DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2004/53

Sequence stratigraphy based on vibrocore description and shallow seismic data from the South-Western Baltic Sea

Based on data from Baltic Pipe Route Survey 2001 *Denmark – Poland*

Charlotte Sedlacek Larsen

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Project description

Dansk Olie og Naturgas A/S (DONG) kindly donated 160 vibrocores and shallow seismic data to GEUS. This report describes 100 vibrocores from the south-western Baltic Sea, while 60 vibrocores from the Great Belt and the Little Belt is not dealt with in this report. All the data comes from a pipeline route corridor survey carried out between Denmark and Poland. All 160 vibrocores are described and treated in Larsen 2003.
This report focus on the interpretation of the shallow seismic data based on sequence stratigraphical principles combined with detailed lithological description of 100 vibrocores and macrofossil analysis from the south-western Baltic Sea (including Fakse Bugt and Køge Bugt). Figure 1 is a bathymetric map showing the location of the vibrocores and the seismic lines in the investigated area.

Marine geological investigations including shallow seismic, sedimentological, stratigraphical and macrofossil studies were carried out in the south-western Baltic Sea. Seismic sequence analythical methods were used, supplemented by detailed lithological descriptions. Detailed correlation's between sediment facies units and seismic sequences resulted in the establishment of four Quaternary depositional sequences: I. Glacial related deposits (till and meltwater sediments), II. Lateglacial freshwater deposits - the Baltic Ice Lake stage, III. Youngest part of Lateglacial time – The marine Yoldia Sea stage/Postglacial freshwater deposits – the Ancylus Lake stage (lake, - bog, - and fluvial sediments), IV. Postglacial marine deposits – The Litorina Sea stage.
Pre-quaternary deposits consist of chalk (probably Cretaceous Limestone and Paleogene Danien-Chalk).
As it is very difficult to separate Yoldia and Ancylus deposit, they are treated in the same depositional sequence III.

Contents

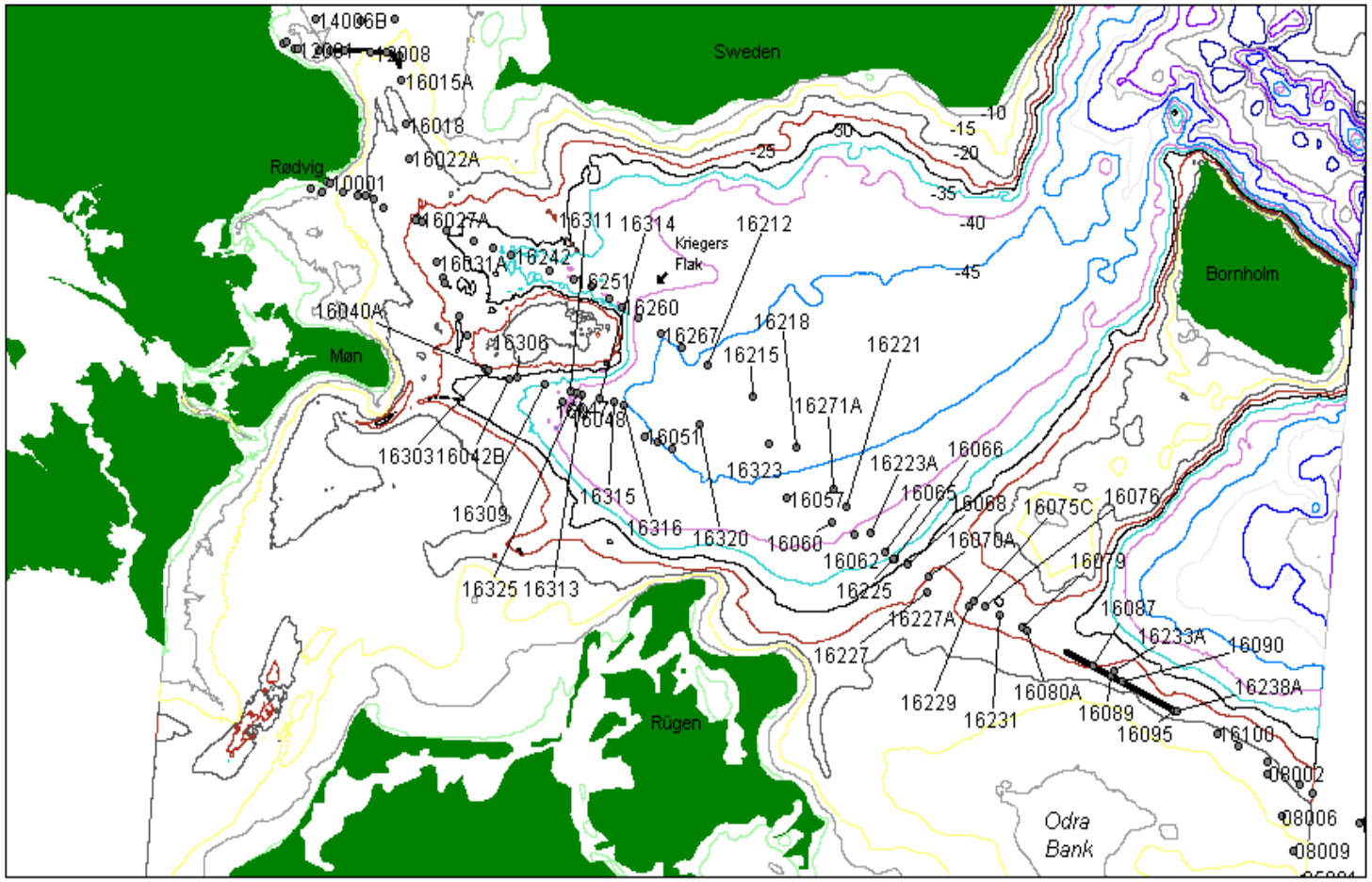

Figure 1. *Bathymetric map showing the investigated area, the location of the vibrocoring and the seismic lines.*

Geological background

The investigated area stretches from Amager, Køge and Rødvig (Denmark) in north-west to Niechorze (Poland) in the south-east located in the western part of the Baltic Sea. Maximum water depth is around 47.0 m in the central part of the investigated area (fig.1).
The area has been covered by the Scandinavian ice cap, and thereby influenced by glacial processes several times during the last ice age, Weichsel (115.000-14.000 B.P.). The ice eroded, reworked and transported the underlying pre-Quaternary sediments and rocks. During the deglaciation glacial sediments and meltwater sediment were deposited. Contemporary with the rising sea level, lake stages were dammed up in front of the retreating ice-cap, The Baltic Ice Lake (13.000-10.300 B.P.) and later The Ancylus Lake (9.500-8.000 B.P.) respectively. Sediments from these Lake stages are deposited in the main part of the investigated area. There are also deposits from a short marine/brackish stage between the two lake stages, the Yoldia Sea stage (11.500-10.200 BP). After the final transgression of the Baltic Sea Littorina Sea marine sediments were deposited.
The pre-Quaternary deposit in the area consists mainly of limestone, probably Skrivekridt (Maastrichtien) and in the area around Stevns Klint also tertiary Danien Chalk.

Methods

Geophysical equipment

Side scan sonar, pinger, boomer/sparker and magnetometer were used to map the surface and the shallow sub-bottom geology. The resolution for the sub-bottom profiler and the boomer is 0.3 m and 1.0 m respectively.

Sequence stratigraphy

Existing literature describes the general sequence stratigraphy for the main part of the survey area. For the area around Fakse Bugt detailed descriptions exist regarding the deglaciation and the final maximum Baltic Ice Lake transgression (Jensen 1993, 1995, 1997; Jensen & Stecher 1992; Bennike & Jensen 1995).

Macrofossil analysis

Macrofossil analysis of samples from the following vibrocores has been carried out by Ole Bennike: V-16022A, V-16032 from profile A-B (Larsen 2003) and V-16070A and V-16075C from profile M-N (fig.9). Detailed lithological logs and results of the macrofossil analysis is found in appendix 1.

Description and interpretation of the shallow seismic data

Figure 2 is a simplified picture of the general stratigraphy in the investigated area. It is compiled by 19 seismic lines combined with information from vibrocores, and covers the area from Kriegers Flak in north-west to the southern part of the Bornholm Basin, north of Odra Bank, in the south-west. It gives a sequence stratigraphical overview of all the studied seismic lines in this report. A description of all the seismic lines is given in the following chapter. Solid coloured lines represent sequence boundaries. The vertical depth in general and the depths of the vibrocores are calculated based on a chosen sound-velocity of 1500 m/s. The level is designated in meter below sea level (m b.s.l.). Sections of five seismic lines illustrate the stratigraphical development and structure combined with profiles of correlated logs. The description of the seismic lines starts in the north-western part of the investigated area and ends in the south-eastern part.

Disk mo1a\ Route 12\ 121s1

The seismic line Disk mo1a\ Route 12\ 121s1 is located in Køge Bugt going through vibrocore 12006A, 12008 and 12010 (fig.1), with a water depth between 14.1 to 15.8 m b.s.l. The depth of the vibrocorings is between 1.10-2.42 metre.
The marked upper light-green reflector has a continuous, parallel, even image and represent an unconformity (caused by erosion). Combined with information from vibrocores the reflector is thought to represent the lateglacial surface. Because of the seismic resolution it was not possible to describe the other reflectors.

Disk 8: RC16-T12+125-002

The seismic line Disk 8: RC16-T12+125-002 (fig.3) is located NW-SE of Kriegers Flak going through vibrocore 16040A, 16303, 16306, 16309, 16311, 16313, 16314, 16315, 16316 and 16320, profile G-H (fig. 4). The water depth varies from 27.5 (in V-16040A) to 46.1 m b.s.l. Figure 4 shows a section of the seismic line from vibrocore 16314-16316.

The purple reflector has a continuous to undulating image and is thought to represent the pre-Quaternary surface. The pre-Quaternary surface is locally raised – bend up - about vibrocore 16311, 16313 and 16314 respectively, confirmed by the coring which contains glacial and pre-Quaternary sediments. Thus, the pre-Quaternary surface is close to the surface in certain parts of the profile which is confirmed from information from vibrocore 16314 which contain pre-Quaternary chalk and vibrocore 16313 and 16309 which contain clay till. The Arkona Basin starts from vibrocore 16314.

The blue reflector has a continuous, even image in the western end and a wavy to undulating image in the eastern end where the Arkona basin starts. It is thought to represent the glacial surface. From about vibrocore 16309-16313 and about 16315 and 16316 the inter-

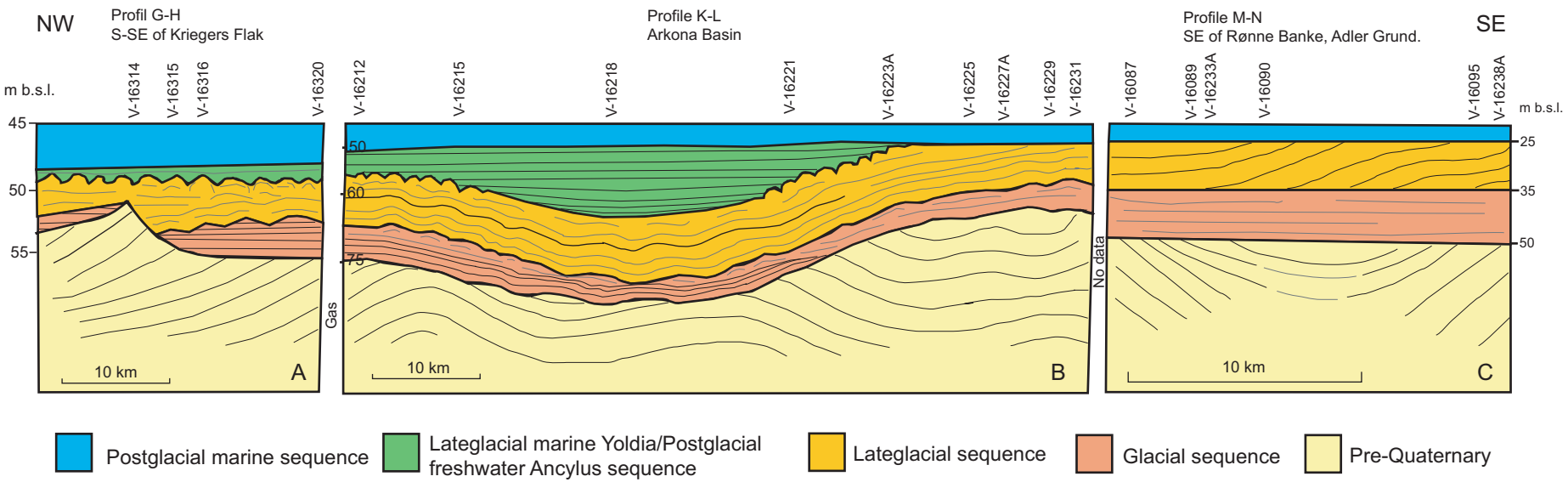

Figure 2. *Simplified picture of the general stratigraphy for the main part of the investigated area from Kriegers Flak in the north-west through the deep part of the Arkona Basin and ending up south-east of Rønne Banke in the south-eastern end of the area. The figure is compiled by the available seismic lines combined with the vibrocores. The location of the vibrocores are designated with a V=Vibrocore. Because the sediments holds a lot of gas between vibrocore 16320 and 16212 it was not possible to follow the reflectors in this area. Between vibrocore 16231 and 16087 there were no seismic data availeble. The level is designated in meter below sea level (m b.s.l.).*
A: section of profile G-H south of Kriegers Flak. The pre-Quaternary surface is high-lying a few places in this part of the area, as for exemple around V-16314. The many parallel, closely packed reflectors in the glacial sequence in A and B indicate layered sediments and is interpreted as a late Weichselian lacustrine deposit. The reflectors in the deep part of the basin in section B indicate permanent water-filled conditions and is interpreted as Lateglacial highstand. Lowstand in the beginning of Yoldia time, 11.500 B.P., and then transgression which is indicated by the on-lapping reflectors and the paralic reflection pattern at the lateglacial surface. In section C the reflectors show a prograding pattern. It is interpreted as a prograding delta.

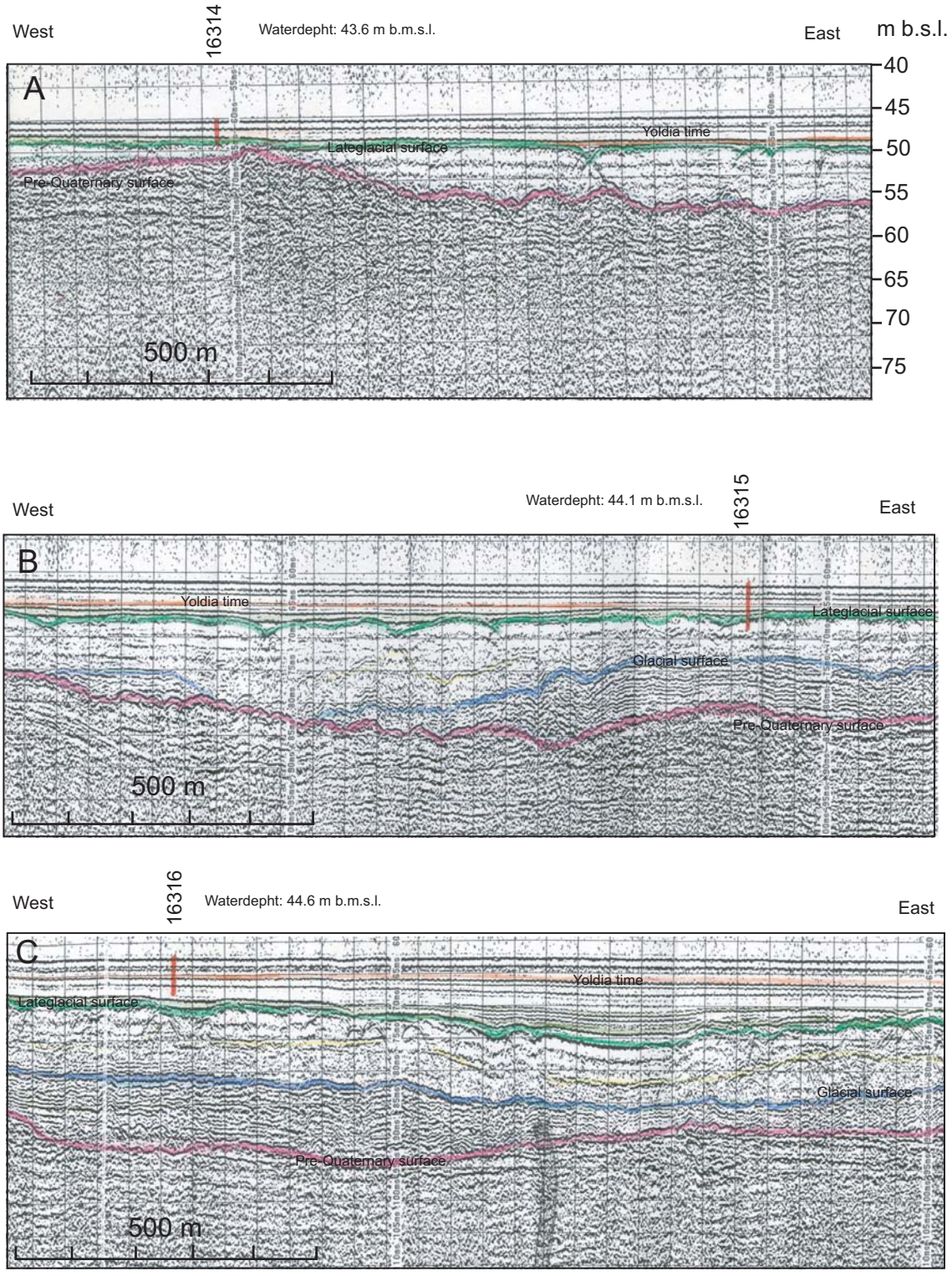

Figure 3. *Section of the west-east trending seismic line Disk 8: RC16-T12+125-002 (profile G-H) with vibrocore 16314, 16315 and 16316, south of Kriegers Flak in the Arkona Basin. The orange reflector represent the Ancylus and/or Yoldia time with postglacial marine sediments above, the green reflector represent the lateglacial surface, the blue reflector represent the glacial surface and the purple reflector represent the pre-Quaternary surface. Note the paralel, closely packed reflectors in the glacial unit, which indicate layered sediments, and the yellow reflector which represent the two-partition af the lateglacial unit.*

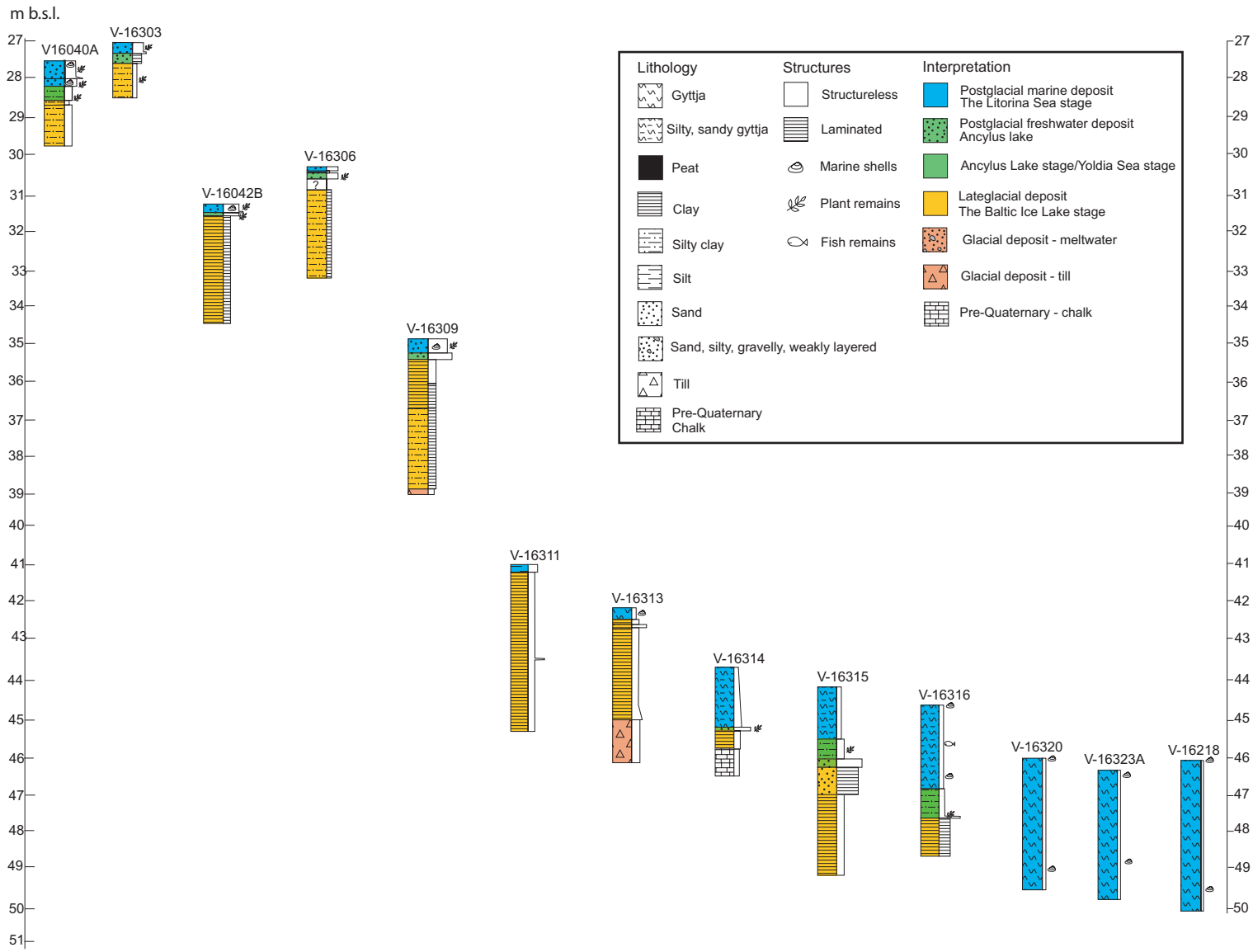

Figure 4. *Profile G-H located south and east of Kriegers Flak in the Arkona Basin. V=Vibrocore*

nal reflector configuration in the glacial unit (between blue and purple) are closely packed and parallel, indicating layered sediments. The blue reflector can be followed between vibrocore 16313-16316; but is otherwise difficult to follow because of the seismic resolution.

The green reflector has a continuous, parallel, even image until 16313 where it is paralic, and represents an unconformity. Combined with informations from vibrocores that penetrate the unit the reflector is thought to represent the Lateglacial surface. The water depth increases from between 27,5 to 46,1 m b.s.l. when it reaches the Arkona Basin in the eastern end of the profile. The green reflector represents the lateglacial surface, with the Yoldia time and/or Ancylus time above.

The orange reflector has a continuous, parallel, even image, but because of the seismic resolution it is not possible to follow it through the whole profile. It represents the Ancylus/Yoldia time surface with the marine postglacial sediments of the Littorina Sea above.

Southeast of vibrocore 16316 the reflectors become indistinct because the sediments hold a lot of gas, and there are no seismic information around V-16320, which consist entirely of gyttja.

Disk 2: RC16-T24-cl-005

The seismic line Disk 2: RC16-T24-cl-005 is located east of Kriegers Flak (see fig.1 and 2) going through vibrocore 16212 (profile K-L, fig. 5), with a water depth of 45.00 m b.s.l. and the depht of core is 4.27 m.
The blue reflector has a parallel to undulating image and is thought to represent the pre-Quaternary surface. The solid reflector above a continuous, wavy to undulating, even image and represents an unconformity, the glacial surface. The green reflector has a continuous, parallel, even image and represent an unconformity (caused by erosion). Combined with informations from vibrocore 16212 that penetrate the unit the reflector is thought to represent the lateglacial surface with postglacial marin clay-gyttja above.

Disk 2: RC16-T24-cl-006

The seismic line Disk 2: RC16-T24-cl-006 is located east of Kriegers Flak going through vibrocore 16215 (profile K-L, fig. 5), the water depth is 46.8 m b.s.l.
The pink reflector has a parallel to undulating image and is thought to represent the pre-Quaternary surface. The blue reflector above has a continuous, wavy to undulating image and represent a unconformity. It is thought to represent the glacial surface. The glacial unit (between blue and pink reflector) consist of many parallel reflectors which indicate layered deposits. The green reflector has a paralic image and represent the lateglacial surface. The lateglacial unit – The Baltic Ice Lake stage - is divided in two (illustrated by the yellow reflector). The orange reflector has a continuous, parallel, even image and represent an unconformity (caused by erosion). Combined with information from vibrocore 16215 that penetrate the unit the reflector is thought to represent the Ancylus and/or Yoldia time sur-

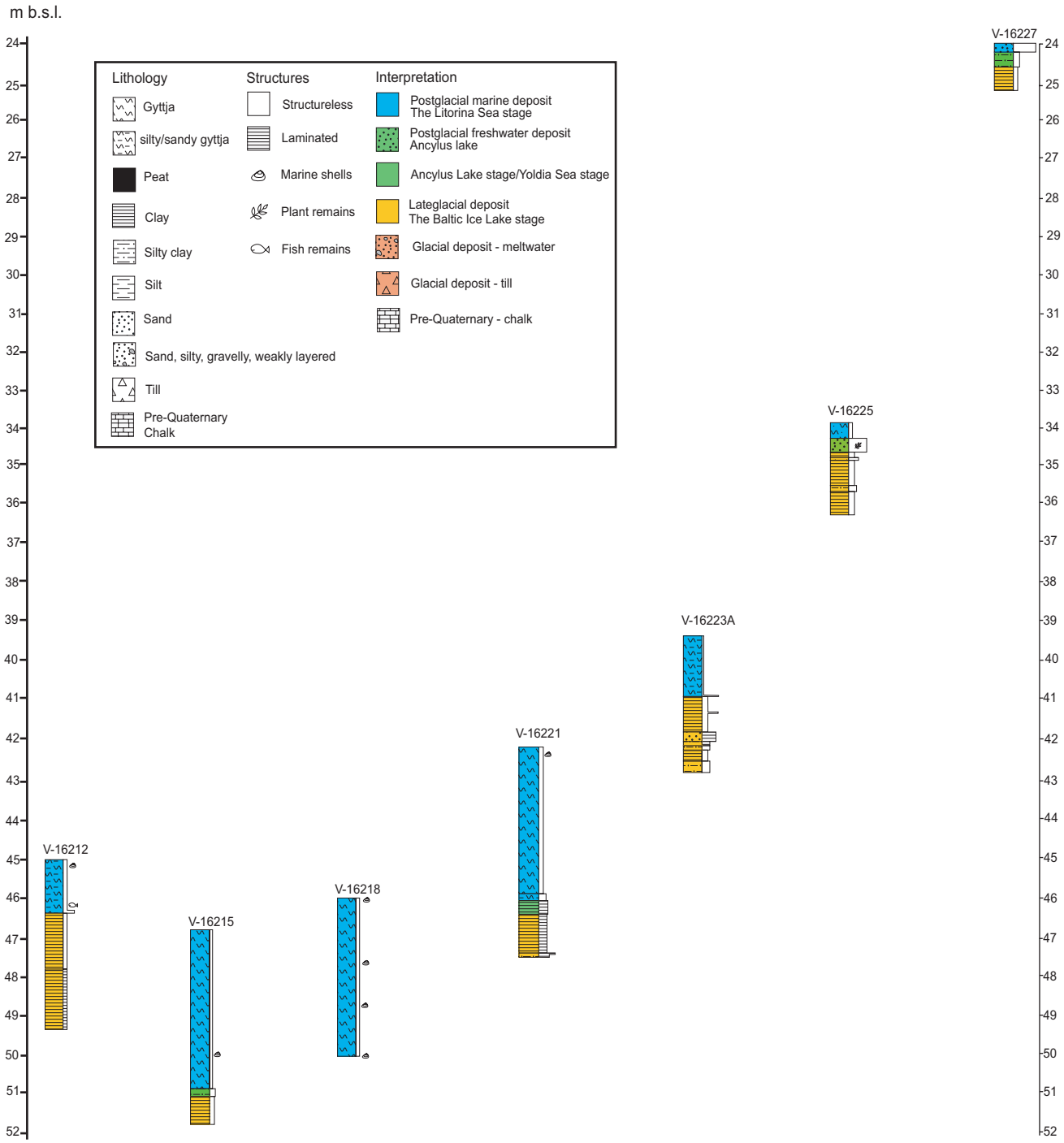

Figure 5. *Profile K-L - northwest-southeast trending profile through the Arkona Basin. V=vibrocore.*

face with the marine postglacial sediments of the Littorina Sea above. The sediments hold a lot of gas after V-16215.

Disk 6: RC16-T24+125-007.

The seismic line Disk 6: RC16-T24+125-007 (fig. 6) is located east of Kriegers Flak going through vibrocore 16212, 16215 and 16218 (profile K-L, fig. 5), the waterdepth varies between 45.0, 46.8 and 46.0 respectively, and the depth of the vibrocores are between 4-5 m.

The purple reflector has a continuous, parallel, even image and is truncated. It is thought to represent the pre-Quaternary surface. The blue reflector has a continuous, parallel, even image and is thought to represent the glacial surface.

The green reflector has a continuous, undulating image until V-16215 where it becomes paralic coincident with a general deepening; the reflector bend down which represent the deeper part of the Arkona Basin. The green reflector is thought to represent lategacial surface - The Baltic Ice Lake Stage (sequence II).
In vibrocore 16212 the Yoldia time unit and/or postglacial freshwater unit (sequence III) is absent – and the orange and green reflectors is lying close (at the rim of the basin). The Yoldia time unit is found in core 16215 (silty clay with little gyttja), overlying fat clay from the lateglacial Baltic Ice Lake stage, and on the seismic line it is interpreted to represent the space between orange and green reflector. The internal seismic reflection pattern indicates a two-partition of the lateglacial sequence, illustrated by the yellow reflector.

The orange reflector has a continuous, parallel, even image and represent the surface of Yoldia Sea stage and/or Ancylus Lake stage (sequence III), together named Yoldia time.

Above the orange reflector the internal reflector pattern has a transparency appearance. Combined with information from vibrocore 16212, 16215 and 16218 which penetrate the unit it is thought to represent postglacial marin gyttja from the The Littorina Sea stage (sequence IV).
The sediments between vibrocore 16215 and 16218 hold a lot of gas.

Disk 3: RC16-T24-200-003, Disk 3: RC16-T24+200-005 and Disk 4: RC16-T24-35-005

The three parallel lying seismic lines is located in the Arkona Basin, north-east of Rügen and west of Adler Grund (Rønne Banke) in a northwest-southeast direction, and contains vibrocore 16218, 16221, 16223A (profile K-L, fig. 5). A section of the seismic line Disk 3: RC16-T24-200-003 is given in figure 7.

The pink reflector represents an unconformity, which is interpreted as the pre-Quaternary surface.
The blue reflector has a continuous, parallel to wavy image and represent the glacial surface (sequence II).

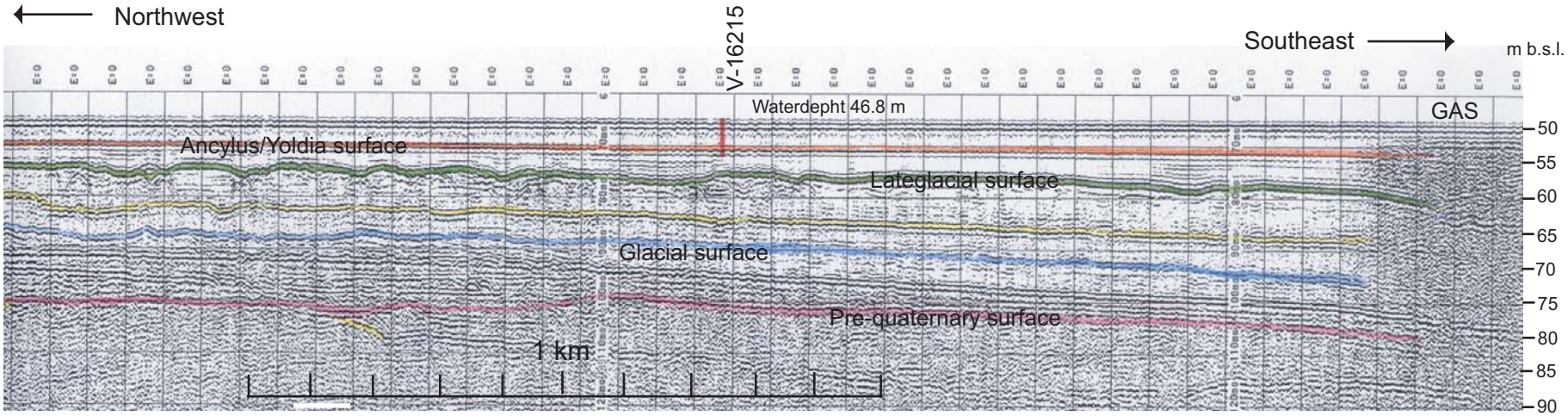

Figure 6. Section of the northwest-southeast trending seismic line Disk6: RC16-T24+125-007 with vibrocore 16215, south-east of Kriegers Flak, Arkona Basin.

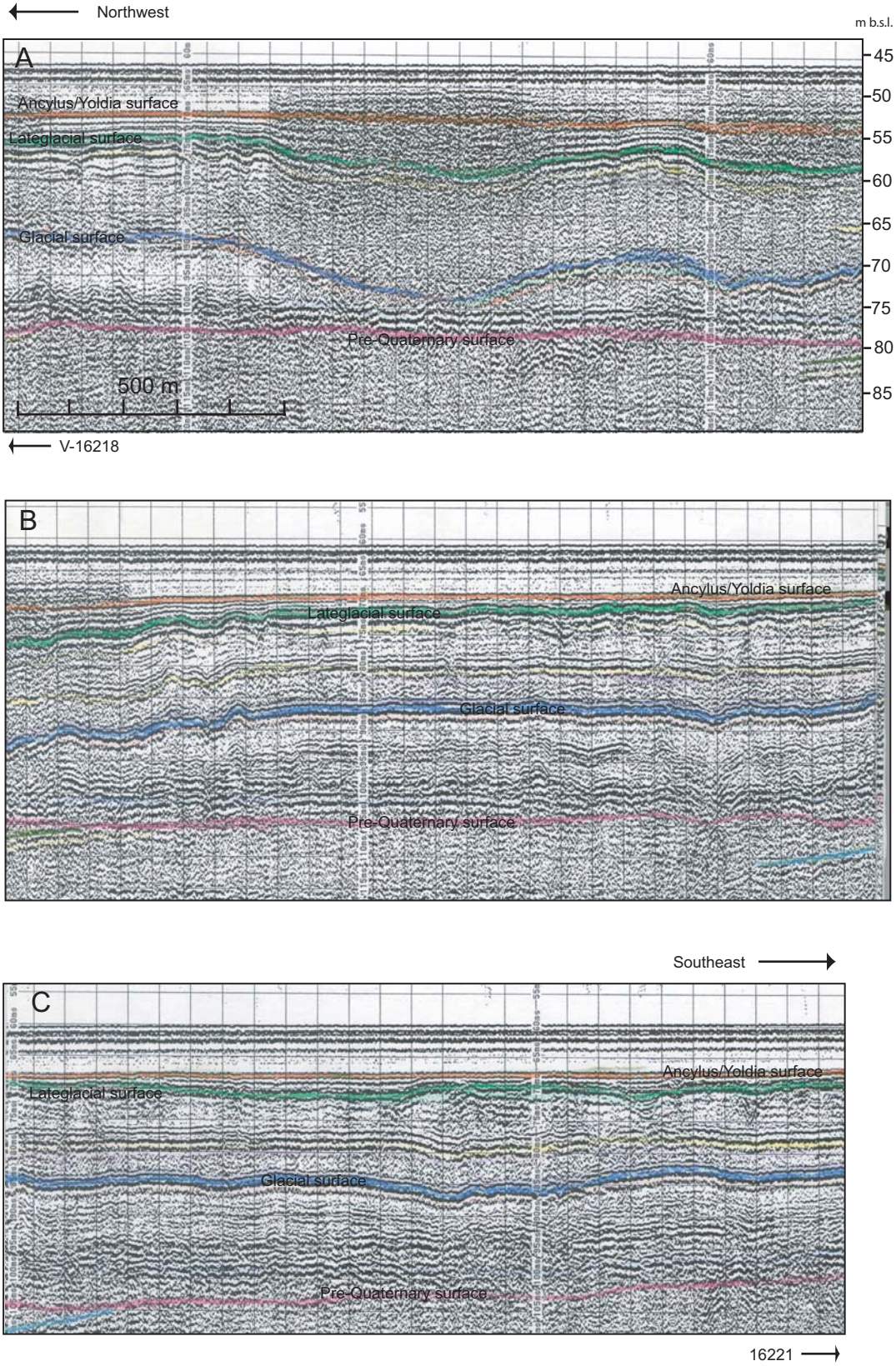

Figure 7. Section of the norhtwest-southeast trending seismic line Disk 3: RC16-t24-200-003, northwest of Adler Grund, Arkona Basin. The orange reflctor represent the Acylus/Yoldia time surface with postglacial marine sediments above. The green reflector represent the lateglacial surface, and the yellow reflector the two-partition of the lateglacial unit. The blue reflector represent the glacial surface and the pink reflector represent the pre-quaternary surface. Note the closely packed reflectors in the lowewr part of the glacial unit, which indicate layered sediments.

The green reflector has an undulating to wavy image in the north-western part of the seismic line and is interpreted as the lateglacial surface. The green reflector bend down after V-16218 representing the deepest part of the Arkona Basin, and bend up before V-16221 so the orange and green reflectors again are lying close. The lateglacial sequence is interpreted as divided in two parts, illustrated by the yellow reflector between green and blue, representing the initial and the final phase of the lateglacial Baltic Ice Lake stage.

The orange reflector has a continuous, parallel, even image and represent an unconformity (caused by erosion). Combined with information from vibrocore 16218, 16221 and 16223A that penetrate the unit the orange reflector is thought to represent the surface of Yoldia Sea Stage/Ancylus Lake stage. Above the orange reflector the reflectors has a transparency appearance, which indicate gyttja deposits. Combined with information from the vibrocores that penetrate the unit it is thought to represent postglacial, marine deposits from the Littorina Sea stage.

Above the pre-Quaternary surface are many parallel reflectors, which indicate layered sediments. The reflectors above are more indistinct and are thought to represent younger Weichselian till sediments.

The lateglacial unit is locally bending up shortly before V-16223A. The structure indicates ice-deformation with the ice-margin on the eastern side with a small depression behind and discharge sediments on the western side. The thickness of the lateglacial unit changes on the eastern side of the deformation; it becomes very thin.
Only the lower part of the lateglacial unit – representing the initial phase – is left.
The seismic line contains sporadically occurrences of gaseous sediments.

Disk 2: RC16-T24-cl-015.

The seismic line Disk 2: RC16-T24-cl-015 (fig. 8) is located north-east of Rügen in the Arkona Basin and contains vibrocore 16221, 16060, 16062, 16223A (profile K-L, fig. 5).
The pink reflector has a continuous, even and parallel image and is truncated and represents the pre-Quaternary surface. Lower dark green reflector is undulating to parallel and represent the glacial surface. Above the pre-Quaternary surface, in the lower part of the glacial unit, there is many closely packed, parallel reflectors, which indicate layered sediments.
The upper light green reflector is continuous, undulating to parallel and paralic. Combined with information from vibrocores it is thought to represent the lateglacial surface with postglacial, marine gyttja above (reflectors with a transparency appearance). A marked reflector in the middle of the unit indicates a two-partition of the lateglacial unit.

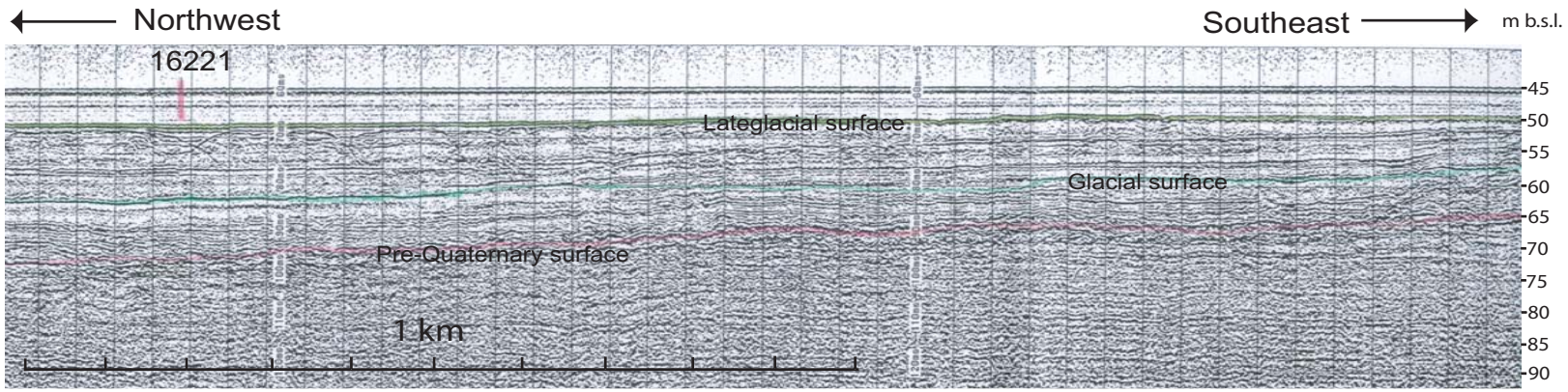

Figure 8. *Section of the seismic line Disk 2: RC16-T24-cl-015 with vibrocore 16221. WNW from Adler Grund, Rønne Banke in the Arkona Basin. The light-green reflector represent the lateglacial surface with marine gyttja deposit above. The green reflector represent the glacial surface and the pink reflector represent the pre-Quaternary surface.*

Disk 2: RC16-T24-cl-016

The seismic line Disk 2: RC16-T24-cl-016 is located WNW from Adler Grund, Rønne Banke at the rim of the Arkona Basin and contains vibrocore 16223A, 16065, 16225, 16066, 16068, 16070A (profile K-L, fig. 5 and profile M-N, fig. 9).
The yellow reflector reflector has a continuous, parallel, even image and represent an unconformity. The surface is truncated and it is thought to represent the pre-Quaternary surface. The orange reflector has a continuous, parallel to undulating image and represent the glacial surface. The green reflector has a continuous, parallel, even configuration and represent the lateglacial surface. The pre-Quaternary surface raises gradually to the surface in the south-eastern end of the profile. Clay till is found in vibrocore 16070A with sandy, organic detritus above, which could indicate deposition in Ancylus or older Yoldia time. The seismic solution indicates gaseous sediments around V-16223A.

Disk 3: RC16-T24+200-004

The seismic line Disk 3: RC16-T24+200-004 is located northwest and south of Adler Grund, Rønne Banke and contains vibrocore 16223A, 16225, 16227A, 16229, 16231 (profile K-L, fig. 5).
The orange reflector represents an unconformity, which is truncated, and is thought to represent the pre-Quaternary surface. Because of the seismic resolution it was not possible to separate the lateglacial unit from the glacial unit, so the blue to orange reflector represent lateglacial and glacial sediments. The blue reflector is thought to represent the lateglacial surface. The upper reflector is very difficult to see because of the seismic resolution. Above the blue reflector the seismic reflectors has a transparent appearance that indicate gyttja deposits and information from vibrocores indicates postglacial marine sediments from the Littorina Sea stage.

Disk 2: RC16-T24-cl-017

The seismic line Disk 2: RC16-T24-cl-017 is located northeast of Rügen, SSV from Adler Grund, Rønne Banke, and contains vibrocore 16227 (profile K-L, fig. 5).
Because of the seismic resolution it was difficult to follow the reflectors above the pre-Quaternary surface. The pink reflector is continuous, even, nearly parallel and is truncated. It is thought to represent the pre-Quaternary surface. The yellow reflector has a nearly parallel image, which terminate (onlap) and could represent the glacial surface. The green reflector has a continuous, parallel, even image and represent an unconformity (caused by erosion). Combined with information from vibrocore 16227 that penetrate the unit the reflector is thought to represent the lateglacial surface. The reflectors above have a transparency appearance and represent postglacial marine sediments.

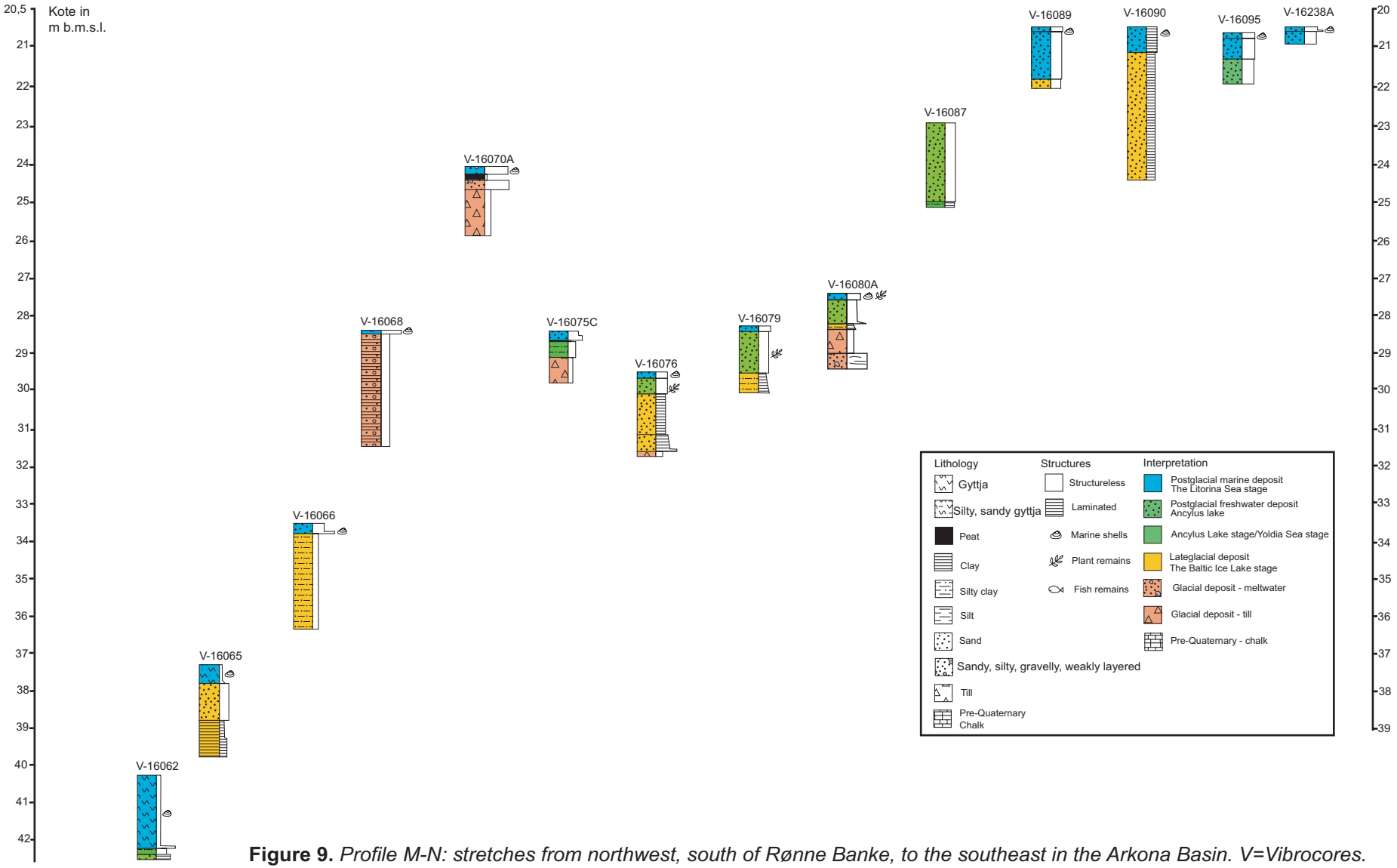

Figure 9. *Profile M-N: stretches from northwest, south of Rønne Banke, to the southeast in the Arkona Basin. V=Vibrocores.*

Disk 3: RC16-T24+125-003

The seismic line Disk 3: RC16-T24+125-003 is located SSV from Adler Grund, Rønne Banke (fig. 1 and 2) and contains vibrocore 16227, 16229, 16076 and 16231. The water depth is 24.0, 27.7, 29.6 and 29.8 m b.m.s.l.
The orange reflector has a continuous, parallel, even image and represent an unconformity. Reflectors onlap to the surface that represent the pre-Quaternary surface (the chalk surface). South of vibrocore 16227 there is a change in the pre-Quaternary sediments. The reflector above is nearly parallel but fades out in the north-western part of the profile, where it down-lap onto the pre-Quaternary surface. The postglacial sediment cower is thin or non-existing in this profile, based on Information from vibrocoring, which indicate the location of the lateglacial surface close to the sediment-water surface.

Disk 4: RC16-T24-35-007

The seismic line Disk 4: RC16-T24-35-007is located SSV from Adler Grund, Rønne Banke (Bornholm Bassin) and contains vibrocore 16068, 16227, 16229, (16075C), (16076) and 16231. The water depht varies between 28.4, 24.0, 27.7, 28.5, 29.6 and 29.8 m b.m.s.l. Same description as Disk 3: RC16-T24+125-003.

Disk 2: RC16-T24-cl-018

The seismic line Disk 2: RC16-T24-cl-018 is located south of Adler Grund, Rønne Banke - a NW-SE trending line through Bornholm Basin - and contains vibrocore 16229, 16075, 16076 and 16231 (fig. 9).
The blue reflector has a continuous, parallel, even image and represent an unconformity. Reflector onlap on to the surface that represent the pre-Quaternary surface (the chalk surface). The green reflector above is nearly parallel but fades out in the north-western part of the profile, where it down-lap onto the pre-Quaternary surface. The green reflector is thought to represent the glacial surface. Glacial sediments (clay till) are found in vibrocore 16229, 16075C and 16076. The postglacial sediment cower is thin or non-existing in this profile, based on Information from vibrocores, which indicate the location of the lateglacial surface close to the sediment-water surface.

The last four seismic lines are parallel; all located north of Oder Banke, Bornholm Basin. The description of the reflectors and the internal reflection pattern is identical for all of the four seismic lines.

Disk 2: RC16-T24+125-001

The seismic line Disk 2: RC16-T24+125-001 (fig. 10) is located north of Odra Bank, Bornholm Basin and contains vibrocore 16090, 16095 and 16238A.
The pink reflector has a continuous, parallel, even image and represent an unconformity. The underlying reflectors on-lap onto the surface, which represent the pre-Quaternary surface. The blue reflector has a continuous, parallel, even image and represent an

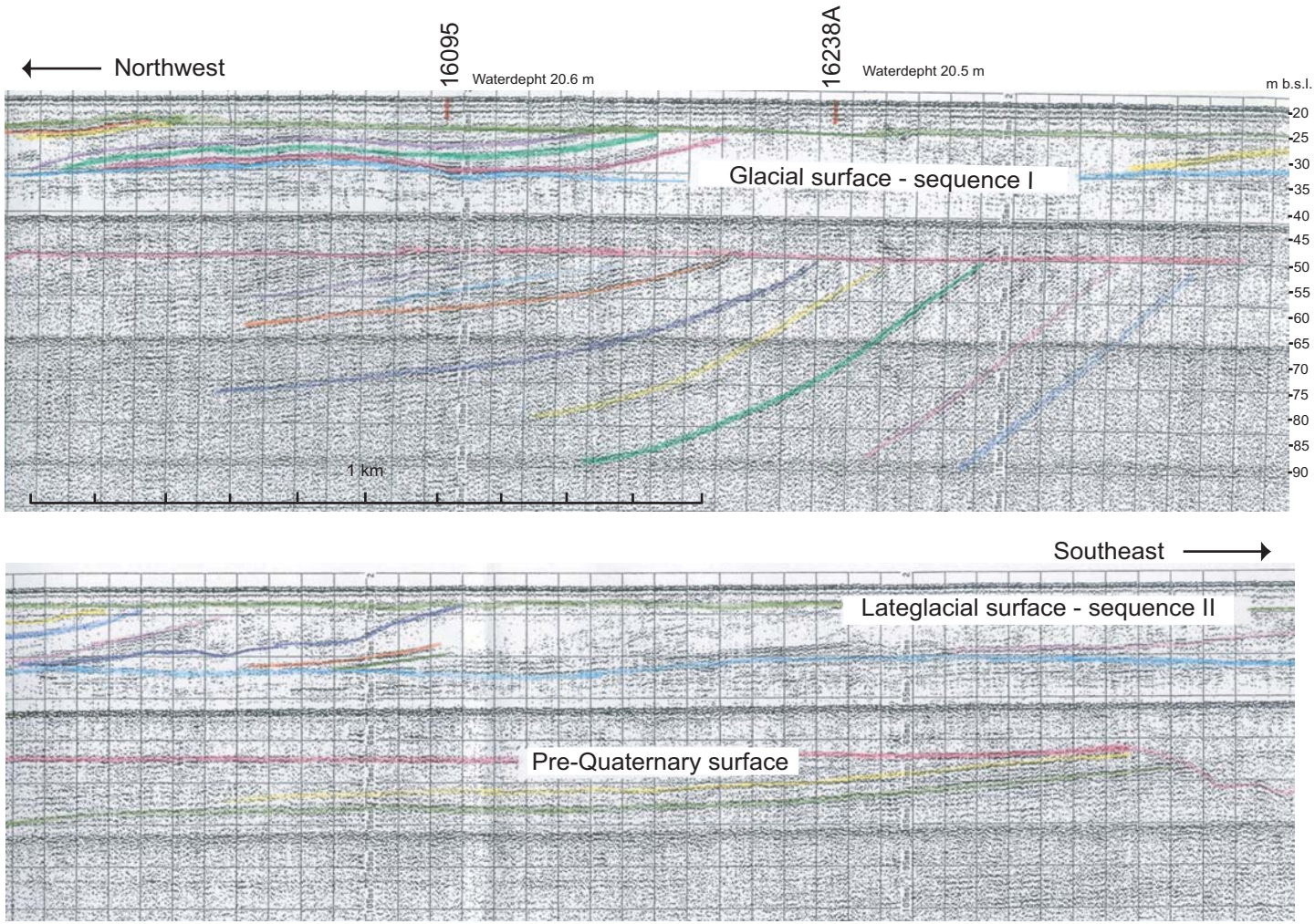

Figure 10. *Northwest-southeast trending seismic line Disk 2: RC16-T24+125-001 with vibrocore 16090 and 16238A, north of Odra Bank. Green reflector represent the lateglacial surface, with postglacial marine sediments above. The blue reflector represent the glacial surface and the pink reflector represent the pre-Quaternary surface.*

unconformity. The overlying reflectors down-lap onto the unit. It is thought to represent the glacial surface. The green reflector has a continuous, parallel, even image and is thought to represent the Lateglacial surface. Information from the vibrocore indicates that the lateglacial deposits are found below the green reflector. The internal reflections pattern below the green reflector – the lateglacial unit - has a prograding trend, which indicate a progradation of the coastline.

Disk 2: RC16-T24+125-002

The seismic line Disk 2: RC16-T24+125-002 is located north of Odra Bank, Bornholm Basin and contains vibrocore 16087, 16089, 16090 and 16233A (profile M-N, fig. 9).
The pink reflector is truncated and the underlying reflectors onlap onto the surface, and it is thought to represent the pre-Quaternary surface. The lower light-blue reflector, only seen in the eastern end of the profile, is thought to represent the glacial surface. The green reflector has a continuous, parallel, even image and represent an unconformity. Combined with information from a nearby seismic line (Disk 3: RC16-T24+35-002) and vibrocores it is thought to represent the lateglacial surface. In the eastern end of the profile the internal reflection pattern in sequence II has a prograding trend.

Disk 3: RC16-T24-125-002

The seismic line Disk 3: RC16-T24-125-002 is located north of Odra Bank, Bornholm Basin and contains vibrocore 16089, 16090 and 16095 (profile M-N, fig. 9). Description is the same as Disk 2: RC16-T24+125-002 and Disk 3: RC16-T24+35-002.

Disk 3: RC16-T24+35-002

The seismic line Disk 3: RC16-T24+35-002 is located north of Odra Bank, Bornholm Basin and contains vibrocore 16090, 16095 and 16238A (profile M-N, fig. 9). Depth of vibrocores is between 0.43-4.0 m.

The lowermost solid reflector has a continuous, parallel, even image and represent an unconformity (an erosion surface). It represents the pre-Quaternary surface.
The middle solid reflector has a continuous, parallel, even image representing an unconformity. It is thought to represent the glacial surface. Sequence I consist of glacial related deposits.
The uppermost reflector has a continuous, parallel, even image and represent an unconformity. Combined with information from vibrocore it is suspected to represent the lateglacial surface. The internal reflectionspattern in the lateglacial unit is prograding and is interpreted as a prograding delta.

Sequence IV (Littorina Sea stage) is more or less transparent and consists of fine sand. Because of lack of ^{14}C-datings it was difficult to separate Sequence III (Postglacial freshwater sediments from the Ancylus stage) from Sequence II (Lateglacial freshwater sediments from the Baltic Ice Lake stage) in these vibrocorings.

Discussion

Section A in figure 2:

The seismic line Disk 8: RC16-T12+125-002 (fig. 3) located northwest to southeast of Kriegers Flak (see fig. 1) and contains vibrocore 16040A, 16303, 16306, 16309, 16311, 16313, 16314, 16315, 16316 and 16320 (profile G-H, fig. 4).

- The pre-Quaternary surface is locally raised around V-16311, V-16313 and V-16314. This bend-up trend could be deformation structures created by the ice.

Section B in figure 2:

The seismic lines Disk 2: RC16-T24-cl-005, Disk 2: RC16-T24-cl-006 and Disk 6: RC16-T24+125-007 located east of Kriegers Flak contains V-16212, V-16215 and V-16218 (see fig. 1).
The seismic lines Disk 3: RC16-T24-200-003, Disk 3: RC16-T24+200-005 and Disk 4: RC16-T24-35-005 is located north-east of Rügen and west of Adler Grund, Rønne Banke (fig. 1) and contains V-16218-16223A (profile K-L, fig. 5). Figure 7 is a section of the seismic line Disk 3: RC16-T24-200-003.
The seismic lines Disk 2: RC16-T24-cl-015 (fig. 8), northeast of Rügen, contains V-16221-16223A (fig. 5), Disk 2: RC16-T24-cl-016, WNW from Adler Grund contains V-16223A-16070A (fig. 5 and 9), Disk 3: RC16-T24+200-004, NW-S of Adler Grund contains V-16223A-16231 (fig. 5), Disk 2: RC16-T24-cl-017, SSW from adler Grund contains V-16227, Disk 3: RC16-T24+125-003, SSW from Adler Grund contains V-16227-16231, Disk 4: RC16-T24-35-007, SSW from Adler Grund, V-16068-16231 and Disk 2: RC16-T24-cl-018, SSW from Adler Grund contains V-16229-16231.
Around V-16215 the lateglacial surface bend down, creating accommodation space for sediments in the Arkona Basin, and around V-16223A the surface bend up. The unit between the lateglacial freshwater deposit and the postglacial marine deposits are supposed to be deposited in the youngest part of the lateglacial period, the brackish Yoldia Sea stage and/or in the early postglacial period, the Ancylus Lake stage. It was difficult to separate these deposits and together they are named Yoldia time. The reflector representing the lateglacial surface is even in the deeper part of the basin. The reflectors above, representing the lower Yoldia time unit is slightly bending in pace with the basin floor. A change in the reflection pattern occur in the upper part of the basin. The reflector, representing the lateglacial surface, is on the edge of the basin paralic, and the reflector in the upper part of the Yoldia time unit on-lap onto the lateglacial surface. The deep part of the basin with the parallel, even lateglacial reflector indicate a period where the basin has been constantly filled with water, in sequence stratigrahic terms named a highstand period. Thus, the deep part of the basin consist of deposits from the youngest part of the lategalcial period – the Yoldia Sea stage (11.500-10.200 BP). The lowstand period in the beginning of Yoldia time is followed of a transgression indicated by the paralic reflectors and the on-lap in the upper part of the basin.

The reflections pattern indicate a two-partition of the lateglacial unit – interpreted as the initial and final phase of the Baltic Ice Lake Stage.
The glacial unit consist in some parts of many closely packed, parallel reflectors which indicate layered sediments. These layered sediments could be similar to the Early Weichsel interstadial sequence of freshwater sediments, 40.000-30.000 BP, found at the Danish island Møn (Houmark-Nielsen & Kjær 2003) and the Weichselian sediments found at Kriegers Flak (Klingberg 1998). The reflectors above the layered sequence are more indistinct and are thought to represent younger Weichselian till sediments.

Section C in figure 2.

The seismic lines Disk 2: RC16-T24+125-001, Disk 2: RC16-T24+125-002, Disk 3: RC16-T24-125-002 and Disk 3: RC16-T24+35-002, north of Odra Bank, Bornholm Basin, contains V-16087, V-16089, V-16090, V-16095, V-16233A and V-16238A.
The internal reflections pattern in the lateglacial unit indicate a prograding system. The prograding system builds out from SE to NW. It could be delta progradation comparable with the event in Mecklenburg Bugt (J.B. Jensen et al. 1997).
Sequence II consist of layered fine sand from the Baltic Ice Lake stage in this area. The transition from the parallel reflection part to the prograding system is seen as a change from grey, fine sand with shells to olive grey silty, fine, laminated sand with charred plant remains in lamina. Sequence II is interpreted as late-glacial ice lake deposits with a local delta inflow from the Oder River. The age of this event occurred probably around 15.000-12.000 B.P. in early Lateglacial, because there are no evidence for an overridden moraine.

- A prograding system is observed on the seismic sections Disk 2: RC16-T24+125-001, Disk 2 : RC16-T24+125-002, Disk 2 : RC16-T24+125-002 and Disk 3 : RC16-T24-125-002 in the southern part of the Bornholm Basin, north of Odra Bank (South-east of Adler Grund). The age is interpreted to around 15.000-12.000 BP. As the system builds out the deposits gets younger in the north-western part of the area, and indicate younger lateglacial age.

  Sediments from the Polish part of the southern Baltic, south-east of Odra Bank is ^{14}C dated to Early lateglacial time – between 13.100-14.060 BP (peat from core W-4, -17.30 m a.s.l.) which is about Allerød time. (Uscinowicz 2003). A south-north trending profile from east of Odra Bank to south of Bornholm contains several ^{14}C datings (Geological Atlas 1995) and is crossing the above mentioned seismic lines near vibrocore 16095. The polish profile A-B contains both younger and older lateglacial units. By comparing the interpreted units in the seismic lines with the ^{14}C dated units in the polish profile it is expected that the upper prograding unit in the seismic line can be correlated with the upper part of unit 13 (Allerød time, 13100-14060 age BP), close to the younger unit 12 (limnic, locally fluvial, sands and silts) (Geological Atlas 1995).

Conclusion

Evidence of deposits from the youngest part of the lateglacial period – the brackish Yoldia Sea stage (11.500-10.200 BP) - in the central part of the Arkona Basin.

- Evidence of deposits from the early part of the postglacial period – the freshwater Ancylus Lake stage (10.200-10.00 BP).
- Parallel reflectors which indicate layered sediments is found in some parts of the glacial unit. The layered sediments could be similar to the Early Weichsel interstadial sequence of freshwater sediments, 40.000-30.000 BP, found at the Danish island Møn (Houmark-Nielsen & Kjær 2003) and the Weichselian sediments found at Kriegers Flak (Klingberg 1998). The reflectors above the layered sequence are more indistinct and are thought to represent younger Weichselian till sediments.
- A prograding system is observed on the seismic sections Disk 2: RC16-T24+125-001, Disk 2 : RC16-T24+125-002, Disk 2 : RC16-T24+125-002 and Disk 3 : RC16-T24-125-002 in the southern part of the Bornholm Basin, north of Odra Bank (South-east of Adler Grund). The age is interpreted to around 15.000-12.000 BP. A north-south trending profile A-B in the polish part of the southern Baltic is crossing these seismic lines and contains ^{14}C dated sediments (Uscinowicz 2003 and Geological Atlas 1995). It is expected that the upper prograding unit in the seismic line can be correlated with the upper part of unit 13 (Allerød time, 13.100-14.060 age BP), close to the younger unit 12 (Geological Atlas 1995).

Literature

Geological Atlas of the southern Baltic (1: 500000). Panstwowy Instytut Geologiency. Sopot – Warszawa 1995. (Plate XXI: location of profile A-B, PlateXIX:Geological cross-section of profile A-B)

Houmark-Nielsen, M. and Kjær, K. H. 2003. Southwest Scandinavia, 40-15 ka B.P: Palaeography and environmental change. J. Quaternary Sci., Vol 18 pp. 769-786. ISSN 0267-8179.

Jensen, J. B. 1993. Late Weichselian deglaciation pattern in the southwestern Baltic: evidence from glacial deposits off the island of Møn, Denmark. Bulletin of the Geological Society of Denmark 40, 314-331.

Jensen, J. B. 1995. A Baltic Ice Lake transgression in the southwestern Baltic: Evidence from Fakse Bugt, Denmark. Quaternary International 27, 59-68.

Larsen, C. S. 2003. Beskrivelse af vibrocorekerner fra den sydvestlige del af Østersøen, nordlige Storebælt og Lillebælt, samt tolkning af seismiske data. Baseret på data fra Baltic Pipe Route Survey 2001 Denmark-Poland. Danmarks og Grønlands Geologiske Undersøgelse rapport 2003/81.

Klingberg, F. 1998. A Late Pleistocene marine clay succession at Kriegers Flak, westernmost Baltic, southern Scandinavia. J. Quaternary Sci., Vol. 13, pp. 245-253.

Uscinowicz, S 2003. Relative sea level changes, glacio-isostatic rebound and shoreline displacement in the Southern Baltic. Polish Geological Institute Special Papers, 10: 1-80.

Appendix 1

Macrofossil analysis

Macrofossil analysis of samples from the following vibrocores has been carried out by Ole Bennike: V-16022A, V-16032 from profil A-B (Larsen 2003) and V-16070A and V-16075C from profile M-N (fig.9). Detailed lithological log and results of macrofossil analysis.

16022A

40-60 cm: Nereis (bristle worm) few, Dynema (hydroids) few, Mytilus (common mussel) few, brown alga commen, Cirsium (thistle) 1 – marine.

70-80 cm: brown alga few, Sphalcellaria few, Mytilus few, Dynem (hydroids) few, Lycopus (gipsywort) – marine.

80-83 cm: Characeae alga commen, birch tree 2, Piscicola (fish leech) 8, Carex (sedge) 1, Cristatella (moss animal) 2, Typha (reed mace) 1, Potentilla anserina (terrestrial plant) 1, Najas minor (a plant which grow on the bottom of a lake) 1, Bithynia tentaculata (snail) 1 lid, Cladocera (crustacean) very common. – Early Holocene lake.

85-90 cm: Scirpus lacustris (bulrush) 15, Menyanthes (buckbean) 6, Potamogeton pectinatus (pondweed) 2, Cladium (twig rush – grow in reed swamp) 1, Juncus (rush) 1, Hippuris (mare´s-tail) 1, Trichoptera (caddis fly) 1, Carex (sedge) 2, Cristatella (moss animal) 2, Characeae (alge) few, Erpobdella (leech) 1, Eleocharis 1, Cladocera (crustacean) very common. – Early Holocene lake.

90-98 cm: wood fragments common, Carex (sedge) 6, Scirpus lacustris (bulrush) 35, Nymphaea (waterlily) 8, Paludella (moss) 1, Pinus bark, some (pine tree), Menyanthes (buckbean) 6, Potamogeon pectinatus (pondweed) 2, Populus tremula (aspen) 3, Hippuris 2, birch tree; nut 1, Sparganium simplex tp 1, Cladium (twig rush) 1, Cladocera (crustacean) common, radiceller common. – Early Holocene lake.

16032

25-30 cm: Cirsium sp. (thistle) 1, birch tree 1, chironomider (gnat) few.
30-35 cm: wood fragments very few.
33-35 cm: wood fragments common., clear-cut – organic detrutis or deposit.
33-44 cm: nothing

16070A

18-31 cm: wood fragments common. wear, phragmites (common reed) few, Zannichellia palustris (water plant) 15, Carex sp. 7, Potentilla anserina (terrestrial plant) 1, fish 1, Scirpus lacustris (bulrush) 2, Cladium (twig rush) 2, Populus tremula (aspen) 4, Batrachium (water crowfoot) 8, Menyanthes (buckbean) 3, Viola 3, Pinus (pine tree) 10, Cenococcum few (sponge – grow in soil), Erpobdella (leech) 1 – Early Holocene lake, organic detritus.

16075C

25-30 cm: Carex (sedge) 1, small roots common – organic detritus.