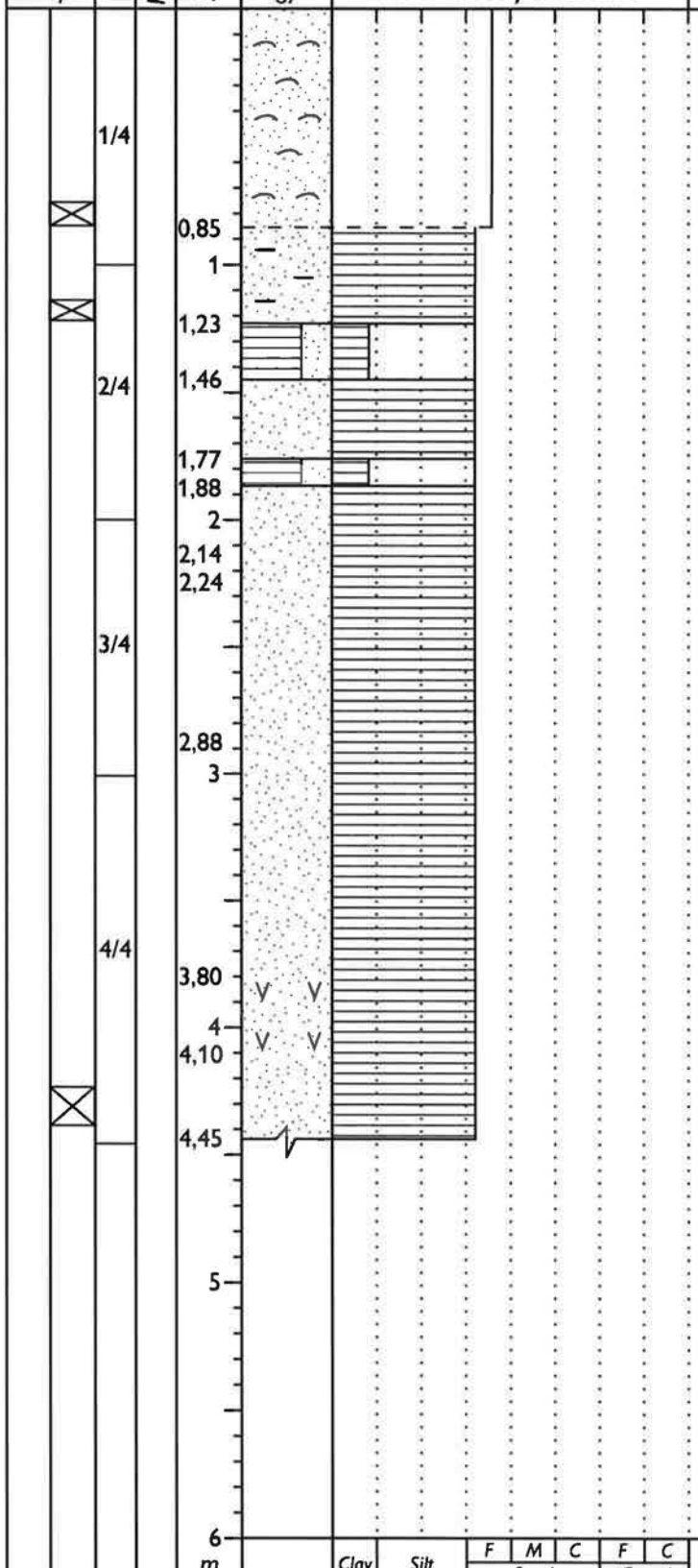
5/7/06 Date: TC Described by:

Geological Survey of Denmark and Greenland

GEUS

SEDIMENTOLOGICAL CORE LOG

CORE NO.: VC 7 (Rigs-3) DGU 560429.28 **POSITION:** 56°07'01.236''N 4°11'23.559''E *Water depth:* 61,05 m



Description

0,00 Sand, fine, silty, structureless, many thick and thin shells, olive gray 5Y 4/2.

0,85 Sand, very fine, silty, horizontal lamination, thin layers of organic material, at 1,22 few shells, gray 5Y 5/1.

1,23 Clay and Sand, Clay silty, horizontal bedding, dark gray 5Y 4/1, sand very fine, gray 5Y 5/1, horizontal layers of organic material, black 2,5/1.

1,46 Sand, very fine, horizontal lamination, gray 5Y 5/1.

1,77 See 1,23

1,88 Sand, very fine, horizontal lamination, gray 5Y 5/1, at 2,14-2,24 and at 2,88-3,00 horizontal layers of organic material, at 3,80-4,10 gyttja layers.

4,45 Bottom.

Environment and age

HS

HV

HS

HV

HS

Enclosure 13

Master Grafisk

5/7/06 *Date:*

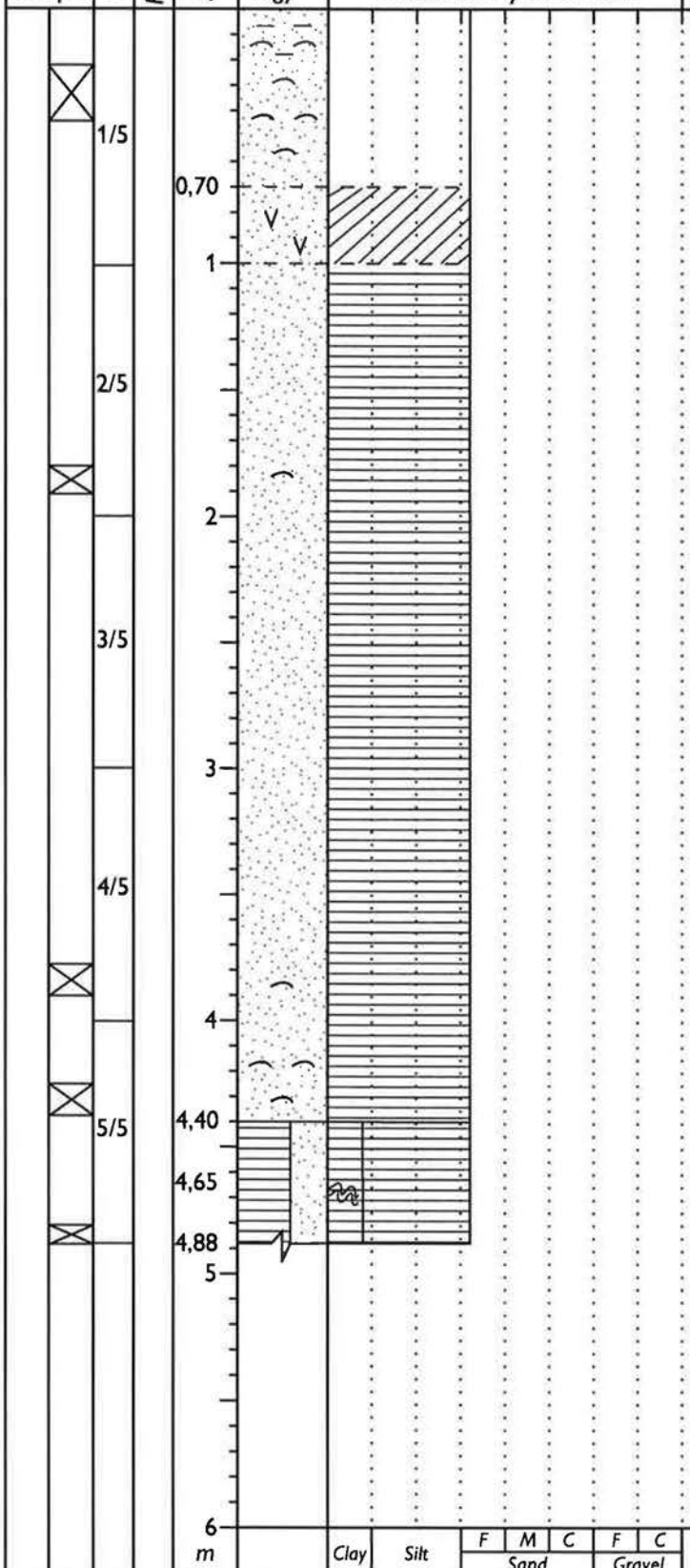
TC *Described by:*

Geological Survey of Denmark and Greenland

GEUS

SEDIMENTOLOGICAL CORE LOG

CORE NO.: VC 8 (Rigs-3) DGU 560429.29 POSITION: 56°07'03.535''N 4°12'56.368''E Water depth: 61,16 m



Description	Environment and age
0,00 Sand, very fine, at 0,00-0,20 silty, structureless, many thick and thin shells, at 0,00-0,20 dark gray 5Y 4/1, lower part grayish brown 2,5Y 5/2.	HS
0,70 Sand, very fine, lamination with low angle, few thin peat layers, gray 2,5Y 5/1.	HS
1,00 Sand, very fine, slightly silty, horizontal lamination, few thin layers of organic material, partly scattered, at 1,80-1,90 very small rounded shell fragments, at 3,80-3,90 small gastropodes at 4,15-4,40 many thin shells, light brownish gray 2,5Y 6/2.	HS
4,40 Clay and Sand, Clay, slightly sticky, horizontal bedding, at 4,65-4,70 disturbed parallel lamination, many plant remnants, clay dark gray 5Y 4/1, sand very fine, gray 5Y 5/1.	HV
4,88 Bottom.	

Enclosure 14

Master Grafisk

6/7/06 Date:

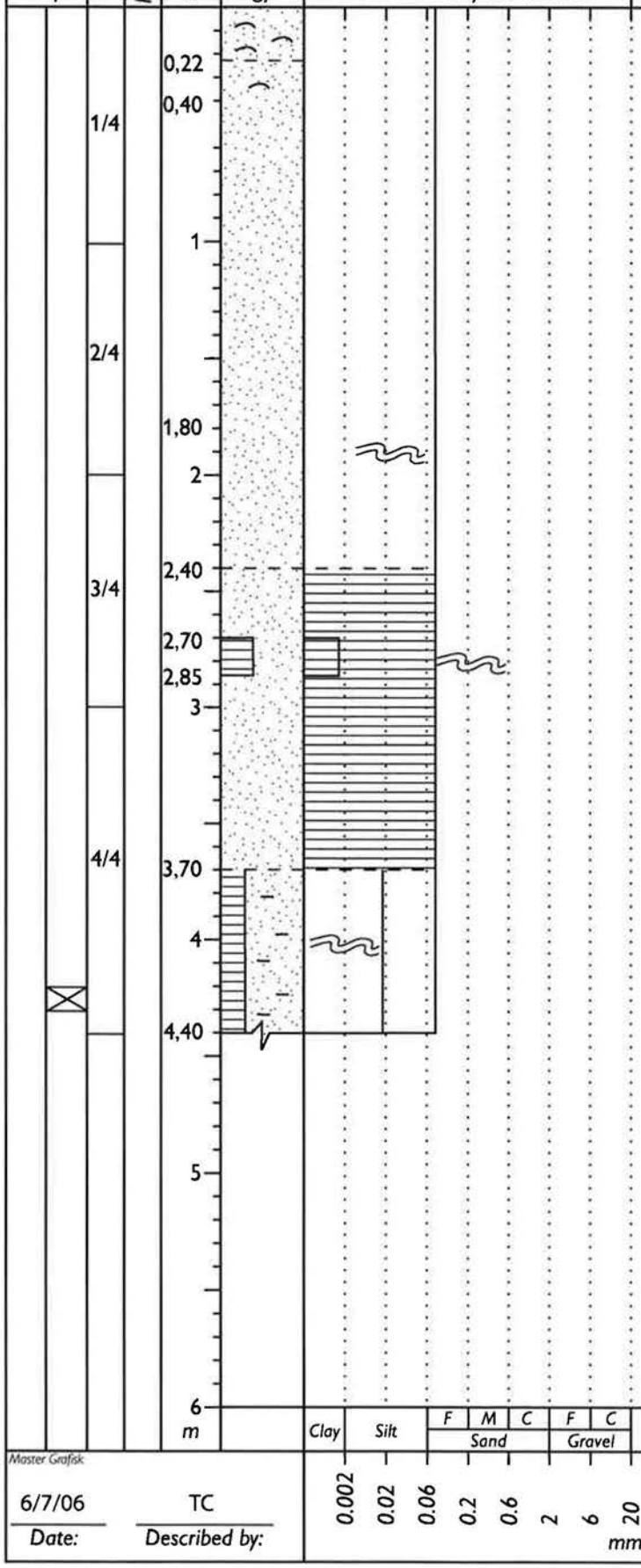
TC Described by:

Geological Survey of Denmark and Greenland

GEUS

SEDIMENTOLOGICAL CORE LOG

CORE NO.: VC 9 (Rigs-3) DGU 560429.30 POSITION: 56°06'13.764''N 4°12'52.078''E Water depth: 61,19 m



	Description	Environment and age
0,00	Sand, very fine, silty, structureless, many thin shells, dark gray 5Y 4/1.	
0,22	Sand, fine structureless, at 0,22-0,40 shell fragments, scattered organic material, at 1,80-2,00 disturbed parallel lamination of organic material, gray 5Y 6/1.	
2,40	Sand, fine, horizontal lamination, at 2,42 layer of organic material and shells (5 cm), gray 5Y 6/1, at 2,70-2,85 clay layers of 1-2 cm, disturbed parallel lamination, dark gray 5Y 4/1.	HS
3,70	Sand, very fine, very silty, few thin clay layers with organic material, disturbed parallel lamination, sand gray 5Y 6/1, clay dark gray 5Y 4/1.	
4,40	Bottom.	HS

Enclosure 15

Master Grafisk

6/7/06 Date: TC Described by:

Geological Survey of Denmark and Greenland

GEUS

Enclosure 16

Shells fra Site Survey RIGS 3 collected at core description.

Analysis of shells by Birger Larsen Aug.4.2006

VC 1	0,1-0,3 m	Cyprina (Arctica) islandica	thick shell fragments	Eem, Holocene
		Acantocardia echinata		Eem, Holocene
		Astarte sulcata		Recent
		Astarte elliptica		
		Dosinia exoleta	thick shell fragments	Holocene
		Dentalium	fragment	
		Natica (Lunatia) catena	small eks.	Recent
	2,38 m	Macoma balthica	only one shell	Eem, Holocene
VC 3	0,40 m	Macoma balthica	only one shell	Eem, Holocene
VC 5	0,0-0,40 m	Cyprina (Arctica) islandica	thick shell fragments	Eem, Holocene
		Acantocardia echinata		Eem, Holocene
		Astarte sulcata		Recent
		Aequipecten opercularis	fragment	Eem
		Thyasira flexuosa	Eem, Late Weichselien, Holocene	
		Syndosmya prismatica		
		Natica (Lunatia) catena	small eks.	Recent
VC 7	0,80 m	Spisula eliptica	fragment	Eem
	1,22 m	Parvicardium scabrum ?		
VC 8	0,20-0,45 m	Cyprina (Arctica) islandica	thick shell fragments	Eem, Holocene
		Acantocardium echinata		Eem, Holocene
		Syndosmya prismatica		
	4,30-4,40 m	Macoma balthica	3 shells	Eem, Holocene
VC 9	2,42 m	Macoma balthica		Eem, Holocene
		Cerastoderma edule	thick shell	Eem, Holocene

Enclosure 17

Analysis of foraminifer-samples from Rigs-3 site by Ebbesen, Hanne (25/9/2006)

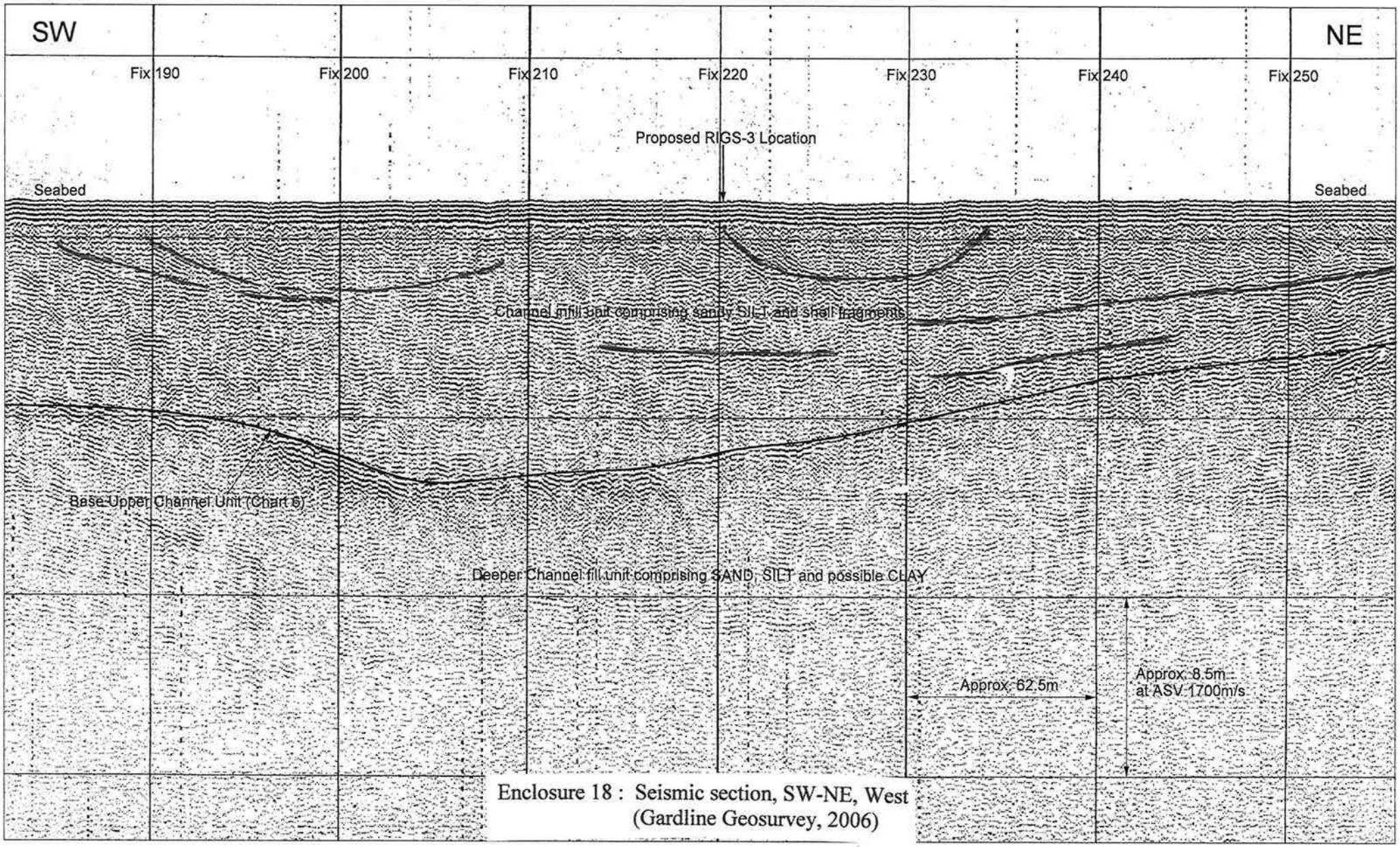
VC1 4/4 3,75 – 3,85 m Clay
72,5% *Elphidium albiumbilicatum*, 20% *E. excavatum*, 2% *Cassidulina reniforme*
This bentonic fauna composition could indicate, that this sample origins from favourable boreal climate with relatively low water depth. Indicates obvious warm climate. This bentonic fauna indicates, that this sample origins from either Saxicava Sand from the Post Glacial or from the Atlantic time period in the Post Glaciale time or from beginning of Post Glacial, about 9600 BP.

VC2 5/5 3,80 – 4,00 m Clay
There is not enough fauna to carry out an analysis.

VC2 5/5 4,70 – 4,80 m Clay
50% E.excavatum, 13% C. reniforme, 22% E. albiumbilicatum
This bentonic fauna is indicativ of a cooler period than samples VC1, 4/4, 3,75 – 3,85 and VC8, 5/5, 4,82 .Fauna composition remindes much on fauna from Yoldia Clay from Late Glacial. But if it is from Post Glacial beds, this could be from the end of the boreal time. Without any other analysis conclusion is Yoldia Clay. Sample origins from deeper water than VC1 and VC8 .

VC3 5/5 5,00 m Clay
There is not enough fauna to carry out an anlysis.

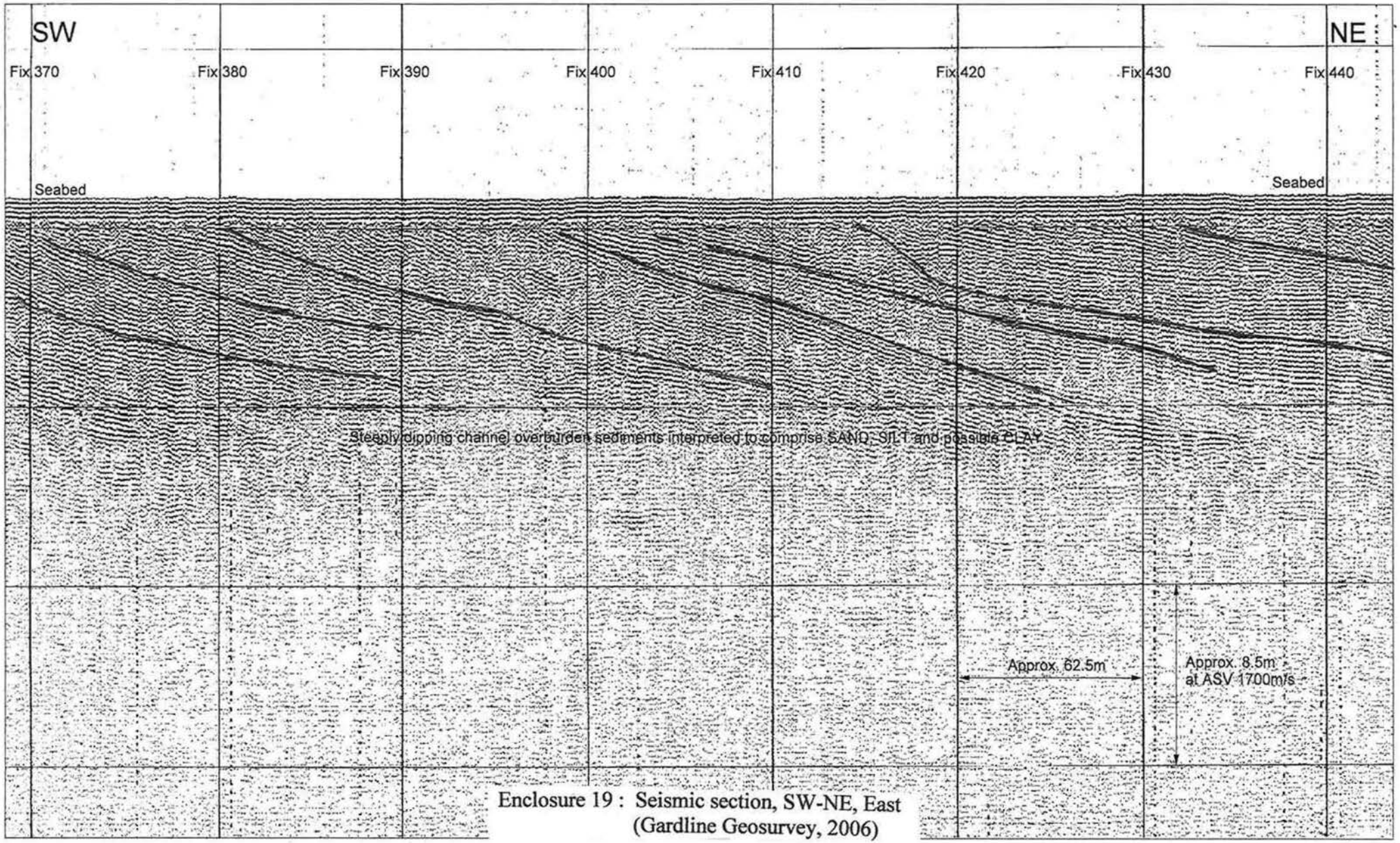
VC8 5/5 4,82 m Clay
73% E. albiumbilicatum, 9% E. excavatum, 2% C. reniforme
This bentonic fauna composition could indicate, that this sample origins from favourable boreal climate with relatively low water depth. Indicates obvious warm climate. This bentonic fauna indicates, that this sample origins from either Saxicava Sand from the Post Glacial or from the Atlantic time oeriod in the Post Glaciale time or from beginning of Post Glacial, about 9600 BP.



Enclosure 18 : Seismic section, SW-NE, West
(Gardline Geosurvey, 2006)

Line AD06-216	PINGER DATA EXAMPLE Soils profile across the Proposed RIGS-3 Location	Fig. 4.4

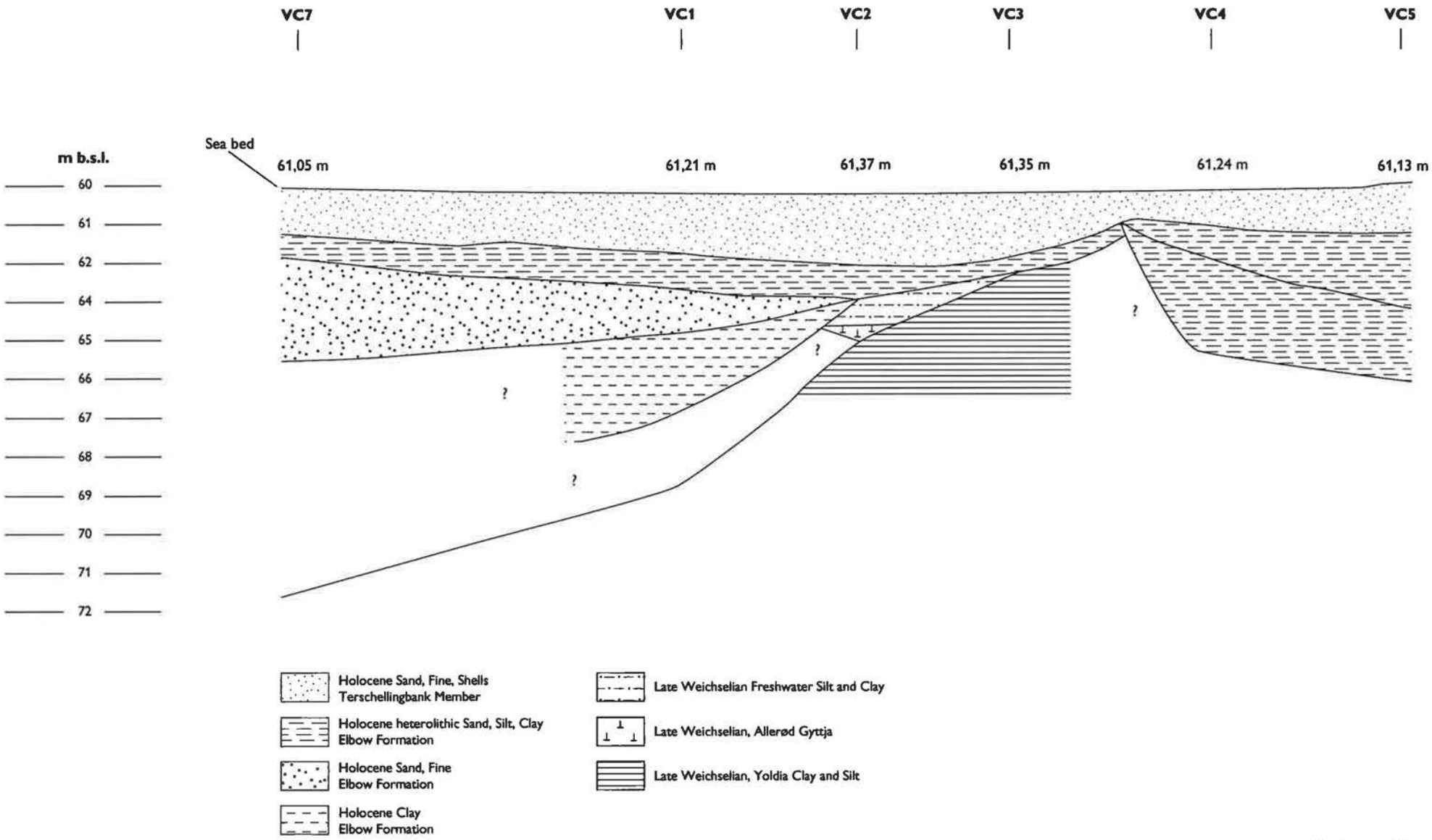
Job No. 6602



Enclosure 19 : Seismic section, SW-NE, East
(Gardline Geosurvey, 2006)

Line AD06-213	PINGER DATA EXAMPLE Illustrating typical soils in the east of the survey area	Fig. 4.6

Job No. 6602



Enclosure 20