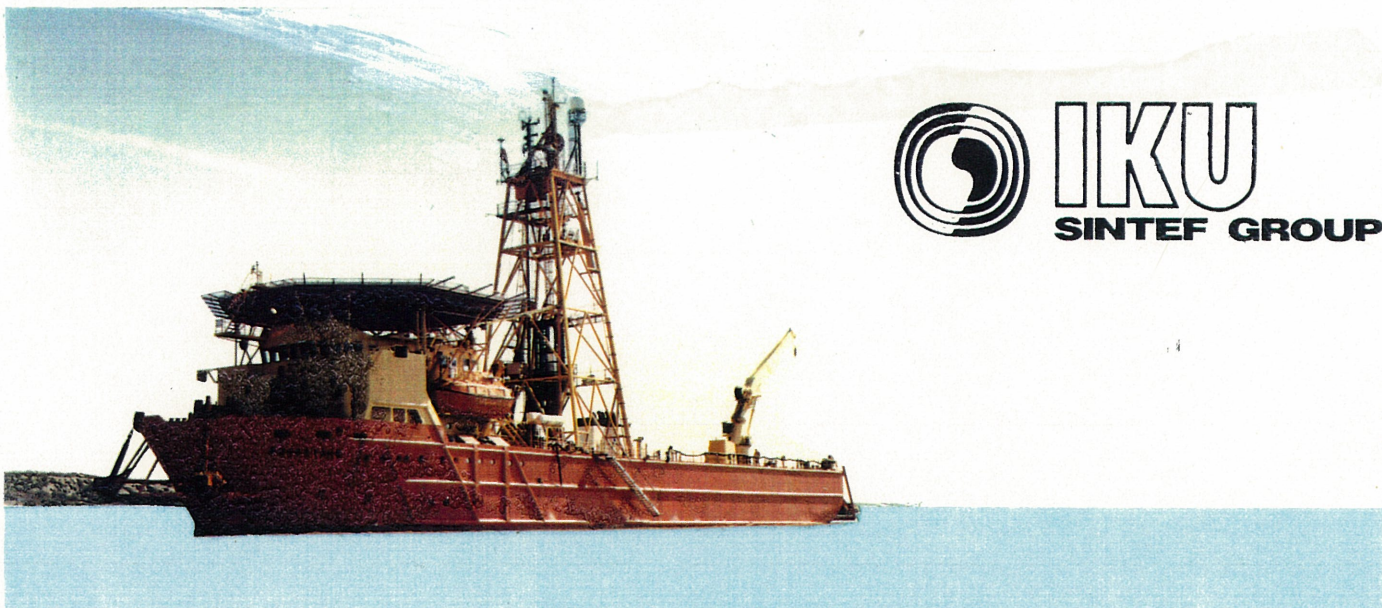
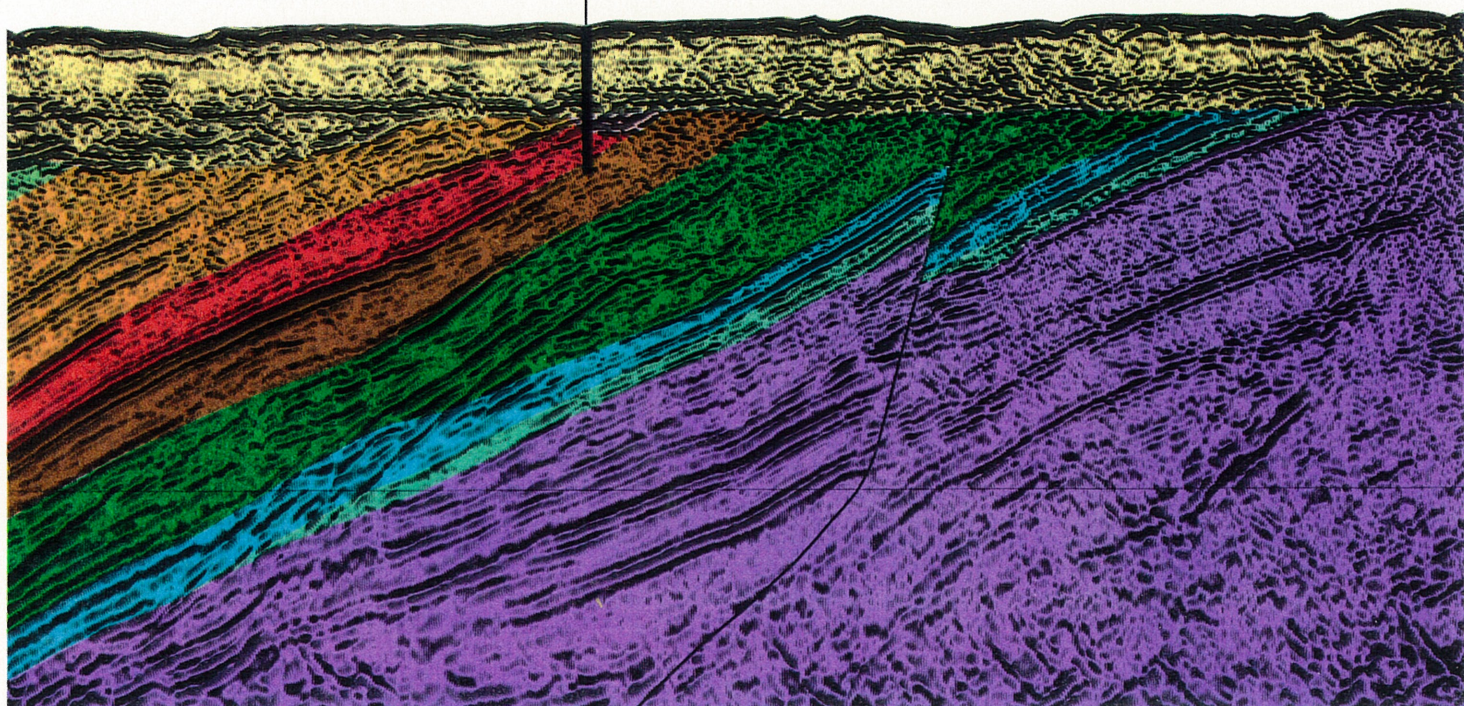




Shallow Drilling Bjørnøya West 1989

Appendix volume 2

Quaternary sediments
and glacial geology





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Appendix volume 2: Quaternary sediments and
glacial geology

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SUMMARY: The present appendix volume contains a report on glacial sediments collected within the project "Shallow drilling Bjørnøya West 1989". A total of 29.35 m of sediment cores was collected in 4 boreholes in outer Bjørnøyrenna. This includes 7.8 m of core obtained from a 15 m thick megablock of Cretaceous rocks embedded in Late Pleistocene till. Total drilled length in Quaternary sediments was 308.6 m. Ages have been assigned to lithologic units of the boreholes based on magnetopolarity and aminostratigraphy. This stratigraphy has been correlated to a seismostratigraphy for the outer shelf and upper slope, and this framework has enabled a quantitative evaluation of glacial erosion rates in the southern Barents Sea for the past 0.2 million years. Our data show that glacial erosion has reached more than 500 m below sea level in the western Barents Sea during the late Weichselian glaciation (about 30 - 13 ka ago).				

KEY WORDS: Shallow drilling	Late Cenozoic
Barents Sea	Glacial geology
Glaciotectonism	Erosion

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PREFACE

The present report gives the results of investigations on Late Cenozoic glacigenic core material collected in boreholes drilled in the IKU project "Shallow drilling Bjørnøya West 1989". Participants are Amoco Norway Oil Company, A/S Norske Shell, Conoco Norway Inc., Elf Aquitaine Norge A.S, Mobil Exploration Norway Inc., Norsk Hydro a.s, Saga Petroleum a.s, Statoil, Total Marine Norsk A/S, Norwegian Petroleum Directorate (NPD).

The objective of that project was to core Tertiary bedrock, but based on a regional background knowledge of the Quaternary seismostratigraphy of the area, it was realized that the site selection for the bedrock drilling offered an excellent opportunity to obtain stratigraphic control on a significant part of the glacigenic sequence. An additional financial support to allow increased sample coverage from the glacigenic sequence was given by Norsk Hydro, Shell, Statoil and the owner of the drillship "M/S Bucentaur" used during the data collection. This support is gratefully acknowledged.

The field work was carried out by the geotechnical drill ship "M/S Bucentaur" under supervision of Tom Bugge. IKU participants during the drilling cruise were: Siv Andersen, Tony Boassen, Tom Bugge, Geir Elvebakk, Stein Fanavoll, Svein Fløttum, Jørgen Hansen, Martin Hamborg, Leslie Leith, Gunn Mangerud, Rune Mogensen, Atle Mørk, Leif Rise, Unni M. Wang, Dag A. Westgaard.

The seismic mapping and the study of the lithology, structures and physical properties of the sediments are done by Joar Sættem as part of a Ph.D. study (Dr. ing.) at the Department of Geology and Mineral Resources Engineering, Norwegian Institute of Technology, University of Trondheim.

David Poole at IBG, University of Tromsø has been responsible for the biostratigraphic analyses. His work will be followed up by a detailed study of the biostratigraphy and isotope variations as part of a doctorate study at the University of Tromsø.

The amino acid measurements were conducted at the University of Bergen under supervision of Hans Petter Sejrup.

Kari Lise Ellingsen, University of Bergen, has studied the magnetic properties of the sediments.

Physical properties (index properties) were measured by Dag Arne Westgaard and Joar Sættem.

Oedometer testing and some routine soil mechanical analyses were performed by the Sintef Division of Geotechnical Engineering.

The biostratigraphy of an allochthonous glaciotectionic megablock of Cretaceous rocks in borehole 7316/06-U-01 was done by Morten Smelror, Robert M. Goll and Jacob G. Verdenius. Atle Mørk was responsible for the sedimentological logging of this core.

The support and contributions are gratefully acknowledged.

In addition, the following IKU staff members have contributed:

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Øistein How, Øystein Rossing, Unni M. Wang.

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1. SUMMARY AND CONCLUSIONS

During ten days in May/June 1989 about 550 km of high resolution shallow seismic data were shot in the Bjørnøya West area. In August, four boreholes were drilled to depths of between 43 m and 160 m into bedrock. In these boreholes 58 samples were collected from the glacial sequence with a total sample length of 29.4 m (Table 3.1 and 3.2). One of the boreholes penetrated 143 m of mainly glacial sediments, including an interval of undisturbed interglacial (Eemian) sediments. The present volume deals with the data on the glacial sediment sequence collected within the project.

Stratigraphies (Chapter 6) are established for each of the boreholes. Three of the boreholes have a reasonable, although variable sample coverage. In the fourth site (7316/03-U-01) the sample coverage is very limited, and poor quality on seismic data across this does not enable this site to be correlated seismically. The borehole stratigraphy of the other three sites has been correlated to a seismostratigraphic framework described in Chapter 4. This has enabled extrapolation of stratigraphic results to the upper slope, and may also provide a basis for correlations on the shelf.

The main stratigraphic results are summarized in Figures 7.1 and 7.2 in Chapter 7. Analysis of magnetopolarity indicates that all samples from site 7317/10-U-01 are less than 730 ka old. Further dating is based on amino acid measurements. The deepermost part of 7316/06-U-01 is older than 200 ka BP and may be older than 730 ka BP. Based on data from sites 7317/10-U-01 and 7316/06-U-01 we have been able to assign finite ages to seismic units D (200 - 130 ka BP), E (130 - 80 ka BP) and G and F (both contain fossils that are 60 - 20 ka old). The latter two units were possibly both deposited during the last glaciation about 30 - 13 ka ago.

The assigned ages have been extrapolated to the upper part of the clastic wedge at the western margin, and have been used to determine the volume of sediments deposited here during known time intervals. This information has been combined with assumptions in the literature about the extent of the possible source area and total volume of the clastic wedge. Rates of erosion on the Barents Shelf have then been estimated for the last 200 ka (0.5 km/Ma) and during the last ice coverage in the area (1.2 km/Ma). These estimates are probably conservative. In light of our results it seems probable to accept a Late Pliocene - Pleistocene age of the clastic wedge in front of Bjørnøyrenna as suggested by Eidvin and Riis (1989). This implies a major erosion phase in the Southern Barents Sea during the Late

Pliocene - Pleistocene. Most of this erosion was probably glacial and may have to a large extent occurred up to several hundred metres below sea level.

The report also includes lithological information and physical property data (Chapters 5 and 6). Of particular importance is the discovery of glaciotectionically displaced mid Cretaceous rocks in a megablock embedded in the late Weichselian unit G (Chapter 8). These rocks were picked up by the glacier somewhere farther east in Bjørnøyrenna and were dragged along by the ice to their present position. The discovery of this glaciotectionic phenomenon illustrates the existence of a very powerful erosional process to depths of about 550 m below present sea level. It also conclusively shows that an ice sheet extended to outermost Bjørnøyrenna during the late Weichselian (about 30 - 13 ka ago).

2. PURPOSE

The overall purpose of the present study reported herein is to obtain background data regarding the glacial phase of the Cenozoic erosion in the Barents Sea. This can only be achieved by stratigraphic control and improvement of the understanding of the glacial history and the glacial processes that have been involved in the area.

The present study attempts to contribute to this by:

- obtaining age control of the flatlying or prograding upper Cenozoic sediments capping older, variously dipping strata in western Bjørnøyrenna.
- study the sedimentology of the cored sediments in order to reveal their origin and genesis.
- describe a seismic unit representing a hummocky, more or less continuous deposit. In borehole 7316/06-U-01 this unit was found to comprise a 15 m thick raft of Cretaceous rocks. This unit is interpreted as a large glaciotectionic megablock complex. The dimensions of the structure illustrate that glaciotectionism may be an important process of erosion of soft sedimentary rocks in the Barents Sea.

3. DATA AND METHODS

3.1 Collected data

The seismic mapping is based on a regional grid of analog and digital shallow seismic data (Figure 3.1). This data are collected by the Norwegian Polar Research Institute, the Norwegian Petroleum Directorate, the University of Tromsø, and IKU.

The sediment cores are collected in four boreholes (Figure 4.1, Tables 3.1 and 3.2). The main objective was to core subcropping bedrock below the angular unconformity at the base of the glacial sediment sequence. The chosen positions also offered an excellent opportunity to obtain stratigraphic control on Late Cenozoic glacial sediments and data regarding highly important glacial phenomena in the area. Details on data recovery are given in Tables 3.2 and 3.3. The cores are partly obtained by hammer sampling (3" core diameter) and partly by rotary diamond coring (5.5 cm core diameter). A great variety of sediment types were cored, including fairly soft to stiff muddy to gravelly diamictons, unconsolidated gravelly sands and consolidated rocks of a large glaciotectionic raft embedded in glacial sediments. Considering this variability, the core quality was generally very good. Some of the soft sediment cores obtained by hammer sampling were, however, partly disturbed.

Table 3.1 *Key data for the boreholes drilled by IKU in the western Barents Sea in 1989.*

Site no.	7316/03-U-01	7316/06-U-01	7316/06-U-02	7317/10-U-01
Seismic line	IKU-BV11-89	IKU-1650-89	IKU-1650-89	IKU-BV13-89
Shot point	~1077	~1688	~1814	~3344
Water depth (m)	297	428	421	465
Quaternary thickness (m)	31.9	65.0	68.5	143.2
Position				
Latitude (N)	73°52'55.8"	73°33'16.5"	73°34'7.7"	73°8'58.5"
Longitude (E)	16°54'28.9"	16°49'59.6"	16°50'0.9"	17°16'13.0"
Northing	373285	368422	368544	379389
Easting	8203472	8167166	8168746	8121151

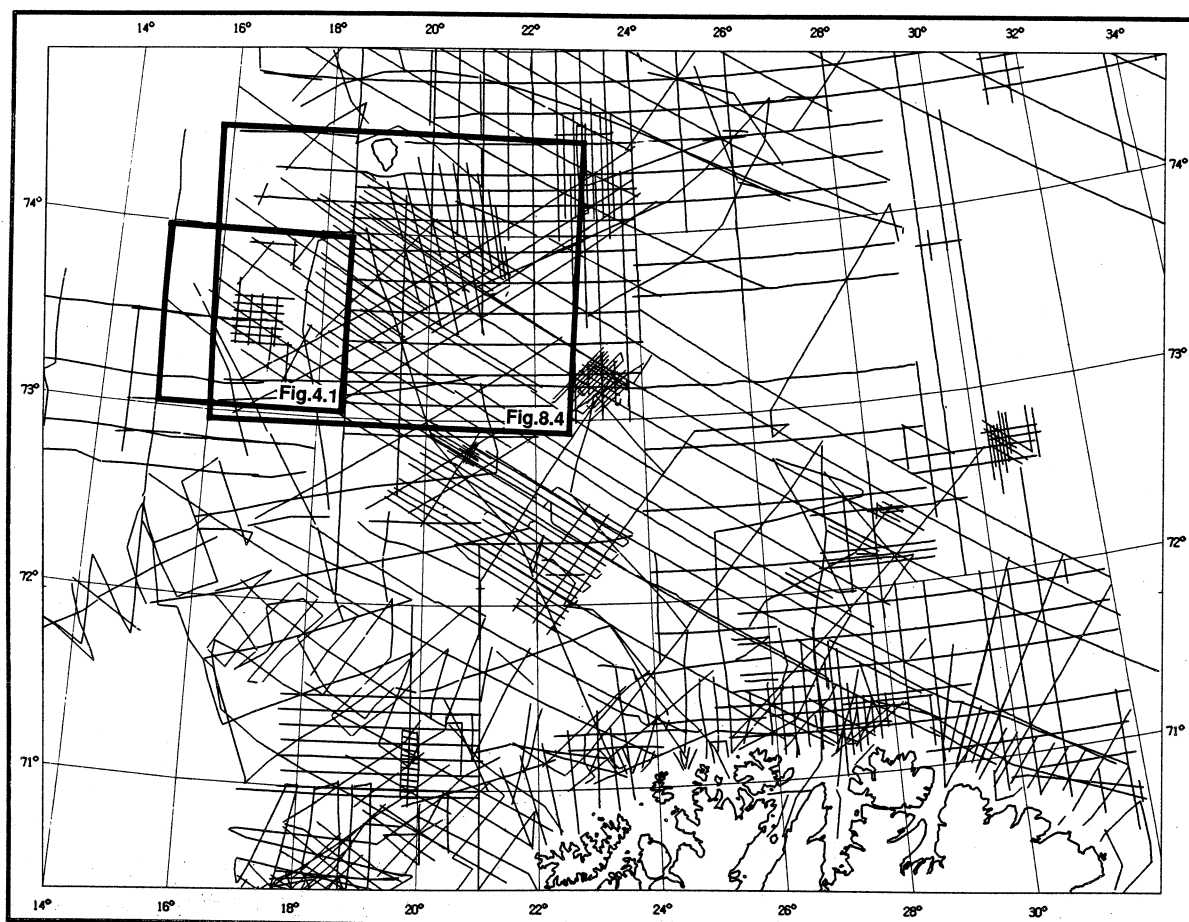


Figure 3.1 Regional shallow seismic grid and location of study areas (see Figures 4.1 and 8.4).

Table 3.2 Summary of Quaternary sample recovery during the 1989 IKU shallow drilling cruise (number of samples and accumulated sample length).

Sites	Rotary cores		Hammer samples		Total	
	Samples	Acc. length (m)	Samples	Acc. length (m)	Samples	Acc. length (m)
7317/10-U-01	3	1.75	32	11.23	35	12.98
7316/03-U-01	-	-	3	0.62	3	0.62
7316/06-U-01	7	12.0	4	1.67	11	13.67
7316/06-U-02	-	-	9	2.08	9	2.08
Total	10	13.75	48	15.60	58	29.35

Table 3.3 *Sample recovery list. All samples are obtained by the use of a hammer sampler (approx. 7.5 cm core diameter) unless it is stated that they are collected by rotary coring (approx. 5.5 cm core diameter). Disturbed samples may comprise only gravel fragments or may be particularly deformed samples.*

Well	Run	Sample length (m)	Depth interval		Type/Remark
			Top (m)	Base (m)	
7317/10-U-01	1	0.65	7.00	7.65	
7317/10-U-01	2	0.65	15.00	15.65	
7317/10-U-01	3	0.63	25.00	25.63	
7317/10-U-01	4	0.53	32.00	32.53	
7317/10-U-01	5	0.72	38.00	38.72	
7317/10-U-01	6	0.66	45.00	45.66	
7317/10-U-01	7	0.42	52.00	52.42	
7317/10-U-01	8	0.18	63.00	63.18	
7317/10-U-01	9	0.21	70.00	70.21	
7317/10-U-01	11	0.22	77.70	77.92	Disturbed
7317/10-U-01	12	0.12	80.60	80.72	Disturbed
7317/10-U-01	13	0.17	81.50	81.67	Disturbed
7317/10-U-01	14	0.34	83.30	83.64	
7317/10-U-01	15	0.05	88.30	88.35	
7317/10-U-01	16	0.35	89.40	89.75	Rotary cored
7317/10-U-01	17	0.35	93.00	93.35	
7317/10-U-01	18	0.10	93.70	93.80	
7317/10-U-01	19	0.95	99.15	100.10	
7317/10-U-01	20	0.70	102.15	102.85	
7317/10-U-01	21	0.35	103.00	103.35	
7317/10-U-01	22	0.45	107.00	107.45	
7317/10-U-01	23	0.45	109.70	110.15	
7317/10-U-01	24	0.49	112.50	112.99	
7317/10-U-01	25	0.40	114.20	114.60	Disturbed
7317/10-U-01	26	0.44	117.20	117.64	
7317/10-U-01	27	0.45	118.20	118.65	
7317/10-U-01	28	0.08	121.50	121.58	
7317/10-U-01	30	0.32	126.00	126.32	
7317/10-U-01	31	0.27	129.00	129.27	
7317/10-U-01	32	0.01	132.14	132.15	
7317/10-U-01	33	0.32	132.15	132.47	
7317/10-U-01	34	0.38	134.55	134.93	
7317/10-U-01	35	0.09	137.55	137.64	Disturbed
7317/10-U-01	36	0.33	140.00	140.33	
7317/10-U-01	37	0.15	140.35	140.50	
7316/06-U-01	1	0.32	5.00	5.32	Runs 6 - 13 are rotary cored
7316/06-U-01	2	0.55	19.30	19.85	
7316/06-U-01	3	0.50	29.30	29.80	
7316/06-U-01	5	0.30	38.90	39.20	
7316/06-U-01	6	1.95	42.75	44.70	
7316/06-U-01	7	2.50	44.70	47.20	
7316/06-U-01	8	2.12	47.75	49.87	
7316/06-U-01	9	0.78	52.07	52.85	
7316/06-U-01	10	0.04	53.91	53.95	
7316/06-U-01	11	2.51	53.95	56.46	
7316/06-U-01	13	2.10	59.95	62.05	

Table 3.3 Continued.

Well	Run	Sample length (m)	Depth interval		Type/Remark
			Top (m)	Base (m)	
7316/06-U-02	1	0.26	5.00	5.26	Disturbed Disturbed Disturbed
7316/06-U-02	2	0.49	19.50	19.99	
7316/06-U-02	3	0.56	31.50	32.06	
7316/06-U-02	5	0.02	45.20	45.22	
7316/06-U-02	6	0.01	50.80	50.81	
7316/06-U-02	7	0.17	59.00	59.17	
7316/06-U-02	9	0.01	62.00	62.01	
7316/06-U-02	10	0.41	65.50	65.91	
7316/06-U-02	11	0.15	65.91	66.06	
7316/03-U-01	1	0.38	7.20	7.58	
7316/03-U-01	3	0.07	16.20	16.27	
7316/03-U-01	7	0.17	31.40	31.57	

3.2 Methods

3.2.1 Seismic mapping

The seismic data (mainly analog data) have been used to establish a geologic framework by analysing seismic facies and seismostratigraphy. This has been based on elements from the till tongue stratigraphy concept developed by King and coworkers (King & Fader 1986, King et al. 1987). A local seismostratigraphy is developed for the study area. The seismostratigraphy is presented as maps and profiles depicting the extent and geometry of the different units (Figures 4.1 - 4.7).

3.2.2 Sediment analyses

Lithology and physical properties

The cores were briefly described on board. Sound velocity was measured horizontally on the cores by use of a portable non destructive ultrasonic (100 kHz) tester, make Pundit, when sample quality allowed. The samples were then wrapped in water tight foil and stored for further analyses on-shore. A few samples were casted in wax to completely avoid moisture loss and mechanical deformation. (During later description it was found that the waxed samples had developed a subvertical fissility pattern which was not seen in other samples. We suggest that this is due to heat shock during waxing, and probably too much and too warm wax was used). The diamond cut

core from site 7316/06-U-01 was frozen on board and cut longitudinally by a diamond saw. A reference slab was then casted in epoxy as an undisturbed reference.

Laboratory analyses of sediment properties include measurement of undrained and remoulded shear strength, water content, density, Atterberg limits (water contents at which the consistency of the soil changes), grain size distribution and compressional oedometer testing). Cubes of 1 cm³ volume were cut from the centre of the core for magnetic analyses. The cores were then cut into shorter lengths and broken apart vertically for analysis and photographing of structures (soft samples were allowed to dry and harden somewhat first). Core pieces were then selected for foraminiferal analysis.

Magnetostratigraphy

Details of the magnetostratigraphic work is covered in Enclosure 1.

Analysis of foraminifera and amino acids

A brief description of microfauna (foraminifera) is given in Chapter 6. This work is made by David Poole and the University of Tromsø. Foraminifera from a number of levels are picked both at the University of Tromsø and the University of Bergen for analyses of the amino acid composition. The amino acid analysis are performed at the amino acid laboratory in Bergen. This work has been supervised by Hans Petter Sejrup.

4. SEISMIC STRATIGRAPHY

4.1 Stratigraphic framework

A local seismic stratigraphy has been established within the northwestern part and flank of Bjørnøyrenna. Several of the mapped reflectors can, however, be traced widely in the southern Barents Sea. A regional seismostratigraphic framework for the entire southern Barents Sea is available on a digital grid format through another IKU project.

Ten seismic units have been mapped in the area (see Figures 4.1 and 4.2). Seven of these units are named by capital letters A - G, and two units mapped in the northwest are named C' and D' indicating the correlation with the units farther south. The lowermost mapped unit is named A₀ and is seismically very different from the units above. From its seismic signature it appears nonglacial in origin. However, correlations made by Vorren et al. (in prep.) in combination with stratigraphic results by Eidvin and Riis (1989) suggest that this unit is of Pliocene-Pleistocene age. Eidvin and Riis (1989) further showed evidence that glacial sediments rest on the unconformity at the base of this unit in the Senja Ridge area. Possibly its genesis indirectly is related to glacial processes, and hence the unit may provide very important evidence on the paleoenvironment of the early "ice ages".

The extent of the different units is shown in Figures 4.1 and 4.2. Thickness variations and acoustic signature are illustrated in Figures 4.3-4.8. Most of the mapped units are bounded by erosional unconformities both at their top and base. The only exception is probably unit G which is bounded upwards by the seabed. The amount of erosion varies laterally and is generally smallest in the deepest part of Bjørnøyrenna towards the shelf break. Most of the units have no internal reflectors, and it is therefore impossible to confidently distinguish between surfaces of glacial molding and glacial erosion. The general impression is that of a complex succession of erosion and deposition (Figures 4.3-4.8). The original geometry of each unit is therefore unknown. Towards the shelf break most units form a prograding pattern.

Several of the seismic units can be correlated into a regional framework established by L. King, M. Hamborg and the first author of the present report (unpublished work). Till tongues, interpreted to represent oscillations of the grounding line of an ice sheet (King & Fader 1986, King et

al. 1987) are found on several unit boundaries. These observations are interpreted as surfaces of tongue shaped till bodies (named till tongues by King & Fader 1986) deposited during major but oscillatory advances. It is, however, not possible from the seismic records alone to decide whether the entire Barents Sea was deglaciated between each advance. The other unit boundaries are generally considered to be intra formational erosional boundaries (King et al. 1987), and the sediments eroded may belong to an earlier glaciation or an earlier sequence of glacier advance and retreat during the same glaciation. The dating of events allowed by the present project is therefore a major step forward in the reconstruction of the glacial history of the area.

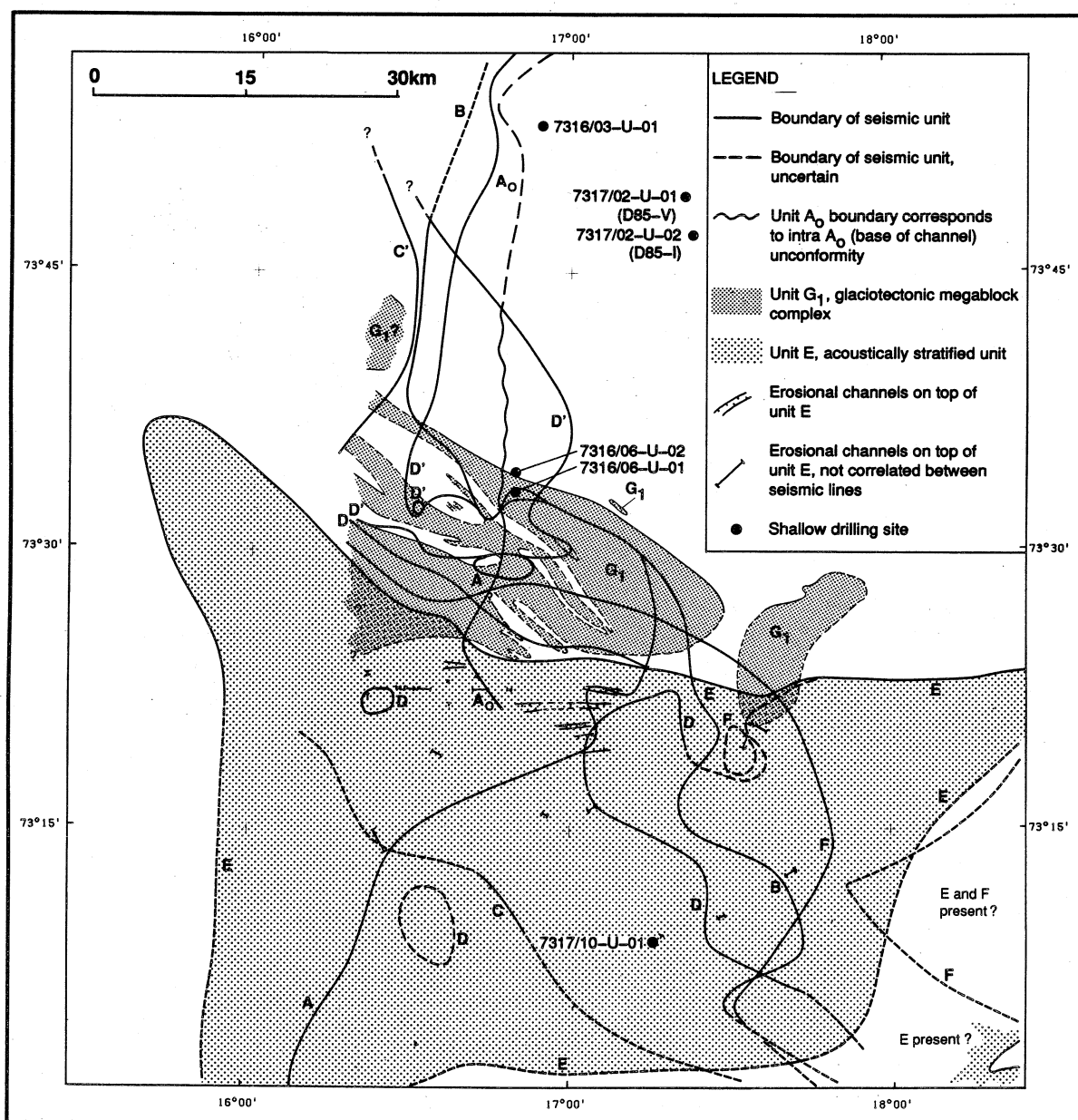


Figure 4.1 Mapped extent of seismic units. Units E and G₁ are shaded. The extent of the other units except for unit G, is highlighted on the maps in Figure 4.2. Unit G is present in the entire map area, on top of the other units.

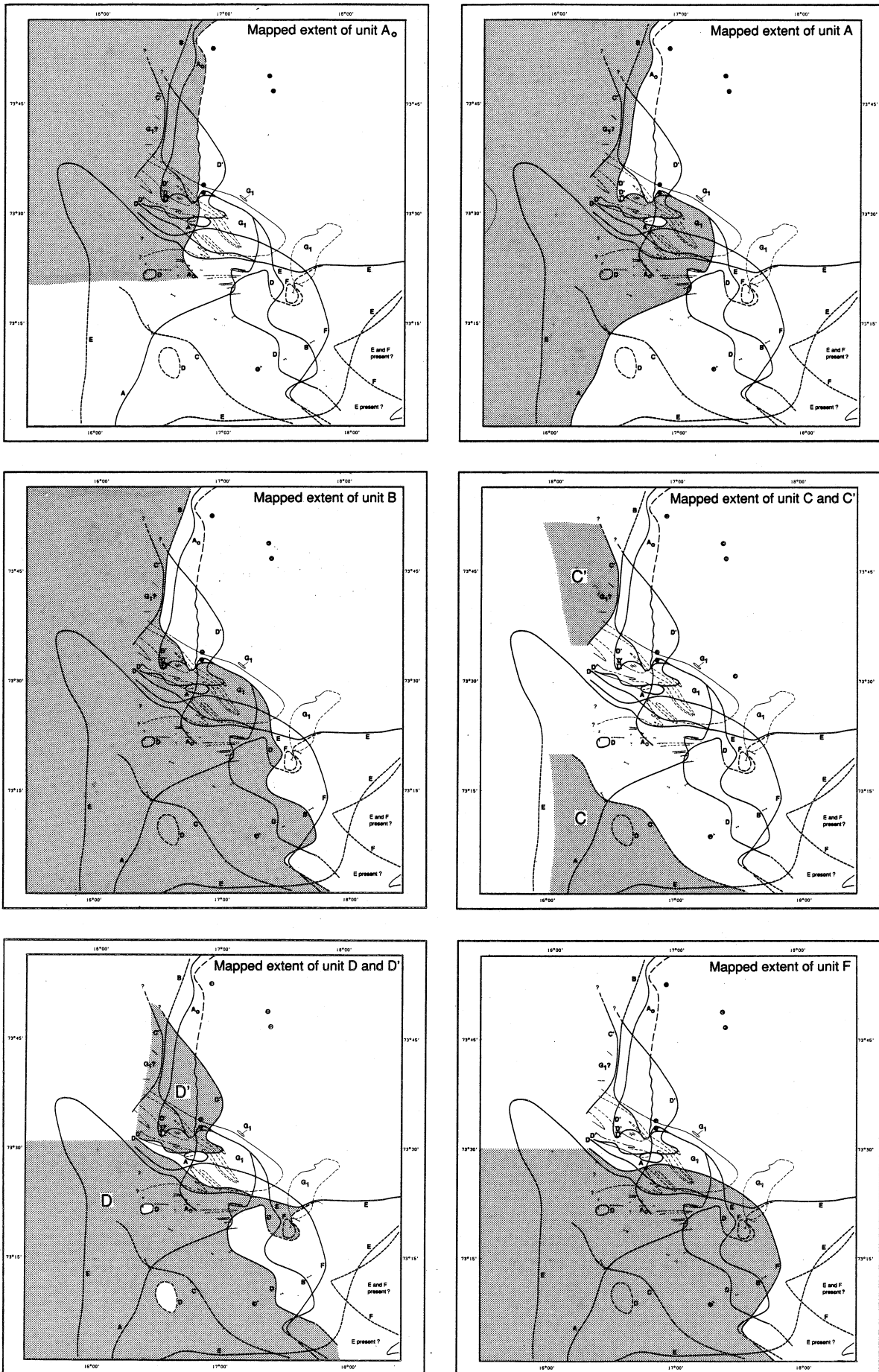


Figure 4.2 Mapped extent of seismic units A_0 , A, B, C, C', D, D' and F.

The seismic reflectors representing unit boundaries are traced mainly on analog sparker or mini airgun data. Where available, also digital shallow seismic (airgun) data is used. This data has, however, less resolution than the analog data, and the impression is that the digital data often record different stratal differences than the analog data which cover a different acoustic frequency band. The tie between different data types is therefore sometimes uncertain.

In an area approximately from the northern boundary of the acoustically stratified unit E to 73°30'N the seismic data are strongly obscured by a chaotic internal reflection pattern and this hampers the seismic mapping.

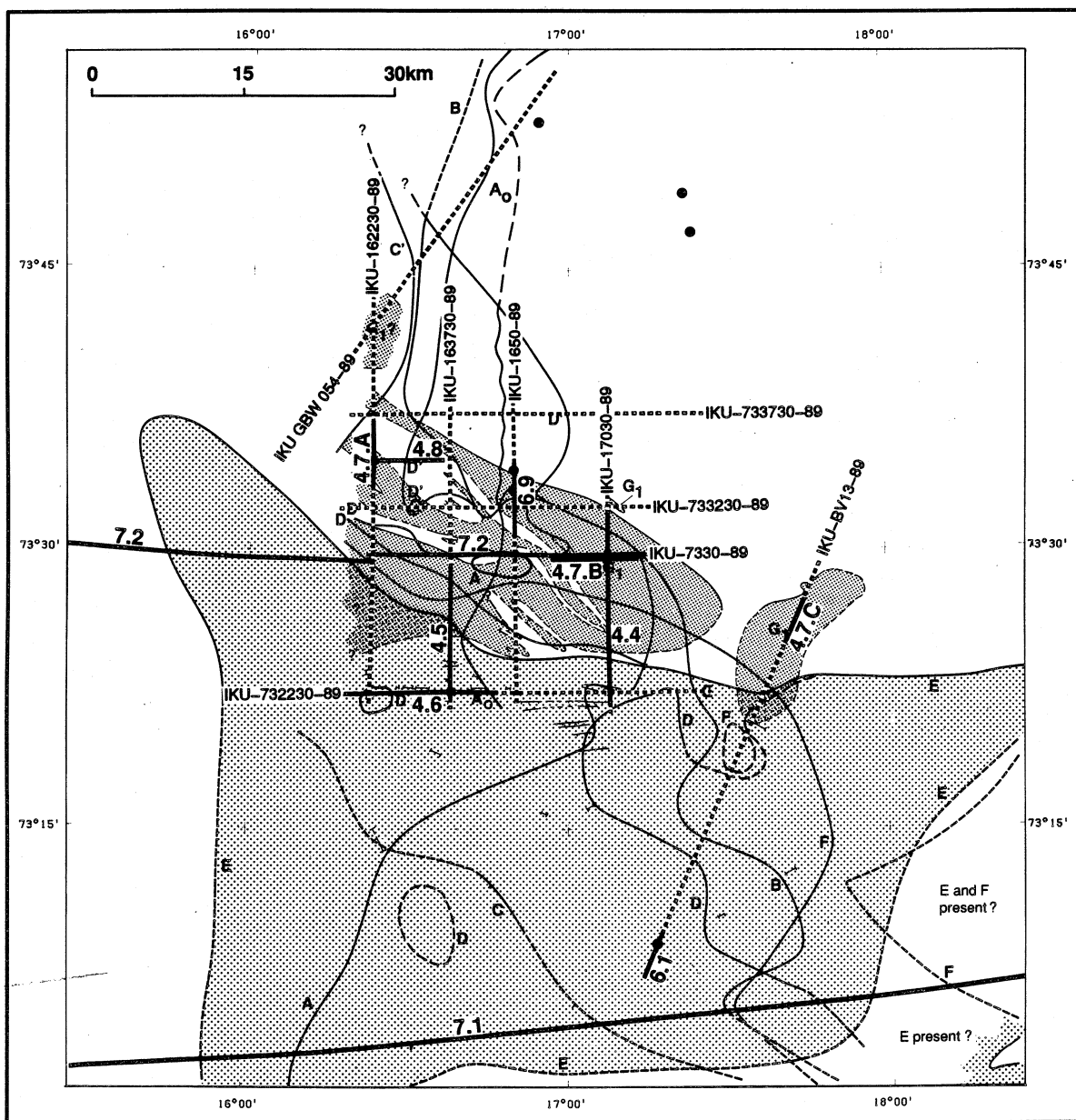


Figure 4.3.A Location of profile examples and simplified seismic sections. Sections shown in Figures 4.3.B and 4.3.C are indicated by dotted lines.

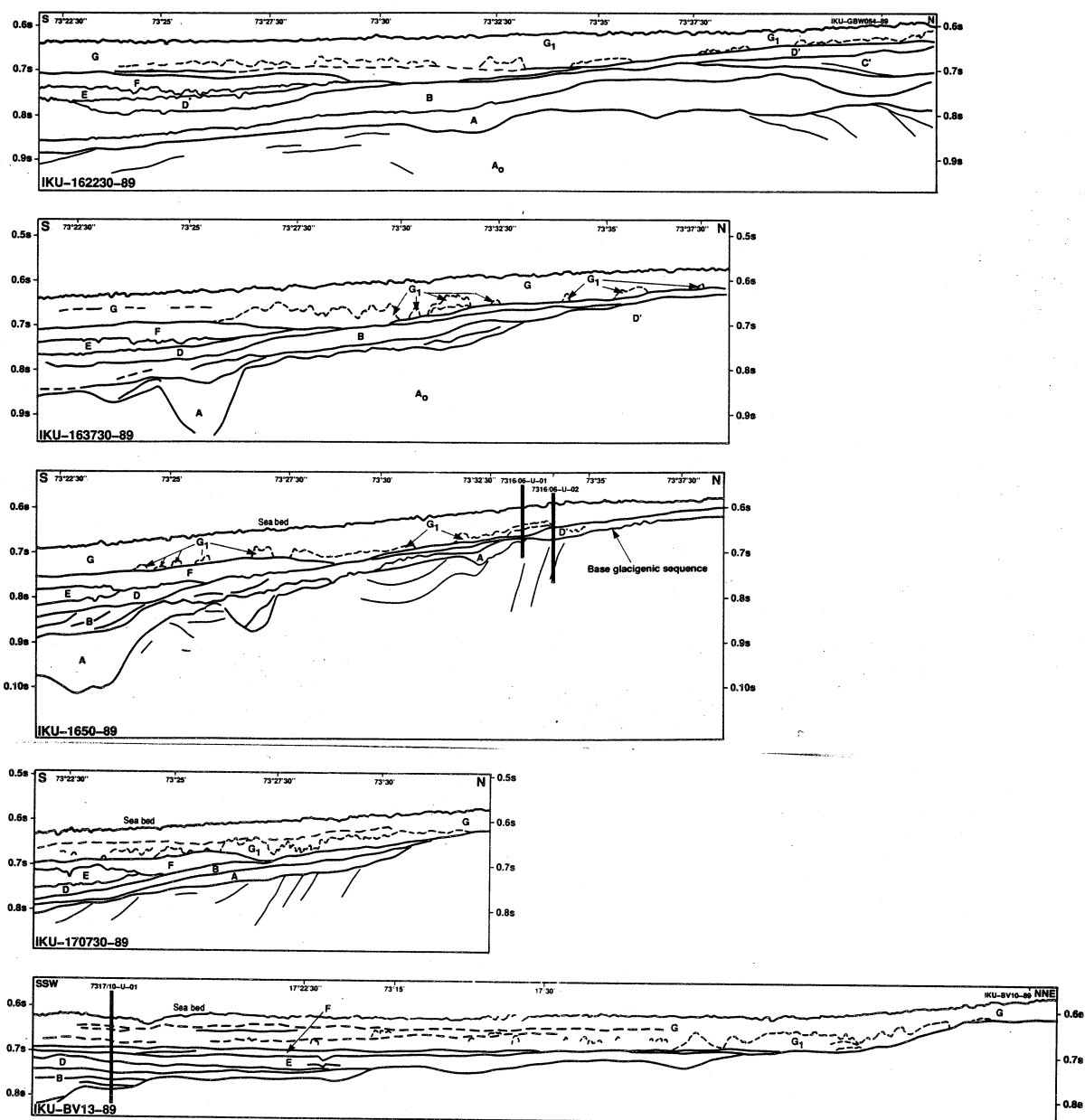


Figure 4.3.B Interpretation of N-S sections of the Cenozoic succession of the northern flank of western Bjørnøyrenna. Profile location is shown in Figure 4.3.A.

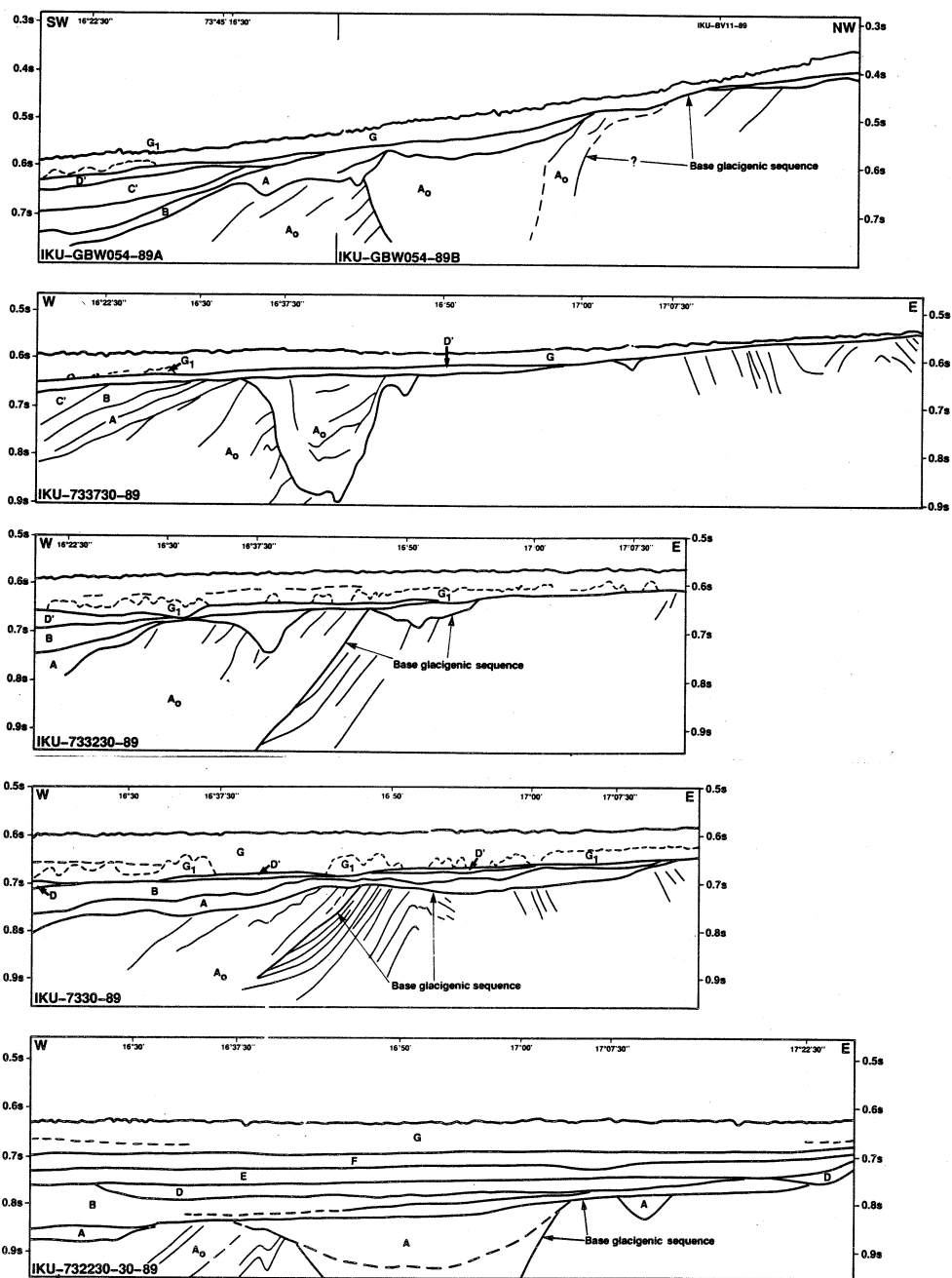


Figure 4.3.C Interpretation of E-W sections of the Cenozoic succession of the northern flank of western Bjørnøyrenna. Profile location is shown in Figure 4.3.A.

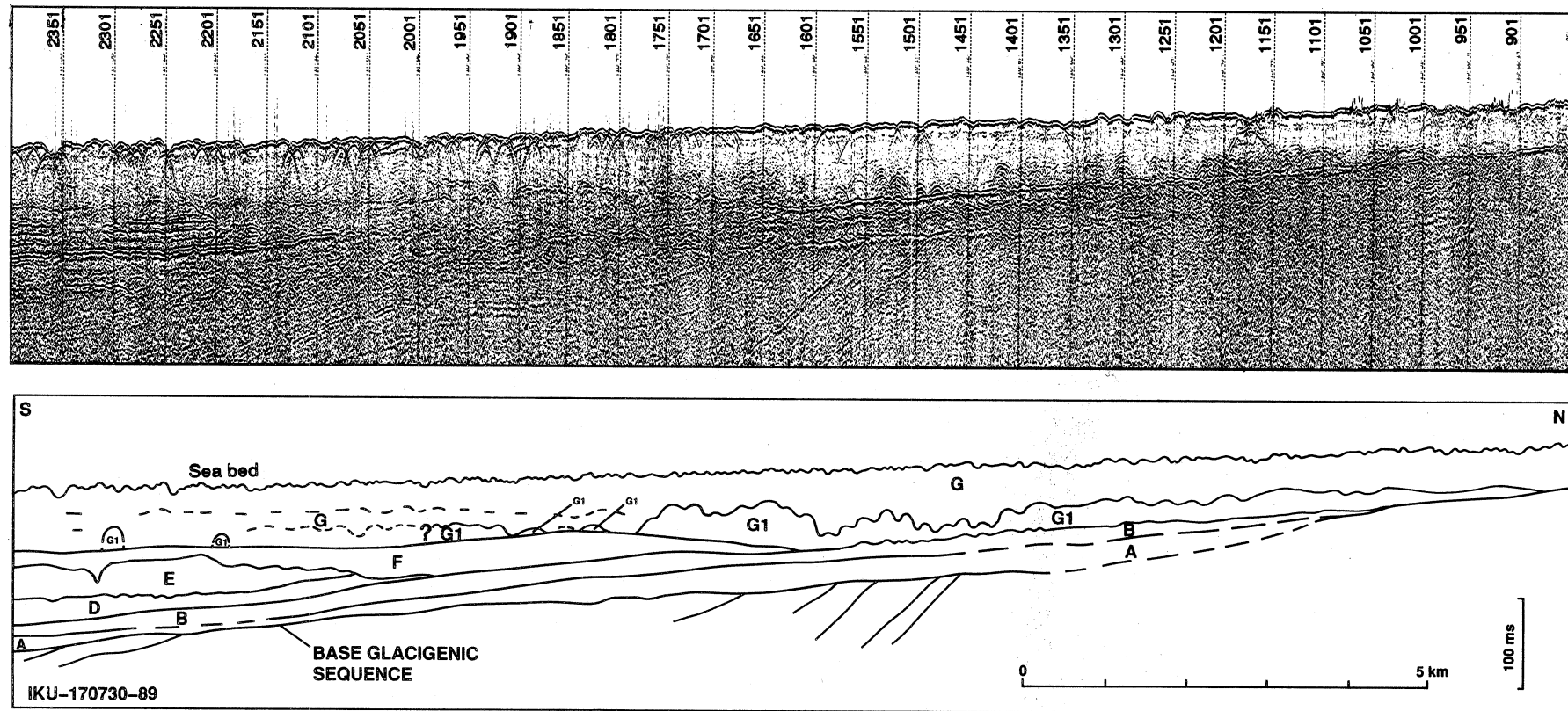


Figure 4.4

Shallow seismic section showing lateral changes in unit boundary reflectors in the northern flank of Bjørnøyrenna. The indistinct character of the reflection at the base of unit G in the south may reflect a southward change from erosion to sedimentation. The section also illustrates how inhomogeneities (glaciotectonic bodies) in the sediment column cause chaotic acoustic conditions. The indistinct character of the base of unit F reflection north of fix 2060 is a characteristic feature of this boundary (see also Figure 4.5). Profile location is shown in Figure 4.3.A.

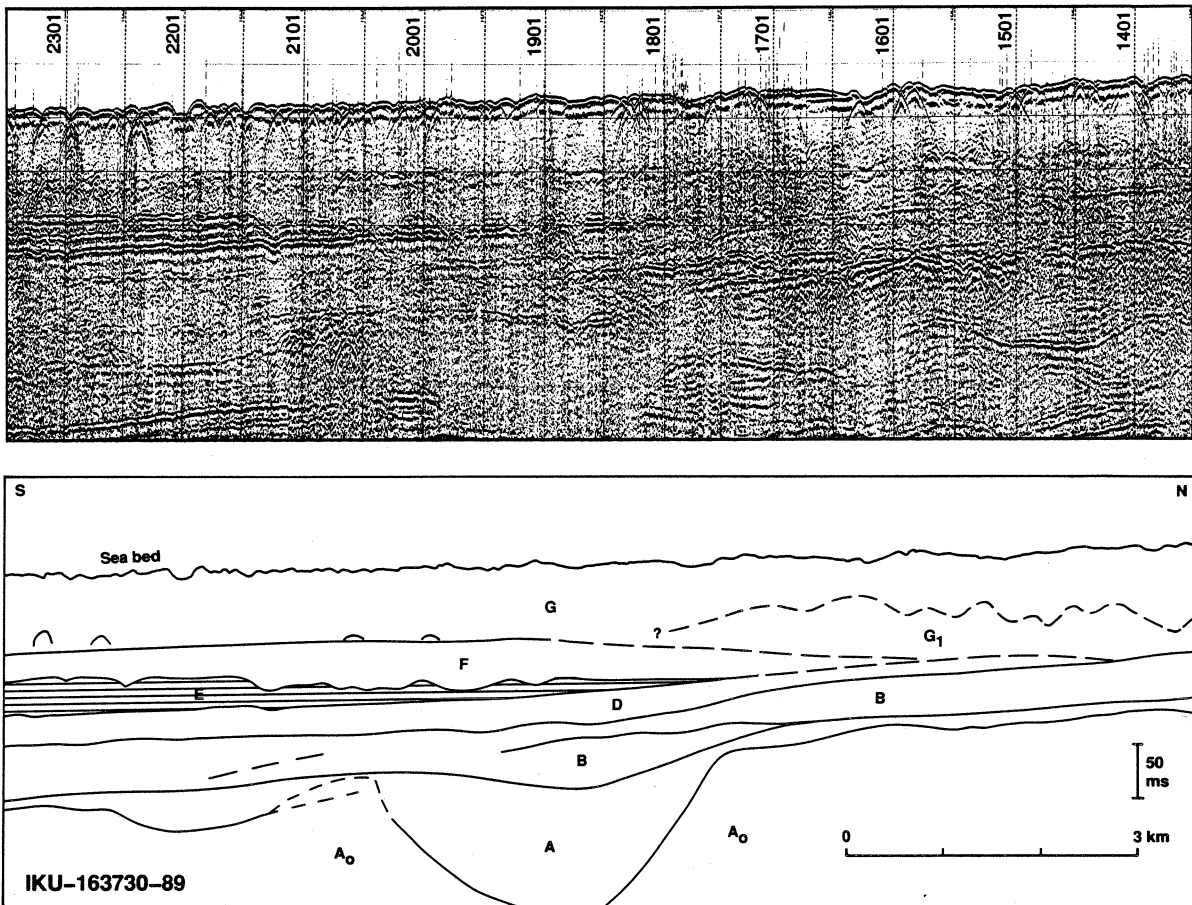


Figure 4.5 Acoustic signature and northward truncation of unit E. Physical property data in borehole 7317/10-U-01 show that unit E represents a low velocity layer, and that the acoustic impedance between the sediments above and below is negligible. This may explain why there is no seismic reflection from the interface between units D and F when unit E is absent. Channels at the base of unit A and sedimentary structures of unit A_0 are seen in the lower part of the section. Note the erosional features at the top of unit A_0 . The unit may be divided into three intervals on this seismic record. A lower stratified and conform interval followed by an acoustically structureless to nonstratified interval capped by a second stratified interval. The base of the unit often truncates underlying reflectors. Profile location is shown in Figure 4.3.A.

4.2 Comments to some of the units

4.2.1 Unit A_0

This unit is described from observations on the digital shallow seismic data. It is characterized by a very even angular unconformity, partly with downlapping reflectors, at the base. On the east-west dip lines there is a series of climbing ripple looking patterns. The "foresets" have an easterly dip of 6°-10°. On the strike lines the "foresets" dip gently to the south.

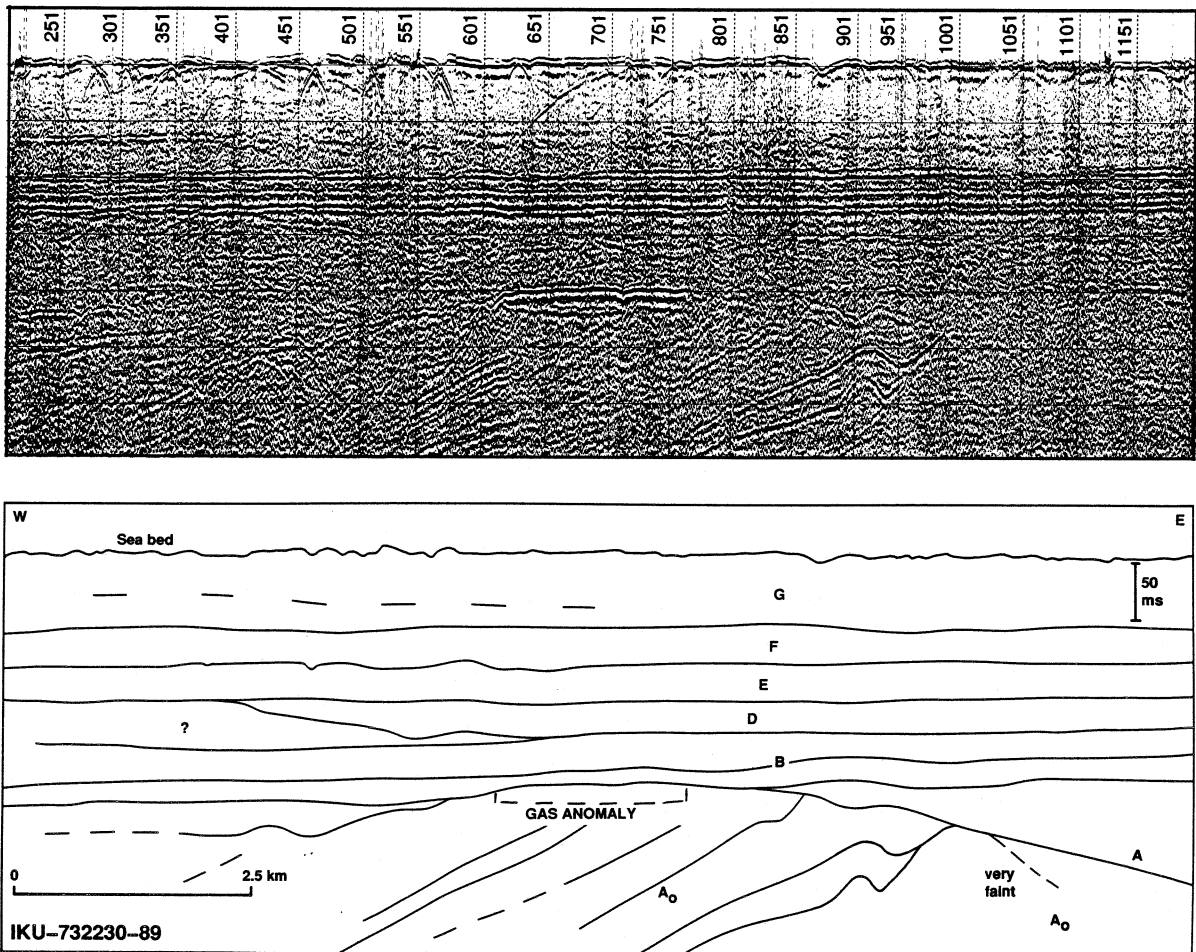


Figure 4.6 Seismic signature of units A_0 , A, B, D, E, F and G. Note the conformable reflection pattern in unit E. The brightspot at the base of unit B probably represents a gas accumulation.

These structures are interpreted as dunes or megaripples deposited in a marine environment.

In Figure 4.8 several megaripple generations can be distinguished. The lowermost megaripple generations are bounded by subhorizontal unconformities (relative to the base unit A_0 unconformity), while several of the upper ripples climb as much as 100 ms. This difference probably reflects difference in interaction between sediment supply, energy regime and relative sea level. The direction of ripple migration seems to have been consistently towards a slightly south of easterly direction. The extent of the structures is, however, typically much less than the aperture of the seismic grid. The western boundary of this facies follows about $16^{\circ}20'E$ and the forms occur north of about $73^{\circ}25'N$. The facies is well developed at $73^{\circ}37'N$ but only sparsely at $73^{\circ}55'N$. The eastern boundary is erosional.

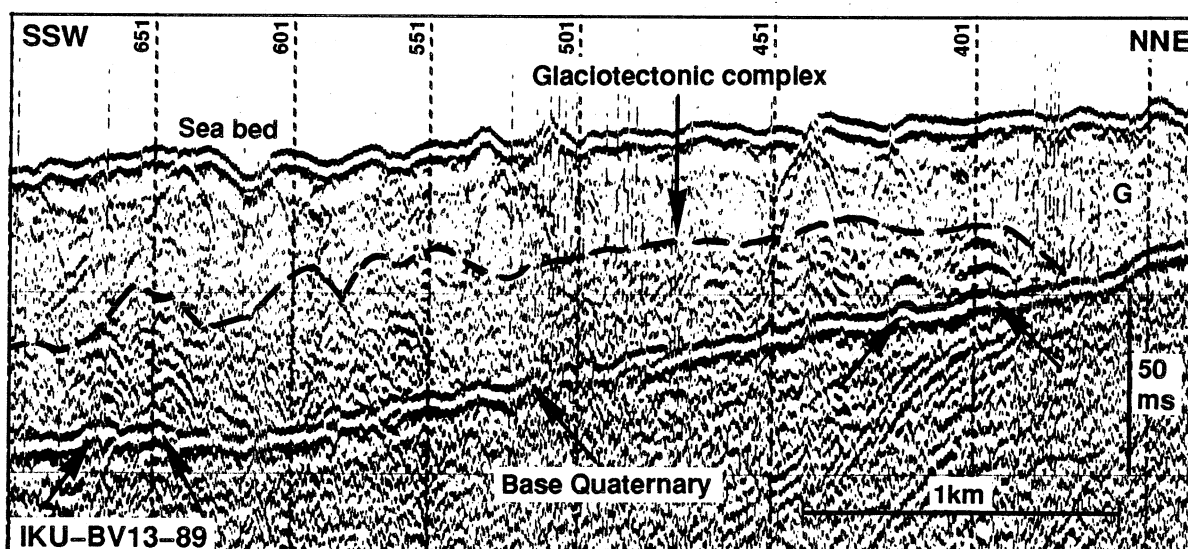
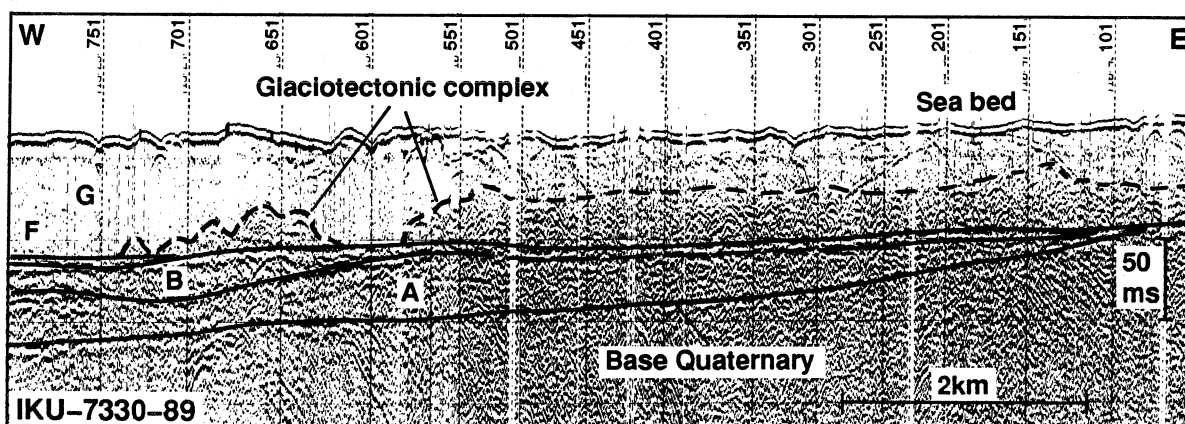
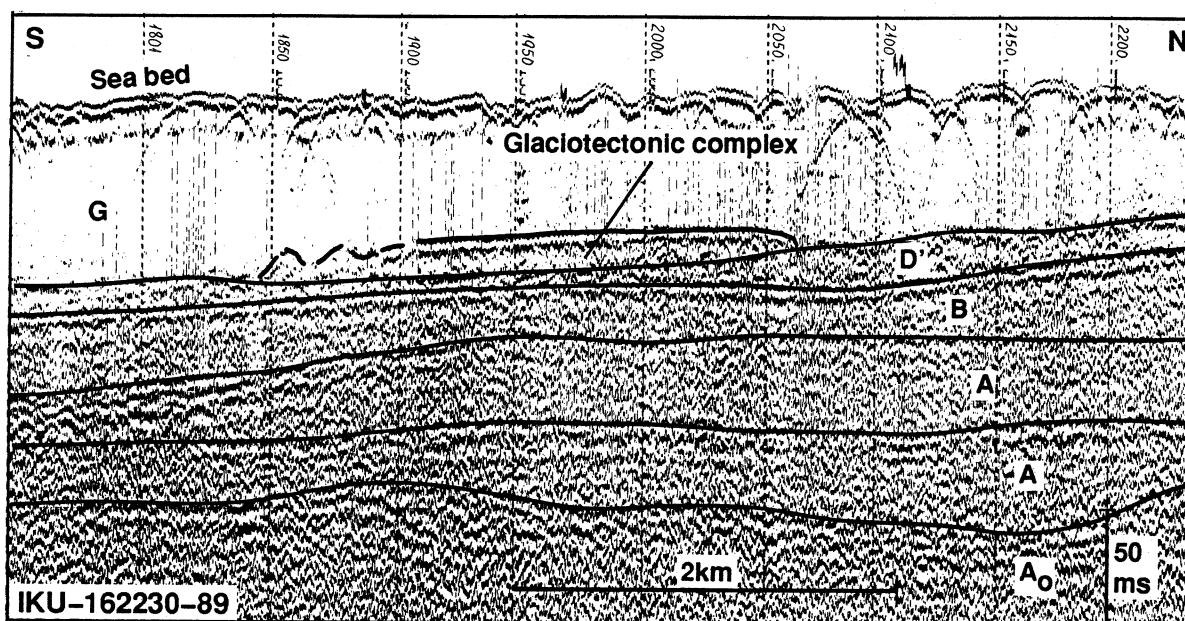


Figure 4.7 Seismic expression of the hummocky unit G_1 interpreted as a glaciotectionic megablock complex. The complex partly rests on bedrock, partly on Quaternary sediments. Note the apparent pull-up effects pointed out by arrows on profile IKU-BV13-89. Profile location is shown in Figure 4.3.A.

Above the interpreted megaripples unit A_0 is characterized by smooth, coherent reflections which are cut by large erosional channels. Cut and fill of channels seems to have occurred repeatedly. Along seismic line IKU-732230-89 a major channel is observed to the east of shot point 960 at the base of unit A_0 . The base of the channel truncates below the level of the base of unit A_0 .

4.2.2 Unit A

Unit A has characteristics differing both from the underlying seismic unit as well as from the seismic units above. Unit A includes the infill of a system of broad channels and a sheet like deposit mapped between the channels. The base of unit A is defined as the unconformity at the base of - and in between the channels (e.g. Figure 4.3). This unconformity can be traced across the shelf break with some confidence down to approx. 1100 ms. On the upper slope smooth, continuous internal reflectors onlap the base of the unit.

The transparent acoustic signature of the channel system within unit A is different from what is found in the channels within unit A_0 . This may indicate a different type of sediment infill, and possibly also a different origin (?) of the upper channels. The upper part of unit A has irregular, discontinuous reflections and the upper boundary of the unit (normally corresponding to the base of unit B) gives a rather irregular, but often high amplitude reflection. In some occasions there are possible lateral phase shifts. This may indicate lateral lithological contrasts and/or trapped gas (e.g. Vorren et al. 1989).

Correlation of the sheet like part of unit A is uncertain because of the rather chaotic reflection pattern and lateral impedance contrast variations (Figure 4.4). The mapped extent of the unit is, however, supported by observations of channel remnants and by acoustic signature.

4.2.3 Comments to the acoustically stratified unit E

Most of the glacial sequence in the Barents Sea is acoustically transparent or has chaotic internal reflections. In a few exceptions, however, acoustically coherent stratification can be found. The main occurrence of the latter type is unit E, which is characterized by strong coherent internal reflections on analog sparker and mini airgun records.

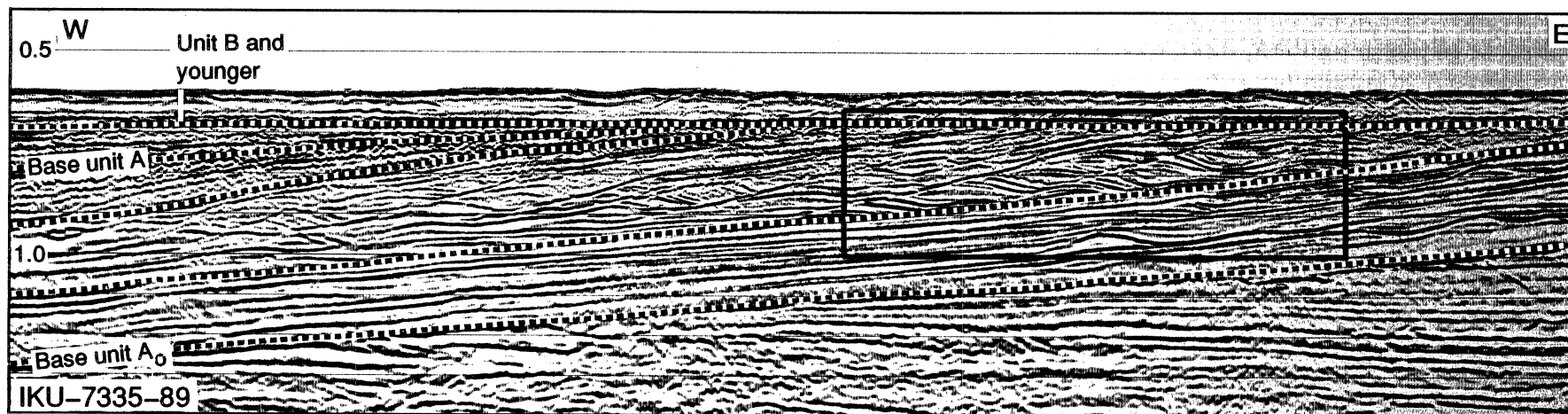


Figure 4.8 Seismic signature of unit A₀. From bottom to top the following characteristic patterns can be distinguished: 1) Smooth, downlapping reflectors. 2) Megaripples bounded by subhorizontal unconformities. 3) Strongly climbing megaripples partly bounded by unconformities. The megaripples are interpreted as sand ridges formed in a marine environment with high sediment supply. Large cut and fill channels occur on top of the ripple succession shown here. Profile location is shown in Figure 4.3.A.

The unit occurs in an area extending more than 3,500 km² and may locally be more than 60 ms (approximately 50 m) thick. Thickness variation is mainly due to erosion.

Some of the seismic records indicate that the unit may be subdivided into three intervals with the following characteristics: A lower part characterized by strong internal conformable reflections, generally draped over the subsurface. This is followed by an interval of poorly developed internal reflections, but which in some occasions tend to vary laterally in thickness within a few metres and to smooth a gently undulating relief. The upper part of the unit is characterized by strong, coherent reflections. This subdivision based on acoustic signature does, however, depend on the thickness of each subunit, seismic source and recording parameters and cannot be traced consistently throughout the seismic grid. The thickness of the upper two intervals is difficult to measure because of limited resolution and obscurity of data. In the thicker part of the unit the lower interval is, however, thicker than the upper.

King and Fader (1986) interpreted acoustically stratified sediments on the continental shelf off Nova Scotia as glaciomarine sediments of different facies, while acoustically nonstratified sediments were interpreted as till. According to the scheme of King and Fader (1986) our unit E may be interpreted as a glaciomarine unit - possibly comprising a complete sequence including a deglaciation glaciomarine phase (lower-middle interval), an interstadial/interglacial phase (middle interval) and a glacial growth glaciomarine phase (upper interval).

A negative acoustic impedance contrast at the top of seismic unit E was found in borehole 7317/10-U-01 (Chapter 6). It is noted that while both the top and the base of seismic unit E give quite pronounced reflections on the seismic records, only a faint reflection is often found northwards where unit E is truncated and the top and base unit E unconformities merge (Figures 4.4 - 4.5). This can be explained by the physical property data recorded in borehole 7317/10-U-01 (Table 5.1.A and Figure 6.1). This data shows that the degree of compaction of the sediments immediately above and below unit E are similar, while unit E is a low velocity layer. Only a rather faint impedance contrast will therefore occur in areas where Unit E pinches out, and even though the hiatus in the sedimentary record becomes greater, the corresponding seismic reflection becomes weaker or is virtually lost.

4.2.4 Hummocky subunit within unit G

A subunit named G_1 has been distinguished within unit G. Unit G is bounded upwards by the seabed. In the north it is bounded downwards by a smooth reflector characterized by high amplitude reflection. Southwards the base becomes more irregular and is often rather diffuse on seismic records. The mini airgun data give two distinctly different seismic signatures from this unit, and this data is the main basis for mapping of subunit G_1 . Unit G is on most seismic sections acoustically transparent, although it is observed that the seismic signature is quite different on intersecting lines and lines with different recording parameters. Subunit G_1 comprises a discontinuous complex of hummocky acoustically chaotic deposits which rest on the base of unit G. This subunit was penetrated by borehole 7316/06-U-01 (Chapter 6.3) and was here found to comprise a raft of consolidated sedimentary rocks probably overlain by a sand. Till was penetrated below this unit, and this stratigraphy is attributed to glaciotectonism. Some comments to this subunit is given below based on seismic mapping, and an interpretation and discussion of the unit is given in Chapter 8.

The geometry of unit E is shown on the map in Figure 4.1 and in interpreted sections in Figure 4.3. Different acoustic expressions are shown in Figures 4.4, 4.5 and 4.7, which also illustrate the hummocky and discontinuous character of the unit. Maximum height of the hummocks above their subsurface is about 55 ms. The southern boundary of the unit is uncertain as there is a gradational change from distinct, hummocky deposits to a generally chaotic signature with frequent point reflections within the lower 1/3 - 2/3 of unit G (Figure 4.5). The top of this chaotic interval may correspond to a faint reflection on profile IKU-BV13-89 across site 7317/10-U-01 and occasionally on other profiles. It is often observed that the presence of isolated hummocks corresponds to acoustic pull up of reflections from surfaces below (Figure 4.7). This indicates that the hummocks comprise bodies of higher velocity than the surrounding sediments. Such "pull ups" are found beyond the indicated southern boundary of subunit G_1 .

5. RESULTS FROM THE LABORATORY ANALYSES

5.1 Data presentation

Chapter 5 gives a summary of all the laboratory analyses together with a brief evaluation and discussion of the results. This is meant as a more detailed background information in addition to the the description of the boreholes in Chapter 6, where results are summarized graphically.

5.2 Physical properties

Physical properties were measured partly on board (sound velocity), partly in the laboratory at IKU, and partly at the Sintef Division of Geotechnical Engineering. In Table 5.1 routine data or index parameters of the samples are summarized. The table also includes calculated acoustic impedance.

Grain size analyses were carried out by the Sintef Division of Geotechnical Engineering on clay samples. Splitting in grain size fractions were also done on the samples prepared for foraminifer analyses at the University of Tromsø. A separate study of the grain size distribution of the fines was conducted by students at the Department of Geology and Mineral Resources Engineering, Norwegian Institute of Technology, University of Trondheim. The methods used were:

- 1: Sintef Division of Geotechnical Engineering: Wet sieving of bulk sample and falling drop analysis of fraction < 63 micrometre.
- 2: The University of Tromsø: Wet sieving of bulk sample and sedigraph analysis of fraction < 63 micrometre.
- 3: University of Trondheim: Wet sieving of bulk sample and sedigraph analysis of fraction < 44 micrometre (The percentage at the 63 micrometre boundary was not determined).

The results from the three analysis sequences are summarized in Figure 5.1. Samples were not taken from the same depth for the three datasets. Thus, variations within each sample interval may be caused by some of the differences observed in Figure 5.1. The sand intervals between 100 m and 110 m are represented only in one of the datasets. The conclusions to be drawn from the figure is firstly that dataset 1 (the falling drop analysis)

Table 5.1A Physical properties of samples. Zero indicates that no value has been recorded. Water contents are given in per cent of dry sample. "Nat." = natural water content, "Liq." = liquidity limits and "Plast." = plasticity limit. The parameters s_u and s_r are undrained and remoulded shear strength respectively, and s_t is sensitivity, which is the dividendum of s_u and s_r . The shear strengths are measured by the falling cone method except from those marked with an * which are measured by one dimensional compression tests.

A: Site 7317/10-U-01

Depth (m)	Water content			s_u kN/m ²	s_r kN/m ²	s_t	Bulk dens. (g/cm ³)	Sound vel. (m/s)	Acoust.imp. 10 ⁶ kg/m ² ·s
	Nat. (%)	Liq. (%)	Plast. (%)						
7.12	30.8	40.1	21.0	24.0	0.0	0.0	1.93	1675	3.23
7.27	30.8	40.1	21.0	30.4	15.2	2.0	1.95	0	0.00
7.50	31.3	0.0	0.0	19.1	15.2	1.3	1.93	0	0.00
15.10	27.6	0.0	0.0	38.7	24.0	1.6	1.96	1701	3.33
15.55	27.1	39.6	20.1	36.8	24.5	1.5	1.98	1701	3.37
25.15	27.7	0.0	0.0	37.8	31.4	1.2	1.97	1997	3.93
25.55	25.9	0.0	0.0	52.5	38.7	1.4	2.02	1775	3.59
32.15	24.6	0.0	0.0	69.2	51.0	1.4	1.99	1769	3.52
32.40	24.7	0.0	0.0	74.1	54.5	1.4	2.02	1813	3.66
38.15	24.7	0.0	0.0	85.4	71.6	1.2	2.02	1746	3.53
38.60	23.3	46.2	20.1	79.5	74.1	1.1	2.04	1709	3.49
45.20	24.8	0.0	0.0	69.2	69.2	1.0	2.01	1717	3.45
45.50	23.4	0.0	0.0	79.5	77.0	1.0	2.05	1729	3.54
52.06	21.7	41.4	19.5	79.5	79.5	1.0	2.12	0	0.00
52.36	20.6	0.0	0.0	100.1	97.2	1.0	2.14	1841	3.94
63.07	23.9	0.0	0.0	66.7	51.0	1.3	2.05	1751	3.59
52.22	21.9	41.4	19.5	110.0	79.5	1.4	2.06	1802	3.71
70.05	31.0	0.0	0.0	52.5	27.0	1.9	1.98	1658	3.28
77.85	28.9	44.9	20.8	50.0	0.0	0.0	0.00	0	0.00
81.57	32.5	40.4	22.4	38.7	22.0	1.8	1.94	1700	3.30
83.35	24.6	41.6	22.5	62.3	56.4	1.1	2.03	1749	3.55
89.44	21.4	40.2	19.9	115.8	102.1	1.1	2.14	1859	3.98
93.20	21.4	0.0	0.0	115.8	112.9	1.0	2.09	1820	3.80
99.70	23.1	42.1	21.2	120.0	0.0	0.0	2.05	1763	3.61
100.01	22.4	0.0	0.0	115.8	0.0	0.0	2.11	0	0.00
102.22	25.1	0.0	0.0	132.0*	0.0	0.0	2.03	0	0.00
103.30	19.8	0.0	0.0	123.0	0.0	0.0	2.15	1810	3.89
109.75	21.9	48.2	22.6	0.0	0.0	0.0	2.03	1798	3.65
112.75	21.9	0.0	0.0	250.0	0.0	0.0	2.06	1796	3.70
114.30	21.1	48.2	24.7	0.0	0.0	0.0	0.00	0	0.00
117.35	22.3	0.0	0.0	0.0	0.0	0.0	2.04	1743	3.56
118.35	17.9	0.0	0.0	0.0	0.0	0.0	2.13	1713	3.65
126.10	18.2	0.0	0.0	201.9*	0.0	0.0	2.14	0	0.00
129.10	19.4	41.4	22.0	0.0	0.0	0.0	2.08	0	0.00
132.30	18.8	0.0	0.0	0.0	0.0	0.0	2.06	0	0.00
134.76	21.0	40.8	21.0	226.0	0.0	0.0	2.10	0	0.00
137.63	0.0	0.0	0.0	0.0	0.0	0.0	2.15	0	0.00
140.32	17.3	0.0	0.0	0.0	0.0	0.0	0.00	0	0.00
143.55	0.0	0.0	0.0	0.0	0.0	0.0	0.00	1625	0.00

Table 5.1 Continued.

B: Site 7316/06-U-02

Depth (m)	Water content			s_u kN/m ²	s_r kN/m ²	s_t	Bulk dens. (g/cm ³)	Sound vel. (m/s)	Acoust.imp. 10 ⁶ kg/m ² s
	Nat. (%)	Liq. (%)	Plast. (%)						
5.15	28.6	36.0	19.9	29.9	24.0	1.2	1.97		
19.55	23.7			71.6	56.4	1.3	2.07	1631	3.38
19.95	26.9	41.6	19.4	74.1	69.9	1.1	2.07		
31.60	22.8	0.0		74.1	46.1	1.6	2.06	1721	3.54
32.00	22.9	34.3	17.6	60.3	60.3	1.0	2.11	1740	3.67
65.60	17.8								

C: Site 7316/06-U-01

Depth (m)	Water content			s_u kN/m ²	s_r kN/m ²	s_t	Bulk dens. (g/cm ³)	Sound vel. (m/s)	Acoust.imp. 10 ⁶ kg/m ² s
	Nat. (%)	Liq. (%)	Plast. (%)						
5.10	29.6	41.1	20.8	24.0	18.6	1.3	2.00		
19.40	23.8		0.0	100.1	69.2	1.4	2.06	1732	3.57
19.75	23.8	42.6	19.9	71.6	69.2	1.0	2.08		
38.97	21.9						2.00		

D: Site 7316/03-U-01

Depth (m)	Water content			s_u kN/m ²	s_r kN/m ²	s_t	Bulk dens. (g/cm ³)	Sound vel. (m/s)	Acoust.imp. 10 ⁶ kg/m ² s
	Nat. (%)	Liq. (%)	Plast. (%)						
7.40	11.7	0.0	0.0	>250.0					
31.49	27.6	0.0	0.0	50.0					

gives systematically 5-10% less clay content than the sedigraph data. This is a significant difference. The possible causes are not further discussed here, but must be carefully considered if grain size data from different laboratories and analysis methods are compared.

The second observation is that vertical variations in grain size distribution in each of the other two datasets is of the same magnitude as the difference between the two datasets. In several instances vertical variations within the two datasets also cancel each other. The conclusion to be drawn is therefore that except from two intervals at about 60-80 m and 100-110 m, the entire sediment column is considered as a uniform silty,

sandy clay with some gravel.

In Table 5.2 only the dataset from the University of Tromsø is given. The gravel content is typically less than a few per cent except for deeper parts of wells 7316/06-U-01 and -02. The content of sand and gravel is, however, considered as underestimated in the grain size analyses as the common, well rounded grey siltstone fragments to a significant extent disintegrated during wet sieving.

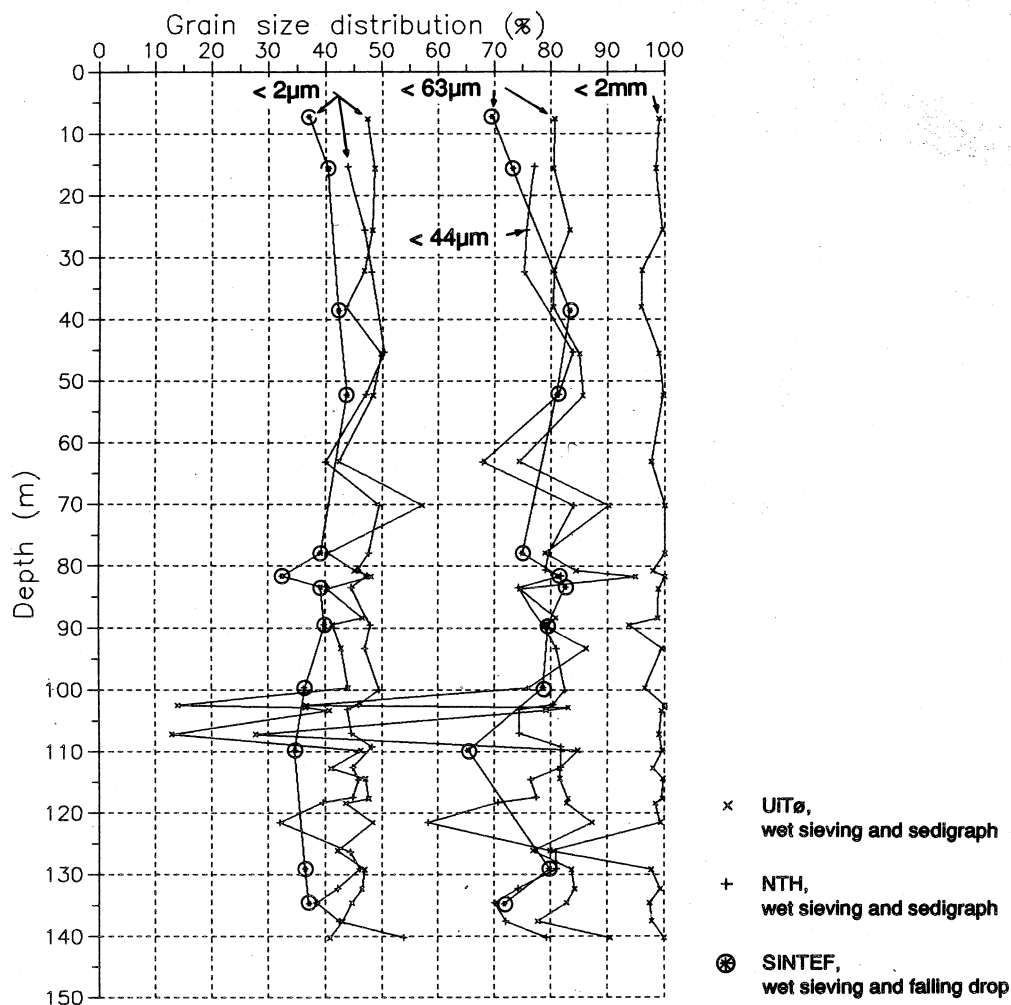


Figure 5.1

Grain size analysis from site 7317/10-U-01. 1: Sintef Division of Geotechnical Engineering: Wet sieving of bulk sample and falling drop analysis of fraction < 63 micrometre. 2: The University of Tromsø: Wet sieving of bulk sample and sedigraph analysis of fraction < 63 micrometre. 3: University of Trondheim: Wet sieving of bulk sample and sedigraph analysis of fraction < 44 micrometre (The percentage at the 63 micrometre boundary was not determined).

Results from investigations of Atterberg limits (consistency limits) are plotted in Figure 5.2. These limits show how the physical properties of the sediment vary with varying water content. The data fall within the area of "glacial clay" of Terzagi and Peck (1967) and close to the "till-line" of Boulton and Paul (1976).

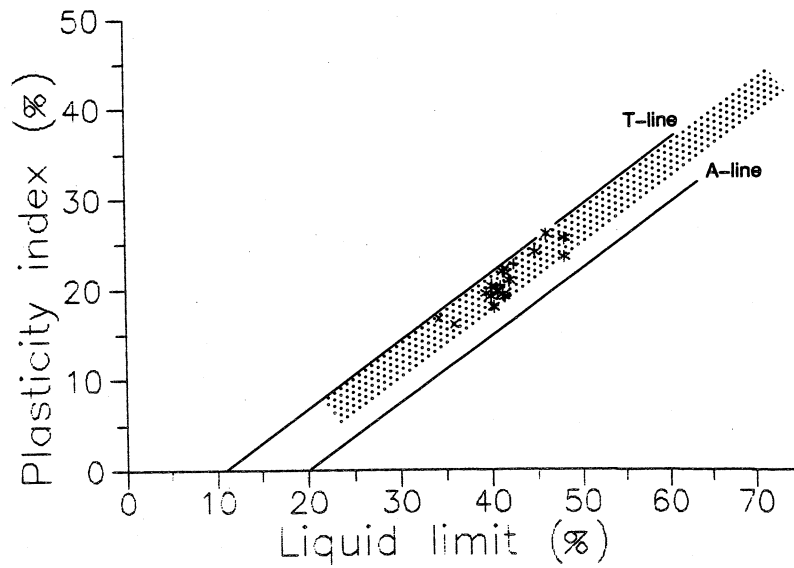


Figure 5.2 Plasticity chart. The A-line is the boundary between sediments of inorganic (above) and organic (below) nature (Casagrande 1948). The T-line is the ("till-line" of Boulton and Paul (1976). Dotted area is the "glacial clay" area in the summarizing diagram of Terzagi and Peck (1967, Figure 7.3).

Most of the samples comprise soft-moderately stiff sediments (Table 5.1). The exception is possibly the deeper part of core 7316/06-U-01. This core was obtained by diamond rotary coring and has partly a high coarse clast content. It was frozen on board to enable preparation of reference slabs, and no parameters were attempted obtained from the thawed core.

Undrained versus remoulded shear strength is plotted in Figure 5.3. The plot shows that the sensitivity is low, between 1 and 2, for all the samples. The two measurements from the acoustically stratified unit E both have a sensitivity close to two, which is somewhat higher than the average for most of the samples. (The point in bracket at $s_u = 30$ and $s_t = 2$ in Figure 5.3 is probably misleading as the s_u value is about 30% higher than recorded 0.2 m above and below (the first three measurements in Table 5.1).

The generally low sensitivity may reflect the effect from shearing and

deformation of the sediment caused by grounded ice or icebergs during or after deposition, a process which also may have caused the shear and fissility structures observed in the cores. It may, however, partly also be an effect of deformation during sampling which is clearly observed to have affected the rims of the samples (Chapter 6). The shear strength was measured by falling cone except a few cases where one dimensional compression tests were done (Table 5.1). It was measured on the sample surface after removal of an about 0.5 cm or slightly thicker slice of sediment. The radiographs indicate that deformation from coring in many cases penetrates deeper into the samples. This implies that s_u may have been measured in partly deformed sediment and hence that the recorded value is a minimum value. Recorded s_u values of the high quality rotary cored samples at about 100 m in borehole 7317/10-U-01 and also of the compression tested samples do, however, fit well with the general dataset, suggesting that this effect is not very strong.

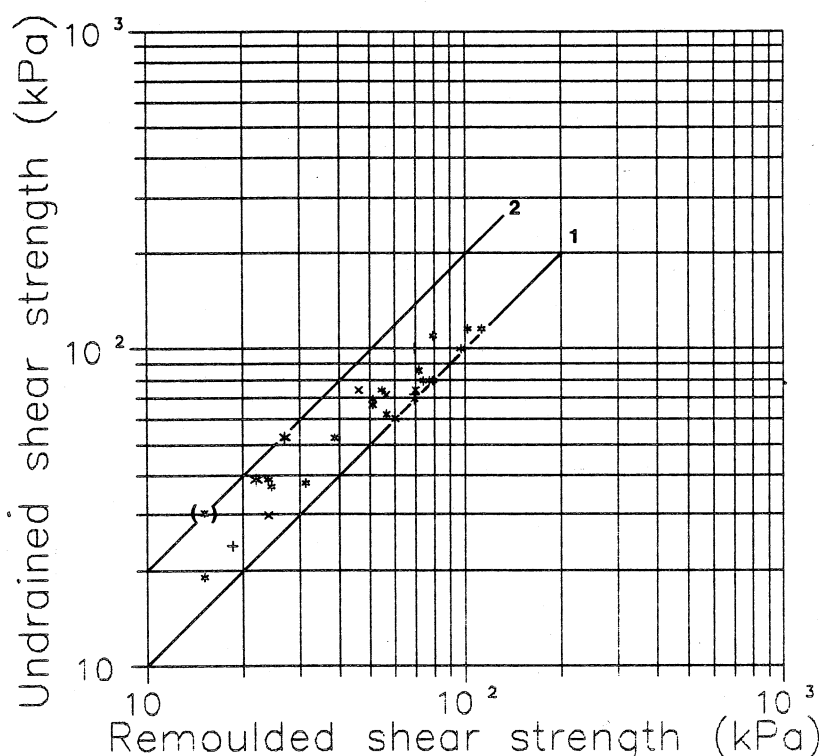


Figure 5.3 Undrained (s_u) versus remoulded (s_r) shear strength measured by the falling cone method. The points in circles are data from the acoustically stratified unit E cored in site 7317/10-U-01. The point in brackets is probably unreliable (too high s_u value).

Table 5.2 Grain size distribution data from analysis carried out at the University of Tromsø.

7317/10-U-01:

Depth (m)	Clay (%)	Silt (%)	Sand (%)	Gravel (%)	Depth (m)	Clay (%)	Silt (%)	Sand (%)	Gravel (%)
7.60	47.47	33.20	18.38	0.95	99.70	44.08	32.05	20.38	3.49
15.57	48.65	31.82	17.99	1.54	102.15	45.61	37.85	13.96	2.58
25.55	48.27	35.03	16.30	0.40	102.49	14.03	22.65	63.32	0.00
32.10	46.81	33.68	15.51	4.00	102.84	36.56	46.53	16.90	0.01
38.08	43.69	36.65	15.54	4.12	103.33	40.79	38.33	20.34	0.54
45.53	49.73	35.28	13.94	1.05	107.00	37.73	43.93	17.03	1.31
52.35	48.40	37.20	14.15	0.25	107.20	13.04	14.82	71.17	0.97
63.04	42.49	31.86	23.28	2.37	109.80	46.34	38.42	14.80	0.44
70.00	53.56	41.97	4.21	0.26	112.74	41.06	40.57	16.36	2.01
70.16	57.18	32.92	9.90	0.00	114.38	47.12	34.47	18.12	0.29
77.85	40.57	38.36	21.04	0.03	117.57	47.67	35.42	16.54	0.37
80.70	45.22	39.14	13.49	2.15	118.35	43.69	39.13	15.59	1.59
81.54	39.43	45.26	14.84	0.47	121.53	48.45	38.85	12.05	0.65
81.66	48.16	46.74	5.10	0.00	126.10	42.21	34.67	3.02	20.10
83.62	40.36	34.18	24.29	1.17	129.20	47.02	36.73	14.01	2.24
88.33	46.56	34.33	17.86	1.25	132.35	46.53	37.76	14.96	0.75
89.43	41.29	37.21	15.19	6.31	134.60	44.78	38.14	14.60	2.48
93.20	42.81	43.42	13.16	0.61	137.60	43.11	34.64	20.08	2.17
					140.28	40.94	49.54	9.52	0.00

7316/06-U-02:

Depth (m)	Clay (%)	Silt (%)	Sand (%)	Gravel (%)	Depth (m)	Clay (%)	Silt (%)	Sand (%)	Gravel (%)
5.23	42.36	30.17	25.07	2.40	31.80	42.60	29.11	26.78	1.51
19.78	37.12	39.27	22.06	1.55	31.90	24.16	63.18	12.48	0.18
					65.60	27.79	22.92	20.96	28.33

7316/06-U-01:

Depth (m)	Clay (%)	Silt (%)	Sand (%)	Gravel (%)	Depth (m)	Clay (%)	Silt (%)	Sand (%)	Gravel (%)
5.26	42.02	33.15	21.96	2.87	60.70	13.42	28.87	47.28	10.43
19.61	42.89	38.45	17.63	1.03	60.73	23.62	21.50	50.55	4.33
29.67	6.49	13.18	80.33	0.00	61.60	0.00	4.00	79.60	16.40
29.75	0.00	17.90	81.20	0.90	61.70	0.00	3.51	77.65	18.84
55.85	26.81	26.50	29.46	17.23	61.80	0.00	4.42	80.33	15.25
					61.87	0.00	5.06	80.91	14.03

7316/03-U-01:

Depth (m)	Clay (%)	Silt (%)	Sand (%)	Gravel (%)	Depth (m)	Clay (%)	Silt (%)	Sand (%)	Gravel (%)
7.35	6.53	3.03	66.48	23.96	31.50	24.80	38.47	35.39	1.34
7.45	26.21	27.00	31.83	14.96					

Determination of preconsolidation

Oedometer tests were run on five samples from site 7317/10-U-01 in order to determine possible effective preconsolidation stress, p_c' , and deformation parameters. None of the tests revealed any p_c' value. The quality of the tests was poor - probably as a result of poor sample quality. This is probably an effect of true fissility/shearing of some cores and artificial fissility suspected to be caused by sampling and the waxing of the geotechnical samples.

Table 5.3 Results from oedometer tests. The test at 15.46 m is done by incremental loading. The other tests are all made by continuous loading.

Site	Depth (m)	p_c' (kPa)	Modulus number	c_v (m ² /yr)
7317/10-U-01	7.27	-	20	1.0
"	15.42	-	19.6	0.8
"	15.46	-	20.6	-
"	52.20	-	17.3	0.8
"	134.84	-	20	0.8

Some indications of the preconsolidation of the sediments can be judged from recorded undrained shear strength versus depth. In Figure 5.4 s_u from all sites is plotted versus a common depth axis. The lines denoted $0.2p_o'$ and $0.3p_o'$ are as a rule of thumb expected to bracket the s_u - depth relationship for normally consolidated clays. In Figure 5.4 this seems to hold only for datapoints above approximately 40 m and below approximately 110 m. In particular the interval between 60 m and 70 m appears very soft compared to the rule of thumb trends.

Janbu (1985) expressed the theoretically expected s_u value as

$$(1) \quad s_u = 1/2(\sigma_{v0}' + \alpha)\sin \phi$$

where: σ_{v0}' is effective in situ stress, α is coulombian attraction and ϕ is the angle of friction.

The use of σ_{v0}' is restricted to specified conditions, but will generalized be the same as p_o . It is then seen that the rule of thumb lines in Figure 5.4 assumes $\alpha=0$ and $\sin \phi=0.4$ or $\sin \phi=0.6$.

Regression analysis of the upper 60 metres of borehole 7317/10-U-01 suggests the following values for the variables in equation (1).

$$\alpha = 60 \text{ kPa, and } \sin \phi = 0.3$$

Compared with typical values for effective strength parameters (Janbu 1985, table 1) it is seen that the attraction is suggestive of a stiff, dense clay, while $\sin \phi = 0.3$ (which corresponds to $\tan \phi = 0.3$) is indicative of a very soft clay. The contradiction between the two parameters may result from two effects. 1) A slight overconsolidation in the upper part of the interval. 2) An "underconsolidation" in the lower part of the interval.

Seismic units F and G (above approx. 69 m) are dated as Weichselian, and were probably mainly deposited between the "Arnøya-interstadial" (30 000 years BP, Andreassen et al., 1985) and about 13 000 years BP. Most of the sedimentation probably occurred subglacially under a state of moderate effective ice load and very restricted drainage conditions at the sediment surface (cf. Alley et al. 1987). The entire sediment column is very fine-grained and has hence a very low permeability. The vertical permeability may be further lowered because of horizontal fissility (Chapter 6). Thus, initially soft sediments within the next 15-20 m below the rapidly deposited units F and G, have not been able to drain the excess pore water. This may have resulted in an increase in pore pressure within and in the vicinity of this zone, maintaining a fairly soft sediment also within the lower metres of unit F.

5.3 Magnetic properties

The magnetostratigraphic work is described in Enclosure 1 of this volume. The main conclusions are summarized below.

The paleomagnetic polarity was determined on 78 samples. After demagnetization a characteristic remanent magnetization (ChRM) of normal polarity could be defined in 64 samples. The sampled sediment sequences were thus deposited during Brunhes normal polarity chron (0-730 ka BP). This conclusion concerns site 7317/10-U-01 down to 140.21 m, site 7316/06-U-02 down to 31.81 m, 7316/06-U-01 down to 19.51 m and site 7316/03-U-01 down to 7.31 m. Lower stratigraphic levels have not been investigated or hold a paleomagnetic signal of poor quality. Two paleomagnetic excursions (short duration reversals of the earth's magnetic field) may have been uncovered in the upper part of site 7317/10-U-01.

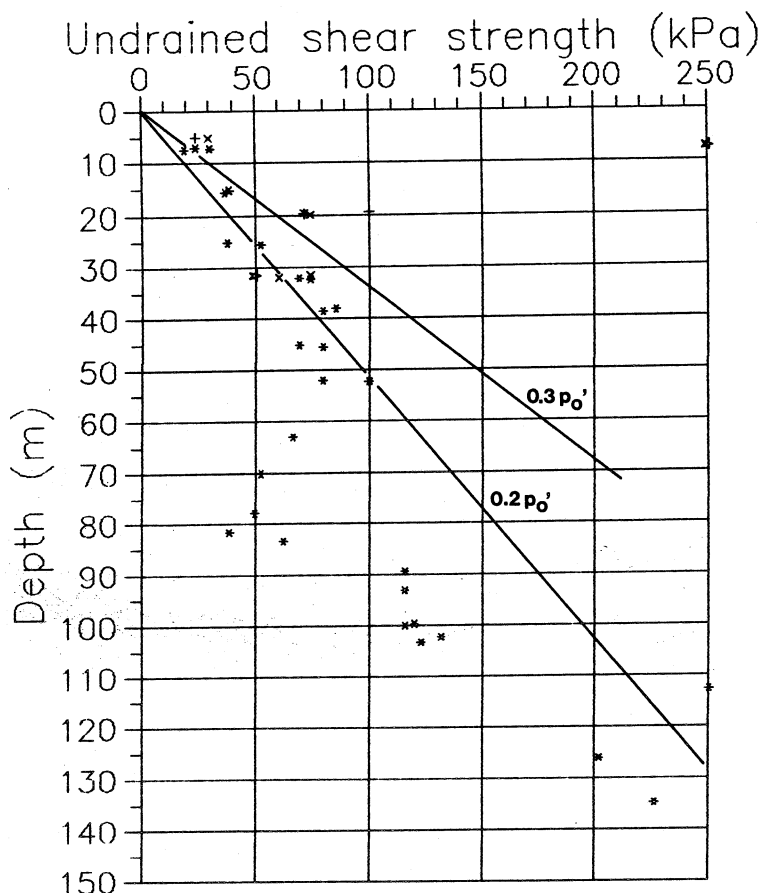


Figure 5.4 Undrained shear strength, s_u , of glaciogenic sediments versus depth for the 1989 boreholes. The lines denoted $0.2 p'_0$ and $0.3 p'_0$ indicate a rule of thumb relationship between s_u and depth for normally consolidated clays corresponding to $\alpha=0$ and $\sin\phi=0.4$ ($0.2 p'_0$) or $\alpha=0$ and $\sin\phi=0.6$ ($0.3 p'_0$).

5.4 Microfauna

A total of 54 samples were analysed with respect to their benthic foraminiferal content. In most cases up to 8 cm of sediment was used. The foraminifera were counted and classified into diverse species and families, and where possible a maximum of 300 foraminifera were classified. The results are discussed in respective sections for each site.

5.5 Amino acid ratios

Amino acid measurements were performed at the University of Bergen under supervision of Hans Petter Sejrup. Ages of carbonate fossils can be estimated based on measured ratio between certain amino acids. This ratio, which often is referred to as the *Ala/Ile* ratio changes as a function of time, temperature and fossil species. Measurements are done both on molluscs (unidentified fragments) and on foraminifera. The results are given in Table 5.4. Much of the fossils represent reworked material, and also the

temperature history of the fossils is uncertain (both before and after possible redeposition). Based on populations of aIle/Ile ratios and published ratios from areas with stratigraphic control, however, reasonable age estimates can be made (Chapters 6 and 7).

*Table 5.4 Amino acid ratios (aIle/Ile) in molluscs and foraminifera from the shallow drillings in the western Barents Sea 1989. Samples marked with an * had a low amino acid content and yield less reliable values. The ratios change as a function of time for a few million years, and can hence be used to estimate ages (Chapter 7).*

Site	Depth (m)	Lab. No.	aIle/Ile			B.marg.
			Molluscs	E. exc.	N. pach. (sin)	
7317/10-U-01	15.60	BAL 2015	0.072	0.035		
"	19.70	BAL 2053				
"	25.25	BAL 2016	0.078			
"	63.14	BAL 2018	0.064			
"	80.70	BAL 2006	0.134			
"	81.64-					
"	81.67	BAL 2007	0.117		0.143	
		BAL 2039				
		BAL 2040		0.082		
"	89.53	BAL 2019	0.298			
"	93.0-					
"	93.2	BAL 2076A		0.109		
"	93.0-					
"	93.2	BAL 2076B		0.101		
"	93.0-					
"	93.2	BAL 2075A				0.062
"	93.0-					
"	93.2	BAL 2075B				0.197
"	93.10	BAL 2047		0.097		
"	102.47	BAL 2042		0.163		
"	103.30-					
"	103.35	BAL 2008	0.481*			
"	107.0-					
"	107.2	BAL 2048		0.146		
"	109.90-					
"	110.15	BAL 2077		0.207		
"	112.15-					
"	112.99	BAL 2078		0.158		
"	117.20-					
"	117.64	BAL 2079		0.150		
"	117.50-					
"	117.64	BAL 2009	0.488			
"	129.20	BAL 2021	0.157			
"	140.23-					
"	140.33	BAL 2005	0.676*			
7316/06-U-02	19.70	BAL 2053		0.035		
7316/06-U-01	54.65	BAL 2003	0.342			
"			0.331			
"	55.40	BAL 2004	0.377			
"			0.370			
"	60.15	BAL 2002	1.090			
"			1.068			

6. DESCRIPTION OF BOREHOLE CORES

The following chapter gives a description of each borehole. The lithologies are described and the boreholes are divided into lithozones. Boundaries between lithozones and foraminifera assemblage zones are rarely penetrated by a cored sample and the exact location of these boundaries is uncertain. In cases where log response or information from the drilling suggest a more accurate boundary depth this level has been chosen.

6.1 Core 7317/10-U-01

6.1.1 Lithology and structures

The stratigraphy of this borehole is summarized in Figure 6.2. The samples from this site generally comprise a nonstratified, very silty clay with varying, but low content of sand and fine gravel. The clay content is typically 40-50% and the silt content typically 35%. The remaining constituent is sand and fine gravel. It has been noted that clasts of rounded claystone observed in bulk samples is absent in the coarse fractions of the split sample. These clasts are mechanically weak and are apparently worn down during sample splitting. The clast content is therefore underestimated in the recorded grain size parameters. The main exceptions are samples between 107.45 m and 102.5 m which partly comprise sands, and samples between 63.18 m and 81.50 m which comprise silty clays. The content of coarse sand and gravel is lower in the latter interval and comprises pyritized burrows (30% of the gravel fraction at 77.85 m).

Eight lithozones, named L1 - L8, are distinguished in this borehole based on variations in colour, petrography, structures and grain size variation. Some of the variations are rather faint.

Statistical work on the petrography is not done, and comments given below are limited to particular observations that appear diagnostic for the different intervals. A "background" content of rock fragments throughout most of the hole comprises various undifferentiated angular - subrounded sedimentary rocks dominated by mudstones and sandstones. Rounded to well rounded clasts form a very common constituent of most of the samples. The roundedness of these clasts is striking. They disintegrate, however, when the samples are dispersed for grain size analysis (causing an error in grain size analysis) and appear mechanically weak. An "artists impression" redrawn of radiographs is included in Figure 6.8 at the end of Section 6.1.

L1, 143.20 m - 118.00 m:

The interval comprises a dark grey-very dark grey silty clay with some sand and fine gravel. The clast content is dominated by rounded-well rounded dark grey claystone-siltstone, commonly less than 1 mm in size. Fine striation is observed on some of these clasts.

The sediments in most of the samples have a well developed shell or disc like fissility (Figure 6.3). Flow around clasts is observed. Folding occurs at 140.30 m (Figure 6.4).

L2, 118.00 m - approx. 108.5 m:

The interval comprises a very dark grey silty clay with some sand and fine gravel. As for the interval below, the clast content is dominated by rounded-well rounded dark grey claystone-siltstone. Noteworthy clast components are numerous angular-subangular fragments of *Inoceramus* prisms, light grey sandstone and glauconitic sandstone, and subrounded-well rounded quartz grains. The fissility is similar to the interval below. Details of fissility and flow around the cast of a larger grain is shown in Figure 6.5.

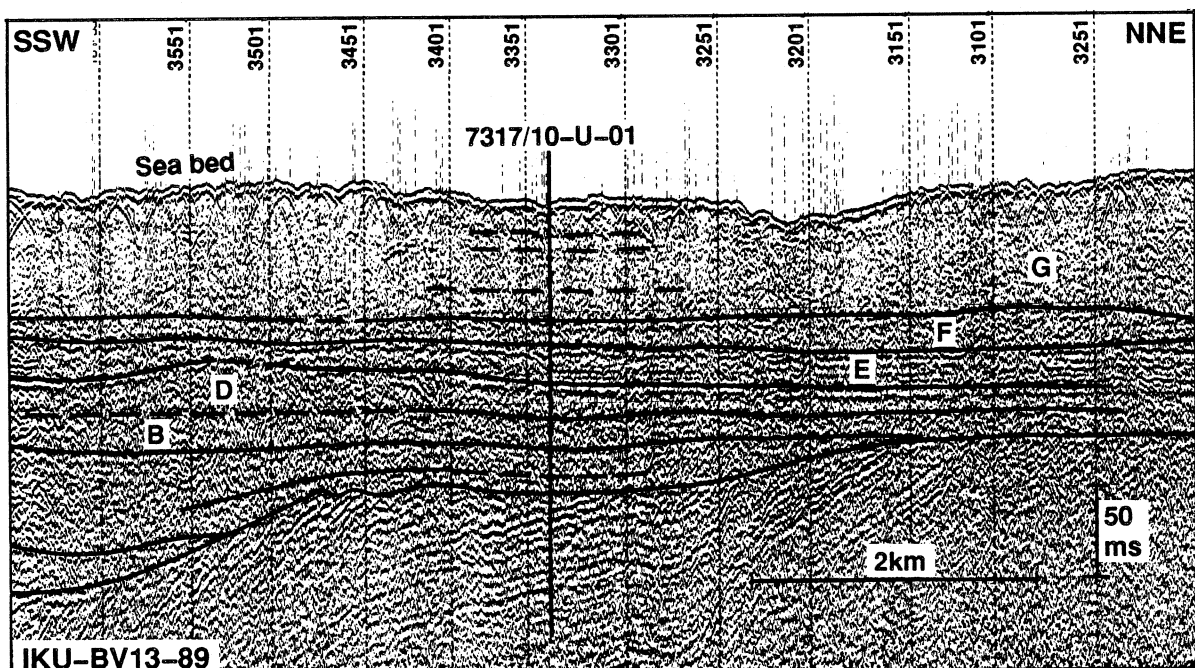


Figure 6.1 Seismic section across site 7317/10-U-01. Correlation between borehole cores and seismic units is given in Figure 6.2 and Table 6.1.

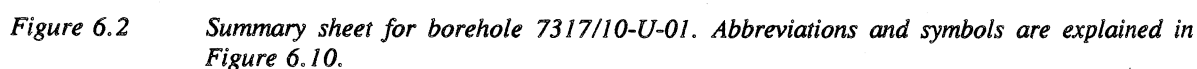


Figure 6.2 Summary sheet for borehole 7317/10-U-01. Abbreviations and symbols are explained in Figure 6.10.

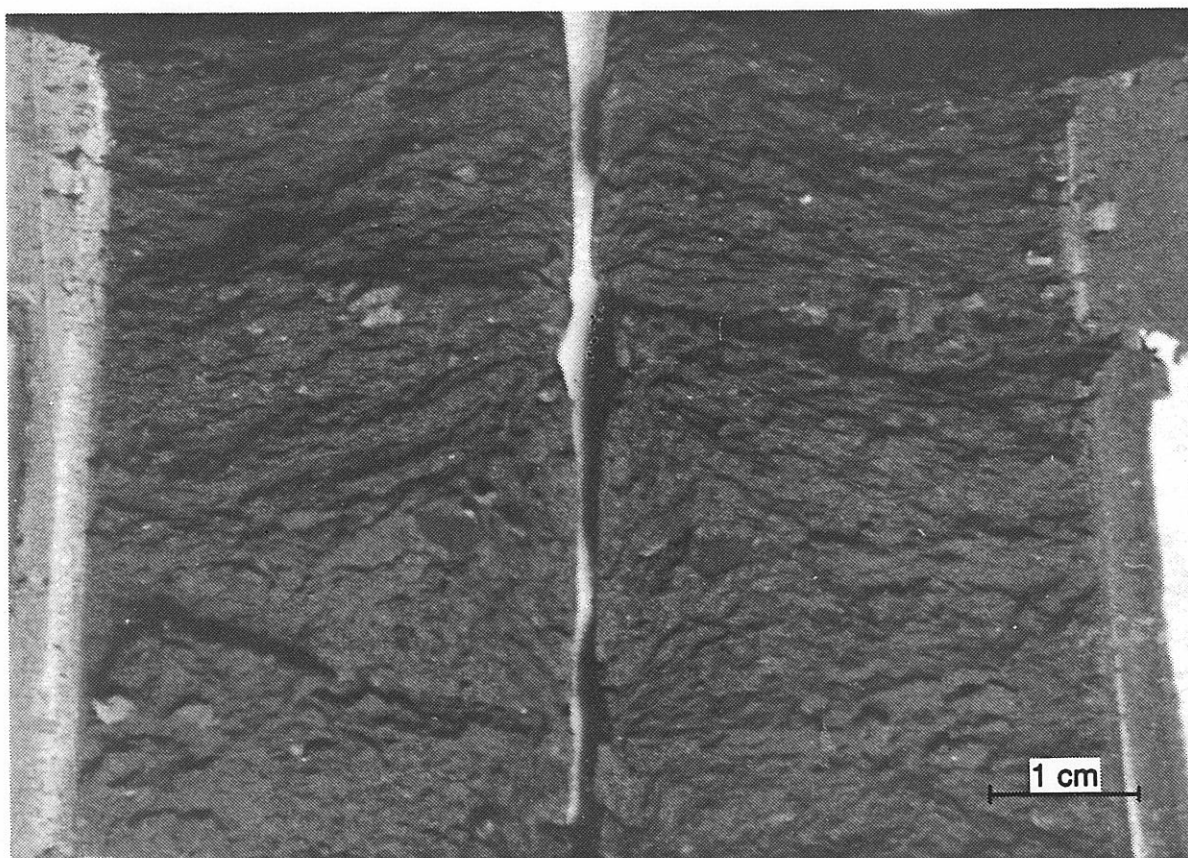


Figure 6.3 Example of shell or disc like fissility at 129.15 m of core 7317/10-U-01.

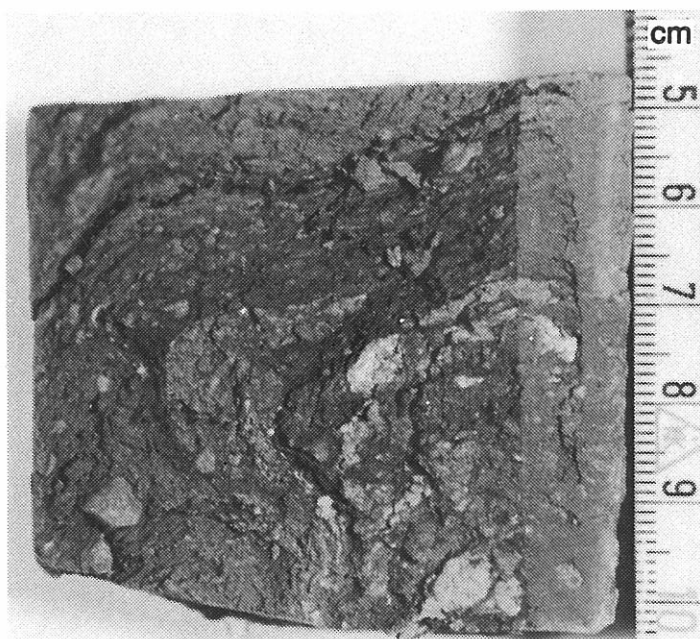


Figure 6.4 Folding at 140.3 m of core 7317/10-U-01. The light constituents are lumps of greenish sandstone.

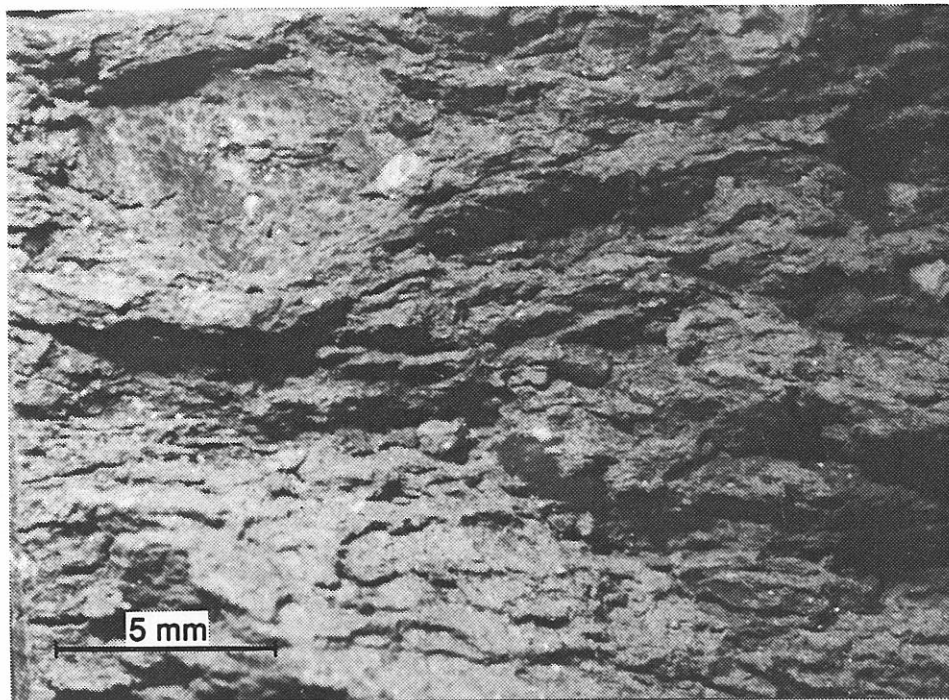


Figure 6.5 *Fissility and flow around cast of larger grain at 109.7 m of core 7317/10-U-01. Examples of the very common rounded claystone clasts are seen in the centre of the photo.*

L3, 108.5 – 101.0 m:

This lithozone comprises a dark grey-very dark grey silty, sandy clay with some fine gravel as well as intervals of light grey-olive grey very fine-fine sand (107.35 – 107.08 m, 102.78 – 102.70 m and 102.50 – 102.42 m). Sand and gravel are absent in the interval between 102.42 m and 102.15 m. The sandy intervals are disturbed, and apparent lamination may be a result of shearing.

Lithozone L3 has a well developed fissility, but with more penetrative shear planes less densely spaced than in the shell structures developed in lithozones L1 and L2. The content of coarse sand and fine gravel in this lithozone is lower than below 108.5 m, and only very few fragments are found of the *Inoceramus* prisms-light grey sandstone-glaucinitic sandstone-quartz grain-assemblage found in lithozone L2.

L4, 101.0 m – 91.5 m:

This interval comprises a homogeneous dark grey silty, sandy clay with some scattered fine gravel. The clast content is low, similar to lithozone L3. A grey-dark grey sandy, clayey silt was cored between 99.71 m and 99.50 m.

The upper 5 cm comprise a chaotic mixing of silt and sand lumps probably due to post depositional deformation. The clast content is low but diverse. At 93.7 m a piece of lighth granitic gneiss was cored from a boulder.

The sample at 93 m has a slight fissility which may have been largely created during sampling. The core at 99.15 m - 100.10 m is, however, rotary cored and has very well preserved primary structures. This core is characterized by a number of cross bedding-like fissility sequences which may represent stacked intervals of fiederspalten created by horizontal simple shear (Figure 6.6).

Lithozones L3 and L4 are fairly similar except from the fissility which seems to be more developed in the deeper samples.

L5, 91.5 m - 84.0 m (?82.5 m):

The top level of this lithozone is uncertain as the sample at 83.64 - 83.30 m is of an intermediate type which may be alternatively correlated to lithozone L6. The physical properties, lack of shear structures and the neutron porosity log, however, suggest that the boundary should be placed at 84.0 m.

The interval comprises a very dark grey silty clay with some sand and fine gravel. The clast content is by visual observation judged as higher than in lithozone L4, although this is not indicated by the grain size data in Figure 6.2. A diverse petrography is found in addition to the dominating occurrence of rounded dark grey claystone-siltstone. Prominent components are angular-subrounded dark grey and light grey claystone/siltstone and angular, micaceous light grey sandstone.

The samples are typically massive and homogeneous. A clear fissility is, however, found in the lower 15 cm of the sample from 89.75 m-89.40 m.

L6, 84.0 m (?82.5 m) - 69.0 m:

This lithozone may be divided into two subzones: The main, upper subzone consists of an olive grey-olive silty clay (sample intervals 80.72 - 80.60 m, 77.92 - 77.70 m and 70.21 - 70.00 m). A sample comprising a dark olive grey silty clay with some sand and a few scattered gravel fragments is cored at 81.67 - 81.50 m. The sample at 83.64 - 83.30 m has a slightly higher gravel content. These samples are here assumed to represent a

subzone of lithozone 6, but are considered as a transitional lithology between lithozones 5 and 6. The clast content of lithozone 6 is low, particularly between 80.72 m and 77.70 m, and the gravel content in a sample from 77.75 m comprises about 30% fragments from pyritized burrows.

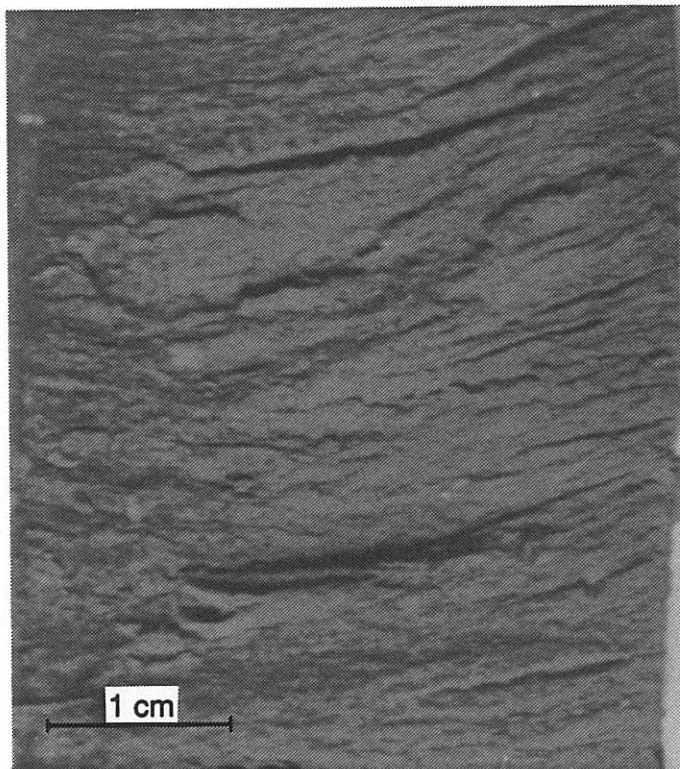


Figure 6.6 Detail of rotary cored sample from approximately 99.2 m of core 7317/10-U-01. The photo shows subhorizontal fissility which is well preserved after coring. Lamination is observed in part of this core interval and the fissility may partly have been developed along lamina planes.

Laminae, 1-2 mm thick, are found in the interval 70.21 - 70.10 m. An apparent slight shearing is present in the top of this lithozone, but clear fissility as observed in the lithozones below, is not found. A strong vertical cleavage found in the sample from 83.64 - 83.30 m is attributed to heat shock on this sample which was casted in warm wax on board the drill ship in order to avoid moisture loss.

L7, 69.0 m - 29.0 m:

The interval comprises a dark grey-very dark grey silty clay with some sand and fine gravel. Rounded claystone fragments are common as in most of the lithozones, and striation is observed on smooth surfaces. In addition there is a diverse petrography of angular-subrounded clasts, dominated by sub-angular-subrounded very fine to fine light grey sandstone.

Most samples are homogeneous and rather structureless, but are slightly sheared. A slight horizontal fissility or shearing along discrete planes is also observed in some samples. This fissility is considered not to be a secondary effect from the strong vertical fissility in the sample periphery caused by the sampling. Flow structure around clasts are found.

L8, 29.0 m - seabed:

This lithozone is quite similar to lithozone L7. The main distinction is a slight difference in colour. Lithozone L8 also corresponds to an upper zone with respect to geotechnical properties. It comprises a very dark grey-very dark greyish brown-dark grey silty clay with some sand and fine gravel. The occurrence of rounded claystone is less common in this interval than in the deeper parts of the borehole, and fine-medium light grey sandstone is rather common. The samples are homogeneous, but a faint, horizontal shearing (- fissility) is found in some intervals.

6.1.2 Physical properties

Recorded physical properties are documented in Chapter 5, and discussed in some detail there. An overview of this data is given in Figure 6.2, and the following main characteristics are drawn attention to:

All parameters directly or indirectly showing the stiffness/consolidation of the sediments (i.e. s_u , water content, bulk density, and sound velocity) show the similar trend. The sediment becomes increasingly stiffer with depth down to about 60 m. A softer zone occurs between about 60 m and 80-85 m. Below this zone the stiffness increases again down to rockhead. The soft zone is surprisingly little consolidated considering its burial depth. This is further discussed in Chapter 5.

The soft sediment zone which is correlated with seismic unit E causes a negative impedance contrast and a phase shift in the reflection at the top of this unit. This is accounted for in the correlation between seismic data and borehole data (Section 6.1.4). Reference is also made to remarks in Chapter 4 regarding acoustic impedance contrasts and the seismic mapping of this unit.

Wireline logs are run inside the drill string. The log responses are therefore attenuated and may partly reflect hole geometry (caving, collapse) rather than lithology. Still, some information can be extracted from the

neutron porosity log (Figure 6.7). The log is shown down to 120 m. Below 113 m (top of drill collars) the log gives no geological information. Above this level, however, a couple of log matif boundaries are found to correspond to lithological unit boundaries. These are indicated in Figure 6.7.

6.1.3 Biostratigraphy and age

Thirty-nine samples were analysed for foraminifers in this borehole. Five distinct foraminiferal assemblages were found (Figure 6.2). Boundaries are drawn according to the same rules as for the lithozones. The lowermost zone (143.2-102.6 m) was dominated by high arctic *E. excavatum* and low high arctic *C. reniforme*. What characterized this zone was a very low frequency of foraminiferal shells. This may be due to bad preservation (high dissolution) of the foraminifera or that the sediment has been reworked many times diluting the fauna.

The second zone (102.6-83.60 m) was characterized by *B. marginata*, *E. excavatum* and *C. reniforme*. The appearance of *B. marginata* may suggest a higher sedimentation rate. Note, however, that the sediment may be reworked. The depositional environment of the sediment may then be different from the environment in which the foraminifera lived. *B. marginata* is presently found in fjord areas both off the coast of Norway and Svalbard.

The base of the third zone is uncertain as samples at about 81.5 m differ both from those above and below. At present we consider a transitional boundary to occur between 83.10 m and 80.70 m. The top of the zone is placed at 74.6 m. The zone is characterized by an abundance of low arctic/high boreal foraminifera in particular *E. nipponica*, *N. barleeaanum* and *C. teretis*. This zone seems to be deposited in an interglacial period, somewhat similar to present climatic conditions.

The fourth zone (74.6-69.0 m) is marked by a decrease in foraminifera/gram and a clear dominance of *G. neosoldanii*. Again a period that seems to be a time of high dissolution, but is contrast to the lower zone characterized by a larger presence of low arctic/high boreal species (*E. nipponica*).

The fifth zone (69.0-0 m) is again dominated by *E. excavatum* and *C. reniforme*. The foraminifera/gram is higher than the

7317/10-U-01

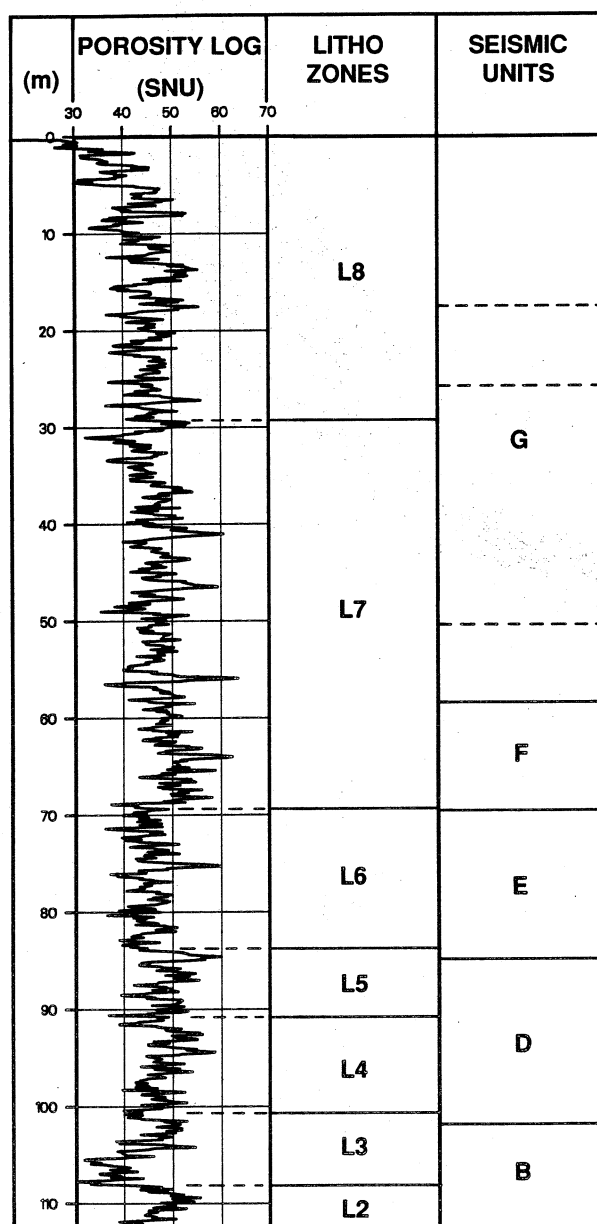


Figure 6.7 Neutron porosity log run inside the drill string in borehole 7317/10-U-01. Lithozone boundaries are indicated.

lowermost zone and the fauna contains a larger amount of "resedimented?" low arctic/high boreal species, maybe derived from diverse interstadials that have occurred in the area.

6.1.4 Correlation to seismic units

A number of seismic reflections are recognized on the mini airgun section across this site (Figure 6.1). Several of these are mapped regionally. The interval between 79.5 ms and 98 ms belongs to the regionally mapped acoustically stratified seismic unit E (Chapter 4). The succession above

this interval is characterized by a diffuse and chaotic reflection pattern, but a few rather diffuse reflections can be traced. Below the acoustically stratified unit several reflectors can be traced. Only one of these (base unit D) has, however, been regionally mapable. At present, this reflector is correlated with the base of lithozone L4. It is, however, possible that this reflector, which is rather diffuse, is a response to the entire lithozone L3, which probably comprizes alternating beds of sand and clay.

The depth conversion of these reflectors is given in Table 6.1. Base Quaternary was penetrated at 143.2 m, and the reflection from the base Quaternary unconformity was picked at 159 ms. This corresponds to an average sound velocity of the Quaternary sediments of 1800 m/s. This is higher than measured in most of the samples. The sample sound velocity is, however, measured horizontally. It may also have been influenced by stress release, which, in particular in the fissile samples, may have caused a lowering of the sound velocity.

*Table 6.1 Depth conversion of seismic reflectors at site 7317/10-U-01, and correlations to seismic units. * = interval velocity of unit E. ** = interval velocity of unit D. The remaining velocities are average velocities below seabed.*

Reflector	Time (ms)	Average velocity (m/s)	Depth (m)	Seismic unit	Lithologic unit (boundary depth in metres)
g-internal	18.3	1688	15.4	G	L8
g-internal (diffuse)	26.5	1717	22.8		29.0
g-internal (diffuse)	51	1734	44.2		
g1	66.3	1746	57.9		L7
f	79.5	1747	69.4	F	69.0
e-internal	89.7	1703*	78.1	E	L6
e	98	1714*	85.1		84.0(?82.5)
d	118.4	1803**	103.5	D	L5 91.5 L4 101.5
b-internal	134.3	1801	121.0	B	L3 108.0 L2 118.0
b-internal	150	1801	134.9		L1
b (=BQ)	159.0	1801	143.2		143.2

7317/10-U-01

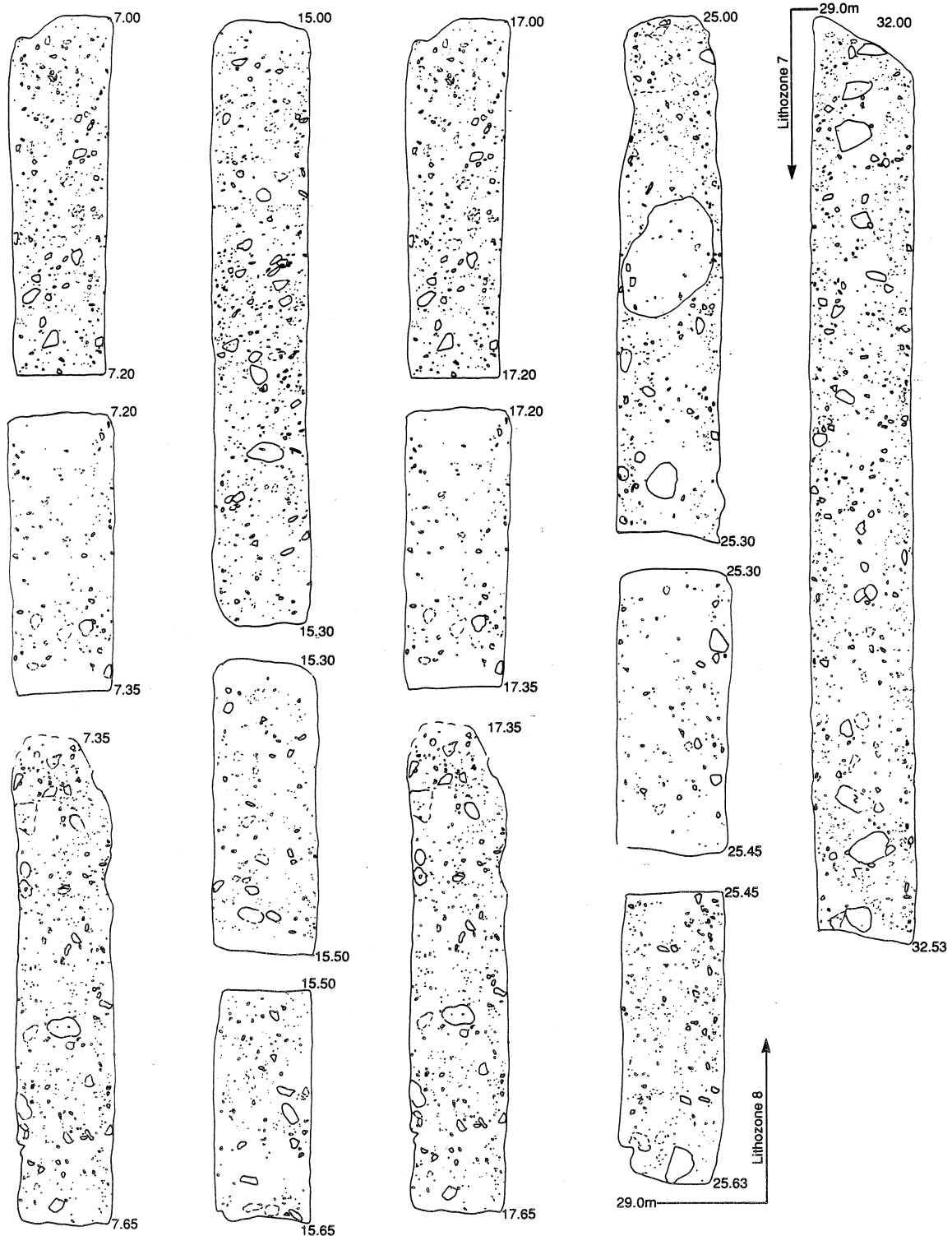


Figure 6.8

Drawing of radiographs of core samples from site 7317/10-U-01. The radiographs are taken of cylindrical cores. This tends to result in an apparently higher content of small clasts in the core periphery and a higher content of coarse clasts along the core axis.

7317/10-U-01, continued

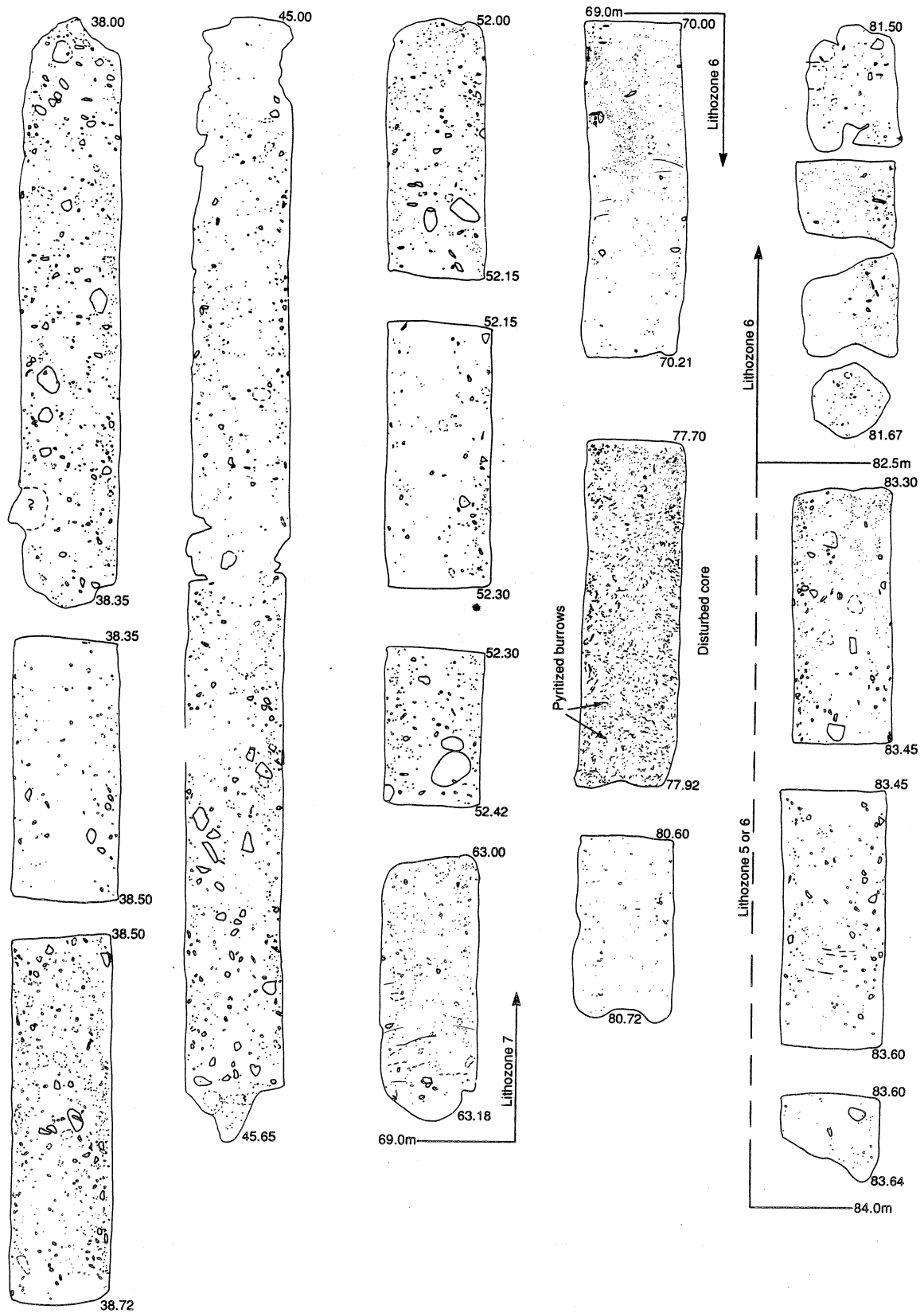


Figure 6.8 continued: Drawing of radiographs from site 7317/10-U-01.

7317/10-U-01, continued

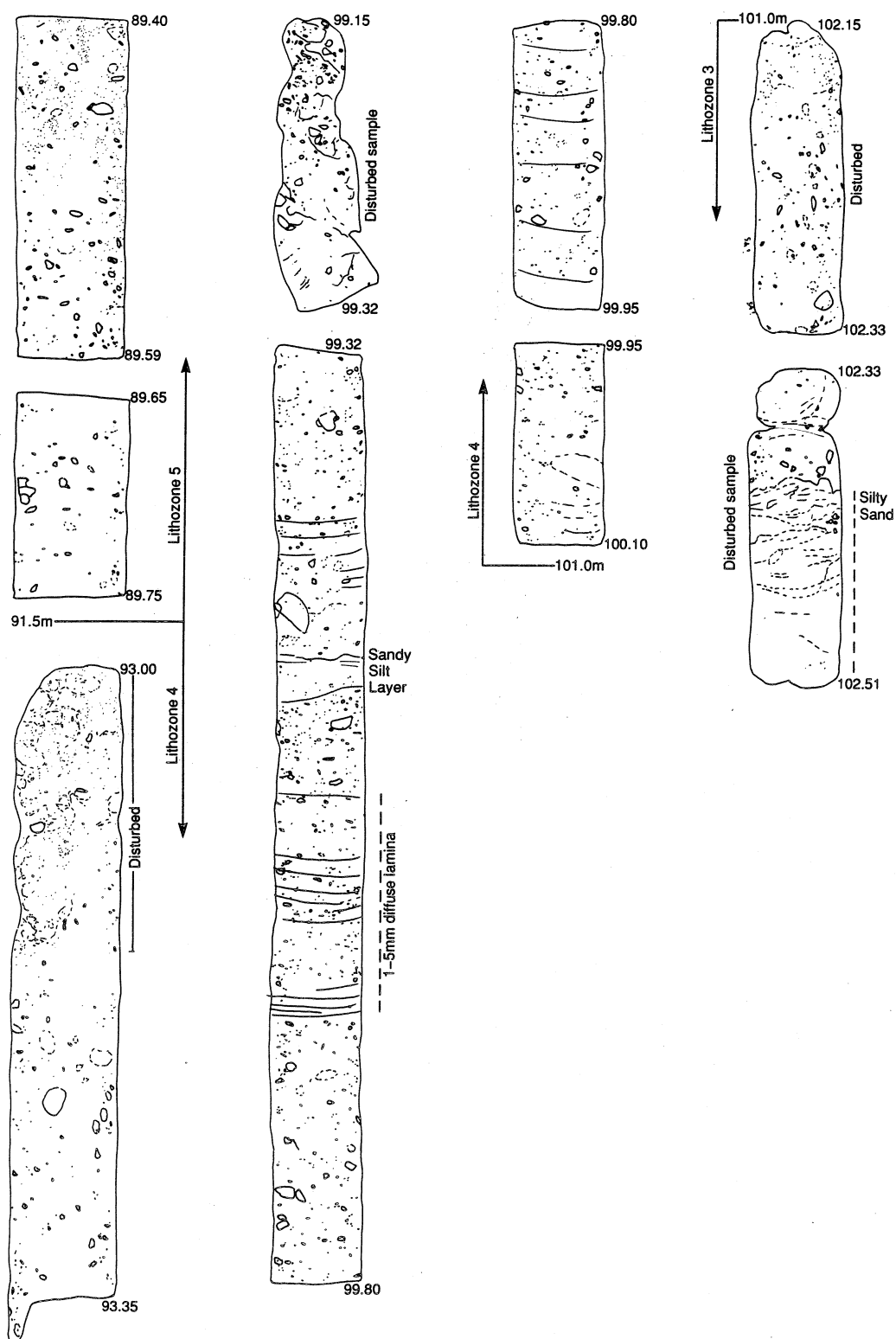


Figure 6.8 continued: Drawing of radiographs from site 7317/10-U-01.

7317/10-U-01, continued

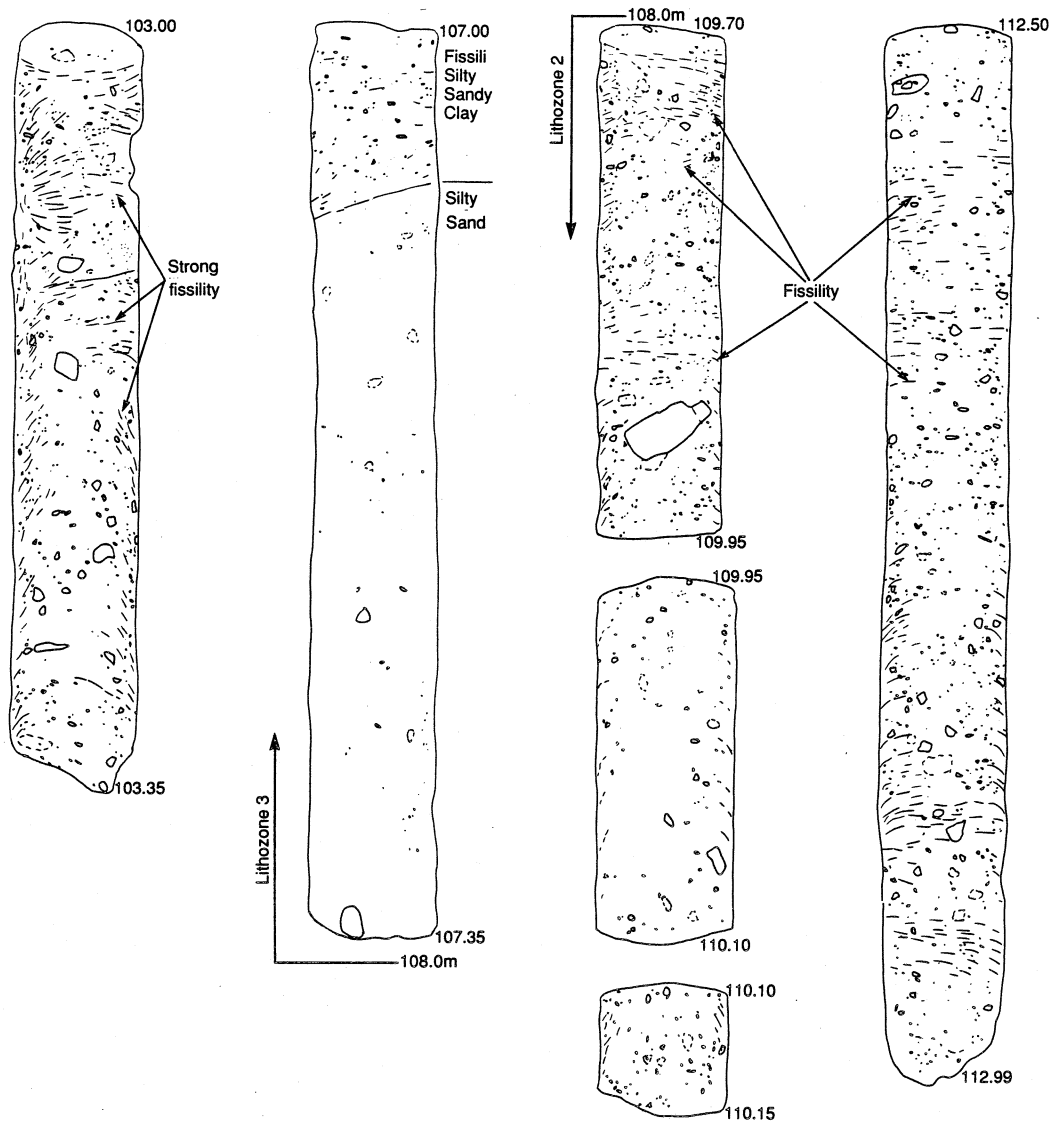


Figure 6.8 continued: Drawing of radiographs from site 7317/10-U-01.

7317/10-U-01, continued

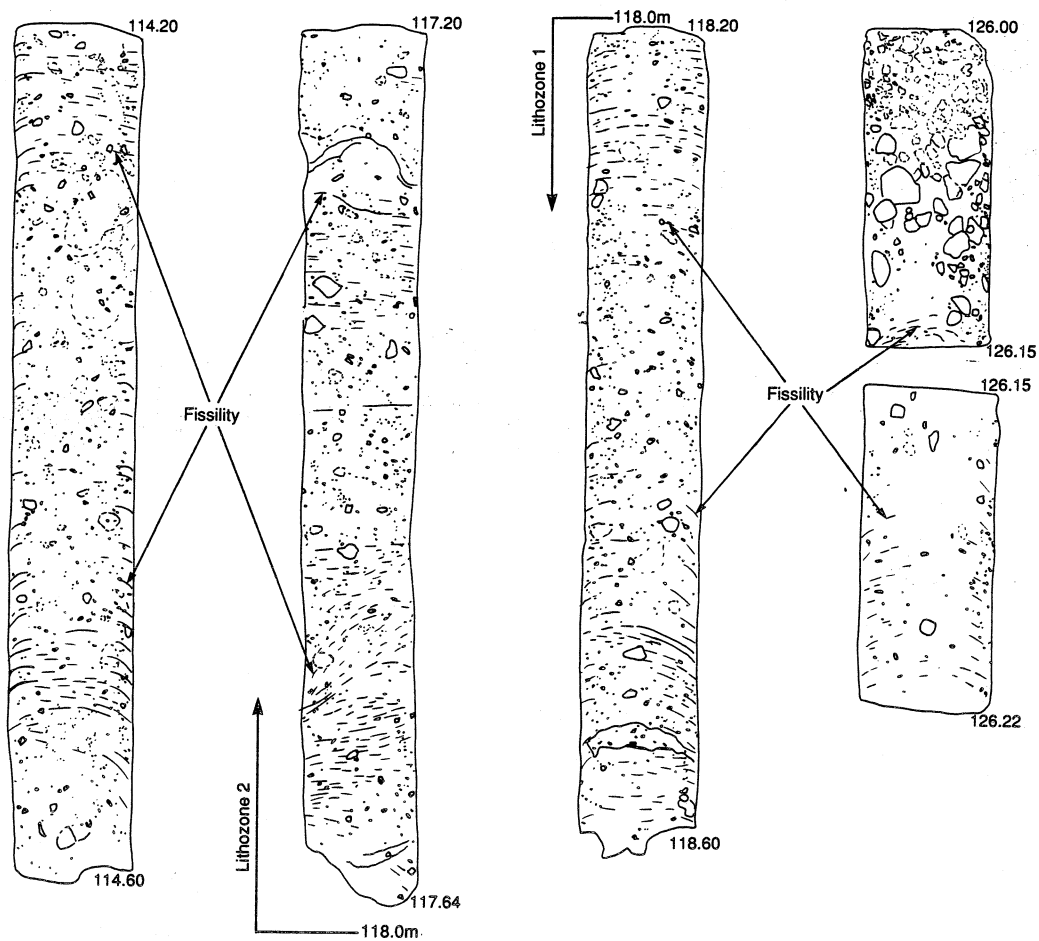


Figure 6.8 continued: Drawing of radiographs from site 7317/10-U-01.

7317/10-U-01, continued

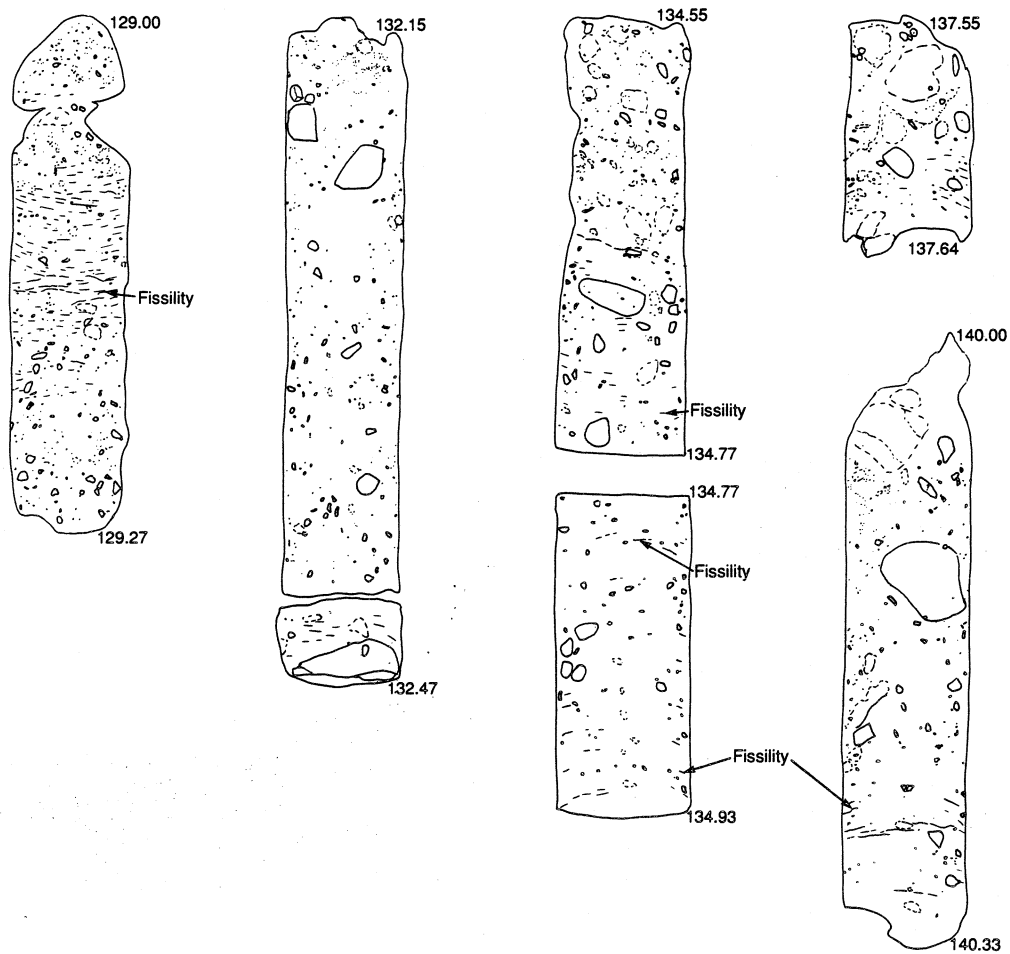


Figure 6.8 continued: Drawing of radiographs from site 7317/10-U-01.

6.2 Core 7316/06-U-02

6.2.1 Lithology and structures

The lithology of this core is partly very different from what is found in the neighbouring borehole 7316/06-U-01. The sample coverage is poor, but two lithozones are distinguished based on the samples and information from the drilling.

M1, 68.50 m - approx. 39 m:

The base of this interval is a sharp boundary towards underlying sedimentary rocks (Figure 6.11). The upper metre of the bedrock is, however, partly sheared and contains a few small lumps of Quaternary sediment in sheared zones. The top of this lithozone is not cored but is placed at approximately 39 m where the driller reported a probable transition in the soil conditions.

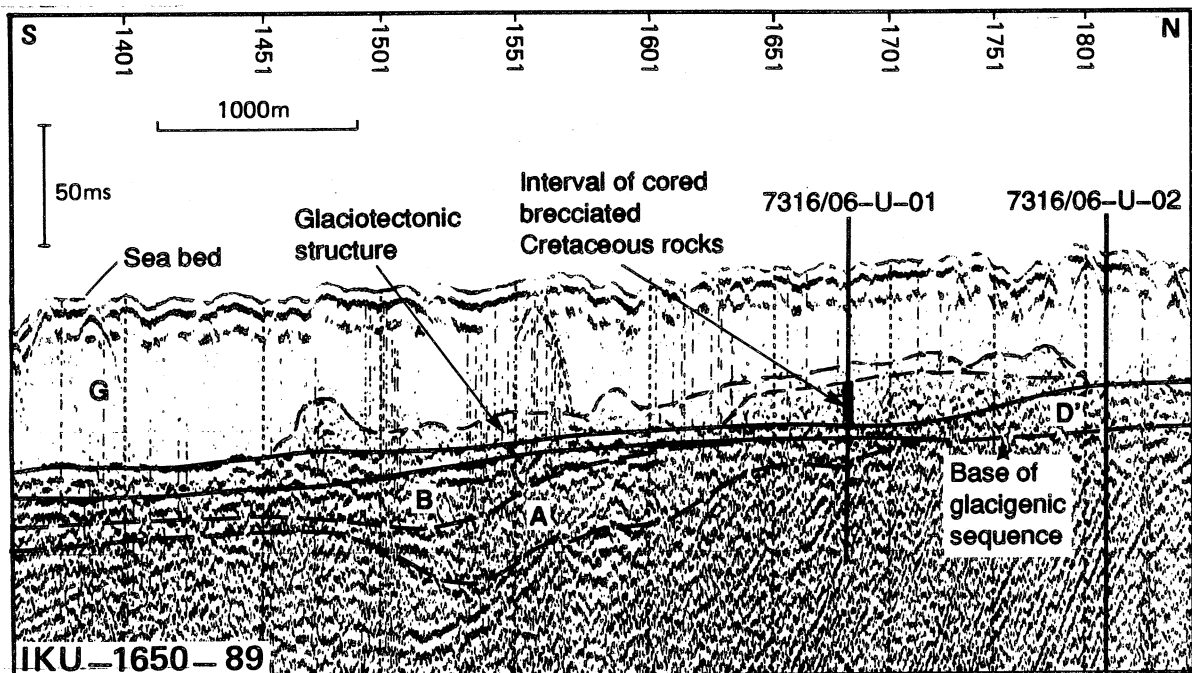


Figure 6.9 Seismic profile across sites 7316/06-U-01 and 7316/06-U-02.

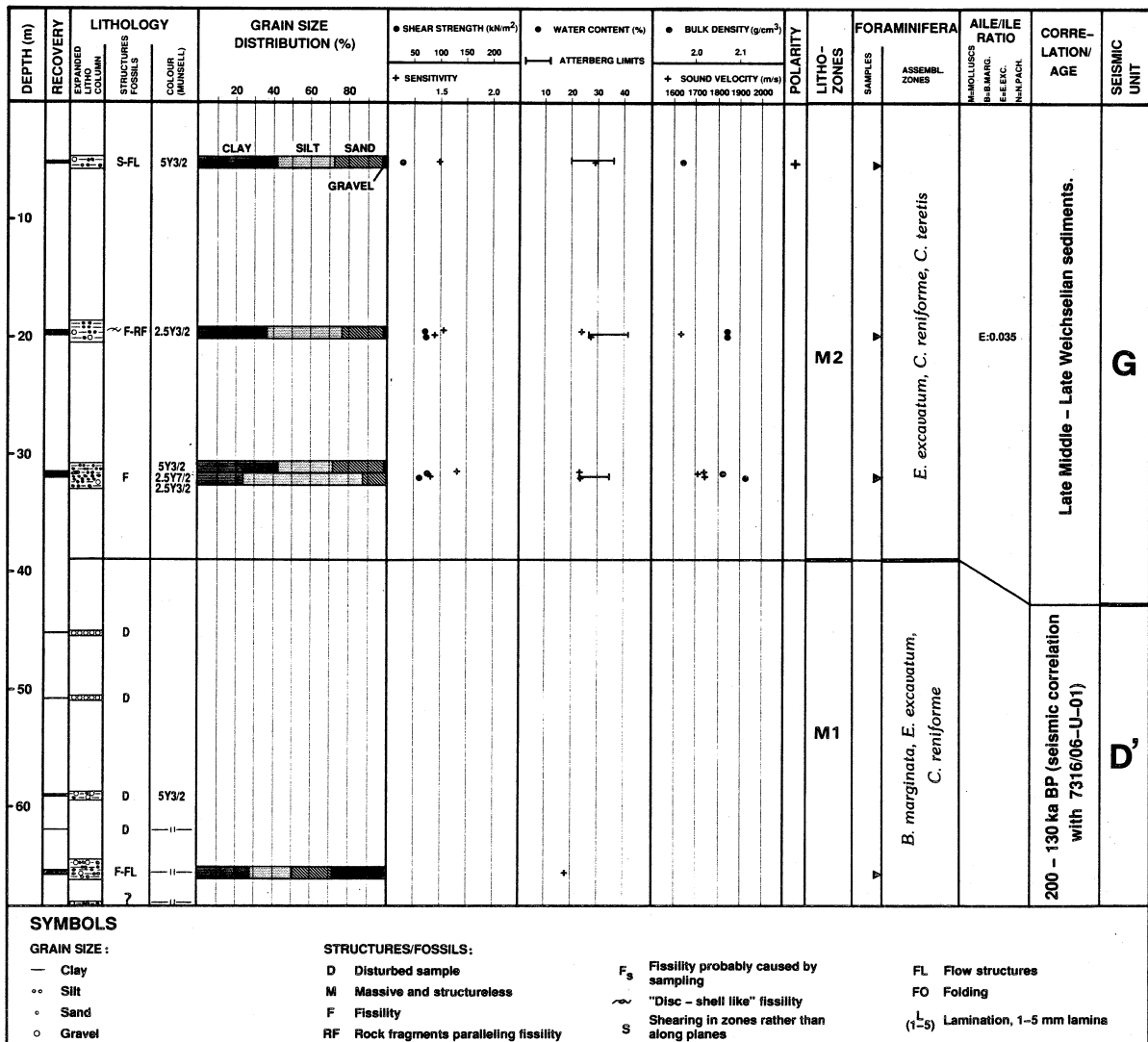


Figure 6.10 Summary sheet of core 7316/06-U-02.



Figure 6.11 Sharp boundary between glacial sediments and Tertiary sedimentary rocks at site 7316/06-U-02.

Five samples were obtained from this interval. The upper two comprise only gravel residual sampled at the bottom of the borehole, and contain angular-subangular fragments of sandstone, claystone and limestone. The other samples comprise a dark olive grey silty, sandy, gravelly (fine) clay. The petrography is diverse and includes angular-subangular gneiss, limestone and greyish sandstone and rounded-well rounded fragments of soft micaceous greenish siltstone and dark grey-brownish grey claystones-siltstones of variable shape.

The undisturbed sample at 65.95-65.50 m has a clear subhorizontal fissility and shows matrix flow around clasts.

M2, approx. 39 m - seabed:

The samples from this interval comprise a dark olive grey-very dark greyish brown, silty, sandy clay with scattered gravel. The sand content is lower in the intermediate than in the upper and lower samples. The petrography is slightly dominated by rounded dark grey claystone fragments, but angular-subangular light grey sandstone is also common. Angular metamorphic rocks are observed. In the sample from 32.06-31.5 m several irregular (sheared?) lumps of sand occur above an about 10 cm thick layer of light grey fine sand. Shearing is observed at all the three cored levels. At 5 m this is

expressed as bulk flow deformation of the sediment rather than a fissility as found at deeper levels (Figure 6.12). The drawing of the radiograph from 5.26-5.00 m give the impression of a sediment quite similar to lithozone L7 and L8 in borehole 7317/10-U-01 and lithozone L5 in borehole 7316/06-U-01.

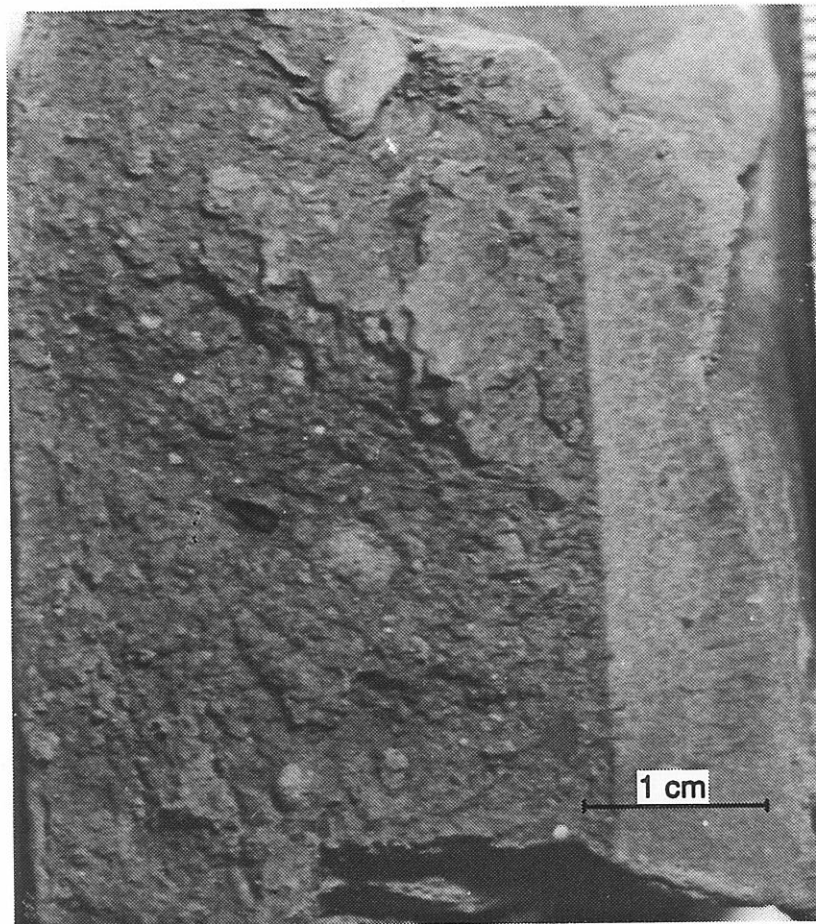


Figure 6.12 *Sheared sediments at about 5 m in borehole 7316/06-U-02. The rightmost 1 cm is cut by knife. The remaining part is broken apart to reveal sediment structures.*

6.2.2 Physical properties

Physical property data are obtained only from the upper lithozone (Table 5.1, Figure 5.4). The clay is moderately stiff, but clearly overconsolidated, at least down to approx. 20 m, judged from water content and shear strength.

Petrophysical logs which were run inside the drill string in the upper part of the hole, did not give any reliable information from the Quaternary sediments.

7316/06-U-02

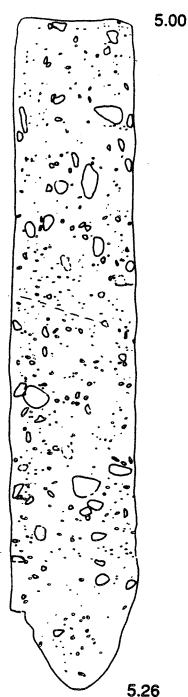


Figure 6.13 Redrawn radiograph from 5.26-5.00 m.

6.2.3 Biostratigraphy and age

This borehole was analysed with respect to 5 samples and the fauna can be grouped into 2 assemblages. The boundary between the two assemblage zones is tentatively placed at the lithozone boundary at 39 m. The lower zone (one sample at 65.60-65.55 m) is dominated by *E. excavatum* and *C. reniforme*, however, *B. marginata* appears (5%) and this zone can possibly correlate with the second zone of 7317/10-U-01 (102.6-83.6 m) and 7316/06-U-01 (59.95-54.13 m).

The upper zone was sampled at 31.90 m, 31.81-31.78 m, 19.8-19.7 m and 5.26-5.2 m (sand).

This zone is characterized by *E. excavatum* and *C. reniforme* and, to a lesser extent, *C. teretis*. It is correlated with the upper zones of 7317/10-U-01 (above 69 m) and 7316/06-U-01 (above 29 m).

6.2.4 Correlation to seismic units

The reflection pattern across this site is much simpler than across the neighbouring site 7316/06-U-01 (Figure 6.9). Two distinguishable Quaternary seismic units are present: an upper acoustically transparent unit and a lower with a somewhat chaotic internal reflection pattern. The latter pattern may partly be due to a sharp but irregular interface between the two units, which is found at 51 ms. The base Quaternary reflection is found at 75 ms, and this surface was penetrated at 68.5 m, corresponding to a sound velocity of 1872 m/s. Sound velocity measurement on samples at about 20 m and 32 m suggests an average value of about 1680 m/s for the upper unit. This value is applied, and places the boundary between the seismic units at 42.8 m. This boundary is correlated with the lithologic boundary at 39 m.

6.3 Core 7316/06-U-01

6.3.1 Lithology and structures

The glacial succession at this site is 65 m thick and have been subdivided into five lithozones denoted lithozone N1-N5. The succession is relatively complex with variation in lithology from coarse gravelly sands and undisturbed megablocks of pre Quaternary sedimentary rocks to the muddy diamictos typically found in most of the Barents Sea. Between 54.13 m and 39.0 m (probably up to 29.3 m) the core comprises sediments which are glaciotectionally emplaced into the glacial sequence (Chapter 8). The lithozones are described below.

N1, 65.0 m - 59.90 m:

This lithozone is divided into two subzones at 60.95 m. The lower part comprises a greyish gravelly sand with less than 3% silt. The gravel content is 20-25%. The results of grain size analyses from the interval 62.05-61.55 m plotted on probability paper (Figure 6.15) reveal two modes, one in the sand fraction finer than 1ϕ , and one in the gravel fraction (coarser than -1ϕ). The sediment plots in the lower part of the till zone in a $M_d - S_o$ diagram (Figure 6.16). The sorting ($S_o = \log d_{75}/d_{25}$) varied between 0.63 and 0.79. The sorting parameter of Folk and Ward (1957) ($S_i = 1/4(\phi_{16} - \phi_{84}) + 1/6.6(\phi_5 - \phi_{95})$) covers a larger part of the grain size range and reveals a much poorer sorting than indicated by the S_o parameter ($S_i = 1.7 - 2.2$). Layering or grading is not found, but the interval has partly a preferred subhorizontal orientation of elongate clasts.

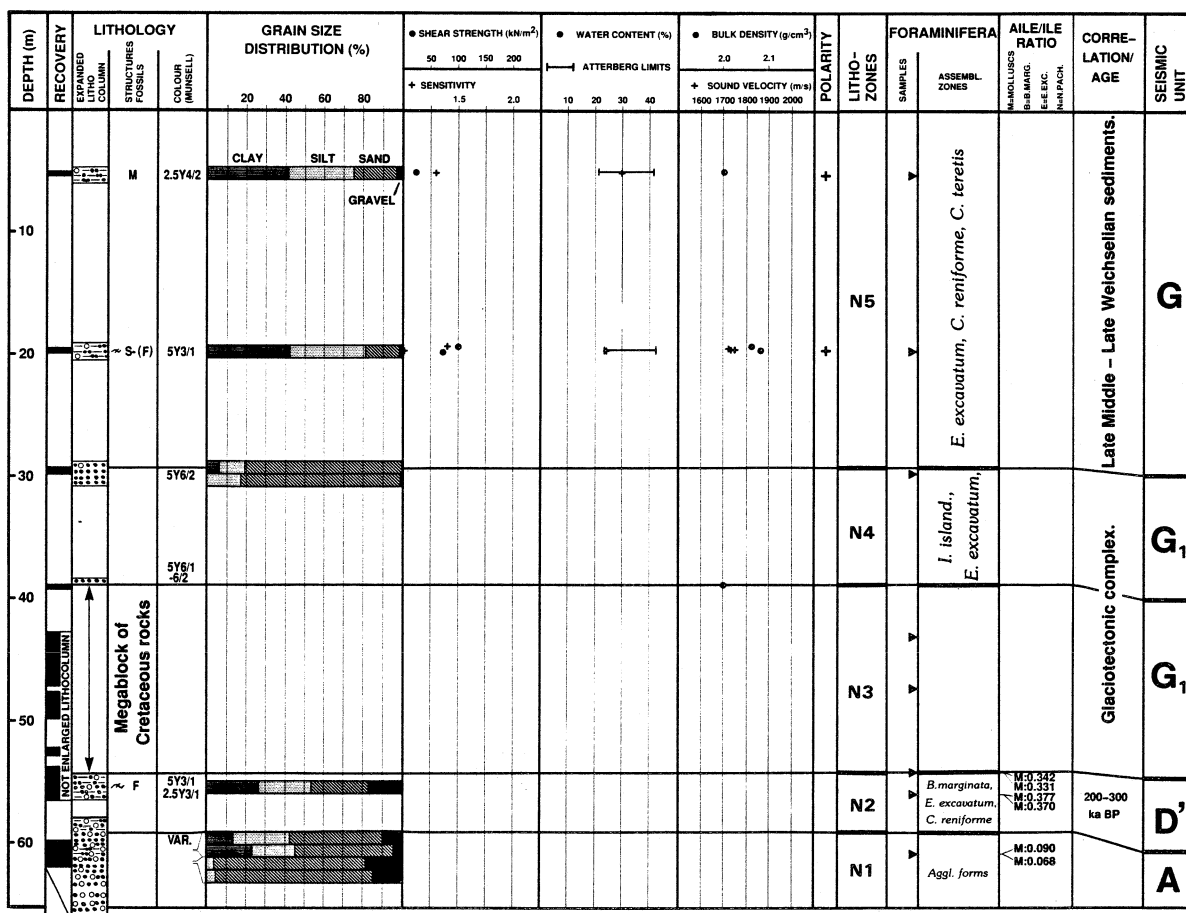


Figure 6.14 Summary sheet, site 7316/06-U-01.

The petrography is diverse. Angular fragments of metamorphic rocks (gneiss and mica schist) and coarse grained sandstone are present, although sub-rounded-rounded-well rounded fragments of quartz, quartzite and other hard rock dominate. Some of the angular fragments are mechanically weak and look weathered. Small scale glacial striation is observed on some of the smooth surfaces.

The subzone between 60.95 m and 59.00 m is more fine-grained and consists of intervals of silty, sandy clay with some gravel, gravelly sand with some silt and clay as well as mixtures of the two sediment types. Clay intervals are very dark grey. Sandy intervals are variable in colour. The clayey intervals are strongly compacted and partly fissile/sheared.

The petrography is diverse also in this interval, and the textural maturity of grains varies from angular to well rounded.

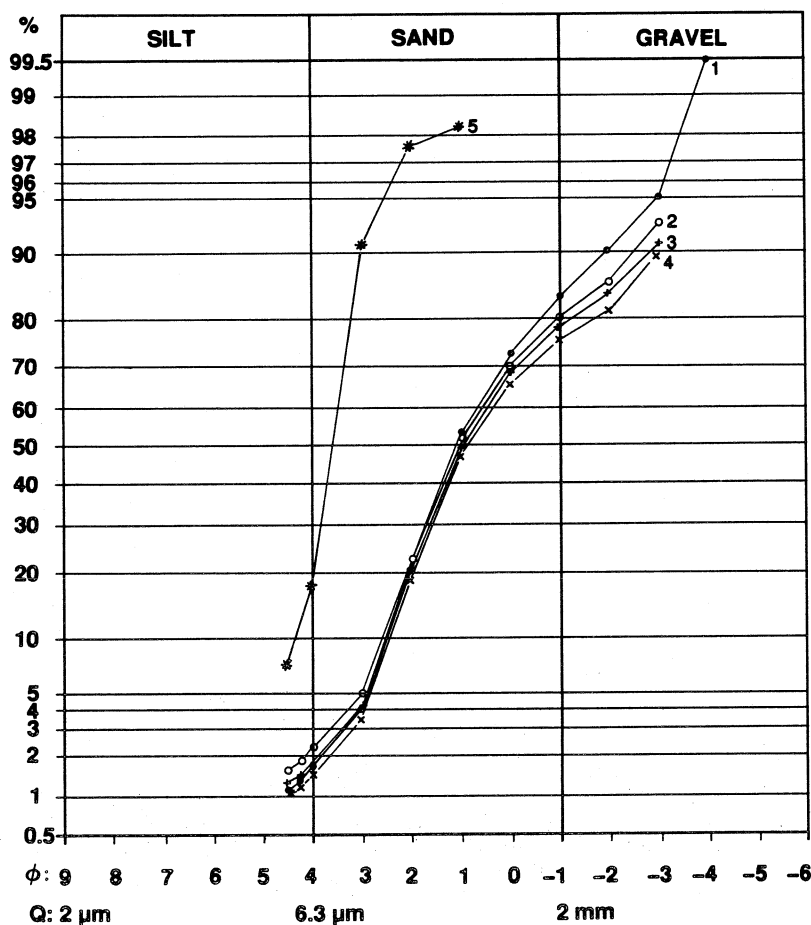


Figure 6.15 Grain size distribution plotted on probability paper. Plots 1-4 are from the interval 62.06-61.55 m (lithozone N1). Plot 5 is from 29.75 m (lithozone N3).

Interpretation:

The entire lithozone N1 is interpreted as a till, but a glaciofluvial influence on part of the lower subzone is not excluded. Arguments for interpreting the sediment as a till are: The sediment probably partly consists of material derived from local bedrock, but the metamorphic fragments clearly have a more distant source. The fact that these fragments are texturally immature and partly mechanically weak is considered indicative of a mainly glacial transport. Faint glacial striation observed on the surface of smooth, rounded clasts suggest that also these grains have been glacially transported.

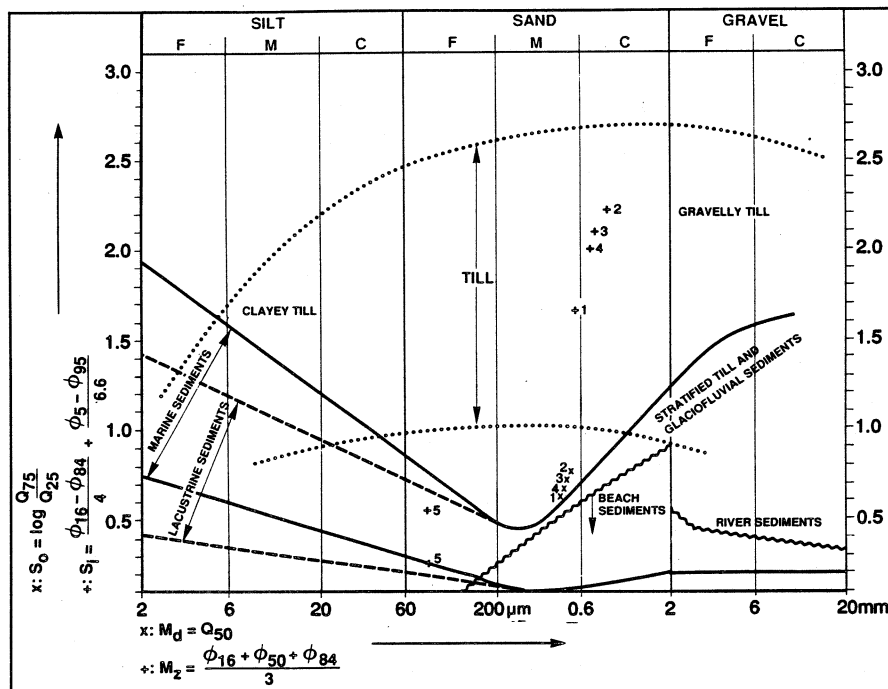


Figure 6.16 $M_d - S_0$ diagram (Modified after Selmer-Olsen 1954) showing mean grain size and sorting of gravelly sand (plots 1-4) at 62.05-61.55 m (lithozone N1) and fine sand at 29.75 m (lithozone N4). Further comments are given in the text.

N2, 59.95 – 54.13 m:

Lithozone N2 comprises a very dark grey silty, sandy, gravelly clay. The boundary to the overlying lithozone comprising the allocthonous sedimentary rock was penetrated at 54.13 m. It is irregular, but sharply defined (Figures 6.17 and 8.3). The upper decimetre below the boundary contains lenses of grey silty sand-sandstone apparently sheared into the diamicton. A decimetre thick sandy interval occurs at 55.4 m.

The sediment is partly fissile (particularly in the upper and lower parts), partly it is rather massive. A certain fabric is observed, with preferred dip of 20°-30° for 0.3-1 cm sized clasts.

The petrography is diverse. Rounded-subrounded dark grey very dark grey claystone dominates among of small clasts. The larger clasts consist of a variety of sandstones, sandy limestone as well as occasional metamorphic fragments. Glacial striation is observed.

N3, 54.13 - 39.0 m:

This lithozone is a core through an allochthonous body of Cretaceous sedimentary rock glaciotectonically transported to this site. Further information on this interval is given in Section 8.2 of this appendix and in Section 3.3.8 of the Main Report.

N4, 29.3 m - 39.0 m:

Two cores of sand were obtained from the top and base of this interval. The driller noted a low mud pressure, indicative of sand in the interval between the two samples. This interval is considered to be part of the glaciotectonic structure clearly evidenced by lithozone N3 and is further described in Section 8.2.

N5, 29.3 m - seabed:

The two samples from this lithozone comprise a homogeneous very dark greyish brown-very dark grey silty, sandy clay with some fine gravel. The sample at 5 m is rather structureless, while a clear horizontal discontinuous fissility is observed at 19 m.

The samples have a diverse petrography including rounded dark grey claystone, and subangular-rounded calcareous sandstone, limestone and poorly consolidated light grey sandstone. At 5 m subangular-rounded grey sandstone and dark grey siltstone dominate.

6.3.2 Physical properties

Soil mechanical data (Table 5.1) could only be measured at approximately 5 m and 19.5 m in this borehole.

The data are indicative of slightly overconsolidated sediments. The cores from below the glaciotectonic structure have a rather high content of coarse fragments and were also frozen after retrieval (for preparation of core slabs). They are therefore not suitable for soil mechanical testing. The clay matrix of these cores did, however, look firm.

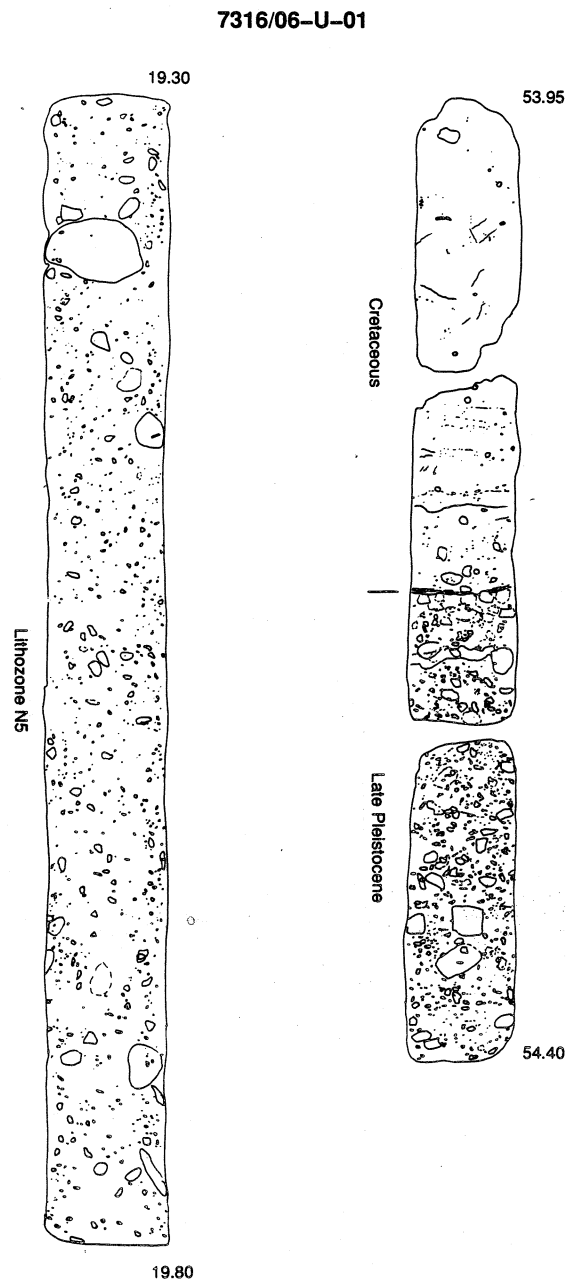


Figure 6.17 Redrawn radiograph showing the character of lithozone N5 and the boundary between mid Cretaceous rocks and Late Pleistocene sediments.

6.3.3 Biostratigraphy and age

Borehole 7316/06-U-01 contains four benthic foraminiferal assemblages shared between 6 samples, thus the borders are highly insecure. Boundaries of assemblage zones are placed at lithozone boundaries. The lower (below

59.95 m) assemblage zone (2 samples) is an agglutinating fauna that contains only two *E. excavatum* shells.

The second (59.95-54.13 m) zone (one sample) contained a fauna with an abundance of *B. marginata* that was similar to the second zone in 7317/10-U-01.

The third zone is represented by one sand sample at 29.65-29.70 m. The sample is dominated by *I. islandica*, *E. excavatum* and *C. lobatulus*. This zone represents a high/low arctic regime. *C. lobatulus* lives in high energy areas. The significance of this sample is, however, uncertain as it contained only 18 specimens (0.17 foraminifers per gram dry sample). It can therefore not be ruled out that the foraminifers may have been reworked into the sand, possibly during the glaciotectionic event.

The fourth zone (29.3 m-seabed) contains the *E. excavatum*, *C. reniforme* and *C. lereii* zone also found in 7317/10-U-01.

Paleomagnetic data indicate reversed polarity of some samples from litho-zone N2 (correlated to seismic unit D), but the results are very scattered. Amino acid analyses (Table 5.4) clearly show that the material is younger than the Brunhes/Matuyama polarity reversal boundary (730 ka BP), and most probably younger than 200 ka. The two measurements at 60.15 m within litho-zone N1 (tentatively correlated with seismic unit A) suggest a minimum age of 1 Ma of the measured shell fragment. This is a maximum age of the sediment. Unit A is therefore undated, but is older than unit D' (130-200 ka).

6.3.4 Correlation to seismic units

The seismic section (Figure 6.9) across this site is characterized by rather chaotic reflections. This is probably largely due to acoustically unfavourable conditions in fractured and discontinuous rocks caused by glaciotectionic activity. Several seismic units become very thin or pinch out in the vicinity of this site. The correlation of seismic units and lithologic units is therefore uncertain for the lower part of the Quaternary section of this core (i.e. below 54.13 m). The base Quaternary was found at 65 m and the top bedrock reflection on the mini airgun was picked at 75 ms. This corresponds to an average sound velocity of 1733 m/s. Sound velocity measurement on one core at about 19 m gave a sound velocity of 1732 m/s. This is slightly higher than what is found for this interval in

the neighbouring core 7316/06-U-02 (1697 m/s), and an average sound velocity of 1700 m/s has been applied for the interval above the allochthonous rock interval. Below 54.13 m a sound velocity of 1733 m/s is applied. The depth conversion and correlation of the reflectors are given in Table 6.3.1.

Table 6.3.1 *Depth conversion of seismic reflectors at site 7316/06-U-01, and correlations to seismic units.*

Reflector	Time (ms)	Average velocity (m/s)	Depth (m)	Seismic unit	Lithologic unit (boundary depth in metres)
g ₂ N5	35	1700	29.75	G ₂	N5 29.3
g ₁ -internal N3	47	1700	39.95	G ₁	N4 39.0
g ₁	63	1733	54.60		N3 54.13
d' N2	70	1733	60.70	D'	N2 59.95
a	75	1733	65.00	A	N1 65.0

6.4 Core 7316/03-U-01

6.4.1 Lithology and structures

Only two sediment samples were obtained from this site. In addition, a few gravel fragments were recovered at about 16.2 m.

The sample at 31.57-31.4 m consists of dark grey clayey silt interlaminated with light grey fine - very fine sand. The lamina surfaces are sharp but irregular, probably due to later deformation (Figure 6.18).

Shearing and folding are observed. The sample quality is, however, poor, and some of this deformation may have been caused by the sampling.

At 7.58-7.3 m a very dark greyish brown, silty, sandy, gravelly clay was cored. The sample is rather disturbed, but primary fissility is probably preserved in the lower part. The upper part is a gravelly sand and is assumingly largely comprised of cuttings from the drilling.

7316/03-U-01

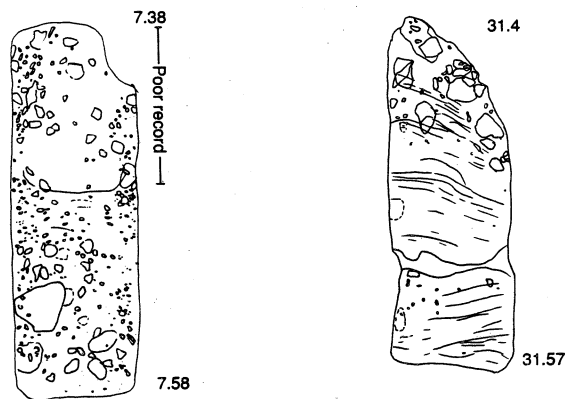


Figure 6.18 Radiographs of samples from 7.58-7.38 m (diamicton) and 31.57-31.4 m (laminated silt and fine sand in lower part, diamicton in upper part).

Greyish limestone and sandy limestone are important constituents of the petrography at this site. In addition, undifferentiated claystones, siltstones and sandstones occur. Fragments smaller than 1 cm are typically subangular-angular.

The sample coverage is not sufficient to allow definition of lithozones, but it is noted that the two cored lithologies are quite different, and a lithologic boundary (possibly at approximately 24 m) may be present.

6.4.2 Physical properties

Shear strength and water content are measured at two levels (Table 5.1). The data indicate stiffer sediments in the top of the borehole (7.4 m) than at 31.5 m.

The uppermost sample was considered as stiff when retrieved, and the s_u -value of >250 kPa at 7.4 m is probably real and indicative of an overconsolidated sediment. The reliability of low shear strength at 31.5 m is uncertain.

6.4.3 Biostratigraphy and age

Only three samples were analysed in this borehole and the fauna can be grouped into 2 distinct assemblages. The lower zone (below 24 m) contained

only one foraminifera *G. dehiscens*? which is not a late Cenozoic foraminifer.

The upper zone (about 24 m) contained an abundance of *C. lobatulus* and *C. reniforme*. It also contained some *I. islandica*.

A normal polarity was found at 7.2 m. Due to sample quality no other age data are yet obtained from this borehole.

6.4.4 Correlation to seismic units

The seismic data across this site has poor resolution. This hampers extrapolation of data from the borehole. Specially processed airgun data to, however, indicate an intra Quaternary reflector at about 14.5 ± 2 ms. Base Quaternary was found at about 37.5 ms corresponding to 31.9 m in the core. This suggest that the intra Quaternary reflector may be at about 10.5-14 m.

This reflector is not attempted correlated with the seismic framework of the study area.

7. DISCUSSION AND CONCLUSIONS

7.1 The record of glaciations

Published work

A number of earlier studies conclude that the Barents Sea has been formerly glaciated (Nansen 1904, 1920, Høltedahl 1929, 1940, Fønstelien 1972, Sundvor 1974, Rokoengen & Bugge 1976, Bugge & Rokoengen 1976, Rokoengen et al. 1976, 1979, 1979b, Andersen 1979, 1981, Grosswald 1980, Elverhøi & Bomstad 1980, Elverhøi & Solheim 1983, Solheim & Kristoffersen 1984, Vorren & Kristoffersen 1986). These studies are largely based on morphology, seismostratigraphy and investigation of surficial seabed samples. Timing and extent of glaciations are poorly constrained. A minimum of four glacial advances to the western shelf area was, however, suggested by Solheim and Kristoffersen (1984). Schytt et al. (1967) and Hoppe (1979) argued for a Late Weichselian ice sheet in the Barents Sea, based on studies of raised beaches on Svalbard. Although disputed by Boulton (1979), their conclusion is now well established (e.g. Elverhøi & Solheim 1983, Solheim & Kristoffersen 1984, Sættem & Hamborg 1987, Solheim et al. 1988, Hald et al. in press.). The westward extent of the Late Weichselian ice sheet in the deep part of the southern Barents Sea as well as age of earlier glaciations are, however, major uncertainties in the published literature.

As reviewed in Section 4.2 in the Main Report, the oceanic record indicates that the first Cenozoic glaciers started to grow at high latitudes with small but significant input of ice rafted debris (IRD) 5.45 Ma (Jansen et al. 1987, 1988, in prep.). This record is apparently in disagreement with some observations of temperate conditions in northernmost America and Greenland (Jansen et al. 1988). The latter observations may, however, probably represent interglacials. Cooling of the Norwegian Greenland Sea started 13.6 Ma (Henrich et al. 1989), and in the Baffin Bay IRD is found in sediments dated to 8 Ma (Arthur et al. 1986). Glaciers may have existed in mountains and highlands in the north long before the first iceberg or sea ice transported IRD into the oceans. Significant glaciations on land Svalbard may therefore have occurred prior to the first IRD record (5.5 Ma), possibly with some glacial activity 8 Ma, or even earlier. Some of these glaciations may have extended into what today is the Barents Sea.

The present study

The main stratigraphic results of the present project are concluded on the cross-sections in Figures 7.1 and 7.2, where age has been assigned to a number of seismic units. The results of further amino acid analyses being undertaken at the University of Bergen may add details/refinements to the stratigraphy. The seismic units are mapped on the outer shelf and on the upper slope (Chapter 4).

The paleomagnetic data show that all the measured sediments were deposited during the Brunhes normal polarity chron (0-730 000 years BP) (Chapter 5, Enclosure 1). A few samples have a reversed polarity, but constraints from amino acid data (Table 5.4) show that they are younger than 730 000 years. A confident interpretation of age based on amino acid measurements must take into consideration which species of mollusc or foraminifera shell that have been tested, the temperature history since the burial of the fossil, and not the least whether the fossils are reworked or not. The age assignments given in Figures 7.1 and 7.2 are made by Hans Petter Sejrup. His interpretation is based on experience from work with amino acid data from a variety of species and ages and accounts for the former two effects. Fossil reworking is probably common in most of the samples, and the fossil ages therefore represent maximum ages for the sediments in which they are found. The sediments of the acoustically stratified seismic unit E are, however, not reworked and are interpreted as distal glaciomarine - marine clays.

We have not been able to assign any age to seismic units A₀ and A (Figure 7.2), although unit A possibly was cored in borehole 7316/06-U-01. One shell fragment from this interval gave an amino acid ratio indicative of an age in excess of 1 million year. The shell fragment is, however, probably reworked, and the sediment may be younger.

The analysed fragments from seismic unit D are interpreted by Sejrup to have an age of 100-200 ka. The Eemian interglacial stage (130-117 ka BP according to Mangerud in prep.) is, however, most likely represented in the overlying unit E. Therefore, a minimum age of 130 ka can be assumed for unit D.

The amino acid ratios of mollusc fragments from seismic units F and G all fall in the middle Weichselian range of Miller and Mangerud (1985), and Sejrup suggests an age of 20-60 ka for these fragments. There is no increase from the value of amino acid ratios found in our unit F to our unit

G. This may suggest that the fossils found in these two units lived at about the same time and thus that both units may be younger than 30 ka BP. Unit E may accordingly comprise both Eemian, Early Weichselian and ?late Middle Weichselian sediments. The above interpretation is preferred, and implies that this part of the Barents Sea was not glaciated during the Early and early Middle Weichselian. An alternative interpretation not considered favoured by the data, is that seismic unit F was deposited during a Middle Weichselian glaciation (Isotope stage 4? (74-59 ka according to Mangerud in prep.)).

The ages assigned above confirm the correlation made by Hald et al. (in prep.) who assign a late Middle - Late Weichselian age to a 50-100 m thick succession covering large parts of the central, southern Barents Sea. Our results further suggest that 50-100 m of sediments probably have been deposited on the upper slope since 30 000 BP. Most of this deposition probably occurred prior to 13 000 BP, thus implying a very high sedimentation rate within a large area. Our dating of seismic unit D further implies that partly more than 1000 m of sediments were deposited during the last approximately 200 000 years on the upper slope (at 73°30'N and 73°N respectively). About 70% of a succession suggested by Vorren et al. (in prep.) to have been deposited during the last 0.8 Ma seems therefore to be less than 200 000 years old. These ages also imply a very high rate of glacial erosion in the sediment source area. This is further discussed in Section 7.3.

Our results also conclude the discussion regarding the extent and age of the last ice sheet covering the deep outer Barents Sea. Above we have shown that seismic unit G and probably also seismic unit F, were deposited by a late Weichselian ice sheet. The glaciotectonic complex described in Chapter 8 rests on the unconformity between units F and G and reaches as deep as 550 m below present sea level. Hence, grounded ice must have been present at that depth in outer Bjørnøyrenna during the late Weichselian. In Section 7.2 the sediments of seismic units F and G are preferably interpreted as till. Further, a moraine ridge expressed on the seabed about 50 km to the south of our study area (Elverhøi & Solheim 1983) is formed on the surface of unit G, probably by ice push. This shows that grounded ice extended this far west also at the very termination of unit G time. The evidence therefore suggests that grounded ice existed in the area during large parts of unit F and G times (Middle - Late Weichselian).

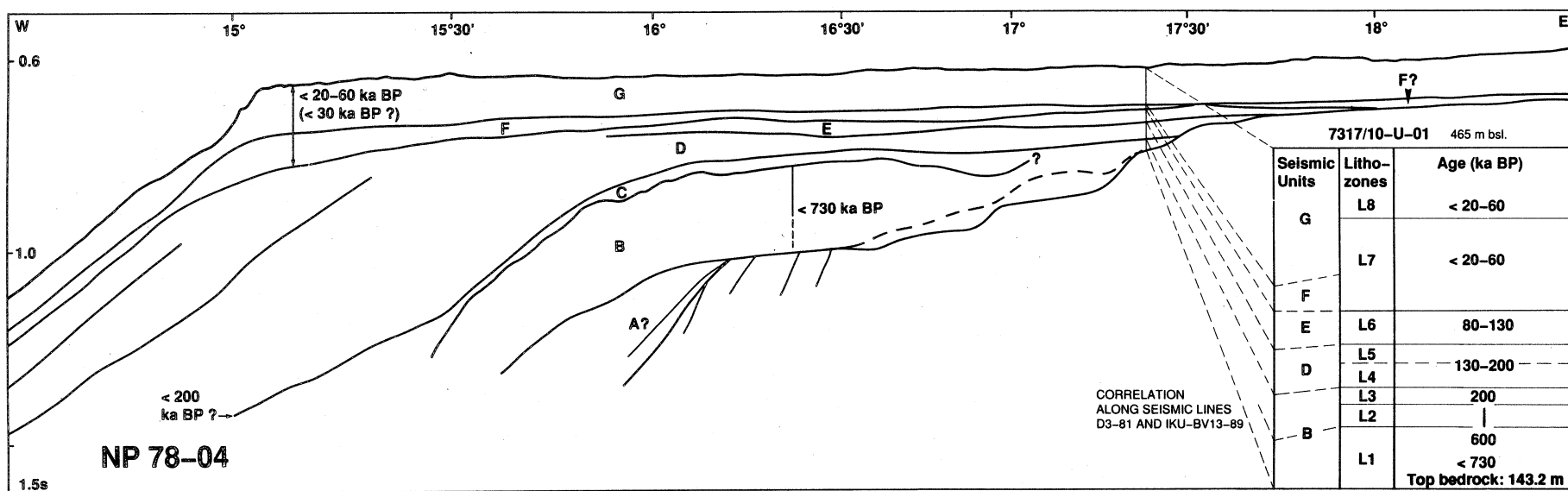


Figure 7.1

Interpretation of a seismic line at 73°N. Seismic units are correlated to the stratigraphy at site 7317/10-U-01. Ages of the seismic units are indicated.

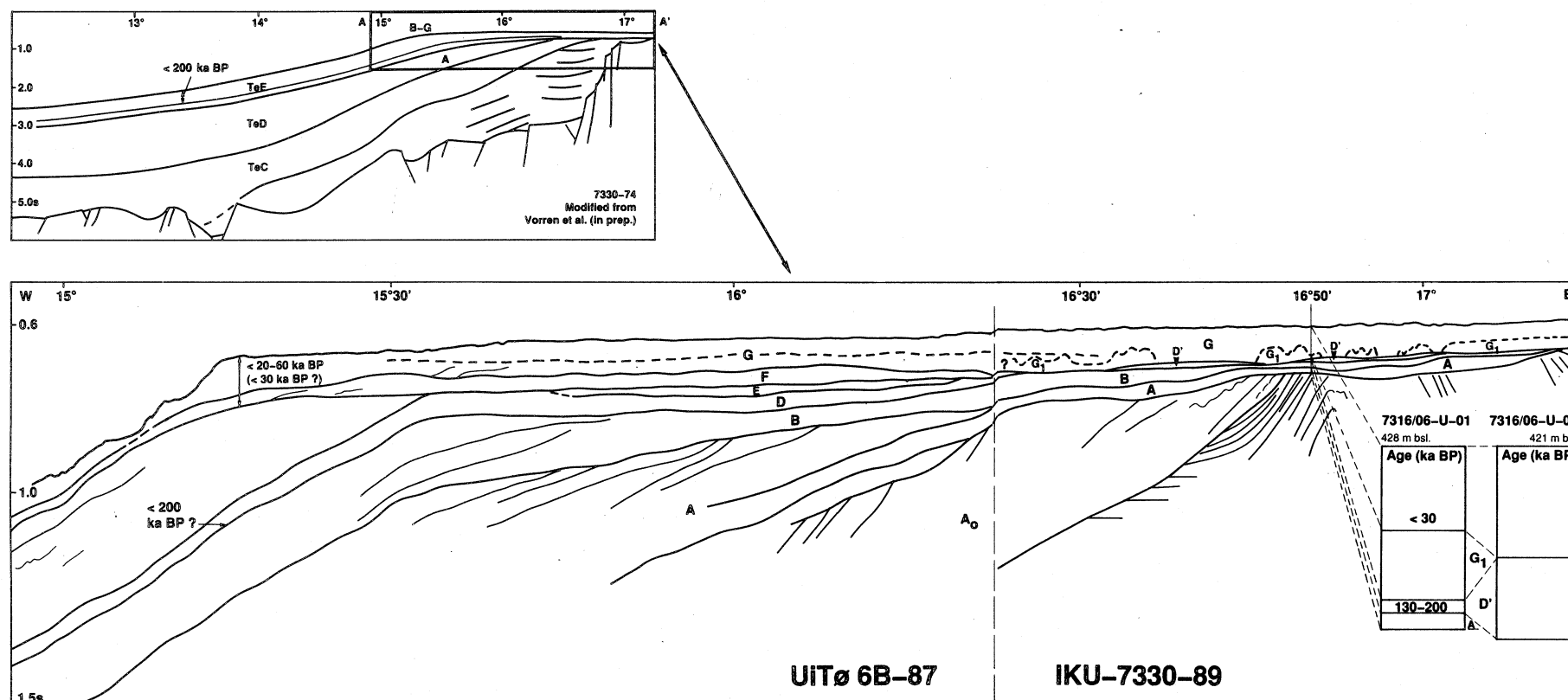


Figure 7.2

Interpretation of seismic lines at 73°30'N. Seismic units are correlated to the stratigraphy in boreholes 7316/06-U-01 and -02. The seismostratigraphy of Vorren et al. (in prep.) is included in the top of the figure, supplied with our datings.

7.2 Origin and genesis of the sediments

The clast composition of the sediments cored in the 1989 shallow drillings is strongly dominated by sedimentary rocks. Although statistical work is not done, it is clear that metamorphic rock fragments occur only in a few places. The sediments are therefore clearly sourced by erosion mainly on the continental shelf. The granulometric composition is that of a muddy diamicton, except from in the lower part of borehole 7316/06-U-01 which is characterized by a poorly sorted gravelly sand, and the sediment of the acoustically stratified unit E, which partly is a silty clay with only occasional clasts. Laminated sediments were found at about 70 m and 100 m in borehole 7317/10-U-01. Otherwise fissile, sheared and folded, sediments are typical. Massive, structureless sediments also occur. In lithozone N2 in borehole 7316/06-U-01 clast fabric was observed. Glacial striation is found on a number of clasts.

All the cored sediments are classified as glacialigenic. A possible exception is part of the sediments in the acoustically stratified unit E, which may be classified as marine mud, but the few clasts indicate a very distal glaciomarine environment. The soft nature, granulometric composition, sedimentary structures, and microfauna all together suggest that seismic unit E comprises marine sediments with a varying influence of glaciomarine conditions.

The sediment with high gravel content in lithozones N1 and N2 in borehole 7316/06-U-01 is interpreted as till. Lithozone N1 may, however, be influenced by glaciomarine processes washing away the fines. Alternatively, the very high sand content of this lithozone may reflect a local sandy bedrock as the source for the till.

The nonstratified muddy diamictons that dominate in all wells is the most difficult sediment to conclusively interpret the genesis of. These diamictons are associated with a structureless or chaotic, discontinuous seismic signature, and may be interpreted as either glaciomarine sediments or tills. The fossil content shows that parts of the sediments have undergone one or more glaciomarine or marine phases. On the other hand, these sediments are clearly sheared and deformed, probably by an ice sheet or ice bergs.

The seismic records indicate that the southern boundary of the glacio-tectonic structure is gradational. This suggests that the sedimentation

southwards grades laterally from a glaciotectonic deformation of the substratum to deposition of till occasionally with inclusions of rafts of pre-existing sediments. Hence, till deposition probably dominates. The interpreted age of seismic units G and F implies a depositional rate in excess of 4 m/ka. The mechanism of transport and deposition may be of the subglacial soft till deformation type as outlined by e.g. Alley et al. (1987). Alley et al. (1987) showed that with reasonable assumptions regarding ice velocity and thickness of deforming zone, subglacial deformation may cause such high rates of sediment deposition within wide areas.

7.3 Glacial erosion

The ages assigned to seismic units D, E, F and G indicate that 350 m to more than 1000 m of sediments were deposited during the last approximately 200 000 years on the upper slope (at 73°30'N and 73°N respectively). About 70% of a succession suggested by Vorren et al. (in prep.) to have been deposited during the last 0.8 Ma seems therefore to be less than 200 000 years old. Vorren et al. (in prep.) evaluate the source area for these sediments, and if we accept their assumptions of source and sink areas and assume our revised age estimates for the upper 70% of this succession, this gives an average erosion rate of 0.5 km/Ma during the last 0.2 Ma.

Our results further suggest that 50-100 m of the sediments probably have been deposited on the upper slope since 30 000 BP. Most of this deposition occurred prior to 13 000 BP, thus implying a net erosion rate of 1.2 km/Ma during the last stadial (17 000 years). Vorren et al. (in prep.) point out that their indicated volumes for the upper units in the clastic wedge (e.g. the unit they suggest to be younger than 0.8 Ma) may have been given too low values. An adjustment to higher values of their "0.8 Ma unit" would cause a corresponding increase in the erosion rates of 0.5 km/Ma and 1.2 km/Ma deduced above.

The erosion rate for the last glaciation (1.2 km/Ma) is further given without accounting for the volume of sediments deposited on the shelf during this period. These sediments may be considered to be "in transit" between bedrock erosion and final deposition. Any increase in the amount of "sediments in transit" from the end of one glaciation to the end of the next should be accounted for in the estimate of erosion caused by the latter glaciation. The data from the present project (the preservation and burial of unit E) suggest that there has been a net gain of sediments in

transit on the outer shelf. It is, however, not known whether this holds for the entire Barents Sea, and the erosion rate of 1.2 km/Ma is maintained.

In Table 7.1 a number of reported rates of glacial erosion are summarized. Our inferred rate of glacial erosion (net erosion rate of 1.2 km/Ma during a glaciation) is comparable to erosional rates at Kongsvegen, Svalbard estimated by Elverhøi et al. (1980). They are three times the rates in the Ice stream B catchment area in West Antarctica inferred by Alley et al. (1987) and higher than found for many Norwegian glaciers eroding metamorphic rocks (Kjeldsen 1981). A number of studies, however, suggest values above 2 km/Ma, and two results from Alaska conclude with erosion rates as high as 19 km/Ma and 30 km/Ma. Soft sediments with low erosion resistance were probably exposed during the early part of the glacial erosion in the Barents Sea, and the water may have been significantly shallower. A net erosion at a rate of 1.2 km/Ma during glaciations may therefore be considered reasonable, and is for reasons discussed above, probably a conservative estimate. In contrast to glacial erosion, subaerial erosion in the Arctic is at present two orders of magnitude lower. Holocene erosion rates in Linnédalen, Spitsbergen (mainly subaerially exposed) are found to be about 15 m/Ma (Svendsen et al. 1989).

Vorren et al. (in prep.) consider from volumetric considerations that possibly 1.2 km has been eroded in the southern Barents Sea during the last 30 Ma. Combining their volume estimates and source area assumptions and the recent results on the stratigraphy of the clastic fan in front of Bjørnøyrenna (Eidvin & Riis 1989), implies an average erosion in the southern Barents Sea of about 0.8 km since about 2.5 Ma. This implies an average erosional rate of 0.32 km/Ma. Combined with the net erosion rate of 1.2 km/Ma during the last glaciation inferred from the dating of seismic units F and G, it could be suggested that grounded ice has occurred in the southern Barents Sea during 25% of the last 2.5 Ma. This proportion actually compares reasonably with the cumulative duration of cold peaks in the pattern of oxygen isotope variation in planctonic foraminifera (e.g. Denton et al. 1986, figure 5). The accumulated duration of all oxygen isotope peaks of similar signature as the late Weichselian glaciation (30-13 ka) summarized for the last 400 ka suggests that similar sized glaciations occurred during 27% of this period. This correspondence is probably rather fortuitous, but may taken as an indication that the estimated values for erosion and net erosion rates grossly are in agreement.

In light of our results on the glacial stratigraphy, it seems probable to accept the Late Pliocene - Pleistocene age of the clastic wedge in front of Bjørnøyrenna as suggested by Eidvin and Riis (1989). It also implies a major erosion phase during the last 2.5 Ma.

Table 7.1 Estimated glacial erosion rates. (Partly adapted from a review by Drewry 1986) A: based on measurement of suspended sediment transport. B: based on suspended and bed load sediment transport. C: based on subglacial till flux.

Area	Erosion rate (mm/a) (=km/Ma)	Source
A:		
Muir, Alaska	19.0	Reid (1892)
Muir, Alaska	5.0	Corbel (1962)
Hidden, Alaska	30.0	Corbel (1962)
Engabreen, Norway	5.5	Rekstad (1911-12)
Storbreen, Norway	0.1	Liestøl (1967)
Heilstugubreen, Norway	1.4	Corbel (1962)
Hoffellsjökull, Iceland	2.8 - 5.6 (max.)	Thorarinsson (1939)
Kongsvegen, Svalbard	1.0	Elverhøi et al. (1980)
St Sorlin, France	2.2	Corbel (1962)
Imat, USSR	0.9	Chernova (1981)
Ajutor-3, USSR	0.7	Chernova (1981)
Fedchenko, USSR	2.9	Chernova (1981)
RGO, USSR	2.5	Chernova (1981)
B:		
Nigardsbreen, Norway	0.165	Kjeldsen (1981)
Engabreen, Norway	0.218	Kjeldsen (1981)
Erdalsbreen,	0.313	Kjeldsen (1981)
Austre Memurubre, Norway	0.313	Kjeldsen (1981)
Vesledalsbreen, Norway	0.073	Kjeldsen (1981)
C:		
Ice stream B, Antarctica	0.4	Alley et al. (1987)

8. A LARGE GLACIOTECTONIC MEGABLOCK COMPLEX IN OUTER BJØRNØYRENNÅ, SOUTH-WESTERN BARENTS SEA

8.1 Brief introduction to glaciotectonism

Glaciotectonics is a fairly specialized field in geology - even in Quaternary geology. A brief, general introduction to the phenomenon is therefore given below. This introduction is partly based on a manuscript in preparation (Sættem in prep.) and partly on Aber et al. (1989).

Aber et al. (1989) defined glaciotectonism as " ... glacially induced structural deformation of bedrock and/or drift masses as a direct result of glacier-ice movement and loading". Descriptions of glaciotectonic processes and structures in onshore areas are abundant in the literature, and a comprehensive bibliography by Aber (1988) includes contributions dating back to 1886. Glaciotectonism is most common in the outer zones of the glaciated areas in both North America and northern Europe. These areas are mainly underlain by Mesozoic and Tertiary sedimentary rocks. The type of substratum deformed and displaced by glaciotectonism includes in addition to Quaternary sediments, sedimentary rocks of Tertiary, Mesozoic and Paleozoic age.

Glaciotectonism includes both shearing and deformation of sediments and sedimentary rocks as well as displacement of small to large slabs or floes. Table 8.1 reviews glaciotectonic landforms (Aber et al. 1989) indicating both typical dimensions and type of deformed material.

Megablocks:

The glaciotectonic structures encountered in the shallow drillings southwest of Bjørnøya in 1989 are considered to be of the megablock type in Table 8.1. A further review of this type of structures is given by Aber et al. (1989). From this review the following characteristics are extracted:

- Most megablocks consist of poorly to moderately consolidated Mesozoic or Cenozoic sedimentary strata.
- All megablocks have some signs of deformation.

Table 8.1 Basic characteristics of constructional glaciotectionic landforms. After Aber et al. (1989).

Landform material	Height (m) morphology	Area (km ²)	Primary	Primary
Large composite ridges	100 - 200	20 - >100	Bedrock	Subparallel ridge and valley system. Arcuate in plan.
Hill-hole pair	20 - 200	<1 - >100	Variable	Ridged hill associatd with source depression.
Small composite ridges	20 - <100	1 - >100	Quaternary strata/ drift	Subparallel ridges and valley system. Arcuate in plan.
Cupola hill	20 - >100	1 - 100	Variable	Smoothed dome to elongate drumlin with till cover.
Megablock	0 - <30	<1 - 1000	Bedrock	Often concealed, flat buttes or irregular hills.

- Megablocks are often thin (<30 m) compared to their lateral dimensions.
- They are often difficult to distinguish from hills formed by bedrock outliers, and this may result in erroneous stratigraphic work.

Some megablocks have been transported subglacially for more than 300 km (Jahn 1950, Ruszcynska-Szenajach 1976, Stalker 1976). They were then transported frozen to the base of the ice. Large scale glaciotectionic thrusting requires some sort of preferred level of decollement in the subsurface. Bluemle and Clayton (1984) studied glacial thrust features in North Dakota and concluded that: "Most of the individual ice thrust features that have been recognized are located over discrete aquifers, and the sizes and shapes of the thrust features are dependant upon the sizes and shapes of the aquifers". This suggests that presence of water and water pressure is important. Interbedded loose, permeable sand and impermeable clay is one favourable condition for this process.

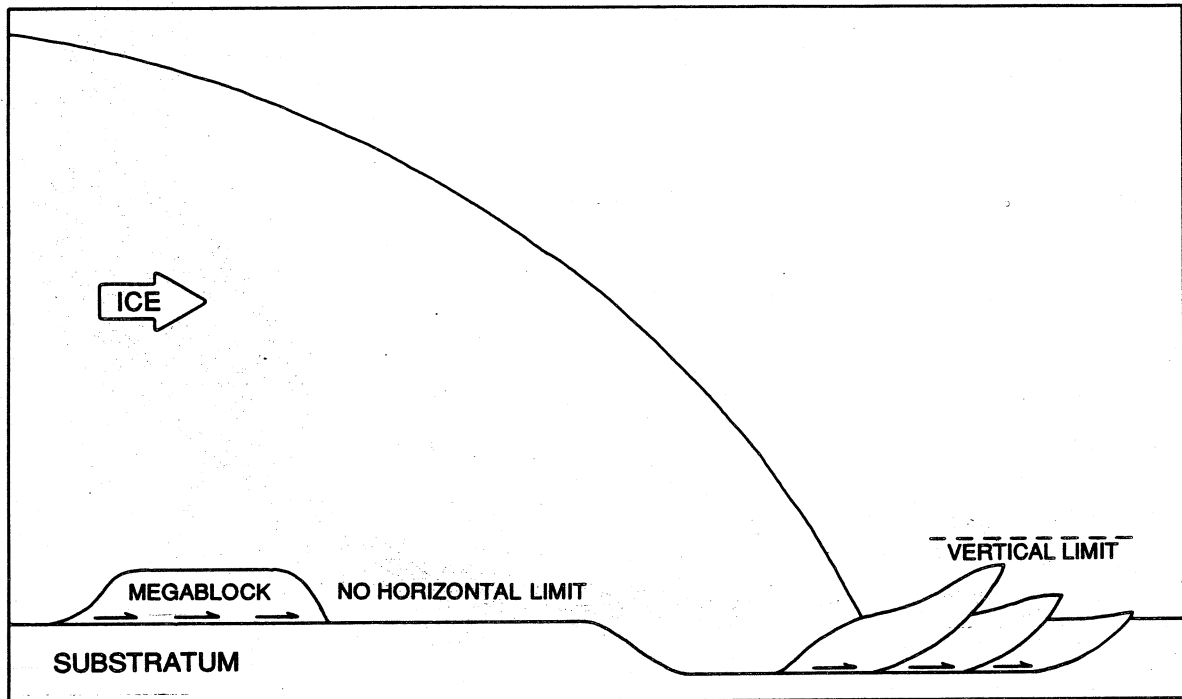


Figure 8.1 Schematic diagram of displacement of thrust megablocks. After Aber et al. (1989).

The first description in the literature of glaciotectionics in offshore deep water settings, except from ice push influenced moraine ridges (e.g. Bugge et al. 1978, Solheim and Pfirman 1985; Boulton 1986; Solheim in prep.), is given by Sættem (in prep.). He described structures on the seabed about 1-1.7 km³ in size, which he interpreted as glaciotectionic structures of the hill-hole type (Bluemle 1970, Clayton & Moran 1974) formed by ice displacing material to form isolated hills downstream of the source depressions ("holes"). Sættem (in prep.) further inferred the possible occurrence of a number of buried glaciotectionic structures influencing both Quaternary sediments and Tertiary sedimentary rocks. The biggest of the structures exemplified was illustrated by a sparker record across a depression about 100 ms (two way travel time) deep and 12 km wide, cutting into possible Eocene sediments. The displaced Tertiary sediments may be completely sheared and transformed into a till or may at the other extreme exist as a large megablock of more or less intact sedimentary rock.

The latter example illustrates two important points:

- 1) Glaciotectionism is a very effective erosional process. Locally (that is up to the scale in the order of more than 10 x 10 km) up to 10 x 10 km 100 m of bedrock may be stripped off instantaneously in a geologic timescale sense. The bedrock relief created by the glaciotectionism will

be less resistant against erosion than a smooth surface, and a generally enhanced erosion is a likely result.

- 2) Displaced and buried floes of rocks or unconsolidated sediments represent pitfalls in borehole stratigraphy, as not only microfauna, but also intact rock may occur stratigraphically out of place.

8.2 Description of the glaciotectonic complex

8.2.1 Summary and interpretation of borehole data

The glaciotectonic structure was penetrated by borehole 7316/06-U-01. The stratigraphy of this borehole is outlined in Section 6.3 and is divided into five lithozones. Top bedrock was penetrated at 65 m below seabed, and is overlain by a gravelly sand interpreted as a till. This zone is overlain by another till comprising a silty, sandy, gravelly clay. At 54.13 m a sharp contact between this till and consolidated, but deformed sedimentary rocks was cored, and cores of sedimentary rocks were recovered up to 39.0 m. A sandy interval is assumed between 39.0 m and 29.3 m, based on samples at the top and base of this interval, comments from the driller, and petrophysical log data. Two samples between 29.3 m and the seabed comprise silty, sandy clay, with some fine gravel. Fissility is observed at 19 m, and the sediment may be regarded as a till or a reworked glaciomarine sediment.

Biostratigraphy assign a mid Cretaceous age to the rocks between 54.13 m and 39.0. Amino acid ratios from the till below these rocks represent a late Pleistocene age, and the boundary between the till and the Cretaceous rocks is seismically correlated with an unconformity which in borehole 7317/10-U-01 is dated to mid-late Weichselian. The sedimentary rocks are therefore clearly allochthonous, and are interpreted as a glaciotectonic megablock (Aber et al. 1989), which probably extends to 29.3 m.

The lithology of the consolidated interval (54.1-39.0 m) is shown in Figure 8.2, and further details are given in the Main Report, Section 3.3.8. In short, a lower interval consists of light grey calcareous sandy-silty claystone - which probably may be considered as a marl. Above this rock a grey, silty shale was cored, and this rock is overlain by a mottled greenish-reddish, partly greyish, glauconitic sandstone.

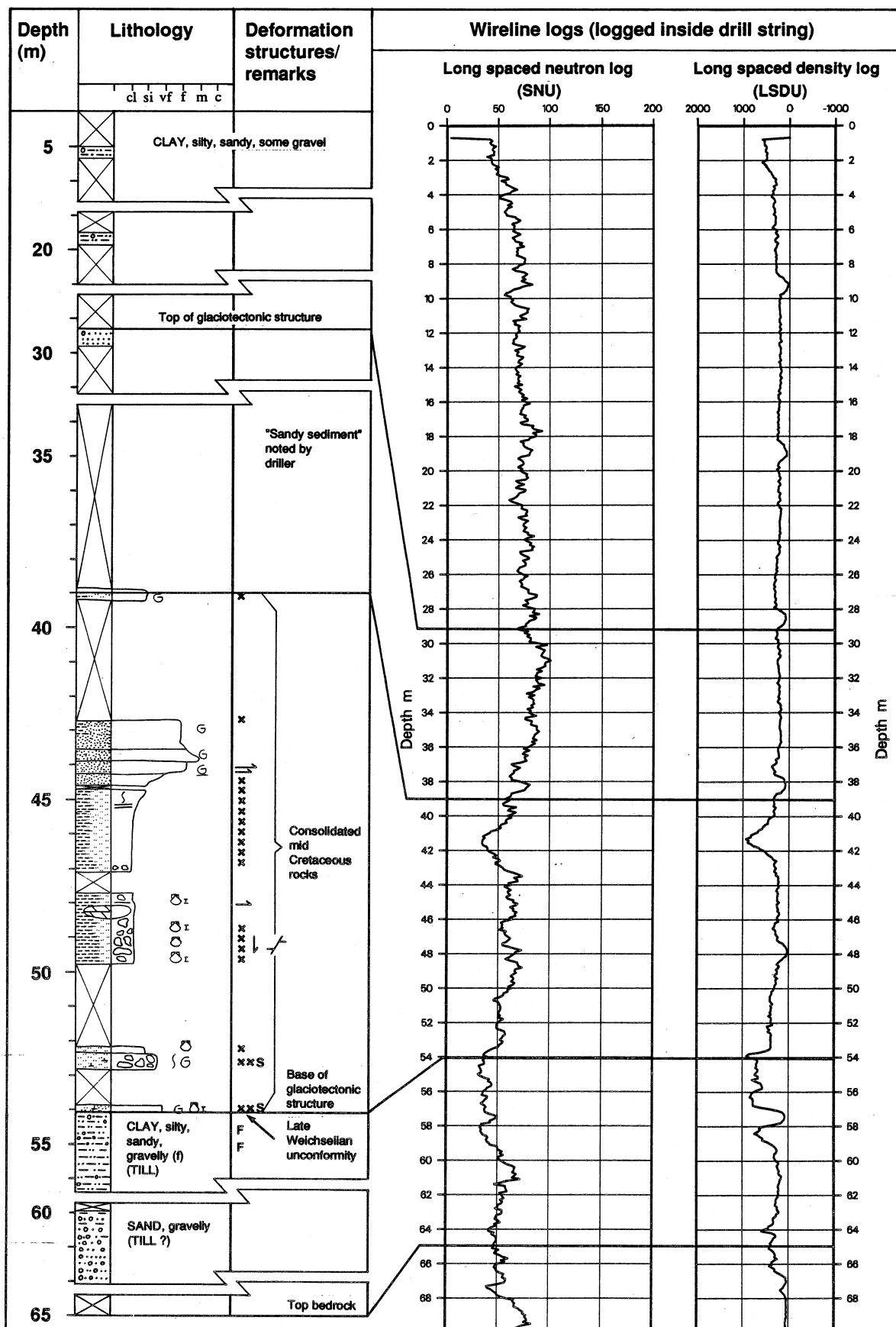


Figure 8.2

Lithology and structures of the cored megablock in borehole 7316/06-U-01. The long spaced neutron density log is obtained through the drillstring. Log motifs and log values can therefore not be used directly. The log, together with the samples at 29.8 - 29.3 m and 39.2 - 38.9 m, and information from drilling is still taken as an indication that the glaciotectionic structure extends upwards to 29.3 m.

Prisms of *Inoceramus* are common in this core. It should be noted that these rocks are allochthonous and probably transported a long distance at the base of a sliding ice sheet. They may therefore not be correctly stratigraphically positioned or oriented. Slickenside surfaces were observed at a lithologic boundary at 44.2 m, indicating that this is a tectonic boundary.

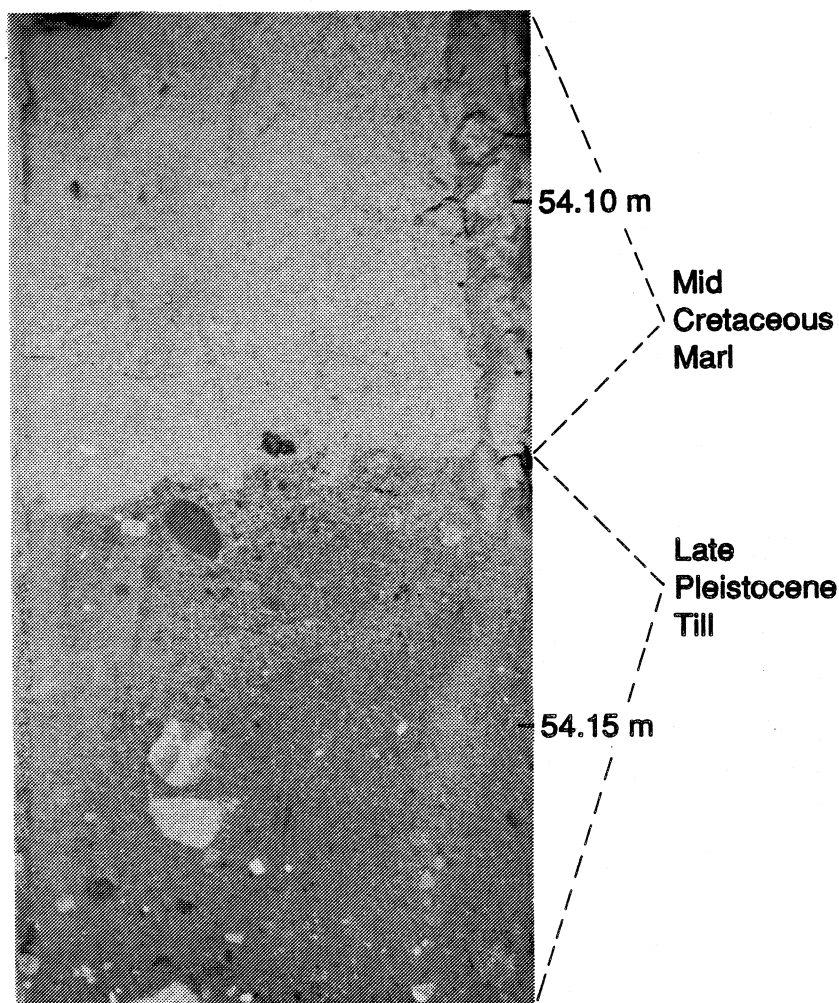


Figure 8.3 *Tectonic boundary between Pleistocene till (below) and allochthonous Cretaceous sedimentary rocks (marl). Fragments of the overlying rocks are found sheared into the till below.*

A light grey-light olive grey sand was cored at 29.8-29.3 m and 30.0-38.9 m. The lower core may represent cuttings or caving, but the upper core was recovered immediately after a marked drop in drilling fluid pressure, and is probably in situ. Low fluid pressure and what the driller commented as "sandy conditions" continued down to 39 m, with a slight drop in penetration rate at 35 m. The wireline logs are included in Figure 8.2. The logs were run inside the drillstring, and because the signal is damped by the drill string and the logs may be influenced from variations in hole geometry (i.e. zones of caving and zones of hole collapse), direct inter-

pretation of lithology or porosity cannot be made. Whatever the reasons are for the log patterns, however, they are considered to indirectly indicate that this interval comprises a different lithology from what was found above and below. On this basis it is considered a part of the glaciotectionic structure.

Biostratigraphic studies are made on the upper sand core. The most common microfossils are *Inoceramus* prisms and recrystallized specimens of *Radiolaria* and the sponge *Geoida*. Rare specimens of *Melonis affine* and *Neogloboquadrina pachyderma* (sin.) are also found, and the latter is indicative of a glaciomarine influence. Dinoflagellates also suggest a reworked and mixed microflora. The reworking may have occurred in several episodes during the Tertiary, but may also be the effect of glacial reworking prior to or during the glaciotectionic event. In conclusion, we consider the upper, assumed sandy interval as part of the glaciotectionic structure. The age of the main constituent of this interval (39.0-29.3 m) is unknown, and it cannot be ruled out that this interval is transported from a different source than the clearly mid Cretaceous rocks.

The core is partly strongly brecciated/deformed, and core loss intervals (53.91-52.85 m, 52.07-49.87 m, 47.74-47.20 m and 42.75-39.2 m) may represent zones that were too fractured to allow core recovery.

The deformation structures indicated in Figure 8.2 are considered not to have been induced by drilling (e.g. Tibbitts & Radford 1985) and are probably formed by tectonic processes prior to or during the glaciotectionism. A nearly vertical zone of fault gouge is found at about 49.5 m. Here the rock is partly crushed to clay with angular fragments of intact rocks. This material was of moderate stiffness before drying out, but the deformation is considered to have occurred in situ, before the glaciotectionic event. The character of the fault gouge possibly indicates that the rock was at moderate depth when faulted.

The observed fracturing and horizontal slickenside planes are most likely a result of the glaciotectionic movements. It is clear that the fracturing is most pronounced in the lower, fine-grained part (i.e. below 44.30 m). In the interval 52.07-49.87 m the drilling penetration rate was very high. This may indicate that this interval comprised weak, cohesionless sediment, possibly of the marl type sediment recovered below this zone. This marl may have acted as a zone of glaciotectionic decollement.

8.2.2 Seismic mapping

A seismic section across sites 7316/06-U-01 and -02 is shown in Section 6.3. The allochthonous rocks penetrated in borehole 7316/06-U-01 in the interval between approx. 29 m and 54 m corresponds to a hummocky seismic subunit within seismic unit G. This subunit pinches out to the south of borehole 7316/06-U-02, and no signs of bedrock rafts were found at this site. It is therefore assumed that the glaciotectonic structure corresponds to the hummocky seismic subunit. Comments to the mapping of the unit are given in Section 4.2.3, but a few remarks are given below.

The complex is mapped as seismic subunit G₁ and occurs as a discontinuous complex of hummocky, acoustically chaotic deposits which rest on the base of unit G.

The geometry of the unit is shown on the map in Figure 4.1 and in the interpreted sections (Figure 4.3). Different acoustic expressions are shown in Figures 4.4, 4.5 and 4.7 which also illustrate the hummocky and discontinuous character of the unit. In several occasions it is observed that the presence of isolated hummocks correspond to acoustic pull up of reflections from surfaces below (Figure 4.7). This indicates that the hummocks comprise bodies of higher velocity than the surrounding sediments. Such "pull ups" are found beyond the mapped southern boundary of the subunit. The southern and western boundaries of the unit are poorly defined on the seismic records (gradational?) while the northward boundary on most profiles is well defined. An area in the east is considered a part of the complex, but is probably a separate body. Maximum height of the hummocks above their sub-surface is about 55 ms.

8.3 Origin of the displaced rocks

The glaciotectonic megablock complex was penetrated in borehole 7316/06-U-01 where it was found to comprise mid Cretaceous rocks. In the following it is assumed that a significant part of the complex consists of such rocks.

It is of interest to find out where the possible source areas for the rocks are. This may tell something about ice flow direction, and also geographically locate the information regarding bedrock age and sedimentary environment. Some megablocks are documented to have been transported subglacially for more than 300 km (Jahn 1950, Ruzsycynska-Szenajach 1976, Stalker 1976).

The source area must therefore be searched for in a wide area.

The megablock complex is interpreted to occur within unit G (Chapter 6), although minor bodies may occur also below the base of this unit (within unit F). The megablock complex is shown on the map in Figure 8.4. The map also shows where Quaternary sediments older than unit G are mapped with confidence. This part of the map can be ruled out as possible source for the displaced bedrock unless the transport has occurred in several steps. This is regarded as unlikely, and is not considered in the following. A map of subcropping bedrock in the area as it is shown in the draft version of the National Atlas of Norway is included in Figure 8.4. The rocks penetrated in borehole 7316/06-U-01 must originate from an area where Cretaceous rocks are exposed at the base of unit G. Within this intersection three local areas denoted 1, 2 and 3 on the map, are considered as possible source areas. Comments to each area are given below.

Area 1 is located in the vicinity of major subcropping fault complex which is the westward boundary of subcropping Cretaceous rocks. Elongate depressions on the base Quaternary unconformity are found to partly coincide with subcropping fault zones. It cannot be ruled out that subcropping Cretaceous rocks occur in fault blocks within this area, and thus that the depressions are candidates as sources for the cored allochthonous rocks. There are, however, some observations that point against this: The bedrock strata have a significant dip within the areas generally denoted area 1. This is unfavourable for displacement of large slabs of rocks which most easily are deformed along bedding planes. Secondly, as the floe complex is mapped seismically it does itself cover the most pronounced (and closest) source depression. Thirdly, the volume of the glaciotectionic complex is clearly far greater than the volume displaced from the depressions. With the supposition that a major part of the glaciotectionic complex consists of Cretaceous rocks, it is suggested that at least part of the complex has another and more distant source.

Areas 2 and 3 are identified by the acoustic character of the base Quaternary unconformity. Regionally this unconformity is represented by a high amplitude, smooth reflection on shallow seismic data. In some areas, however, the seismic signature of this surface is that of a weak and often irregular reflection, suggestive of a "blocky and tectonized" surface. This signature was for example observed at the base of the buried glaciotectionic depression noted by Sættem (in prep.). Areas 2 and 3 are characterized by this type of morphology at the base Quaternary unconformity.

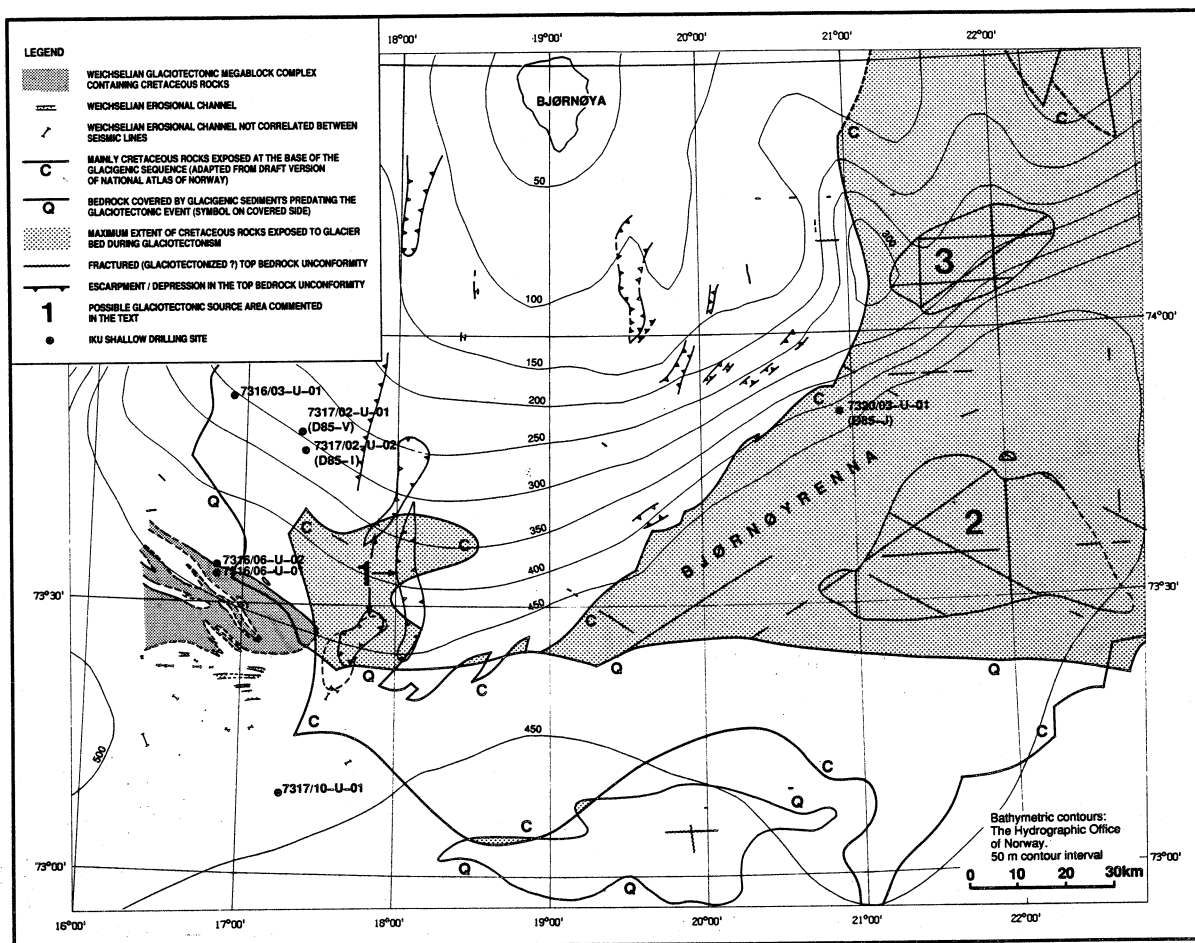


Figure 8.4 Location of a glaciotectionic megablock complex in western Bjørnøyrenna penetrated in borehole 7316/06-U-01. The cored rocks were dated to mid Cretaceous, but were probably transported to their present position during the late Weichselian (13 000 - 30 000 years ago). Possible source areas for the displaced rocks must be located in areas where Cretaceous rocks were exposed to the ice sheet at the time of formation (shaded). Candidate source areas denoted 1, 2 and 3 are discussed in the text.

The bedrock strata in this area are more or less flatlying and may be weak to horizontal simple shear if the rock consists of interbedded claystone/siltstone, sandstone and marl as found in core 7316/06-U-01. The boundaries of these areas are drawn with reasonable confidence, but the quality of the shallow seismic data in the area is highly variable, and partly poor. A wider occurrence of this type of seismic signature of the base Quaternary unconformity is therefore possible. Isolated observations on some seismic lines may suggest this.

For the origin of the cored allochthonous Cretaceous rocks we conclude that the areas denoted 1, 2 and 3 in Figure 8.4 are three likely source areas.

Area 1 is the closest candidate. It is, however, itself partly covered by the structure, and is not likely to be the only source area. Areas 2 and 3 are more comparable in size to the megablock complex. Although they are located farther away, the distance is only in the range of 3 - 4 times the width of the complex itself. If a major part of the glaciotectionic complex consists of middle Cretaceous rocks, one may therefore be inclined to suggest that areas 2 and 3 are more likely source areas than area 1. The confidence of this conclusion is not strong, and it can not be ruled out that all signs of the true source area are swept away by later erosion.

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ENCLOSURE 1

PALEOMAGNETIC POLARITY - BARENTS SEA

SITES 7317/10u01, 7316/03u01, 7316/06u01 AND 7316/06u02

INTERNAL REPORT

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SUMMARY

The paleomagnetic polarity of 78 samples from sites 7317/10u01, 7316/03u01, 7316/06u01 and 7316/06u02 in the Barents Sea have been determined. After demagnetization (by alternating field or thermal) a characteristic remanent magnetization (ChRM) of normal polarity could be defined in 64 samples. The sampled sediment sequences thus were deposited during Brunhes normal polarity chron (0 - 730 ka B.P.);

This conclusion stratigraphically concerns site 7317/10u01 down to about 140.21 m, site 7316/03u01 down to 7.31 m, site 7316/06u01 down to 19.51 m and site 7316/06u02 down to 31.81 m depth. Lower stratigraphic levels have not been investigated, or hold a paleomagnetic signal of poor quality.

Two paleomagnetic excursions may have been uncovered in the upper part of site 7317/10u01.

BULK MAGNETIC SUSCEPTIBILITY

The bulk magnetic susceptibility (BMS) reflects the types and concentrations of magnetic minerals. It was determined for each sample on a highly sensitive induction bridge (KLY-2). The BMS values vary between 169 and 668 $\times 10^{-6}$ (SI units), usually exceeding 300 $\times 10^{-6}$.

The susceptibility results will not be discussed any further, but are included in Table I in case of future lithostratigraphic applications.

DEMAGNETIZATION AND ChRM

The natural remanent magnetization (NRM) of a sediment ideally reflects the direction of the geomagnetic field at the time of deposition. This primary depositional remanent magnetization (DRM) may be influenced by processes inducing secondary magnetizations of viscous and/or chemical origin, or by any deformation of the sediment in nature and during sampling. Thus the NRM may be composed of two or more magnetic components. By stepwise demagnetization of a sample, the direction and intensity of all sub-components in the sample may be uncovered. The component with highest magnetic stability will be chosen as the characteristic remanent magnetization (ChRM), as it will most likely represent the syn-depositional DRM of the sediment.

Alternating field demagnetization was performed on 59 samples in progressively increasing fields up to 600 Oe (Table II). In general, the samples show definite magnetization directions with intensities decreasing gradually with increasing demagnetizing field. Magnetically "soft" components were removed from about 50% of the samples, but seldom (only for 7 samples) constitutes more than 50% of the NRM intensity.

For all but one sample (51) it was possible to identify a ChRM, and for about 50% of the samples this ChRM is carried by 100%

of the NRM intensity (table I). ΔDI , which indicates the angular precision of the calculated ChRM direction, is usually less than 10° and only once exceeds 20° (sample 73), indicating a high directional precision in the determination of the ChRM.

Several samples show directional scatter for fields above 400 Oe, indicating that an ARM (anhysteretic remanent magnetization) or VRM (viscous remanent magnetization) induced during demagnetization may dominate at these high fields. However, stable demagnetization directions at lower fields, and low residual intensities still made it possible to define a ChRM.

To verify the magnetopolarities uncovered after alternating field demagnetization, 8 dried samples from site 7317/10u01 were subjected to stepwise thermal demagnetization in a Schönstedt furnace at progressively higher temperatures (Table II). Above 250°C a dramatic increase in susceptibilities was observed for all samples, probably due to phase changes of the magnetic minerals. However, demagnetization directions up to 250°C allowed for a ChRM to be determined, confirming the ChRM found by alternating field treatment. This is exemplified by identical ChRM directions of sample 45 and 47 which are from the same level, and subjected to alternating field and thermal demagnetization (Table I).

A total of 11 samples have not been demagnetized due to low NRM intensities (samples 55 to 63), fragmented character (sample 50) or practical reasons (11).

MAGNETOPOLARITY

Results

Site 7317/10u01

The NRM directions are dominated by positive inclinations of more than 40°. 4 samples have negative or shallow inclinations (sample 3, 73, 8 and 25). Declinations are random, as expected for

internally unoriented samples.

ChRM directions confirm all the positive NRM inclinations. The shallow inclinations of samples 8 and 25 become steeper, while samples 3 and 73 at 25.61 and 32.30 m depth respectively, carry negative ChRMs (Table I). The high ΔDI of sample 73 is caused by fluctuating declinations, the inclination being clearly negative.

Site 7316/03u01

The three samples (48, 50, 51) show positive NRM inclinations, confirmed by the ChRM of sample 48. Sample 50 was too fragmented to be demagnetized by tumbling in the alternating field apparatus, and sample 51 shows a directional behaviour upon demagnetization which prevents the definition of any ChRM, and hence polarity.

Site 7316/06u01

The upper samples (52 - 54) show steep and positive NRM inclinations, confirmed by the ChRM directions.

The NRM inclinations show a highly scattered pattern below 39 m depth (samples 55 - 63) with intensities too low for reliable demagnetization treatment.

The diamicton covering the sequence of samples 56 to 63 was frozen before being sawed along its core-length. This may have influenced the remanent magnetization properties of these samples. The low NRM intensities prevent unambiguous determination of the polarities of samples 55 - 63.

Site 7316/06u02

The samples from site 7316/06u02 are dominated by positive inclinations, confirmed by the ChRM directions. Samples 65 and 66 show shallow/negative NRM inclinations. A negative, "soft" component is removed during demagnetization, resulting in positive ChRMs for both samples.

Discussion

The sites are located at 73°N, at which latitude a normal axial geomagnetic field has an inclination of 81°.

The positive ChRM inclinations which dominate the sediments, are greater than 50° for 82% of the samples. The observed scatter of inclination values may have several explanations;

First, at such high latitudes, the secular variation will give rise to inclinations significantly different from 81°, allowing for the registration of both steeper and shallower inclinations in rapidly deposited sediments.

Second, stratigraphically adjacent samples are expected to show almost identical ChRM inclinations. However, deviations up to 18° is observed, even more for samples 23 - 25 which were cut close to the outside of the core (on purpose to confirm the effect of core-surface deformation). Thus, even if the ChRMs show high directional stability and unambiguous polarity, the precision of the "recording-process" which should reflect the direction of the geomagnetic field during or shortly after deposition, gives rise to very local directional variations in these diamictos.

The results imply that the sediments sampled at the four sites, were deposited during Brunhes normal polarity chron (0 - 730 ka B.P.).

A reservation from this general conclusion is raised for the lower part of sites 7316/03u01 and 7316/06u01 where no ChRMs were identified.

The negative inclinations at site 7317/10u01 may represent paleomagnetic excursions (rapid, high amplitude directional

fluctuations of the geomagnetic field), which have occurred several times during the Brunhes chron. This seems strange for sample 73 where positive inclinations are registered close to the negative level. However, the depths of samples 70 - 80 which were sawed out later, were measured with a precision of ± 10 cm only, relative to the first sample series (Reidar Løvlie pers. comm.). In any case, spurious spot readings with negative inclination within the Brunhes are impossible to correlate to any specific excursion as long as the chronological frame of the actual stratigraphic level is too wide.

Table I. Paleomagnetic data for sites 7317/10u01, 7316/03u01, 7316/06u01 and 7316/06u02, showing the NRM (natural remanent magnetization) directions and intensities, ChRM (characteristic remanent magnetization) directions, angular precision (ΔDI), %intensity of the NRM and polarity. Bulk susceptibilities (susc) are given in SI units $\times 10^{-6}$.

SITE 7317/10u01	SAMPLE NUMBER	DEPTH (m)	dec	NRM inc	int mA/m	SUSC	dec	ChRM inc	ΔDI	%int	POLARITY
run											
1	1	7.21	1	44	5.6	350	334	51	6	103	+
2	2	15.23	216	66	17.0	310	214	67	4	100	+
"	71	15.34	250	76	11.2	356	179	76	6	76	+
"	70	15.54	232	75	7.7	295	242	60	8	74	+
3	3	25.61	297	-56	4.3	333	296	-43	9	94	-
4	74	32.11	64	84	13.1	370	69	83	5	100	+
"	72	32.25	28	61	15.5	462	27	61	6	100	+
"	73	32.30	324	3	4.7	402	301	-31	25	64	-
"	4	32.33	3	52	5.6	354	25	68	5	81	+
"	5	32.35	59	74	4.6	364	99	83	9	120	+
5	6	38.20	269	39	10.4	382	244	47	5	52	+
6	7	45.58	327	57	7.4	357	328	53	13	100	+
7	8	52.16	273	-11	8.9	386	269	23	5	39	+
9	9	70.16	183	62	4.6	304	140	64	10	77	+
11	10	77.75	350	64	104.3	668	350	63	6	100	+
"	11	77.82	347	72	73.3	sample not demagnetized					
14	12	83.43	91	70	22.3	392	94	66	4	87	+
16	13	89.56	225	74	22.9	434	219	74	6	100	+
17	14	93.25	29	60	13.6	563	40	67	9	101	+
19	15	99.55	25	78	63.0	627	63	76	3	38	+
20	16	102.47	327	87	2.8	169	168	74	14	38	+
21	17	103.12	124	74	7.3	327	121	74	12	100	+
22	18	107.33	184	76	2.5	210	204	78	17	100	+
23	19	109.91	338	65	8.6	303	330	63	9	100	+
"	20	109.93	159	77	8.3	329	222	67	5	46	+
24	21	112.61	26	75	10.7	328	25	77	6	100	+
25	22	114.23	281	46	7.3	302	291	48	10	79	+
"	23	114.25	312	67	4.6	304	317	68	12	100	+
"	24	114.25	269	40	4.4	297	273	43	13	100	+
"	25	114.25	338	9	3.7	266	200	44	13	70	+
"	26	114.41	226	64	12.0	309	232	62	7	100	+
"	27	114.43	250	67	10.3	275	246	62	5	63	+
26	28	117.41	281	66	8.9	303	278	62	12	100	+
"	29	117.43	293	45	8.7	300	288	44	10	100	+
"	30	117.57	180	81	7.4	337	187	84	14	100	+
27	31	118.23	335	61	7.5	338	336	59	13	100	+
"	32	118.25	309	62	5.4	279	315	60	9	88	+
"	33	118.48	328	67	8.1	354	330	62	10	100	+
30	34	126.07	322	79	1.0	537	7	71	7	85	+
"	35	126.14	235	53	2.3	274	231	51	6	100	+
31	36	129.21	60	78	10.9	383	58	75	2	77	+
"	37	129.23	303	64	9.3	360	5	73	0	42	+
33	38	132.24	270	80	5.1	421	62	87	8	110	+
"	39	132.37	318	77	5.7	374	180	80	7	55	+
"	40	132.39	346	60	2.9	304	356	63	6	83	+
34	41	134.72	261	49	6.0	382	259	46	6	83	+
"	42	134.74	106	62	8.1	367	114	62	13	100	+
35	43	137.61	318	69	5.9	370	312	65	13	100	+
36	44	140.08	290	46	10.3	387	286	45	8	100	+
"	45	140.19	24	70	25.3	548	33	71	8	100	+
"	46	140.20	22	63	27.5	500	28	62	4	84	+
"	47	140.21	30	74	24.2	492	31	74	1	100	+

Table I. Continued.

SITE		SAMPLE NUMBER	DEPTH (m)	NRM		SUSC	ChRM			POLARITY	
7316/03u01				dec	inc		dec	inc	ADI		Xint
run					int mA/m						
1		48	7.31	8	69	370	0	71	8	103	+
5		50	7.33	276	61	378	Fragmented sample				
7		51	31.50	82	36	423	Undefined ChRM				
SITE		SAMPLE NUMBER	DEPTH (m)	NRM		SUSC	ChRM			POLARITY	
7316/06u01				dec	inc		dec	inc	ADI		Xint
run					int mA/m						
1		52	5.24	127	75	369	131	76	3	100	+
5		53	5.26	98	70	309	56	73	5	74	+
2		54	19.51	251	57	336	274	76	18	138	+
5		55	39.07	30	-62	304	232 Samples show low NRM intensities				
11		56	54.36	254	73	225	234 and a scattered inclination pattern				
5		57	54.68	93	-8	232	209 (not demagnetized)				
5		58	54.94	302	74	234					
5		59	55.19	300	38	288					
5		60	55.30	330	22	236					
5		61	55.52	225	85	244					
5		62	55.63	329	-25	258					
5		63	56.11	284	-47	258					
SITE		SAMPLE NUMBER	DEPTH (m)	NRM		SUSC	ChRM			POLARITY	
7316/06u02				dec	inc		dec	inc	ADI		Xint
run					int mA/m						
1		64	5.22	276	56	337	278	54	4	100	+
2		75	19.52	146	76	379	170	60	9	50	+
5		76	19.64	25	58	457	7	81	2	54	+
5		65	19.84	99	9	347	94	42	15	25	+
5		66	19.86	37	-4	369	28	44	3	49	+
3		77	31.52	265	76	305	297	65	7	55	+
5		78	31.57	105	80	305	117	74	3	61	+
5		79	31.65	177	86	298	172	88	4	100	+
5		80	31.72	144	87	345	100	81	4	68	+
5		67	31.79	27	61	364	347	76	7	51	+
5		68	31.81	355	57	335	342	60	7	55	+

Table II. Demagnetization results for sites 7317/10u01 (site 1), 7316/03u01 (site 2), 7316/03u01 (site 3) and 7316/06u02 (site 4). Alternating field strengths are given in Oe, under the "temp" column.

The "temp" column-heading is marked by "x" for samples which are thermally demagnetized (5, 12, 20, 27, 36, 41, 46, 47), and the column in these cases indicate the temperature in °C for each step.

The NRM data for each sample is given in the temp 0 row.

Site 7317/10u01

SAMPLE:1 SITE: 1 (strike/dip: 0 180)

Vec	Temp	Dec	Inc	Int	XInt
1	0	1	44	5.57	100
2	10	347	51	5.49	98
3	50	336	53	5.74	103
4	100	334	53	3.73	67
5	150	331	52	3.56	64
6	200	331	58	3.20	57
7	300	326	57	2.25	40
8	450	128	65	0.47	8
9	600	298	60	0.52	9

SAMPLE:2 SITE: 1 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	XInt
1	0	216	66	16.98	100
2	10	214	67	14.88	88
3	50	208	68	11.78	69
4	100	206	69	7.24	43
5	150	201	69	6.36	37
6	200	205	67	5.49	32
7	300	207	69	3.68	22
8	450	246	54	0.72	4
9	600	171	59	0.42	2

SAMPLE:71 SITE: 1 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	XInt
1	0	250	76	11.23	100
2	50	194	82	9.23	82
3	100	187	78	8.52	76
4	250	173	77	7.12	63
5	360	153	81	4.23	38
6	460	282	82	2.40	21
7	560	119	46	1.43	13

SAMPLE:70 SITE: 1 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	XInt
1	0	232	75	7.72	100
2	50	241	69	6.05	78
3	100	245	62	5.75	74
4	250	260	60	3.94	51
5	360	245	60	2.12	27
6	460	287	60	1.49	19
7	560	321	52	1.03	13

Table II. Continued.

SAMPLE:3 SITE: 1 (strike/dip: 0 180)

Vec	Temp	Dec	Inc	Int	%Int
1	0	297	-56	4.30	100
2	10	115	-44	4.04	94
3	50	298	-39	3.42	79
4	100	303	-33	2.42	56
5	150	300	-32	2.13	49
6	200	306	-28	1.53	35
7	300	306	-32	1.36	32
8	450	293	-12	0.35	8
9	600	328	35	0.30	7

SAMPLE:74 SITE: 1 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	%Int
1	0	64	84	13.14	100
2	50	77	81	9.11	69
3	100	90	79	7.68	58
4	250	109	76	4.59	35
5	360	14	85	2.21	17

SAMPLE:72 SITE: 1 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	%Int
1	0	28	61	15.47	100
2	50	30	59	9.73	63
3	100	30	60	8.76	57
4	250	37	59	4.40	28
5	360	14	70	2.83	18
6	460	74	40	2.29	15
7	560	20	40	1.59	10

SAMPLE:73 SITE: 1 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	%Int
1	0	324	3	4.70	100
2	50	278	-38	3.01	64
3	100	286	-36	3.24	69
4	250	308	-51	1.25	27
5	360	231	-41	1.00	21
6	460	237	-63	1.37	29
7	560	191	-12	1.66	35

SAMPLE:4 SITE: 1 (strike/dip: 0 180)

Vec	Temp	Dec	Inc	Int	%Int
1	0	3	52	5.61	100
2	10	186	60	5.52	98
3	50	20	67	4.57	81
4	100	25	67	3.18	57
5	150	25	70	3.12	56
6	200	29	67	2.68	48
7	300	51	67	1.73	31
8	450	17	56	0.57	10
9	600	275	-33	0.11	2

SAMPLE:5 SITE: 1 (strike/dip: 0 180)

Vec	Temp X	Dec	Inc	Int	%Int
1	0	59	74	4.61	100
2	100	85	81	5.54	120
3	200	13	82	2.76	60
4	250	41	52	1.18	26

Table II. Continued.

SAMPLE:6 SITE: 1 (strike/dip: 0 0)					
Vec	Temp	Dec	Inc	Int	%Int
1	0	269	39	10.43	100
2	10	263	43	9.17	88
3	50	253	48	5.73	55
4	100	247	48	4.49	43
5	150	248	46	3.94	38
6	200	245	49	3.09	30
7	300	241	51	1.87	18
8	450	305	53	0.26	3
9	600	292	47	0.68	7

SAMPLE:7 SITE: 1 (strike/dip: 0 0)					
Vec	Temp	Dec	Inc	Int	%Int
1	0	327	57	7.41	100
2	10	331	55	6.51	88
3	50	331	68	3.74	50
4	100	339	84	2.54	34
5	150	311	88	1.94	26
6	200	184	85	1.46	20
7	300	53	73	1.24	17
8	450	241	76	0.20	3
9	600	46	15	0.27	4

SAMPLE:8 SITE: 1 (strike/dip: 0 180)					
Vec	Temp	Dec	Inc	Int	%Int
1	0	273	-11	8.89	100
2	10	276	-3	7.75	87
3	50	270	5	4.08	46
4	100	268	22	2.90	33
5	200	267	19	2.01	23
6	300	261	19	1.34	15
7	450	230	-27	0.27	3

SAMPLE:9 SITE: 1 (strike/dip: 0 0)					
Vec	Temp	Dec	Inc	Int	%Int
1	0	183	62	4.61	100
2	10	162	60	4.10	89
3	50	138	61	2.94	64
4	100	136	69	2.33	50
5	150	143	71	2.03	44
6	200	114	71	1.65	36
7	300	108	75	1.14	25
8	450	128	63	0.43	9
9	600	91	71	0.32	7

SAMPLE:10 SITE: 1 (strike/dip: 0 90)					
Vec	Temp	Dec	Inc	Int	%Int
1	0	350	64	104.34	100
2	10	350	62	102.99	99
3	50	350	61	76.50	73
4	100	352	64	28.34	27
5	150	358	69	23.11	22
6	200	354	70	19.42	19
7	300	355	66	14.57	14
8	450	350	57	9.59	9
9	600	354	54	6.37	6

SAMPLE:11 SITE: 1 (strike/dip: 0 0)					
Vec	Temp	Dec	Inc	Int	%Int
1	0	347	72	73.33	100

Table II. Continued.

SAMPLE:12 SITE: 1 (strike/dip: 0 0)

Vec	Temp X	Dec	Inc	Int	%Int
1	0	91	70	22.30	100
2	100	93	65	19.36	87
3	200	99	68	13.86	62
4	250	94	69	12.41	56

SAMPLE:13 SITE: 1 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	%Int
1	0	225	74	22.88	100
2	10	218	77	19.73	86
3	50	221	81	11.41	50
4	100	217	82	4.34	19
5	150	202	83	3.48	15
6	200	192	86	2.90	13
7	300	85	88	1.98	9
8	450	348	63	0.96	4
9	600	255	64	0.85	4

SAMPLE:14 SITE: 1 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	%Int
1	0	29	60	13.57	100
2	10	41	65	13.75	101
3	50	45	70	10.16	75
4	100	57	72	3.99	29
5	150	75	74	3.23	24
6	200	67	77	2.72	20
7	300	61	78	1.82	13
8	600	111	51	0.64	5

SAMPLE:15 SITE: 1 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	%Int
1	0	25	78	62.98	100
2	10	22	80	56.81	90
3	50	37	80	33.03	52
4	100	49	80	11.53	18
5	150	56	77	9.40	15
6	200	67	78	7.69	12
7	300	63	78	5.07	8
8	450	31	81	2.26	4
9	600	313	78	0.91	1

SAMPLE:16 SITE: 1 (strike/dip: 0 90)

Vec	Temp	Dec	Inc	Int	%Int
1	0	327	87	2.79	100
2	10	282	85	2.39	86
3	50	255	80	1.47	53
4	100	214	83	0.59	21
5	150	177	76	0.42	15
6	200	166	81	0.37	13
7	300	158	83	0.30	11
8	450	327	70	0.19	7

SAMPLE:17 SITE: 1 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	%Int
1	0	124	74	7.32	100
2	10	114	72	6.25	85
3	50	131	67	3.49	48
4	100	144	72	1.53	21
5	150	75	85	1.53	21
6	200	80	77	1.12	15
7	300	130	57	0.60	8

Table II. Continued.

SAMPLE:18 SITE: 1 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	%Int
1	0	184	76	2.54	100
2	10	215	82	2.13	84
3	50	130	75	1.54	61
4	100	139	66	0.51	20
5	150	74	69	0.34	13
6	200	121	64	0.23	9
7	300	49	66	0.29	12
8	450	128	61	0.22	9
9	600	146	41	0.27	11

SAMPLE:19 SITE: 1 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	%Int
1	0	338	65	8.59	100
2	10	338	65	7.62	89
3	50	349	68	4.51	52
4	100	14	75	1.54	18
5	150	31	71	1.32	15
6	200	56	81	1.16	14
7	300	52	72	0.75	9
8	450	85	14	0.44	5
9	600	107	8	0.26	3

SAMPLE:20 SITE: 1 (strike/dip: 0 0)

Vec	Temp X	Dec	Inc	Int	%Int
1	0	159	77	8.26	100
2	100	153	73	6.79	82
3	200	105	61	3.45	42
4	250	100	39	2.95	36

SAMPLE:21 SITE: 1 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	%Int
1	0	26	75	10.66	100
2	10	23	75	6.26	59
3	50	354	76	5.65	53
4	100	6	74	2.31	22
5	150	17	72	2.03	19
6	200	20	70	1.78	17
7	300	1	71	1.28	12
8	450	9	53	0.57	5

SAMPLE:22 SITE: 1 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	%Int
1	0	281	46	7.28	100
2	10	293	51	4.82	66
3	50	299	51	3.86	53
4	100	297	48	1.58	22
5	150	305	49	1.43	20
6	200	298	46	1.30	18
7	300	300	33	0.93	13
8	450	5	42	0.35	5
9	600	67	13	0.28	4

SAMPLE:23 SITE: 1 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	%Int
1	0	312	67	4.63	100
2	10	336	72	2.98	64
3	50	328	71	2.57	56
4	100	319	70	1.07	23
5	150	317	72	0.82	18
6	200	305	72	0.70	15
7	300	339	65	0.49	10
8	450	24	40	0.42	9
9	600	171	-5	0.20	4

Table II. Continued.

SAMPLE:24 SITE: 1 (strike/dip: 0 0)					
Vec	Temp	Dec	Inc	Int	%Int
1	0	269	40	4.41	100
2	10	273	41	2.96	67
3	50	266	40	2.66	60
4	100	258	36	1.10	25
5	150	260	38	0.94	21
6	200	261	24	0.84	19
7	300	269	17	0.63	14
8	450	220	18	0.30	7

SAMPLE:25 SITE: 1 (strike/dip: 0 0)					
Vec	Temp	Dec	Inc	Int	%Int
1	0	338	9	3.70	100
2	10	347	4	3.09	84
3	50	332	42	1.82	49
4	100	188	55	1.07	29
5	150	201	60	1.09	30
6	200	187	43	1.03	28
7	300	184	45	0.71	19
8	450	166	33	0.41	11
9	600	97	-12	0.30	8

SAMPLE:26 SITE: 1 (strike/dip: 0 0)					
Vec	Temp	Dec	Inc	Int	%Int
1	0	226	64	11.96	100
2	10	229	65	7.73	65
3	50	229	63	7.10	59
4	100	235	62	2.95	25
5	150	222	58	2.63	22
6	200	231	58	2.39	20
7	300	232	57	1.66	14
8	450	179	60	0.62	5
9	600	107	62	0.40	3

SAMPLE:27 SITE: 1 (strike/dip: 0 0)					
Vec	Temp X	Dec	Inc	Int	%Int
1	0	250	67	10.28	100
2	100	250	63	8.67	84
3	200	252	58	3.09	30
4	250	316	52	1.26	12

SAMPLE:28 SITE: 1 (strike/dip: 0 0)					
Vec	Temp	Dec	Inc	Int	%Int
1	0	281	66	8.88	100
2	10	287	63	6.05	68
3	50	280	62	5.50	62
4	100	276	56	2.23	25
5	150	282	59	2.18	25
6	200	282	53	1.88	21
7	300	289	47	1.41	16
8	450	155	77	0.52	6
9	600	351	26	0.42	5

SAMPLE:29 SITE: 1 (strike/dip: 0 0)					
Vec	Temp	Dec	Inc	Int	%Int
1	0	293	45	8.72	100
2	10	298	47	5.58	64
3	50	296	48	5.27	60
4	100	290	45	2.25	26
5	150	285	40	2.09	24
6	200	290	39	1.92	22
7	300	297	37	1.44	16
8	450	335	37	0.36	4
9	600	38	29	0.47	5

Table II. Continued.

SAMPLE:30 SITE: 1 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	XInt
1	0	180	81	7.42	100
2	10	173	85	5.28	71
3	50	181	78	4.51	61
4	100	196	74	1.55	21
5	150	180	73	1.53	21
6	200	191	60	1.29	17
7	300	209	62	1.16	16
8	450	102	62	0.54	7

SAMPLE:31 SITE: 1 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	XInt
1	0	335	61	7.48	100
2	10	348	62	5.05	68
3	50	354	71	3.97	53
4	100	29	77	1.39	19
5	150	44	68	1.16	16
6	200	35	81	0.94	13
7	300	240	75	0.47	6
8	450	96	6	0.54	7
9	600	163	-7	0.35	5

SAMPLE:32 SITE: 1 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	XInt
1	0	309	62	5.38	100
2	10	323	61	3.93	73
3	50	333	61	3.16	59
4	100	337	60	1.16	22
5	150	354	60	0.87	16
6	300	5	53	0.66	12
7	450	63	11	0.31	6

SAMPLE:33 SITE: 1 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	XInt
1	0	328	67	8.13	100
2	10	334	64	5.58	69
3	50	336	73	4.53	56
4	100	320	76	1.67	21
5	150	340	74	1.36	17
6	200	346	79	1.21	15
7	300	318	75	0.66	8
8	450	83	62	0.69	8
9	600	163	-1	0.55	7

SAMPLE:34 SITE: 1 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	XInt
1	0	322	79	0.97	100
2	10	4	72	0.67	70
3	50	14	62	0.42	43
4	100	16	60	0.12	13
5	150	359	41	0.06	6

SAMPLE:35 SITE: 1 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	XInt
1	0	235	53	2.30	100
2	18	234	54	2.03	88
3	58	240	57	1.39	61
4	100	233	55	0.99	43
5	150	259	61	0.70	30
6	200	312	60	0.38	16

SAMPLE:36 SITE: 1 (strike/dip: 0 0)

Vec	TempX	Dec	Inc	Int	XInt
1	0	60	78	10.90	100
2	100	59	75	8.39	77
3	200	59	78	3.66	34
4	250	68	78	2.30	21

SAMPLE:37 SITE: 1 (strike/dip: 0 0)					
Vec	Temp	Dec	Inc	Int	XInt
1	0	303	64	9.26	100
2	18	303	67	8.64	93
3	58	303	73	7.35	79
4	100	313	77	6.18	67
5	150	316	80	5.51	60
6	200	335	79	4.95	53
7	300	5	73	3.85	42

SAMPLE:38 SITE: 1 (strike/dip: 0 0)					
Vec	Temp	Dec	Inc	Int	XInt
1	0	270	80	5.07	100
2	18	260	88	5.51	109
3	59	77	86	5.53	109
4	100	70	82	4.50	89
5	150	76	82	3.91	77
6	200	72	83	2.65	52
7	300	16	71	2.45	48
8	450	96	44	0.82	16

SAMPLE:39 SITE: 1 (strike/dip: 0 0)					
Vec	Temp	Dec	Inc	Int	XInt
1	0	318	77	5.67	100
2	18	310	79	4.97	88
3	58	297	86	3.95	70
4	100	180	79	3.14	55
5	150	214	85	2.34	41
6	200	226	65	1.37	24
7	300	290	83	1.00	18

SAMPLE:40 SITE: 1 (strike/dip: 0 0)					
Vec	Temp	Dec	Inc	Int	XInt
1	0	346	60	2.95	100
2	10	3	63	2.44	83
3	50	355	67	2.11	72
4	100	40	74	0.68	23
5	300	58	63	0.42	14
6	450	157	-3	0.17	6

SAMPLE:41 SITE: 1 (strike/dip: 0 0)					
Vec	Temp X	Dec	Inc	Int	XInt
1	0	261	49	5.96	100
2	100	258	46	4.95	83
3	200	256	36	2.46	41
4	250	251	40	1.79	30

SAMPLE:42 SITE: 1 (strike/dip: 0 0)					
Vec	Temp	Dec	Inc	Int	XInt
1	0	106	62	8.06	100
2	18	106	62	7.13	89
3	58	107	72	5.24	65
4	100	122	70	4.52	56
5	150	121	75	3.85	48
6	200	87	86	2.78	34
7	300	109	82	2.16	27
8	450	33	58	1.49	19
9	600	60	29	1.13	14

SAMPLE:43 SITE: 1 (strike/dip: 0 0)					
Vec	Temp	Dec	Inc	Int	XInt
1	0	318	69	5.92	100
2	18	322	66	5.17	87
3	58	339	63	4.32	73
4	100	2	69	2.90	49
5	150	339	74	2.24	38
6	200	48	74	1.70	29
7	300	20	43	1.65	28

Table II. Continued.

SAMPLE:44 SITE: 1 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	XInt
1	0	290	46	10.28	100
2	18	286	48	9.22	90
3	58	286	54	6.91	67
4	100	285	59	4.94	48
5	150	288	64	3.61	35
6	200	297	65	3.02	29
7	300	324	61	1.88	18

SAMPLE:45 SITE: 1 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	XInt
1	0	24	70	25.34	100
2	18	27	68	24.63	97
3	58	26	67	25.24	100
4	100	31	68	20.57	81
5	150	35	68	15.80	62
6	200	33	68	13.68	54
7	300	27	62	8.65	34
8	450	12	30	5.15	20

SAMPLE:46 SITE: 1 (strike/dip: 0 0)

Vec	TempX	Dec	Inc	Int	XInt
1	0	22	63	27.45	100
2	100	24	61	23.03	84
3	200	360	50	5.33	19
4	250	351	50	3.57	13

SAMPLE:47 SITE: 1 (strike/dip: 0 0)

Vec	TempX	Dec	Inc	Int	XInt
1	0	30	74	24.16	100
2	100	33	73	19.41	80
3	200	39	65	2.43	10
4	250	37	73	1.69	7

Site 7316/03u01

SAMPLE:48 SITE: 2 (strike/dip: 0 180)

Vec	Temp	Dec	Inc	Int	XInt
1	0	8	69	7.00	100
2	63	3	72	7.18	103
3	112	343	75	6.00	86
4	213	354	73	4.86	69
5	360	312	81	3.01	43
6	460	266	82	1.96	28

SAMPLE:50 SITE: 2 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	XInt
1	0	276	61	8.22	100

SAMPLE:51 SITE: 2 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	XInt
1	1	82	36	4.49	100
2	63	82	22	4.13	92
3	112	85	14	2.84	63
4	213	89	1	2.06	46
5	360	144	18	2.21	49
6	460	89	18	5.08	113

Table II. Continued.

Site 7316/06u01

SAMPLE:52 SITE: 3 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	%Int
1	0	127	75	17.07	100
2	63	131	77	14.60	86
3	112	135	78	12.96	76
4	213	134	80	8.90	52
5	360	116	78	5.08	30
6	460	122	74	3.01	18

SAMPLE:53 SITE: 3 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	%Int
1	0	98	70	8.79	100
2	63	71	71	7.67	87
3	112	59	74	6.51	74
4	213	58	74	4.93	56
5	360	49	70	2.90	33
6	460	64	78	2.20	25
7	560	153	81	1.16	13

SAMPLE:54 SITE: 3 (strike/dip: 0 180)

Vec	Temp	Dec	Inc	Int	%Int
1	1	251	57	1.66	100
2	63	275	76	2.29	138
3	112	314	67	1.94	117
4	213	284	84	1.12	67
5	360	335	35	0.78	47

SAMPLE:55 SITE: 3 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	%Int
1	0	30	-62	0.34	100

SAMPLE:56 SITE: 3 (strike/dip: 0 90)

Vec	Temp	Dec	Inc	Int	%Int
1	0	254	73	1.00	100

SAMPLE:57 SITE: 3 (strike/dip: 0 90)

Vec	Temp	Dec	Inc	Int	%Int
1	0	93	-8	1.42	100

SAMPLE:58 SITE: 3 (strike/dip: 0 90)

Vec	Temp	Dec	Inc	Int	%Int
1	0	302	74	1.72	100

SAMPLE:59 SITE: 3 (strike/dip: 0 90)

Vec	Temp	Dec	Inc	Int	%Int
1	0	300	38	0.41	100

SAMPLE:60 SITE: 3 (strike/dip: 0 90)

Vec	Temp	Dec	Inc	Int	%Int
1	0	330	22	0.75	100

Table II. Continued.

SAMPLE:61 SITE: 3 (strike/dip: 0 90)

Vec	Temp	Dec	Inc	Int	XInt
1	0	225	85	0.32	100

SAMPLE:62 SITE: 3 (strike/dip: 0 90)

Vec	Temp	Dec	Inc	Int	XInt
1	0	329	-25	0.24	100

SAMPLE:63 SITE: 3 (strike/dip: 0 90)

Vec	Temp	Dec	Inc	Int	XInt
1	0	284	-47	0.43	100

Site 7316/06u02

SAMPLE:64 SITE: 4 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	XInt
1	0	276	56	13.61	100
2	10	277	56	9.81	72
3	50	275	55	8.73	64
4	100	276	53	3.56	26
5	150	274	54	2.94	22
6	200	273	54	2.78	20
7	300	278	59	1.71	13
8	450	239	61	0.85	6
9	600	217	70	0.33	2

SAMPLE:75 SITE: 4 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	XInt
1	0	146	76	10.26	100
2	50	169	62	5.13	50
3	100	170	51	3.33	32
4	250	167	59	3.17	31
5	360	159	65	1.64	16

SAMPLE:76 SITE: 4 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	XInt
1	0	25	58	14.84	100
2	50	7	74	8.39	57
3	100	7	81	8.08	54
4	360	11	76	3.09	21

SAMPLE:65 SITE: 4 (strike/dip: 0 180)

Vec	Temp	Dec	Inc	Int	XInt
1	0	99	9	6.89	100
2	10	90	12	3.80	55
3	50	69	33	3.17	46
4	100	60	47	1.28	19
5	150	50	48	1.05	15
6	200	44	57	0.95	14
7	300	29	51	0.80	12
8	450	14	34	0.59	9

Table II. Continued.

SAMPLE:66 SITE: 4 (strike/dip: 0 180)

Vec	Temp	Dec	Inc	Int	XInt
1	0	37	-4	6.32	100
2	10	31	7	4.34	69
3	50	27	32	3.49	55
4	100	26	40	3.67	58
5	150	27	45	1.24	20
6	200	28	44	1.03	16
7	300	22	43	0.64	10
8	450	28	48	0.51	8

SAMPLE:77 SITE: 4 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	XInt
1	0	265	76	12.35	100
2	50	288	70	8.59	70
3	100	297	65	6.85	55
4	250	301	61	4.72	38
5	360	282	58	3.13	25
6	460	308	62	1.99	16

SAMPLE:78 SITE: 4 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	XInt
1	0	105	80	11.28	100
2	63	127	77	7.50	66
3	112	115	73	6.86	61
4	213	119	75	4.07	36
5	360	107	68	2.14	19

SAMPLE:79 SITE: 4 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	XInt
1	0	177	86	9.48	100
2	63	207	87	6.92	73
3	112	145	88	5.40	57
4	213	135	86	3.11	33
5	360	213	77	2.00	21
6	560	191	76	1.55	16

SAMPLE:80 SITE: 4 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	XInt
1	0	144	87	12.06	100
2	63	94	81	8.16	68
3	112	88	82	5.56	46
4	213	76	78	4.02	33
5	360	42	77	2.29	19

SAMPLE:67 SITE: 4 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	XInt
1	0	27	61	12.47	100
2	10	24	61	8.99	72
3	50	13	71	6.71	54
4	100	354	75	2.49	20
5	150	356	79	1.89	15
6	200	322	76	1.74	14
7	300	320	73	1.08	9
8	450	15	67	0.53	4
9	600	217	86	0.20	2

SAMPLE:68 SITE: 4 (strike/dip: 0 0)

Vec	Temp	Dec	Inc	Int	XInt
1	0	355	57	8.96	100
2	10	9	55	6.59	73
3	50	355	58	5.28	59
4	100	342	58	1.95	22
5	150	336	59	1.48	16
6	200	343	60	1.31	15
7	300	338	56	0.87	10
8	450	357	44	0.40	4
9	600	312	44	0.48	5

Shallow Drilling Björnöya West 1989

Appendix
volume 2

Quaternary
sediments and
glacial geology



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