BERICHTE AUS DEM MARUM UND DEM FACHBEREICH GEOWISSENSCHAFTEN
DER UNIVERSITÄT BREMEN

Postglacial drainage systems in the northern German Bight
PalaeoDogger

Bremerhaven (Germany) – Bremerhaven (Germany)
May 11 – May 27, 2016,

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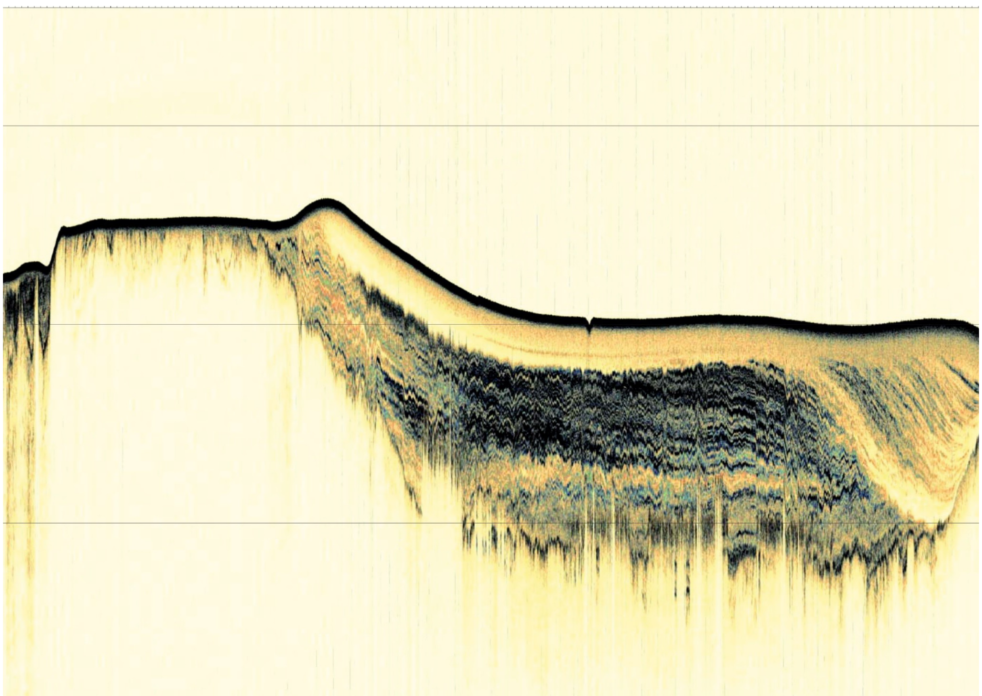

2017

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1 Summary

Cruise HE463 was carried out within the framework of MARUM reseach project SD2 (Climatic control on large scale sedimentary structures) and aimed on the investigation of the infill structures of the Elbe Palaeovalley northward of the German territorial waters by acoustic and sedimentological means. These studies in Danish and Norwegian waters represent a continuation of cruise He405 (2013) to reconstruct the Holocene infill history of the palaeovalley in its interaction with the Holocene sea level rise. The applied methods include the shallow-water multichannel seismic system of the Fraunhofer IWES (Micro-GI-Gun, 96 channel digital seismic streamer (HTI)), the shipboard parametric subbottom profiler SES2000 (Innomar) and for the sampling of the predominantly sand-covered sediments a 6 m vibro corer (Geo Marine Survey Systems).

According to these objectives, initially several long overview lines were seismoacoustically surveyed close to the northern boundary of the German waters and in the Danish sector east of Dogger Bank to gain an overview on the yet unknown extent of the palaeovalley and the variability of its infill structures. The infill patterns, which were already known from cruise He405 here, showed significant lateral variations. Also pronounced recent drift structures could be imaged at the eastern flank of the Dogger Bank. Subsequently one of the overview profiles was sampled with a total of 12 vibro corer sites to address all observed infill units sedimentologically. Additional seismoacoustic densification lines as well as several additional sampling sites helped especially to improve the coverage of the highly variable drift structures.

After completion of the investigations in the Danish sector, the studies were continued for another three days in Norwegian waters south of the Oslo Channel. Here further indications of bottom current influenced sedimentations could be observed, however, the further course of the palaeovalley and its infill could be determined much less clear than south of Dogger Bank.

The last working days were used to map a potential palaeo-tributary of the Elbe Palaeovalley, which was known from previous data and presumably was part of the drainage system of the former Doggerland, as far upstream as possible. For this purpose, a grid of parallel echosounder survey lines was attached to the existing data lines at the German Ducks Beak area. The line spacing was set to 400 m. The course of the river could thereby be further reconstructed. In doing so, a strong variability in width, shape and infill of the river could be imaged. Furthermore, this whole area is characterized by several additional incisions suggesting an extended network of drainage channels.

In total 3680 km of acoustic profiles were surveyed during the very successful expedition He463 of which 1100 km were also multichannel seismic lines. 20 sampling sites provided ca. 100 m core length of sediment. Of the 16 working days 3 days were lost due to bad weather conditions. These days we stayed in the working area to minimize time losses.

Zusammenfassung

Ausfahrt Heincke He463 wurde im Rahmen des MARUM Forschungsprojekts SD2 (Climatic control on large scale sedimentary structures) durchgeführt und hatte zum Ziel, die Verfüllungsstrukturen des Elbe-Urstromtales nördlich der deutschen Hoheitsgewässer akustisch und sedimentologisch zu erkunden. Diese Arbeiten in dänischen und norwegischen Gewässern stellen eine Fortführung der Expedition He405 (2013) dar, um die holozäne Verfüllungsgeschichte des Urstromtales in ihrer Wechselwirkung

mit dem holozänen Meeresspiegelanstieg zu rekonstruieren. Die eingesetzten Methoden umfassten das seismische Flachwasser-Mehrkanalsystem (Micro-GI-Gun, 96 Kanal digitaler Streamer (HTI)) des Fraunhofer IWES, das schiffseigene parametrische Sedimentecholot SES2000 (Innomar) sowie zur Beprobung der vorwiegend von Sandlagen abgedeckten Sedimente ein 6 m Vibrolot (Geo Marine Survey Systems).

Entsprechend dieser Ziele wurden zunächst nahe der nördlichen Grenze der deutschen Gewässer und im dänischen Sektor östlich der Doggerbank mehrere lange Übersichtsprofile seismoakustisch vermessen (Abb. 1), um einen Überblick über die dort noch unbekannte Ausdehnung des Urstromtales sowie die Variationen seiner Verfüllung zu erhalten. Dabei zeigten sich deutliche laterale Veränderungen in den von He405 bekannten Verfüllungsmustern, sowie ausgeprägte rezente Driftstrukturen an der östlichen Flanke der Doggerbank. In der Folge wurde eines der Übersichtsprofile mit insgesamt 12 Vibroloten beprobt, um möglichst alle Verfüllungseinheiten sedimentologisch ansprechen zu können. Weitere seismoakustische Verdichtungslinien sowie einige zusätzliche Kernlokationen halfen insbesondere die große Variabilität der Driftstrukturen besser zu erfassen.

Nach Abschluss der Untersuchungen im dänischen Sektor wurden die Arbeiten für weitere drei Tage in norwegischen Gewässern südlich des Oslo-Kanals fortgesetzt. Hier zeigten sich weitere Hinweise auf stark strömungsbeeinflusste Sedimentation, der Verlauf des Urstromtales sowie dessen Verfüllung war jedoch deutlich weniger deutlich zu bestimmen, als südlich der Dogger Bank.

Die letzten Arbeitstage der Expedition wurden genutzt, um einen aus früheren Daten bekannten potentiellen Paläo-Nebenfluss des Elbe-Urstromtales, der vermutlich zum Entwässerungssystem des alten Doggerlandes gehörte, möglichst weit flussaufwärts zu kartieren. Hierzu wurde ein Netz aus parallelen Echolotvermessungslinien an die vorhandenen Daten im deutschen Entenschnabel angeschlossen. Der Linienabstand betrug hier 400 m. Der Flusslauf konnte so weiterverfolgt werden, wobei sich eine starke Variabilität in Breite, Form und Verfüllung zeigte. Darüber hinaus ist dieses Gebiet auch durch mehrere weitere Einschnitte gekennzeichnet, was ein ausgedehntes Netz von Entwässerungsrinnen vermuten lässt.

Insgesamt wurden während der sehr erfolgreichen Expedition He463 insgesamt 3680 km akustische Profile vermessen, davon 1100 km mit Mehrkanalseismik. 20 Kernstationen lieferten ca. 100 m Kernmaterial. Von den 16 Tagen Arbeitszeit wurden 3 Tage durch schlechte Wetterbedingungen verloren. Diese Tage wurden im Arbeitsgebiet abgewettert um die Zeitverluste zu minimieren.

2 Participants

Table 2.1 Participants of expedition HE463

Name	Discipline	Institution
Keil, Hanno, Dr.	Geophysics / Chief Scientist	GeoB
Hepp, Daniel, Dr.	Sedimentology	MARUM
Otto, Daniel	Sedimentology	MARUM
Ehrhardt, Sophie	Sedimentology	MARUM
Dos Anjos Oguro, Aisgo	Geophysics	GeoB
Brune, Rouven Benedikt	Geophysics	GeoB
Pavlak, Johanna	Geophysics	GeoB
Ehmen, Tobias	Geophysics	GeoB
Andreasen, Trine	Geophysics	AU

MARUM Zentrum für Marine Umweltwissenschaften, Universität Bremen

GeoB Universität Bremen, Fachbereich Geowissenschaften

AU Aarhus University, Department of Geosciences, Denmark

3 Research Program

Not much is known so far on the location and infill of the post-glacial drainage in the North Sea area. This holds also true for the EPV and the south-eastern Dogger Bank drainage system. After the formation of these systems prior to the final post-glacial transgression, the associated river systems acted as main drainage channels for the surrounding lands. During the Holocene transgression these pathways have been filled with sediments and subsequently, these deposits have been covered with the widespread North Sea mobile sand unit. The latter processes are most likely closely linked to the development of the shallow marine circulation system in the central North Sea in the course of the transgression. Current induced variations forming distinct seafloor expressions can be observed along the margin of the EPV from south to north, e.g., by the formation of a sediment bulge along parts of the western boundary of the EPV (Fig. 3.1) varying in height and width.

These actual findings pose three scientific questions and which were addressed by cruise HE463:

(1) What was the role of the southeastern Dogger Bank palaeo-river system in draining Mesolithic Doggerland?

Primary objective here was to extend the mapping of the fluvial system south of Dogger Bank towards the northwest and the northeast with high frequency acoustic measurements to fully understand the linkage of the two different valley generations with the EPV and also to be able to reconstruct the source areas of both valley systems.

The system has been mapped further to the north-west of the already known area, close to the Danish border in German territorial waters of the Duck's Beak. Also four six meter long sediment cores were taken in the center and near the rim of the valley infill, targeting mainly on suspected marshland deposits.

(2) What is the exact pathway of the EPV in its northern extension?

The path of the EPV through Danish and Norwegian waters is still partially speculative and defined, if at all, so far largely by corresponding seafloor bathymetry. However, as the data of the southern palaeovalley show, the EPV does not appear as a simple depression in the seafloor, but partially it even can be slightly elevated. High-resolution sub-bottom profiler data has proven to be perfectly suitable to image the base of the EPV. Therefore a couple of longer overview profiles with a parametric SES 2000 subbottom profiler have been surveyed in Danish and Norwegian waters to locate and map the extension of the EPV further to the north and to define its infill variations.

These surveys were partially supported by high frequency multichannel seismic measurements to provide additional information on deeper lying structures, but also to overcome signal penetration limitations of the SES where gassy sediments or higher reflective sediments cause limitations.

(3) How is the infill of the Elbe Palaeovalley related to the formation of large scale circulation patterns in the North Sea and how are these patterns related to palaeotopographic constrains?

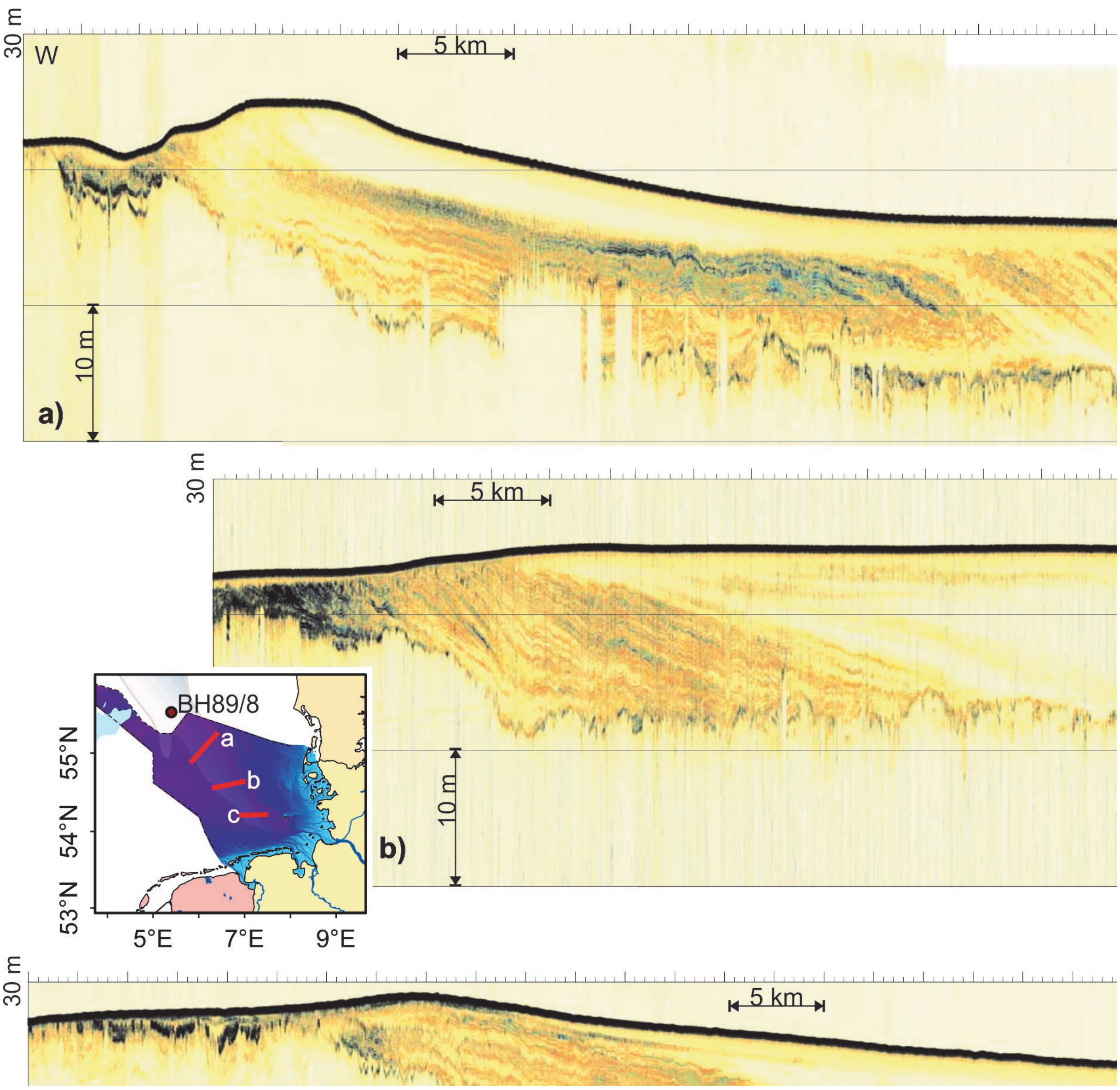

Fig. 3.1 SES 2000 parametric subbottom profiler lines crossing the EPV at three different latitudes as indicated in the inset. The images show a colour coded display of the envelope of the recorded signal. The depth scale has been calculated assuming a sound velocity of 1500 m/s.A-E.

Recent studies (Özmaral et al., in prep.) suggest a predominantly current related sedimentation pattern in the Holocene infill of the EPV. Knowledge on the extension of the related sedimentary units and their variations along the path of the palaeovalley will help to understand the corresponding circulation pattern in the young North Sea in terms of onset, duration, extension and intensity.

For this purpose and based on the overview profiles especially the highly variable sedimentary infill of the EPV in the Danish sector was surveyed by a dense net of subbottom profiler and multichannel seismic lines to get a spatial understanding of the depositional environment. These lines incorporated the position of drill site BH89/8 (Konradi, 2000) for future reference. A set of 12 6 m long sediment cores was taken, their location chosen to sample all observable infill units. They will be dated and further analyzed in terms of grain size variations, source material variations and so on.

Figure 3.2 shows an overview of the research area including the survey lines and sampling sites.

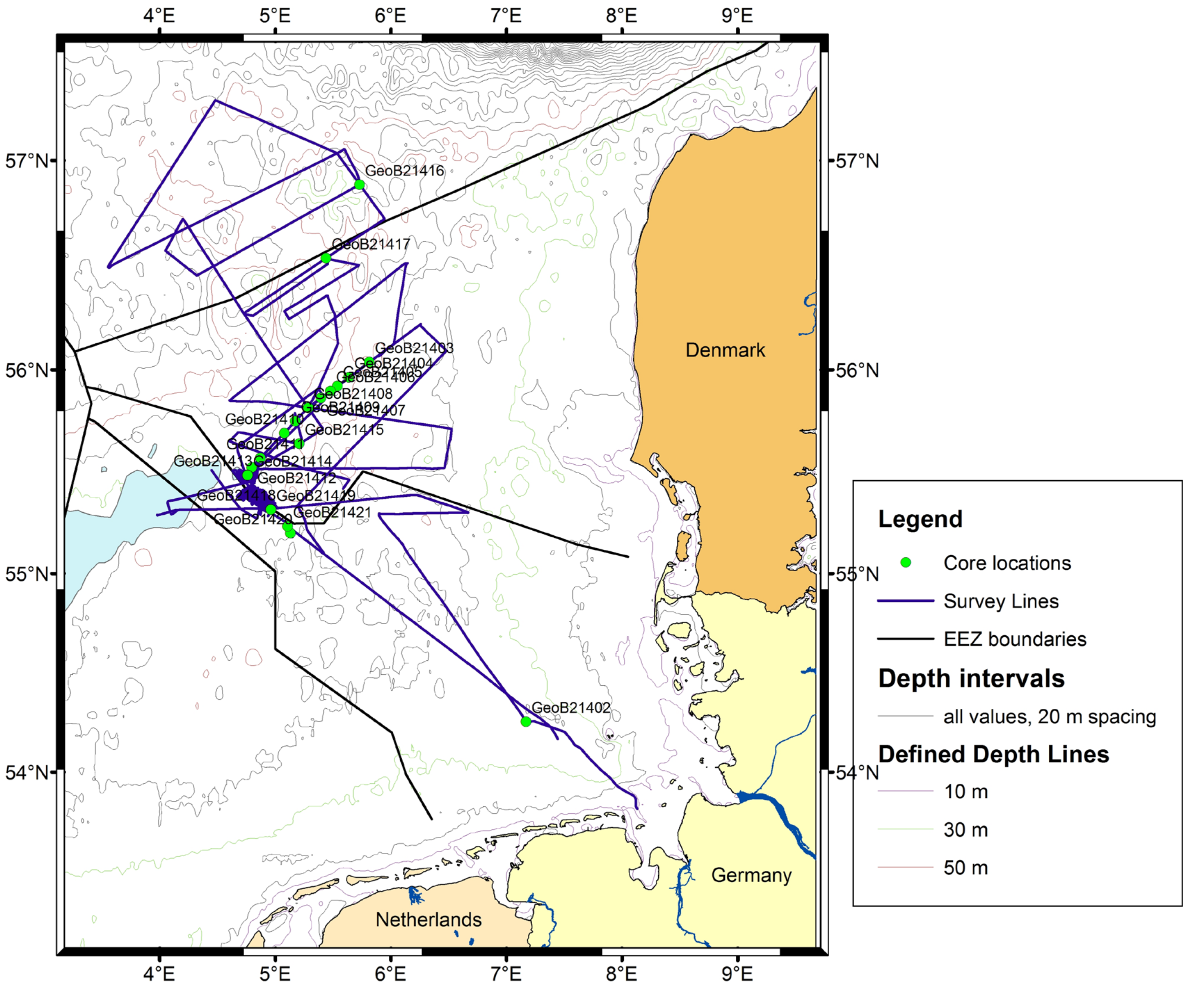

Fig. 3.2 Track chart of R/V HEINCKE cruise HE463. Bathymetry from EMODnet. Acoustic survey lines as well as core locations are marked.

4 Narrative of the Cruise

RV Heincke left the port of Bremerhaven on the 11th of May at 8:00 in bright sunlight at moderate 3 to 4 Bft easterly winds. We were prepared for seismic surveying using a 96 channel digital streamer and a Micro-GI gun as well as for sampling the upper 6 meters of North Sea sediments using a Vibrocorer. Additionally we intended to survey the study areas using the shipboard subbottom profiler SES2000. After an early safety drill we proceeded fast with the tide current to our first two vibrocorer sampling sites just north of the German Bight western approach tanker route. These sites were selected on the basis of an older SES2000 profile. The hope was to be able to penetrate the infill material of a small incision in the Pleistocene base of the Elbe Palaeovalley. On both sites cores could be successfully retrieved, however, potentially due to a technical problem with a valve of the vibrocorer some air was captured in the core barrel at the second site and the retrieved sediment was significantly disturbed. Nevertheless regarding this sampling as a successful start we continued with a 10 hour transit towards North West getting close to the northern boundary of the German exclusive economic zone. After retrieval of a sound velocity probe to calibrate the swath echosounder we deployed the multichannel seismic equipment. As often when equipment is deployed for the first time on a cruise some initial technical problems had to be solved until all systems worked satisfactorily. At 3:00 on the 12th of May we could successfully start our first acoustic survey period which should provide us first some profiles close to the Danish economic zone and consecutively some longer overview lines in the Danish sector to give us a first clue on the upper sedimentary structures and especially on the extent of the Elbe Palaeovalley in this area.

In the evening of the 12th of May this first seismic survey lead us in the Southwestern Danish waters and during the early night we had a fascinating few on a couple of impressive oil and gas rigs which are densely distributed along the eastern boundary of the Dogger Bank. In the morning of the 13th the announced increase in wind speed and the parallel turn to North West yielded steadily increasing swell waves topped by wind sea. At wave heights partially above 3 meters we had to end all in-water activities and the seismic equipment was recovered. We continued to image the Elbe Palaeovalley infill with the shipboard sediment echosounder on suitable directions and the scientific team found the time to fix and maintain some equipment pieces and eventually fight sea sickness.

At midnight of the 13th, however, the final decision had to be made to stop all survey activities. The wave height reached up to 5 meters and the data quality was severely degraded. The ship therefore stayed on site and tried to find a more or less comfortable orientation. The weather forecast was worse and we had to wait until the afternoon of Sunday (15th) 15:00 until we again started to survey with the SES. However, wave height at that time was still at more than 3 meters and the data quality suffered from these conditions.

Until the evening of the 16th we added two longer echosounder profiles in east west direction, steaming at rather low speed to keep the noise level in the data as low as feasible. A third longer profile was then acquired during the night of the 16th/17th with the digital multichannel seismic system to get some more insight in the deeper structures forming the eastern Dogger Bank and the base of the Palaeovalley. Based on the first valley crossing profile we defined a total of 15 interesting coring positions, forming a full profile across the valley in a way to access all observed infill structures with the short core length given. A couple of structural units are visible in the acoustic data, which luckily significantly vary in thickness but also in depth below seafloor so that all of them can be accessed at specific locations.

Consequently on the 17th of May the sedimentology team on board and the ships' deck crew was quite busy retrieving in total 6 vibrocores in 5 hours. The mean coring time was only 20 minutes per core, showing that the teams worked well-established after the first two cores. The second sequence of another six cores was then taken on the 18th, while in the night between we did again some surveying using multichannel seismics and the subbottom profiler. Three of the originally selected coring sites were skipped due to time constraints and minor importance. Nearly all cores recovered quite successfully more than 5 m and reached the intended targets. Only on the westernmost part some problems were encountered. One core did not penetrate as expected, potentially due to some geologic circumstances in the subsurface, a second core penetrating a small incision had a damage at the core catcher after retrieval.

After another night of regional surveying with the subbottom profiler we ended the coring marathon with one more vibrocore in the central Palaeovalley in the morning of the 19th of May. These activities finished our reconnaissance of the western central Danish waters and we started a two day overview of the northern Danish and southern Norwegian waters using the multichannel system and for the first time also the boomer system. The latter had suffered from some technical problems in the beginning which could be fixed with the help of the ship's electrician. After the deployment we first acquired a long profile in northward direction crossing a ridge structure extending from the eastern Dogger Bank towards east. This ridge forms together with its western counterpart structures closer to Denmark a small gap and pathway for water exchange below 40m water depth and we expected some significant changes in the current controlled recent sedimentation south and north of this gap. North of the ridge we turned to east to get one more parallel line crossing the Palaeovalley structures and then we finally turned north in Norwegian waters and accomplished a set of three long overview profiles. These profiles showed, that current systems seemed to have shaped some extended topographic features, however, the base of the Palaeovalley could not be reliably determined. Also, the Holocene sedimentation patterns are much more heterogeneous than south east of Dogger Bank and determination of a general trend needs further investigation. Since the time frame of the cruise did not allow for longer investigations in this area, another vibrocore was taken in the afternoon of the 21st in a presumably current controlled environment right north of the Danish border before the survey net was densified by two additional lines acquired with the subbottom profiler only.

After returning to the Danish waters in the early morning of the 22nd of May we decided to sample one more vibrocore just north of the eastern Dogger Bank pathway to allow investigation of variations in Holocene current influenced sedimentation southward and northward of this pathway. With this sampling site we ended our activities in the main working area of this cruise and headed for the second area at the southern ducks beak.

We started our activities there by shooting the short seismic lines in a well-studied pockmark area in Netherlands waters south of Eastern Dogger Bank. This area has already been of major interest on several cruises in the past, however, on all these expeditions only chemistry, water sampling and water column imaging were carried out. On the early 23rd we had the opportunity to add some information on the deeper geologic structures, an information still missing so far. One of the profiles was acquired with different streamer geometries. In an experiment the streamer was towed in an as variable depth as possible, meaning that its depth increased from head to tail from 1 m to about 7 m. This was meant as a test of a rather new approach to suppress ghost reflections and flatten the spectral composition of the recorded signals.

We then moved quickly to a known palaeoriver-channel encountered on an industry-related survey at the southern ducks beak. Since it is assumed, that this river was part of a Dogger Bank drainage system that existed after the last Holocene glaciation, our aim was to continue mapping this river with high frequency acoustic methods north-westward direction. Before the start of the mapping two more vibrocores were taken from the infill structures of this river valley on the late afternoon of the 23rd. In the following we started mapping with the subbottom profiler at a line spacing of 800 m to gain a first overview on the pathway of the river. Unfortunately weather conditions quickly worsened and all work had to be stopped by midnight 23rd at wave heights beyond 4 m. After 24 hours the wind speed decreased slightly and allowed continuation of the survey efforts. There was still enough time to add two additional longitudinal lines in the area and to densify the grid spacing down to 400 m.

In the morning of the 26th the North Sea showed us her calmest face with heavy fog, but nearly flat sea. We used the opportunity to sample two additional virbrocores in the vicinity of the palaeoriver and after that finally ended the scientific activities and headed off for Bremerhaven. After a very successful and exciting cruise we safely reached the port in the early morning of the 27th of May.

5 Preliminary Results

Cruise HE463 concentrated mainly on acoustic and sedimentological investigations. For this purpose a multichannel seismic system as well as a single channel boomer system were used as towed acoustic systems. For the high resolution imaging of the Holocene sediment coverage the shipboard parametric subbottom profiler SES2000 (Innomar) was used. Also the shipboard swath echosounder EM710 (Kongsberg) was operated continuously.

Sedimentological sampling was performed using a 6 m long Geo-Corer 6000 Vibro-coring system (Geomarine Survey Systems).

5.1 Subbottom Profiler SES 2000 Medium

(Keil, H. and Shipboard Scientific Party)

5.1.1 System Overview and Data Processing

The shipboard parametric sediment echosounder SES 2000 Medium (Innomar) was operated continuously throughout the whole cruise on a 24 hour schedule. As on many other cruises the system worked extremely reliable without any issues or breakdowns and mostly unattended. The measurement range was set to 70 m and due to the very shallow water conditions met in the study area, the recording delay could remain mostly constant at 30 m. The system was configured in multi-frequency mode, that means that as secondary parametric frequencies 4, 8 and 12 kHz were generated alternately. This still provided a ping rate between 0.3 and 0.45 s per frequency and thus a very high lateral resolution. The sound speed was set to an average velocity of 1480 m/s. The aperture angle of the system is only 1° due to the high primary frequency of ~100 kHz.

The recorded raw data converted using the custom converter software ps32sgy to the seismic SEG-Y format, the associated navigation was cleaned and smoothed using the custom software cdpbinclean and finally all data was loaded into our interpretation software (KingdomSuite, HIS). This allowed a very fast geroreferenced visualization of the data which helped in cruise planning.

The system provided as expected new genuine insights in the infill structures of the Elbe Palaeovalley and other Holocene deposits. However, penetration is limited due to the high frequencies and reached at most ~30 m in fine grained sediments, but commonly not more than 5 m in the typical sandy North Sea sediments.

5.1.2 Sedimentary infill structures of the EPV

Based on the laterally variable infill structures of the EPV in the German sector known from previous cruises we expected some significant variations due to the vicinity of the Dogger Bank in the surveyed Danish sector of the study area. This expectation was confirmed by the first SES profiles in that area, however, several additional sedimentary units could be imaged showing a highly complicated depositional environment. Figure 5.1 shows one of the most prominent examples, a more than 100 km long profile crossing the area east of Dogger in east-west direction. Several lense shaped sediment bodies can be recognized suggesting laterally heterogeneous sedimentation environment, presumably influenced by lateral sediment transport. In between these units sequences of densely spaced higher reflective layers have been deposited, resembling higher amplitude units known from further south (see also figure 3.1). Note the strong vertical exaggeration of the image.

This line was later selected for a core transect to sample all visible sedimentary units. This was possible since due to the strong lateral heterogeneity all units get close enough to the seafloor at certain locations.

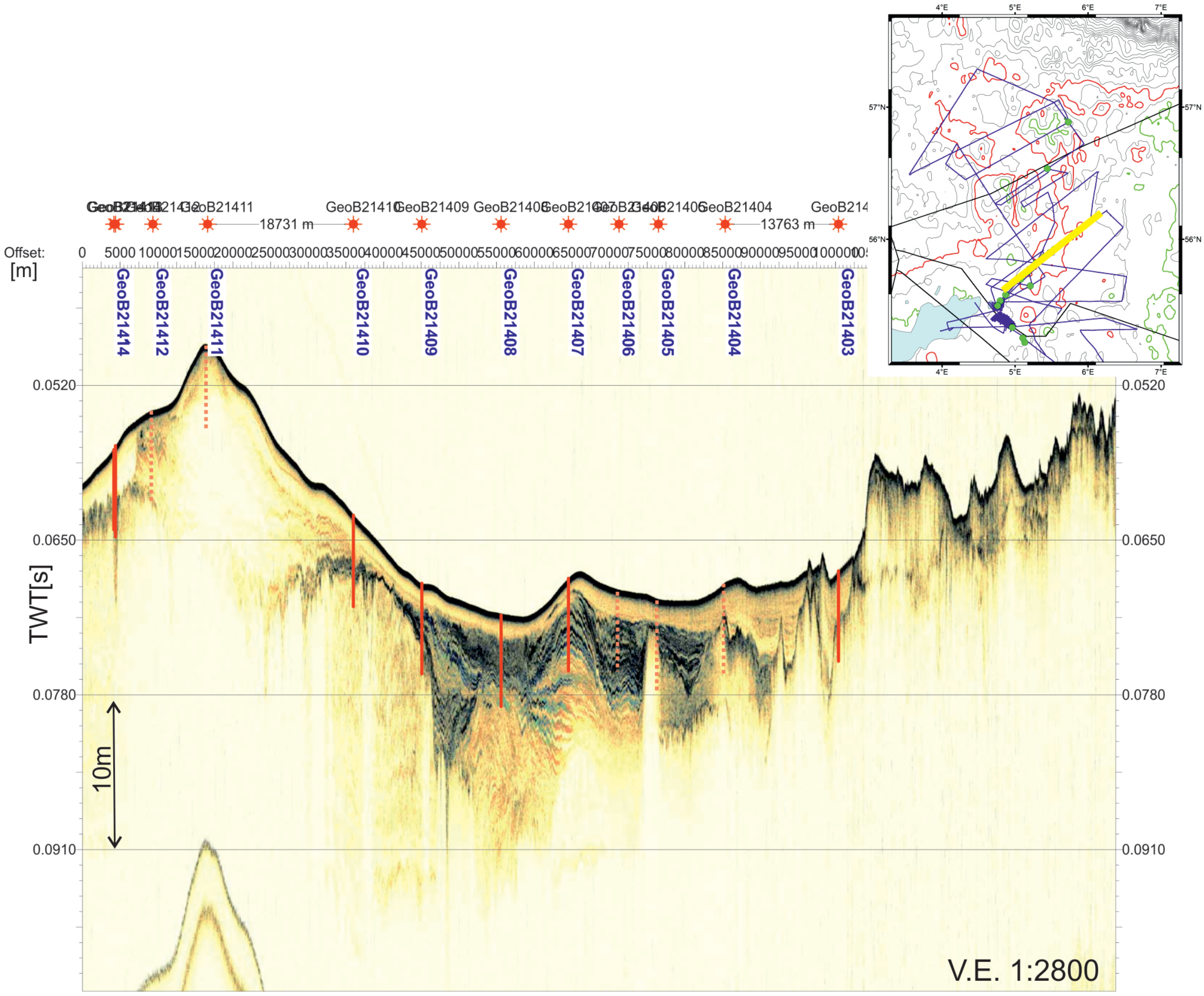

Fig. 5.1 SES 2000 line passing from the eastern Dogger bank up to 140 km to the west in Danish territorial waters. See embedded map for exact location. Sampling sites are marked by red lines.

5.1.3 Holocene deposits north of Dogger

North of Dogger Bank the depositional environment changes significantly. However, at certain locations presumably Holocene deposits could be observed, that resemble in their internal structure to sedimentary units encountered further to the south. Figure 5.2 shows an example section with a nearly acoustically transparent top layer draping underlying higher reflective sediments that show lateral variations in thickness and partially even erosive truncations at the upper boundary. These sediments were deposited on top of a highly reflective base reflector with some incised valley structures. At the current state direct comparison with the infill structures of the EPV, however, cannot be made.

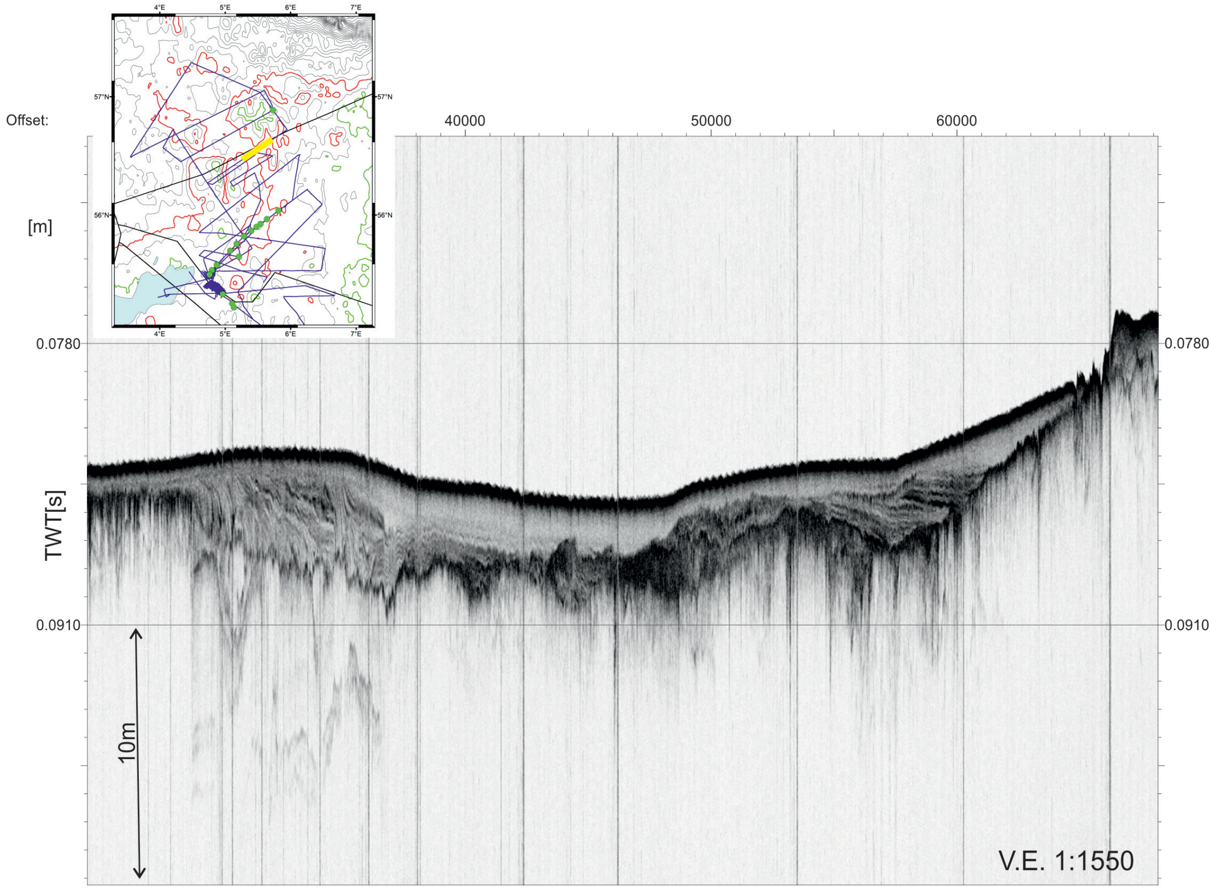

Fig. 5.2 SES 2000 line recorded in East-West direction north of Dogger Bank. See embedded map for exact location

5.1.4 5Imaging the south-eastern Dogger drainage system

The south-eastern Dogger Bank is characterized by a very flat, erosive surface with a thin acoustically transparent sand layer draping the underlying Holocene base (figure 5.3). This base surface shows numerous incision, which are up to 10 m deep and exhibit v- or u-shaped flanks. The infill also varies, but mostly highly reflective subparallel inclined or wavy reflectors can be recognized, sometimes mimicking the underlying base, sometimes rather independent. Previous cruises have shown, that these incisions form meandering systems (citations?) and therefore they were attributed to palaeo-river systems, draining the Dogger Bank in early post-glacial periods.

5.2 Bathymetry

(Keil, H. and Shipboard Scientific Party)

5.2.1 System Overview and Data Processing

FS Heincke provides a shipboard medium water depth swath echosounder Kongsberg EM710. This system was also operated continuously throughout the cruise on a 24 hour schedule. The swath width was kept fix to totally 120°. The EM710 operates at a frequency of 70 – 100 kHz and provides 256 beams and a maximum swath angle of 140°. Two water sound velocity profiles were measured in the southern and northern

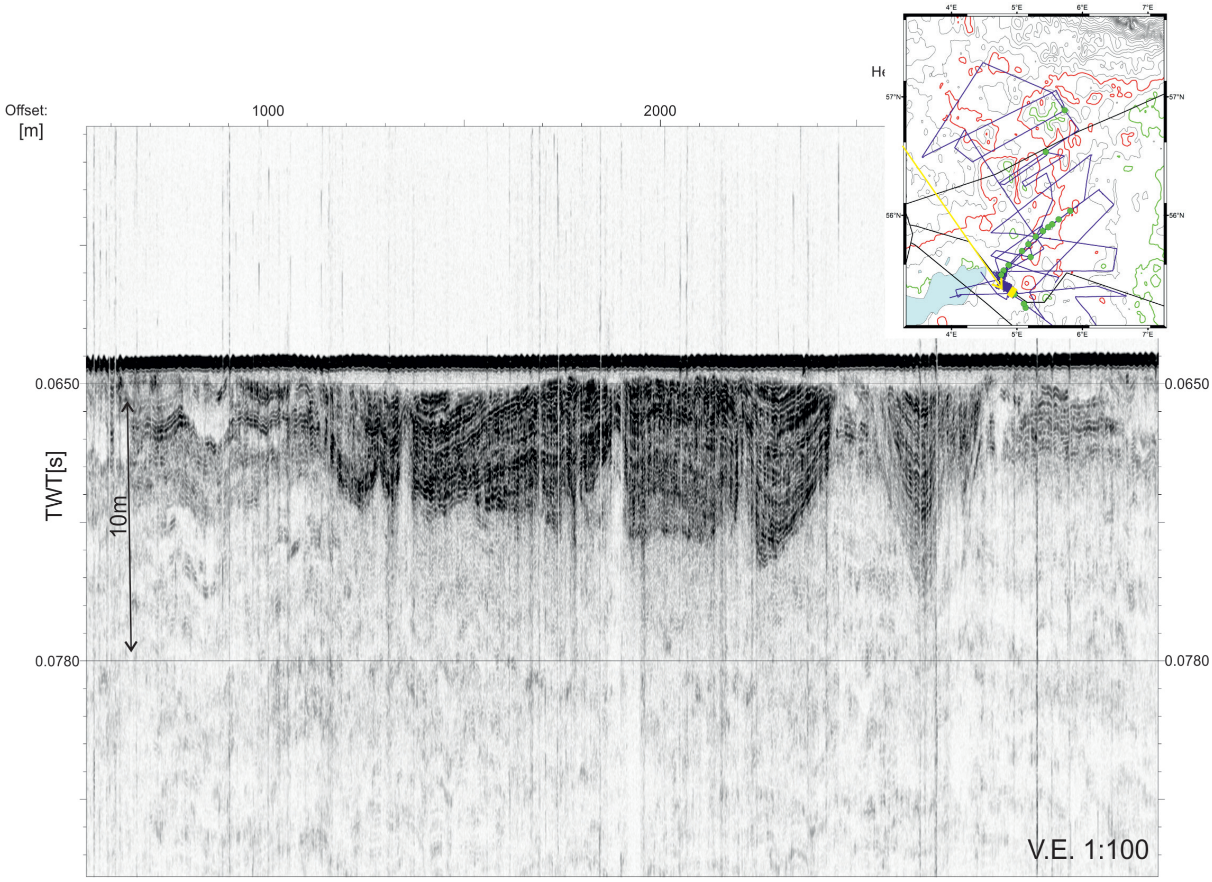

Fig. 5.3 SES 2000 line recorded at the south-eastern rim of the Dogger Bank. See embedded map for exact location.

part of the working area using the shipboard sound velocity probe to provide an optimized sound velocity profile for all measurements. Since the focus of the cruise was on sub-bottom imaging and since the towed systems prohibit a frequent update of the SVP-profiles, not more SVP deployments were carried out.

The system worked reliably and mostly unattended as usual. However, on a couple of occasions communication between the sonar control computer and the operator PC failed and required complete reboots of the whole system.

The high quality of the existing EMODnet bathymetry was absolutely sufficient for all cruise planning and data analysis tasks. Therefore the bathymetry data was only recorded and stored, but not investigated during the cruise. However, it might be useful for later high resolution images of certain small seafloor features.

5.3 Multi- and singlechannel seismics

(Keil, H., Dos Anjos Oguro, A., Ehmen, T., Brune, R., Pavlak, J., Andreasen, T.)

To obtain highest quality multichannel seismic data the latest development in the special Bremen shallow water seismic design was operated on cruise He463. This development started in early 2000 with a 48 channel analogue streamer consisting of single hydrophones at 1 m channel spacing and lead to todays 96 channel digital and analogue streamers with improved and specialized designs. Additionally the Boomer system of the German Federal Bureau of Hydrography (BSH) was tested for applicability in the North Sea. In the following, all used components are described in detail.

5.3.1 Sources

The main seismic source used was a Mini-GI-Gun (Sercel), equipped with special shuttles to reduce the chamber volumes down to 0.1 L each (generator and injector), further on labeled Micro-GI. This source model provides optimal control on the signal shape and in parallel offers high shot rates due to the small air consumption. The bandwidth of the signal frequency is between 30 and 600 Hz. It was operated in harmonic mode at a mean pressure of 130 bar.

The airgun was towed on the port side approximately 12 m behind the stern of the vessel using a custom downsized adaption of Sercels standard hanger assembly. The gun depth was controlled by a buoy above the hanger to a total towing depth of ca. 1m. Towing geometry is shown in Figure 5.4. The gun was fired at an interval of 3500 ms (profiles GeoB16-279 – 282) and 4000 ms (profiles GeoB16-283 – 302), respectively, limited mainly by the air supply of the compressor.

On few selected profiles also an electrical boomer plate was used. This boomer plate was manufactured by Nautic Nord. This source is installed underneath a lightweight catamaran like crate with two flotation tubes on each side, resulting in a plate towing depth of ~ 0.4 m. The Boomer was towed on the starboard side, 14 m behind the stern of the vessel.

5.3.2 Compressor

Compressed air was generated by a small electrically driven compressor WP4341-100 (Sauer Compressors). It provides ~ 700 l/min at a pressure of 150 bar. The compressor worked absolutely reliable during the whole cruise.

5.3.3 Streamers

Behind the center of the ship’s stern a specially designed solid digital streamer (HTI) was towed. It consists of 3 active streamer sections with 24 channels each, channel spacing 1 m, one PVDF hydrophone per channel and additionally 2 active sections with 12 channels each in the same configuration as the 24 channel sections. In between the sections the data is digitally recorded by four 24-channel Seamux3-AD-converter modules, each providing 12 channels in both connector directions. This resulted in a total number of 96 channels and a total active streamer length of 98 m (see fig 5.5 for setup of streamer geometry).

The first channel was towed 28.7 m behind the vessel, separated by a 12 m isolation section and the lead-in cable. 20 m behind the streamer a small tail buoy was connected to allow a visual position control. The streamer towing depth was kept to approximately 1 m controlled by 4 depth levelers attached to the streamer cable.

On profiles where the Boomer was additionally used, also a 3 m long analogue single channel streamer was towed starboard of the Boomer at 13 m behind the vessel. This Mini-Streamer has a small amplifier in the data line.

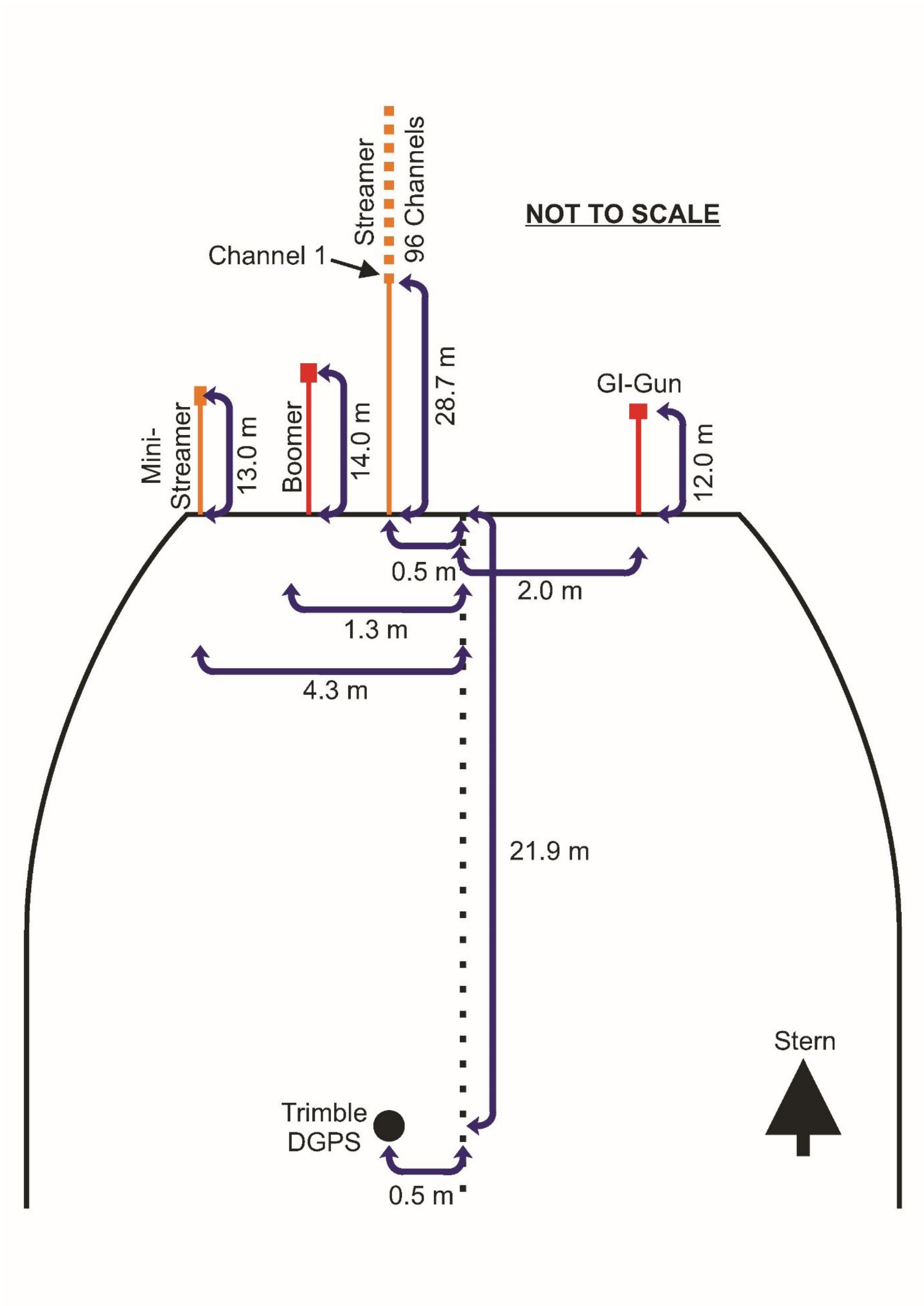

Fig. 5.4 Geometric layout of the towed equipment on cruise Heincke HE463.

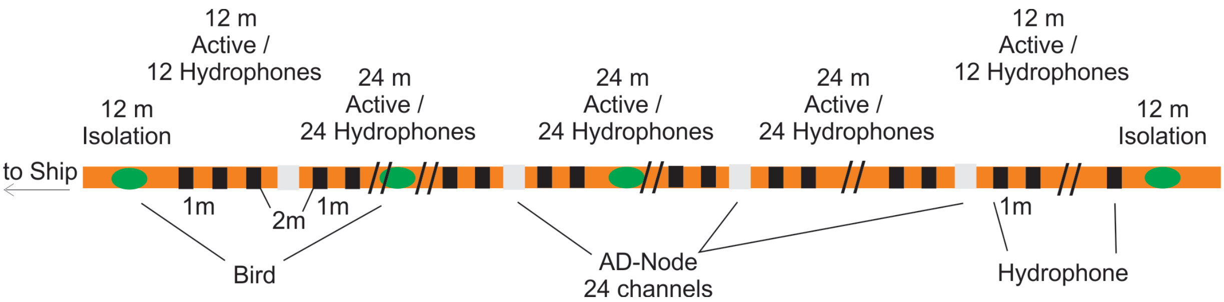

Fig. 5.5 Streamer layout

5.3.4 Depth Levelling

Depth control of the streamer was achieved by 4 attached ION DigiBirds 5011. They were connected at the beginning of the isolation section and at the ends of section 1, 2 and 4 respectively (see fig. 5.5). The birds were programmed in depth keeping mode for 1 m towing depth. This worked quite well for the balanced streamer cable.

5.3.5 Data Recording

The digitized data was recorded and quality controlled using an NTRS2 (HTI) recording system which is an integral part of the HTI Seamux3 Streamer system. The data was sampled at a sample rate of 4 kHz and stored on an internal disk in SEG-D data format.

Analogue data from the Mini-Streamer was recorded using the custom made Bremen MaMuCS recording system. It consisted of a PC with 3 NI 6052E AD-Converter cards, each providing 330 kHz maximum sample rate and 3 external NI SCXI1102C Multiplexer Boards, each providing 32 differentially coupled input channels. The system hence provides recording of 96 channels at a maximum sample rate of 10 kHz/ channel (although only one channel was used for the Mini-Streamer). The data are visualized by the custom MaMuCS software, also providing online brutestack views of the data. Data were sampled at 40 kHz and stored in SEG-Y format on the internal harddisk.

5.3.6 Trigger System

The trigger unit controls the timing of the seismic source and the recording unit. On cruise HE463 the custom made 6 channel trigger generator (SCHWABOX) was used in conjunction with a two channel trigger amplifier driving the solenoid valves of the Micro-GI-gun. The SCHWABOX is connected via USB to a control notebook and programmed with a small custom software tool. The system allows defining arbitrary combinations of trigger signals which is especially helpful to operate several sources in flip-flop mode, as for instance in the combination of Air-Gun and Boomer. Table 5.1 shows the applied trigger times.

Table 5.1 Trigger scheme list

Profiles	Sources, shooting rate, Trigger scheme	Recording
GeoB16-279 – GeoB16-282	Micro-Gi 0.1 L, 3500 ms	96 channel digital, recording delay 0 ms, recording length 1000 ms
GeoB16-283 – GeoB16-291	Micro-Gi 0.1 L, 4000 ms	96 channel digital, recording delay 0 ms, recording length 1000 ms
GeoB16-292 – GeoB16-298	Micro-GI 0.1 L, 4000ms Boomer, 500 ms Delay Source 0 Micro-GI 1000 Boomer 1500 Boomer 2000 Boomer 2500 Boomer 3000 Boomer 3500 Boomer	96 channel digital, recording delay 0 ms, recording length 1200 ms 1 channel analogue, recording delay 0 ms, recording length 200 ms.
GeoB16-199 – GeoB16-301	Micro-Gi 0.1 L, 4000 ms	96 channel digital, recording delay 0 ms, recording length 1000 ms
GeoB16-302	Micro-GI 0.1 L, 4000 ms Boomer, 500 ms See Profiles 292 – 298 for details	96 channel digital, recording delay 0 ms, recording length 1200 ms 1 channel analogue, recording delay 0 ms, recording length 200 ms.
GeoB16-303 – GeoB16-304	Boomer, 500 ms	1 channel analogue, recording delay 0 ms, recording length 200 ms.

5.3.7 Navigation and time synchronization

Time synchronization of all systems was done based on GPS time, using the shipboard Trimble GPS system data distributed via Ethernet UDP broadcast in the ship's network. Raw navigation data was recorded for the whole cruise on a separate navigation PC which also provided a map view of the study areas.

5.3.8 Onboard processing

First back-up copies were created on two external disks. In parallel to the data acquisition a reduced processing flow was applied on most of the profiles to quickly allow an evaluation of the data quality and also to support further cruise planning. This flow mainly comprised the following steps: Conversion of SEG-D to SEG-Y, Geometry setup, bulk shift of gun delay, brute stack, NMO correction using constant velocity, CMP stack, eventually migration. This was carried out using the commercial software package VISTA for Windows (Schlumberger). Geometry setup for this purpose was carried out using the custom seismic geometry software Wingeoapp.

After the preliminary processing the data were loaded into our seismic interpretation system Kingdom Suite (IHS). This step provided a very fast means to visualize the recorded data nearly immediately after recording in a georeferenced system and allowed a highly flexible survey planning based on the observed sedimentary structures.

Profiles

In total 26 multichannel seismic lines were shot, summing to a total of approximately 1125 km of seismic data. The seismic source for all these lines worked absolutely reliably over the whole time and fired in total 208000 shots (see table 6.1 for the complete profile list.

The data quality of the digital system was generally very good, although on some profiles rough weather conditions slightly degraded the quality and require increased processing efforts, especially for static correction.

5.3.9 Preliminary Results

While the longer wavelength of the seismic data das not provide detailed information on the upper meters of sediment, it allows deeper penetrating images of the subsurface revealing especially glacial structures like tunnel valleays and moraine structures. Figure 5.6 shows a brute stack section of a seismic line that was shot at the very southern rim of the Norwegian sector of the study area in west-east direction covering a distance of 30 km. The profile crosses a slightly depressed very flat section of the seafloor. The signal penetration reaches up to 600 ms TWT (Two Way Travel Time), however, only the upper 400 ms are shown here. The flat seafloor and the underlying hummocky reflectors reach a thickness of roughly 15 – 20 m (20 – 26 ms TWT). The most striking features in the subsurface are several deeply incised v-shaped valley structures. Their depth reaches up 370 ms (corresponding estimated 300 m) and they are filled with a unit expressed by parallel to subparallel weaker amplitude reflectors. Similar structures are found at many places in the North Sea and can usually be attributed to glacial tunnel valleys which have later been filled by post-glacial terrigenous or marine deposits (see e.g. Lutz et al., 2009).

5.4 Sampling with Vibrocorer

5.4.1 Vibrocorer operation

(D. A. Hepp, S. Ehrhardt, D. Otto)

A Geo-Corer 6000 Vibrocoring system (VC) with a barrel length of 5.80 m was used to recover long sediment cores from different infill strata of the Elbe Palaeovalley and

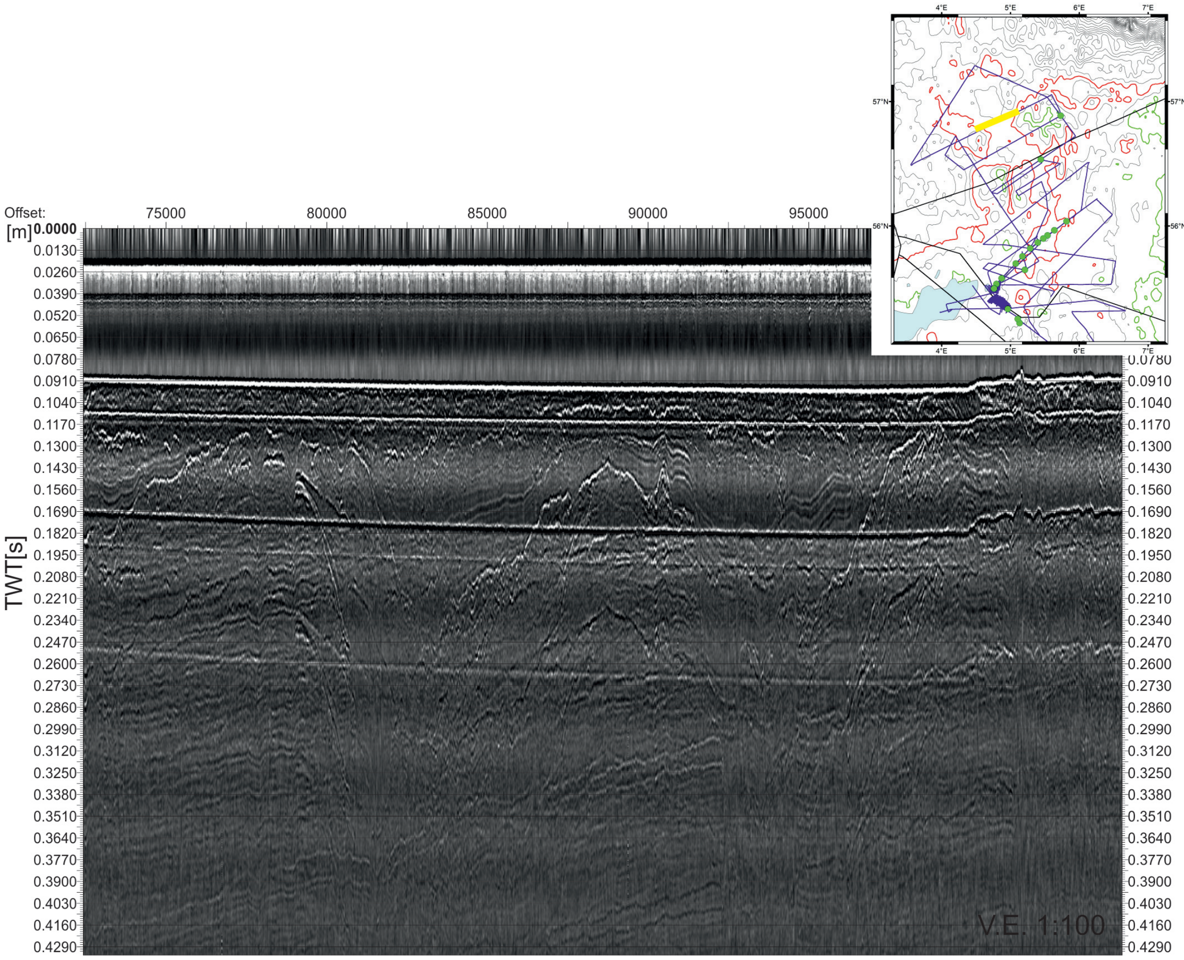

Fig. 5.6 Brutestacked multichannel seismic line GeoB16-298. See embedded map for location

valleys, which are interpreted to be tributaries to the Elbe Palaeovalley. The VC, owned by the company Geo-Engineering.org in Bremen, is equipped with a 28 Hz vibromotor. With a penetration time of ideally one to two minutes for the full 5.80 m core length, the VC achieves optimum results in fine, middle and coarse sands, which are characteristically for the uppermost meters of the North Sea seabed. The Geo-Corer 6000 Vibrocoring system was field tested for the first time by MARUM scientists during the FS HEINCKE expedition HE405 in 2013. The VC performance was successfully coped in the course of the expedition.

For a proper operation on the small RV Heincke deck the diameter of the base frame footprint of the VC was reduced in width, from 4.7 m to 3.26 m, by removing the outermost module elements of two facing feet (Fig. 5.7, top right).

The VC was operated using the cantilever beam on starboard. The wire rope of the winch, which maintains the motor of the VC, was deflected twice times by idler pulleys on deck. Once the VC has touched the seafloor, the wire rope slacked and the idler pulleys toppled. An electrical cable (250 m maximum length) was held by hand. The cable supplied the vibromotor with power and connected the VC with the control unit on deck. The control unit enabled manual runs and stops of the vibromotor and provided online feedback of vibromotor performance and automatic magnetic stop as soon as the maximum penetration depth of the core barrel in the seafloor was reached.

Thanks to the ship's crew and the bridge, which were highly experienced in operating VCs, the ship could be hold on position as required and the VC operation was simple, quick and successful. The common duration time for a complete operation from station begin to station end took about 15 Minutes only, referred to 50 m water depths. A station was complete after the positive check that the core line was properly filled with sediment by opening the spring centered valve at the head of the core barrel. The actually measured penetration time for the full 5.80 m core barrel depended on the sampled sediment type and varied generally from 2.0-2.5 minutes for sands and 3.0-4.0 minutes for clayey sands and pure clays. Only three VC samples with clays in the lower core sections took extraordinary penetration time and two of them have to be stopped manually after 4 minutes (cores GeoB21401-1 and GeoB21411-1).

Fig. 5.7 Vibrocorer operation. From left to right and up to down: retrieving the VC, VC on deck, releasing the cutting shoe, and cutting the core liner into 1-m sections

In total 22 cores with a total length of 106.95 m and a recovery of 97.0% were retrieved.

GeoB21402-2 was not properly filled with sediment and, furthermore, about 25 cm of the uppermost sediments were lost in the core barrel during pulling the liner out of the barrel. From the sediment lost in the barrel a small sample was retained in sample bags. We recognized that air was trapped in the upper third of the core liner, maybe caused by a not proper opened valve during the coring process, whereby the top of the sediment was squeezed out due to the air pressure. The top of the sediment that remained in the core liner was set to zero meter below sea floor (mbsf); with the remark that about the uppermost 25 cm are missing.

At sample sites in sediments, which are designated as valley infills of tributaries, the core catcher often failed and was hardly damaged (GeoB21413-1, GeoB21414-1, GeoB21418-1 and GeoB21419-1). In the case of GeoB21414-1 more than 70 cm of sediment was lost during the lifting process and sediment was still squeezing out after the core was on deck.

5.4.2 5Core handling onboard

Before coring operation the plastic core liners, which would receive the sediments, were marked with a lengthwise line to ensure the orientation of the core after cutting it into its segments. This line was also used as rule for the splitting. The outer faces of the liners were treated with biodegradable dish liquid to ensure a smooth extraction of the sediment filled core liners from the barrel.

After coreing operation the sediment filled liners were extracted from the barrel, cut in 1-m segments on deck (Fig. 5.7, lower right), and labeled following the GeoB labelling scheme (Fig. 5.9, top left). The cores were stored on board in a reefer at about 4 °C as whole rounds or in labelled D-tubes after splitting (Figure 5.8).

Fig. 5.8 Core sections stored at about 4°C in the reefer as whole rounds and half sections (D-tubes).

For core description the cores were then split lengthwise from bottom to top into working and archive halves using a a circular saw installed on a saw bank with a special guide for the core liner and a hand held acoustic plain steel. Immediately after splitting the sediment surface of the archive halves were cleaned from material that may have been transported on the split face during splitting (Fig. 5.9, lower left). The sediment surface of the archive halves were photographed using a Canon 450D with a Sigma 24-60 mm objective (Fig. 5.9, top right). The photos were shot with a focal length of 24 mm, a film speed of ISO-200, an f-number of f/2.8, and a shutter speed between 1/8 and 125 sec.

5.4.3 Visual core description

Sediment color was determined qualitatively using Munsell soil color charts. Sediment components and grains size were semi-quantitatively determined using a hand lens, binocular microscope, smear slide examination and an Eijkelkamp sand ruler. Information from macroscopic and microscopic examinations of each core section was recorded by hand on a primary description form and transferred afterwards into a digital core description form (see attachment).

5.4.4 Sampling strategy

The main target of the sampling strategy was to provide a complete sedimentological record of the infill material across the EPV. Other targets were to provide sedimentary reference samples to the infill north of the EPV, to understand the sedimentary infill history of valley structures in the area between the Dogger Bank and the western flank of the EPV, and to test the hypothesis that the valley is accompanied by marshlands.

Fig. 5.9 Core handling and visual core description performed in the wet lab of RV Heincke. From left to right and up to down: core labelling, core imaging, core preparation for description, and core description

In total, 22 sediment cores were taken at 21 sites. All sites are located along seismic survey tracks and were chosen based on the acoustic profiles shot during the current expedition or expedition HE405 in 2013, respectively. The main focus of the sampling program was on 12 core sites (GeoB21403-1 to GeoB21414-1) along the acoustic profile GeoB16-283/284, which crosses the EPV from northeast to south west, south of the south eastern extension of the Dogger Bank.

One vibrocore (GeoB21415-1) was taken south of the acoustic profile GeoB16-283/284, as reference to borehole BH89/8 (Konradi, 2000), which penetrated the base of the EPV at the same location down to 51 m depth. Two cores (GeoB21416-1 and GeoB21417-1) were taken north of the acoustic profile, at assumed drainage pathways of the EPV toward the Norwegian Channel. Both cores were taken understand in which manner the sediments differs from the infill sediments of the EPV.

The infill sediments and surroundings of valley structures which are supposed to be part of a huge tributary system which drained the Dogger Bank toward the north western flank of the EPV since the Late Weichselian (Hepp et al., accepted 2016), were sampled with 7 cores at 6 sites (GeoB21413-1 to GeoB21414-1, and GeoB21418-1 to GeoB21421-2). Two of the cores are also located on acoustic profile GeoB16-283/284.

During RV Heincke expedition HE405 in 2013 we were able to penetrate the infill of an incision in the southern most area of the EPV (GeoB17718-3) which is supposed to be part of a drainage system of the early phase of the EPV. We used the transit to the actual study area to sample two additional incisions (cores GeoB21401-1 and GeoB21402-1), which are located on the same seismic profile sampled during HE405 expedition.

5.4.5 Preliminary results and interpretations from core description

Eleven cores were opened and visually described onboard (see supplement). Ten sites are located along the long seismic transect GeoB16-283/284 and one site is located at the infill of an internal incision in the southern most area of the EPV (see figure 3.2 for location).

The sediment composition ranges from clay to medium sand. Medium gravel was observed in core GeoB21403-1 only, at depths between 2.80-2.94 mbsf. Clayey, silty clayey and fine sandy core intervals are often stratified by layers of silty clay, silty fine sand, fine sand or black organic matter. Carbonate occurs as single bivalves or gastropods, scattered shell fragments, shell fragment layers, or fossil mussel beds. Plant fragments and pieces of wood were observed in a few cores. HCl tests reveal remarkable high calcium carbonate concentrations in laminated clay intervals of cores GeoB21409-1 and GeoB21410-1 below 458 mbsf or 456 mbsf, respectively.

The following first interpretation of the infill of the EPV and the deposits at its western flank is tentative and based on a core descriptions and a very rough interpretation of the seismic profiles GeoB16-283/284 (Fig. 5.1 & 5.10). The combined profile is about 137 km long and reveals geological structures of the subseafloor down to 35 mbsf.

<u>Infill sediments of the Elbe Palaeovalley along seismic cross profile</u>

The western flank of the EPV is overlaid by a ~4 km wide and up to 13.5 m high sediment body with can be associated with the morphological expression of the White Bank. Based on sediment cores (GeoB21410-1 to GeoB21412-1) as well as prominent seismic reflectors this body can be divided into an upper (Fig. 5.10 - 1) and a lower unit (Fig. 5.10 - 2). The upper unit is up to 7 m thick and composed of dark grayish brown medium sand interspersed with bivalves, shell fragments and black organic mat-

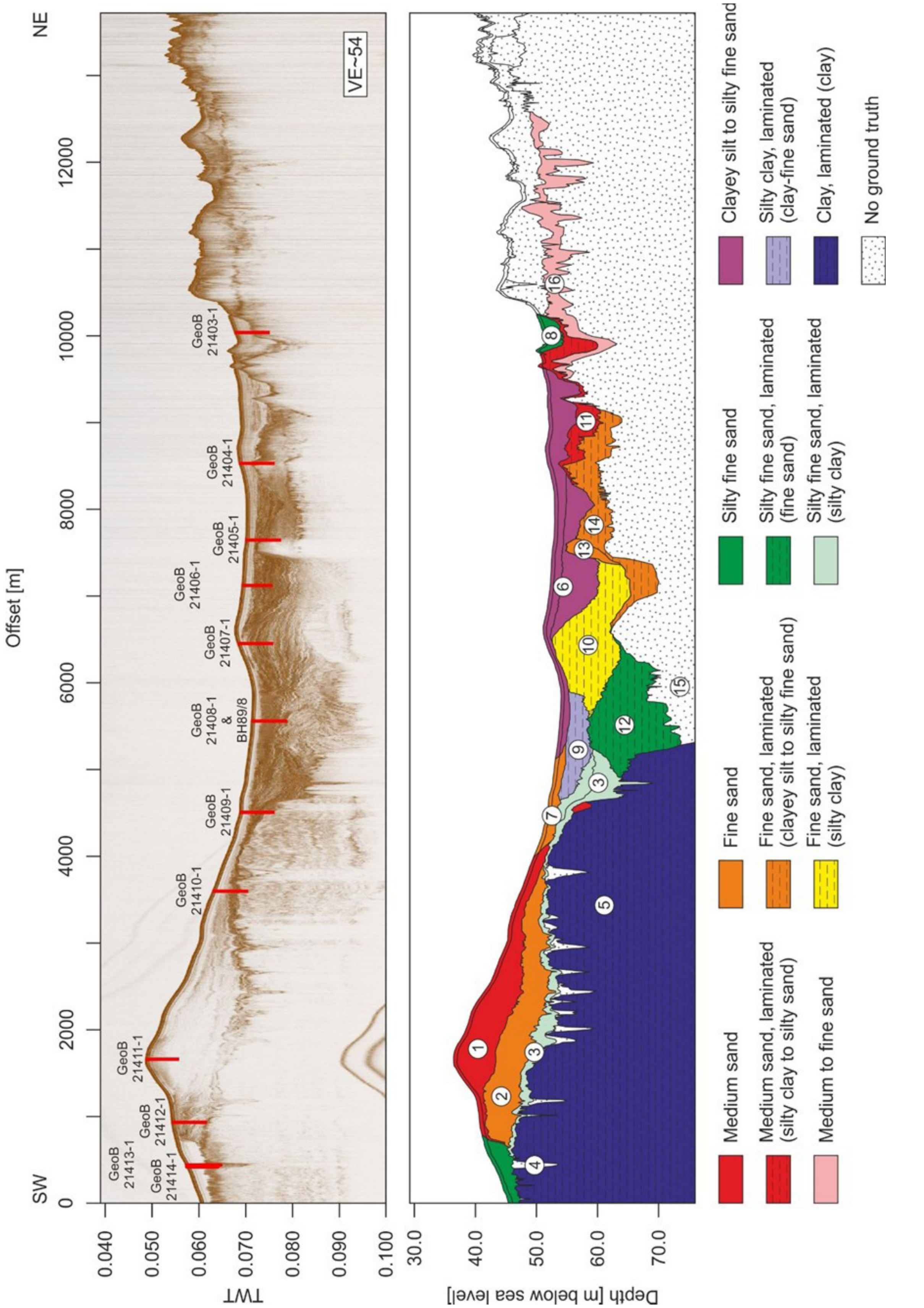

Fig. 5.10 SES profile GeoB16-283/284 and tentative interpretation and separation in sedimentary units. Coring locations and penetrations are marked in red.

ter. Irregular discolorations, which are often associated with shell nodules and which smelled fishy after core splitting (GeoB21411-1) suggest that these sediments were recently deposited. The contact to the underlying lower unit is sharp and associated with a layer of bivalves (Cardiidae; GeoB21410-1, 122.5 cm).

The lower unit is up to 6.5 m thick and composed of dark grayish brown fine sand, which is stratified by thin layers of black organic matter. Shell fragments are rare.

The sediment body rests on an up to 4 m thick layer (Fig. 5.10 - 3) of dark greenish gray silty fine sand with 1-15 mm thick, alternating layers of silty clay, silty very fine sand or black organic matter (GeoB21409-1, GeoB21410-1 and GeoB21412-1). This layer was observed only at the western flank and slope of the EPV.

This layer covers a number of valleys (Fig. 5.10 - 4), which are incised into the underlying sediments (Fig. 5.10 - 5). The underlying sediments are composed of laminated dark grayish brown to dark olive brown clays with organic matter. These clays differ conspicuously in type and stiffness from the overlying sediments and the sediments from the actual infill of the Elbe Palaeovalley (GeoB21409-1 and GeoB21410-1). The sediments show a remarkable high calcium carbonate content (HCl test), compared to the overlying sediments, and have a soft to stiff or stiff consistency (1.24 kg/cm² or 2,0 kg/cm²; pocket penetrometer test). Small grain size, structure, carbonate content and stiffness point to proglacial lake sediments, however, thorough analysis is needed to confirm this assumption.

The infill of the EPV can roughly be divided into 9 units. Furthermore the infill sediments can be divided in upper (Fig. 5.10 - 6-8), middle (Fig. 5.10 - 9-11) and lower units (Fig. 5.10 - 12-14). The upper unit is up to 7 m thick and dominated by sediments of clayey silt or clayey silt with sand layers, which cover the most parts of the valley infill; especially in the eastern valley part (Fig. 5.10. - 6). This deposit seems to be the stratigraphically youngest. A small, up to 2 m thick unit at the foot of the White Bank, composed of fine sands (Fig. 5.10 - 7), and a small, up to 3.5 m thick unit in the eastern most part of the valley, composed of silty fine sands (Fig. 5.10 - 8), form the sea floor as well.

The middle infill units are mostly located in the western part of the valley. The sediments of an up to 4.5 m thick unit, which is expressed as a lens shaped depression (Fig. 5.10 - 9), are composed of silty clay, laminated by layers of clay, silty clay, very fine sand and fine sand (GeoB21408-1). This unit overlies at its eastern part an up to 11 m thick unit (Fig. 5.10 - 10), which is composed of fine sand, laminated with layers of silty clay or black organic matter (GeoB 21407-1). Shell fragments are very rare, but plant fragments occur.

A special feature is the up to 9 m thick layer in the eastern part of the valley infill (Fig. 5.10 - 11). This unit is composed of fine to medium sands toward the valley center and medium sands at the eastern valley flank. The lower boundary of this unit is characterized by a sharp erosive contact, seen in both cores GeoB214030-1 and GeoB21404-1. At the base of the unit (GeoB 21403-1), a layer of well-preserved thick-walled autochthonous bivalves (70 mm shell height), preliminary referred as Arctica islandica, accompanied by high to low spheric and subangular to subrounded medium gravel (10-20-mm) and a few shell fragments are found directly above the sharp horizontal contact. At GeoB 21404-1 the deposition above the inclined sharp contact is characterized by 5-15 mm thick partially reworked layers and clasts of silty clay within the medium sand. However, the character of the deposits above the contacts differs in both cores but hints toward very shallow water environments (transgressional horizon, shore or beach line).

The sediments of the lower units of the valley infill are composed of silty fine sands with sandy layers in the western part (GeoB21408-1), and of fine sands with organic layers and rare shell fragments in the eastern part (GeoB21404-1):

a) Lower infill units in the western valley part: The sediments of core GeoB21408-1 coincides with the upper silt section of BH89/8 described by Konradi (2000). The author describes the sediments between 0 and 17.5 m as “interlaminated silt, clayey of fine sandy, and of sand, fine and often silty”. Especially the section from 1.85 to 5.35 mbsf of BH89/9 composed of laminated silty clay coincides with the section from 0.6 to 4.71 mbsf of GeoB 21408-1 (Fig. 5.10 - 12) described as silty clay, stratified with layers of clay, silty clay, very fine sand and fine sand. Based on rich and diverse benthic foraminiferal fauna, Konradi (2000) interprets this deposits originating from a marine environment. He dates the base of the section on 10250 ±80 yr cal BC and the interval between 1.85 to 5.35 mbsf on 8230 ±80 to 8250 ±75 yr cal BC, based on radiocarbon dates of mollusk shells. The base of the section represents the start of the Holocene marine transgression into the EPV which results in an estuary situation. The interval between 5.35 and 1.85 mbsf represents an abrupt change in marine environment.

b) Lower infill units in the eastern valley part: The sediments in the eastern valley part are composed of fine sand or fine sands, which are laminated with layers of clayey silt, silty fine sand or organic matter (GeoB 21404- and GeoB21405-1; Fig. 5.10 - 13-14). They are comparable in composition to the lower part of the White Bank body described above.

c) Sediments below the infill units: The sediments below these units were not reached by vibrocores during the expedition, but are known from the BH89/8 core (Fig. 4.15). The sediments consist of upward fining sands with a low content of reworked Pleistocene foraminifers, which are supposed to be of fluvial origin. The base of the EPV might not been imaged with the SES.

Incisions at the base of the Elbe Palaeovalley

The base of the EPV is characterized by a number of incisions, which are supposed to be channels of a braided river system (Özmaral et al., in prep). During HE 405 we were able to penetrate the infill of such an incision in the southern most area of the EPV (GeoB17718-3). We used the transit to our study area to core two additional incisions on the same seismic profile (GeoB21401-1 and GeoB21402-1). GeoB21401-1 penetrated the incision. The uppermost 457 cm comprise very uniform marine sediments composed of dark greenish gray fine sand (90-125 µm), commonly intermixed with 2-5 mm small shell fragments. The shell fragment abundance varies slightly over depth. Below 457 cm the core penetrated sediments of the incision infill and covering strata and coincides with little offset (<40 cm) with strong reflectors observed in the seismic profile. They show rapid sequences of clear distinguished sediment units of different grainsizes ranging from silty clay to medium sand. The contacts are often sharp and erosive or marked by in-situ layers of bivalves, which are characteristic for coastal shallow water environments. The medium sand units comprise tower shells (Turritellidae), which are marker for coastal areas. Rapid changes in grain size, erosive contacts and suggest short term changes in transport energy and the fauna, which hints to tidal environments. Note that the lower section is moderately bioturbated and the lowermost parts, below the in-situ shell layer (548-579 cm) are bare of preserved and fragmented shells or gastropods.

6 Station and Profile List(s)

Table 6.1 List of seismic profiles of cruise HE463.

Profile Nr.	Start Date	Time	End Date	Time	Start Lat [N]	Lon [E]	End Lat [N]	Lon [N]	Start Shot Nr	End Shot Nr	Nr of shots	Length [km]	Source
GeoB16-279	11.05.2016	23:56	12.05.2016	03:55	55°17.771'	06°06.208'	55°18.07'	06°39.466'	30	4052	4022	35,2	Micro-GI
GeoB16-280	12.05.2016	03:55	12.05.2016	07:09	55°18.07'	06°39.475'	55°23.279'	06°13.534'	4053	7370	3317	29,1	Micro-GI
GeoB16-281	12.05.2016	07:09	12.05.2016	16:44	55°23.279'	06°13.527'	55°19.514'	04°58.721'	7371	15381	8010	79,4	Micro-GI
GeoB16-282	12.05.2016	16:44	12.05.2016	18:45	55°19.579'	04°58.429'	55°26.406'	04°45.385'	15382	17265	1883	18,7	Micro-GI
GeoB16-283	12.05.2016	18:45	13.05.2016	00:37	55°26.285'	4°45.609'	55°48.838'	05°16.840	17266	22548	5282	53,2	Micro-GI
GeoB16-284	13.05.2016	00:37	13.05.2016	09:04	55°48.841'	05°16.847'	56°13.224'	06°15.451'	22549	30155	7606	75,9	Micro-GI
GeoB16-285	16.05.2016	16:37	17.05.2016	05:03	55°51.727'	04°37.723'	56°30.588'	06°06.935'	1	11186	11185	117,2	Micro-GI
GeoB16-286	17.05.2016	15:15	17.05.2016	16:28	55°49.223'	05°17.193'	55°54.496'	05°22.333'	1	1105	1104	11,2	Micro-GI
GeoB16-287	17.05.2016	16:43	17.05.2016	22:47	55°54.706'	05°23.177'	55°36.994'	04°40.286'	1322	6792	5470	55,6	Micro-GI
GeoB16-288	17.05.2016	22:48	18.05.2016	00:40	55°36.984'	04°40.286'	55°27.842'	04°45.723'	6794	8481	1687	17,9	Micro-GI, BO
GeoB16-289	18.05.2016	00:40	18.05.2016	01:20	55°27.842'	04°45.733'	55°30.889'	04°48.383	8482	9085	603	6,3	Micro-GI
GeoB16-290	18.05.2016	01:20	18.05.2016	04:37	55°30.893'	04°48.389'	55°38.976'	05°13.918'	9086	12034	2948	30,8	Micro-GI
GeoB16-291	18.05.2016	04:37	18.05.2016	06:14	55°38.986'	05°13.919'	55°46.643'	05°10.397'	12036	13485	1449	14,7	Micro-GI
GeoB16-292	19.05.2016	08:27	19.05.2016	09:59	55°38.993'	05°14.361'	55°42.74'	05°24.476'	1	1384	1383	12,7	Micro-GI
GeoB16-293	19.05.2016	09:59	19.05.2016	17:22	55°42.75'	05°24.482'	56°16.189'	04°43.648'	1385	8018	6633	75,2	Micro-GI
GeoB16-294	19.05.2016	17:22	20.05.2016	02:09	56°16.161'	04°43.677'	56°43.384'	05°56.588'	8019	15912	7893	90,1	Micro-GI
GeoB16-295	20.05.2016	02:09	20.05.2016	06:32	56°43.384'	05°56.588'	57°01.955'	05°32.116'	15913	19867	3954	42,5	Micro-GI
GeoB16-296	20.05.2016	06:32	20.05.2016	13:29	57°01.955'	05°32.116'	57°16.964'	04°28.854'	19868	26116	6248	69,5	Micro-GI
GeoB16-297	20.05.2016	13:29	21.05.2016	00:02	57°16.964'	04°28.854'	56°29.593'	03°33.129'	26117	35598	9481	104,5	Micro-GI
GeoB16-298	21.05.2016	00:02	21.05.2016	13:40	56°29.593'	03°33.129'	57°02.668'	05°34.093'	35599	47868	12269	137,4	Micro-GI
GeoB16-299	23.05.2016	07:22	23.05.2016	08:15	55°21.484'	04°04.534'	55°17.591'	04°05.878'	1	798	797	7,4	Micro-GI
GeoB16-300	23.05.2016	08:15	23.05.2016	08:43	55°17.591'	04°05.878'	55°18.797'	04°09.113'	799	1224	425	4,1	Micro-GI
GeoB16-301	23.05.2016	08:43	23.05.2016	09:58	55°18.797'	04°09.113'	55°17.404'	03°59.424'	1225	2350	1125	10,6	Micro-GI
GeoB16-302	23.05.2016	09:58	23.05.2016	11:48	55°17.404'	03°59.424'	55°18,889'	04°08.734'	2352	3995	1643	10,2	Micro-GI
GeoB16-303	23.05.2016	16:14	23.05.2016	16:53	55°17.717'	04°57.15'	55°19.967'	05°00.45'	287738	292362	4624	7,4	BO
GeoB16-304	23.05.2016	16:53	23.05.2016	17:29	55°19.967'	05°00.45'	55°18.15'	04°56.7'	199198	296671	97473	7,7	BO
										Total:	**208514**	**1124,5**	

Table 6.2 List of seafloor sampling stations during expedition HE463

GeoB Nr.	Ship's station Nr.	Area	Device	Bottom Contact Date [dd.mm.yy]	Time [UTC]	Latitude	Longitude	Water depth [m]	Recovery [cm]	Remarks
GeoB21401-1	HE463/001	Elbe Palaeovalley	VC	11.05.16	12:40:00	54°15.580'N	07°14.060'E	39.7	579	sampling duration 4.00 min., aborted
GeoB21402-1	HE463/002	Elbe Palaeovalley	VC	11.05.16	13:41:00	54°15.453'N	07°10.134'E	39.0	537	sampling duration 2.40 min, loss of uppermost ~25 cm
GeoB21403-1	HE463/007	Elbe Palaeovalley	VC	17.05.16	09:17:00	56°02.207'N	05°48.868'E	50.7	571	sampling duration 3.00 min.
GeoB21404-1	HE463/008	Elbe Palaeovalley	VC	17.05.16	10:54:00	55°57.810'N	05°38.211'E	52.4	567	sampling duration 3.30 min.
GeoB21405-1	HE463/009	Elbe Palaeovalley	VC	17.05.16	11:55:00	55°55.298'N	05°32.232'E	53.4	568	sampling duration 2.30 min.
GeoB21406-1	HE463/010	Elbe Palaeovalley	VC	17.05.16	12:42:00	55°53.801'N	05°28.269'E	52.8	563	sampling duration 2.00 min.
GeoB21407-1	HE463/011	Elbe Palaeovalley	VC	17.05.16	13:36:00	55°51.778'N	05°23.800'E	51.9	574	sampling duration 2.30 min.
GeoB21408-1	HE463/012	Elbe Palaeovalley	VC	17.05.16	14:34:00	55°48.945'N	05°17.146'E	54.3	575	sampling duration 2.20 min.
GeoB21409-1	HE463/014	Elbe Palaeovalley	VC	18.05.16	07:08:00	55°45.024'N	05°10.444'E	52.0	571	sampling duration 2.30 min., CC as bag sample
GeoB21410-1	HE463/015	Elbe Palaeovalley	VC	18.05.16	08:04:00	55°41.505'N	05°04.599'E	47.6	575	sampling duration 3.40 min., CC as bag sample
GeoB21411-1	HE463/016	Elbe Palaeovalley	VC	18.05.16	10:01:00	55°34.211'N	04°52.273'E	36.5	538	sampling duration 4.00 min., aborted
GeoB21412-1	HE463/017	Elbe Palaeovalley	VC	18.05.16	11:01:00	55°31.419'N	04°47.728'E	40.9	572	sampling duration 3.30 min.
GeoB21413-1	HE463/018	Elbe Palaeovalley	VC	18.05.16	11:40:00	55°29.211'N	04°45.706'E	43.3	575	sampling duration 3.30 min., CC damaged
GeoB21414-1	HE463/019	Elbe Palaeovalley	VC	18.05.16	12:07:00	55°29.112'N	04°45.608'E	43.3	504	sampling duration 2.00 min., CC damaged, sed. loss
GeoB21415-1	HE463/021	Elbe Palaeovalley	VC	19.05.16	07:35:00	55°38.393'N	05°12.453'E	50.3	522	sampling duration 4.00 min.
GeoB21416-1	HE463/023	Elbe Palaeovalley	VC	21.05.16	15:24:00	56°53.205'N	05°43.730'E	55.4	574	sampling duration 2.40 min.
GeoB21417-1	HE463/026	Elbe Palaeovalley	VC	22.05.16	11:50:00	56°32.218'N	05°26.387'E	53.9	575	sampling duration 2.50 min.
GeoB21418-1	HE463/029	Entenschnabel	VC	23.05.16	14:52:00	55°19.099'N	04°57.682'E	47.9	580	sampling duration 3.00 min., CC damaged
GeoB21419-1	HE463/030	Entenschnabel	VC	23.05.16	15:19:00	55°18.992'N	04°57.691'E	47.9	577	sampling duration 3.00 min., CC damaged
GeoB21420-1	HE463/032	Entenschnabel	VC	26.05.16	07:29:00	55°11.996'N	05°07.893'E	42.0	570	sampling duration 2.30 min.
GeoB21421-1	HE463/033	Entenschnabel	VC	26.05.16	08:03:00	55°14.007'N	05°06.313'E	42.4	270	sampling duration 2.10 min., CC failed, loss of sed.
GeoB21421-2	HE463/034	Entenschnabel	VC	26.05.16	08:42:00	55°14.005'N	05°06.332'E	42.4	558	sampling duration 2.10 min.

Table 6.1 List of applied device acronyms

Acronym	Device
VC	Vibrocoring System
BO	Boomer
Micro-GI	Micro-GI-Airgun

7 Data and Sample Storage and Availability

Sediment cores will be stored in the MARUM core repository. Core descriptions and other related data are available from the PANGAEA data bank. Sample requests have to be sent to the chief scientist and will be reviewed in order not to overlap with current scientific work. After the 5-year-memorandum samples are open for further research (June 2021).

Profiling hydroacoustic and seismic data will be stored on local data servers within the working group. Data extracts are available on request and will be reviewed in order not to overlap with current scientific work. Table 7.1 lists the database, tentative submission, access date and responsible scientists

Table 7.1 Data storage and availability

Type	Database	Available	Free Access	Contact
Bathymetry		Jun. 16	Jun. 2016	hkeil@uni-bremen.de
SES 2000		Jun.16	Jun. 2021	hkeil@uni-bremen.de
MCS		Jun.17		hkeil@uni-bremen.de
Core samples	PANGAEA	Jun. 17	Jun. 2021	dhepp@marum.de

8 Acknowledgements

The cruise was coordinated and carried out by MARUM Center for Marine Environmental Sciences at the University of Bremen. The research program is part of the DFG Research Center and Cluster of Excellence "The Ocean in the Earth System" in Research Area "Seafloor Dynamics", project SD2 "Climatic control on large scale sedimentary structures". The cruise was financed by MARUM, the German Research Foundation (DFG) within SD2. The shipping operator Reederei Briese Schiffahrts GmbH & Co KG provided technical support on the vessel. We would like to specially acknowledge the master of the vessel Robert Voss, and his crew for their continued contribution to a pleasant and professional atmosphere aboard R/V Heincke.

Multichannel seismic processing software Vista and the interpretation software KingdomSuite that helped in a fundamental way to achieve our goals are granted to the University of Bremen in the framework of the academic donation programs of Schlumberger (Vista) and HIS (Kingdom).

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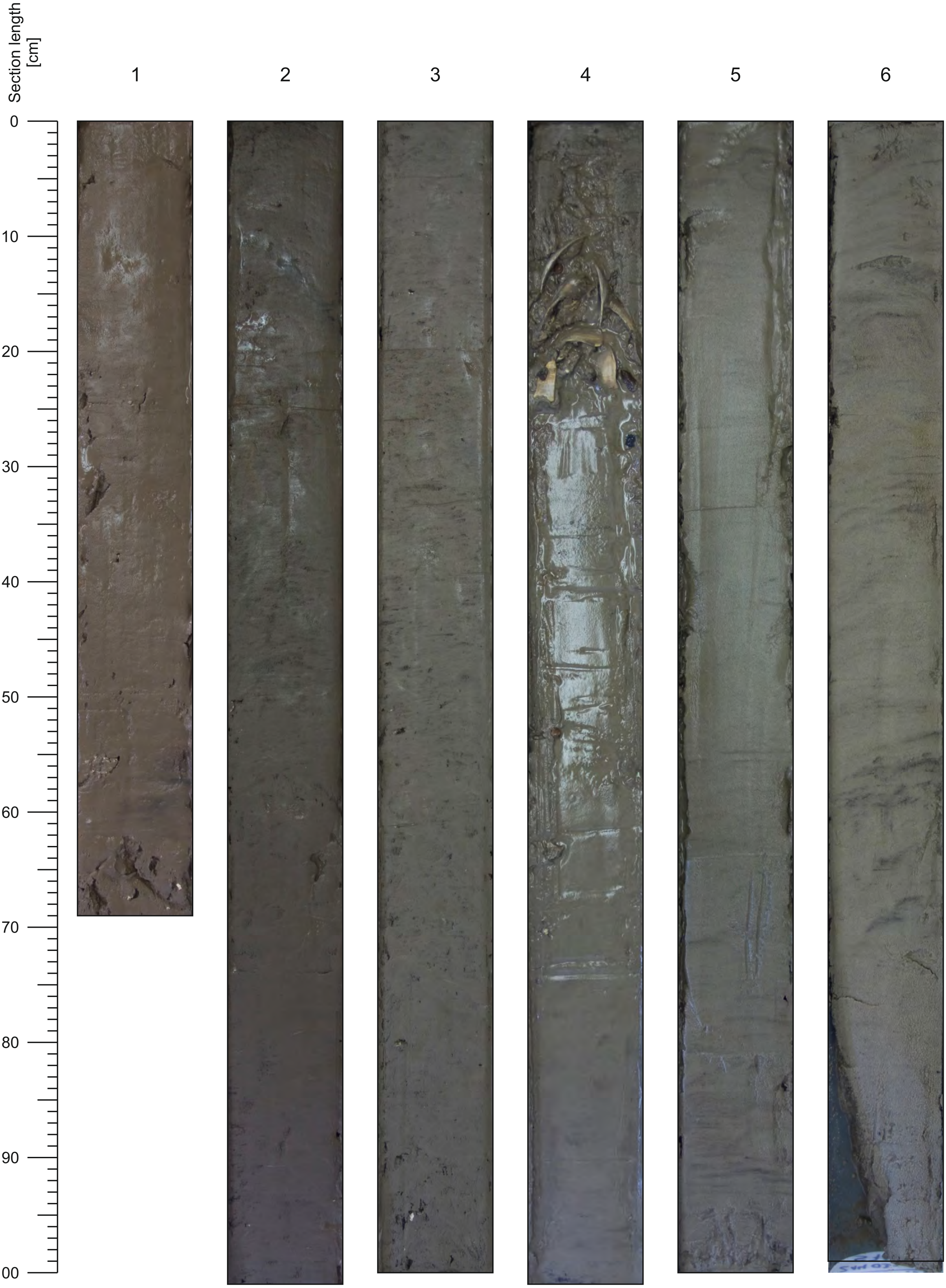
10 Appendix

I. Core Photographs

II. On Board Visual Core Descriptions

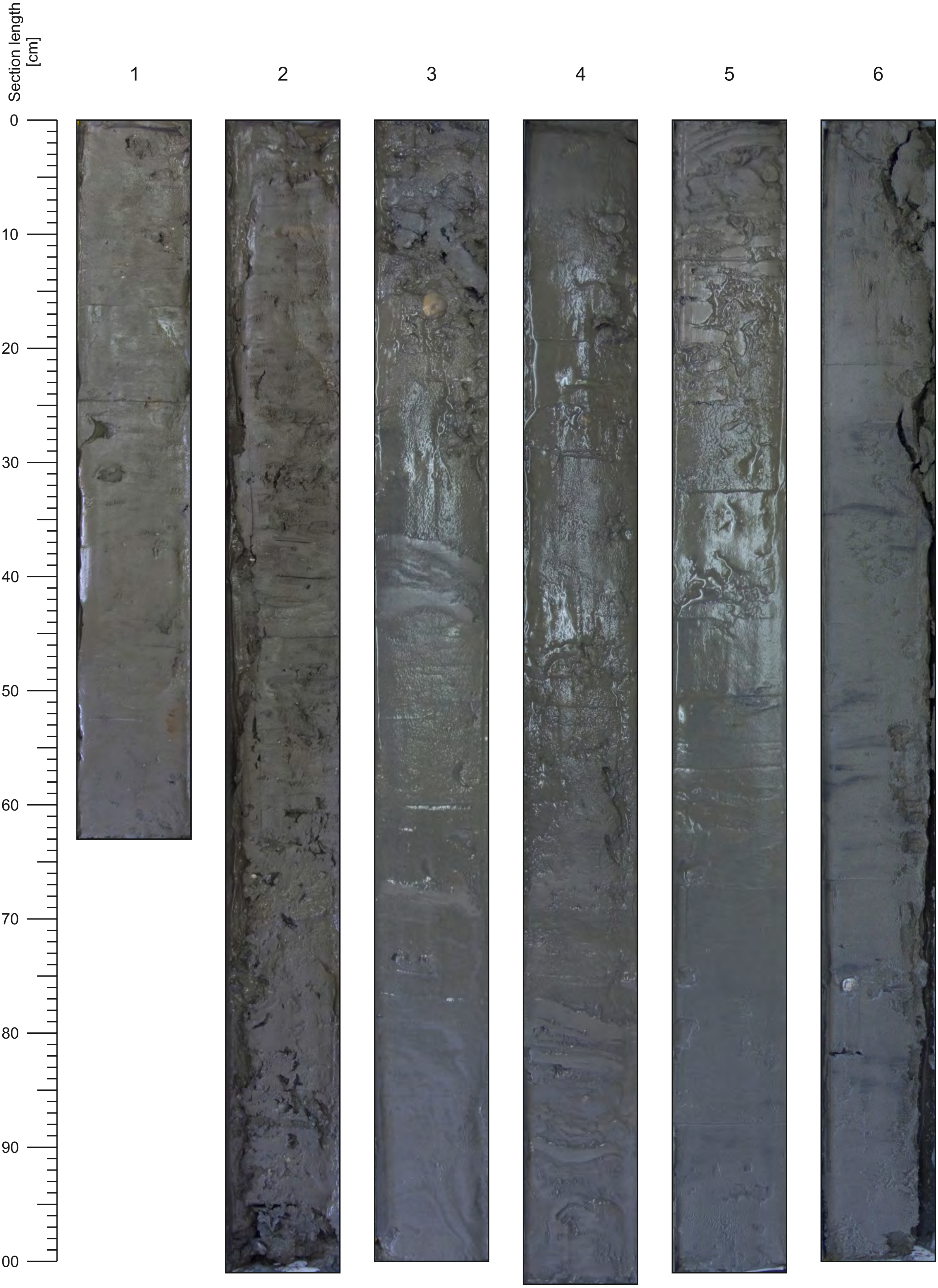
GeoB 21403-1

Latitude: 56°02.207' N | Longitude: 05°48.868' E | Water depth: 50.70 m
Target depth: 5.80 mbsf | Sample depth: 5.71 m | Recovery: 98.5%



GeoB 21404-1

Latitude: 55°57.810' N | Longitude: 05°38.211' E | Water depth: 52.40 m
Target depth: 5.80 mbsf | Sample depth: 5.67 m | Recovery: 97.8%

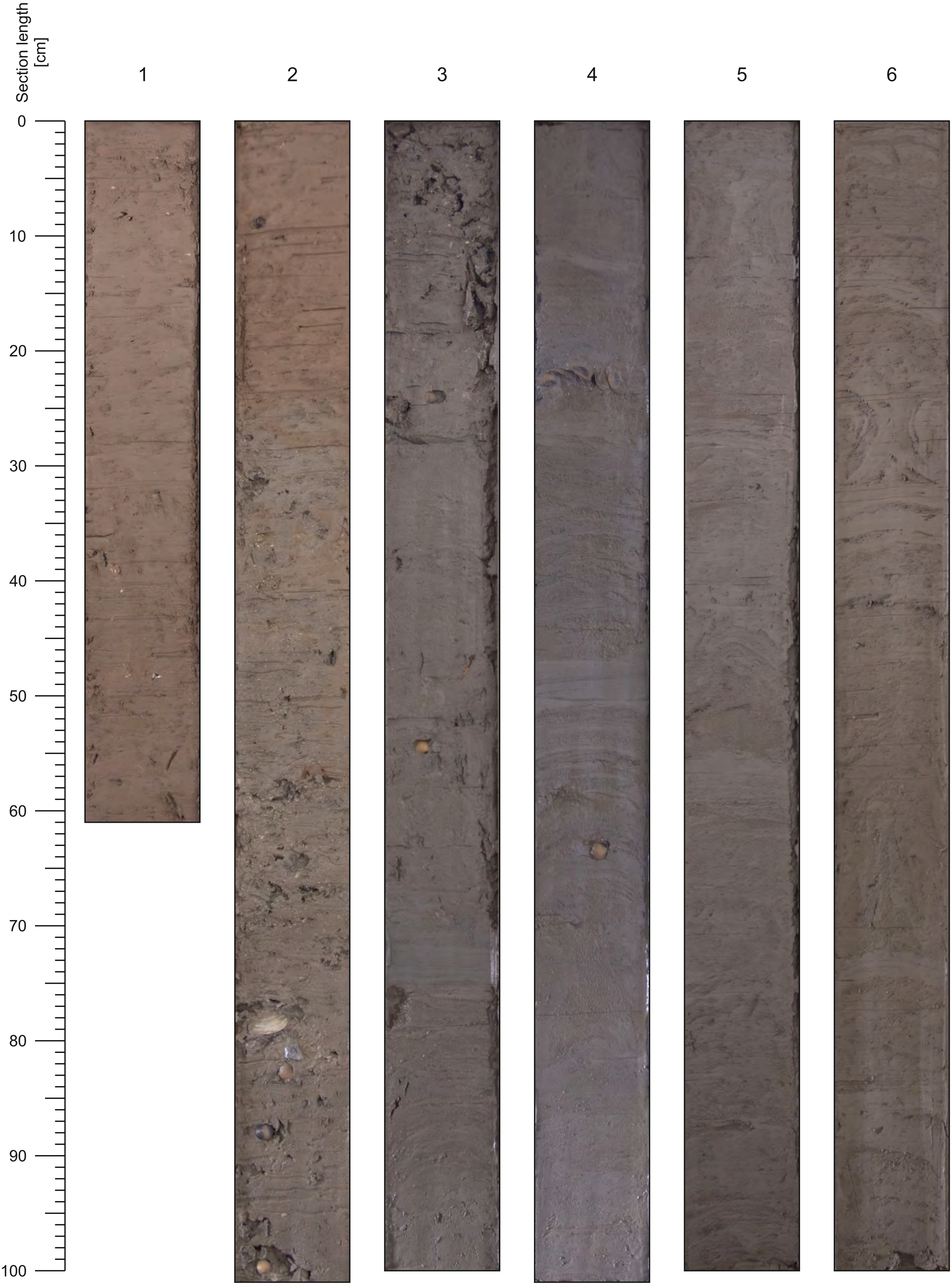


GeoB 21405-1

Latitude: 55°55.298' N | Longitude: 05°32.232' E | Water depth: 53.40 m
Target depth: 5.80 mbsf | Sample depth: 5.68 m | Recovery: 97.9%

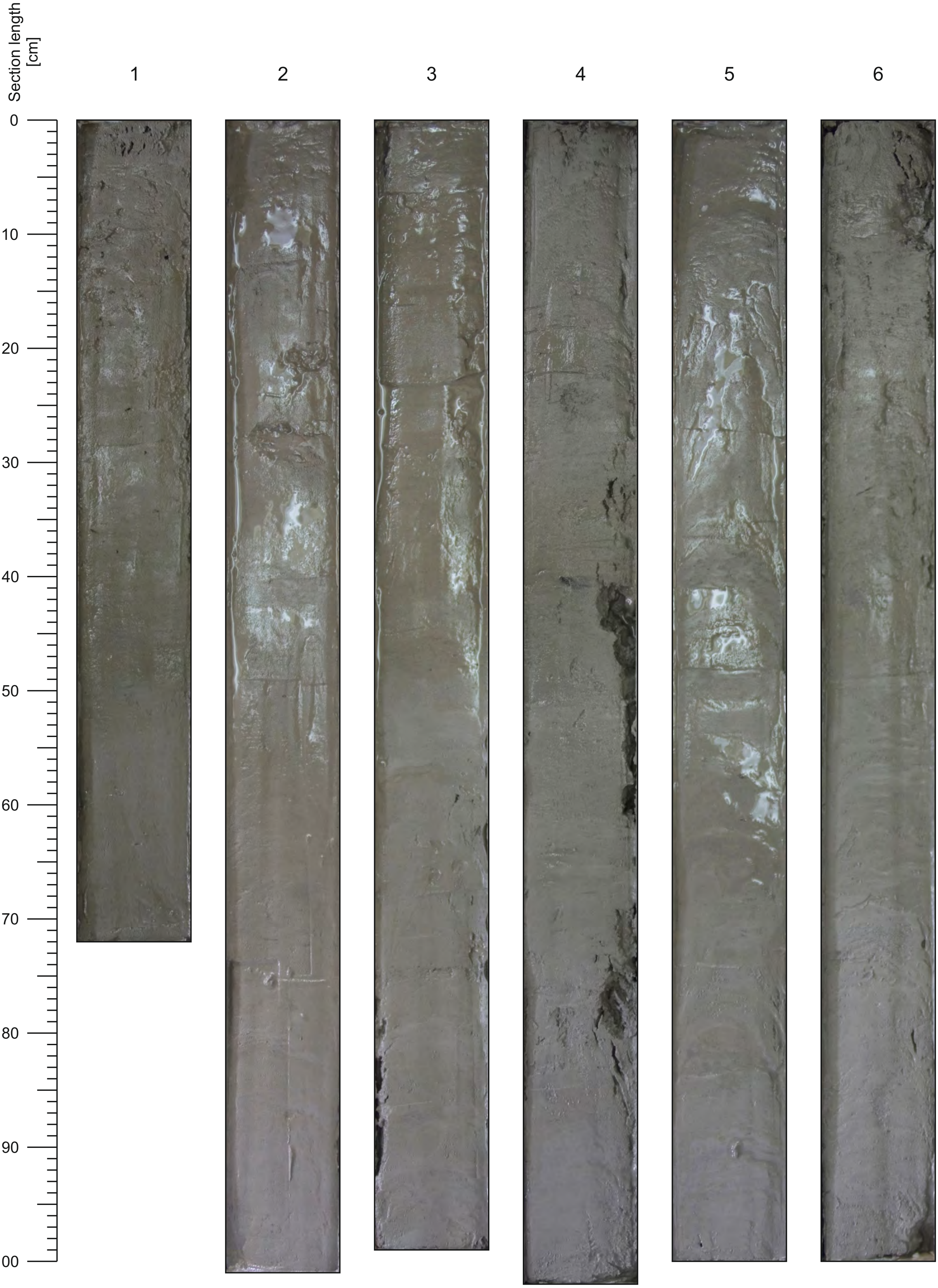
GeoB 21406-1

Latitude: 55°53.801' N | Longitude: 05°28.629' E | Water depth: 52.81 m
Target depth: 5.80 mbsf | Sample depth: 5.63 m | Recovery: 97.1%



GeoB 21407-1

Latitude: 55°51.778' N Longitude: 05°23.800' E Water depth: 51.90 m
Target depth: 5.80 mbsf Sample depth: 5.74 m Recovery: 99.0%

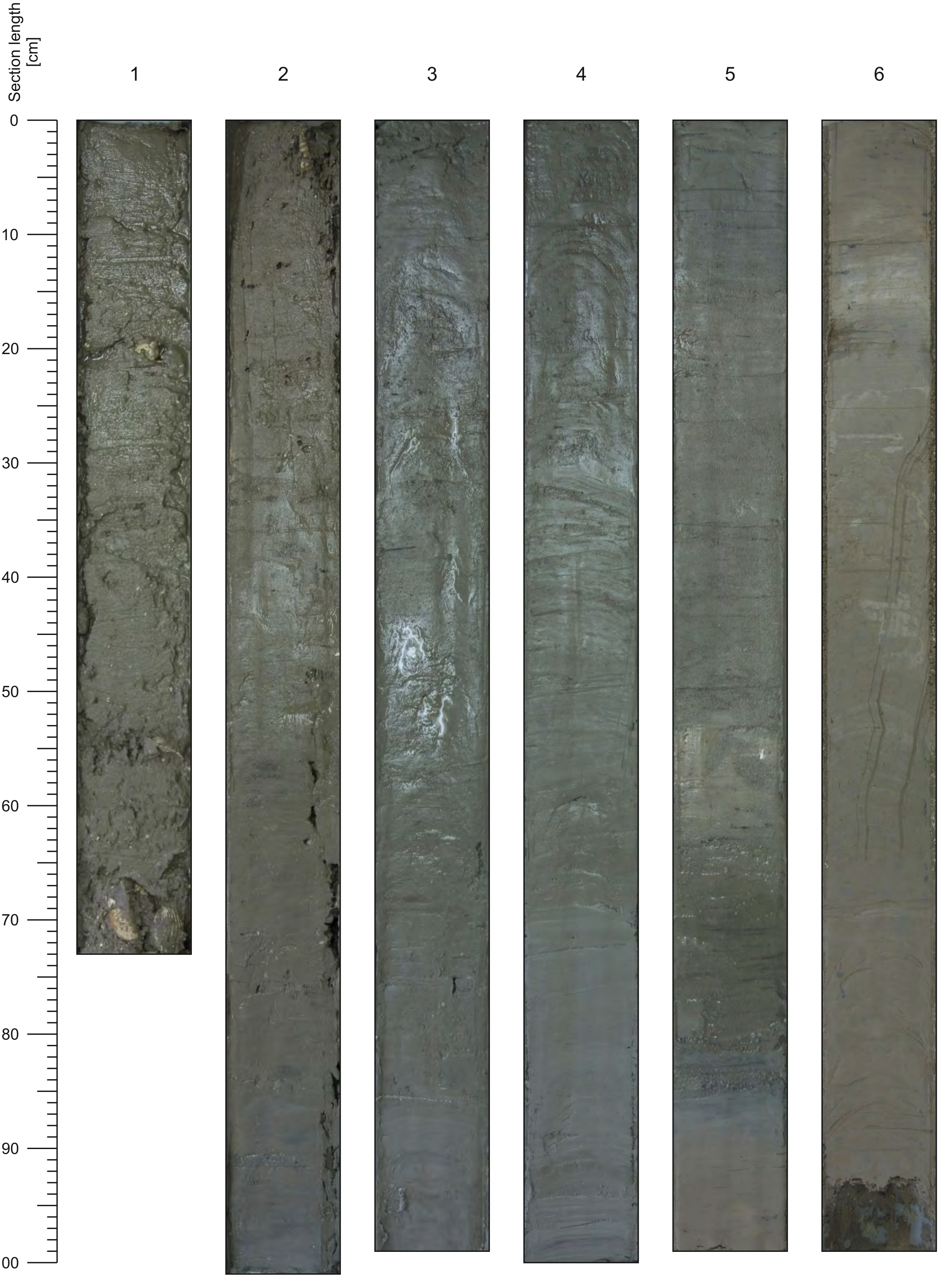


GeoB 21408-1

Latitude: 55°48.945' N
Longitude: 05°17.146' E
Water depth: 54.30 m
Target depth: 5.80 mbsf
Sample depth: 5.73 m
Recovery: 98.8%

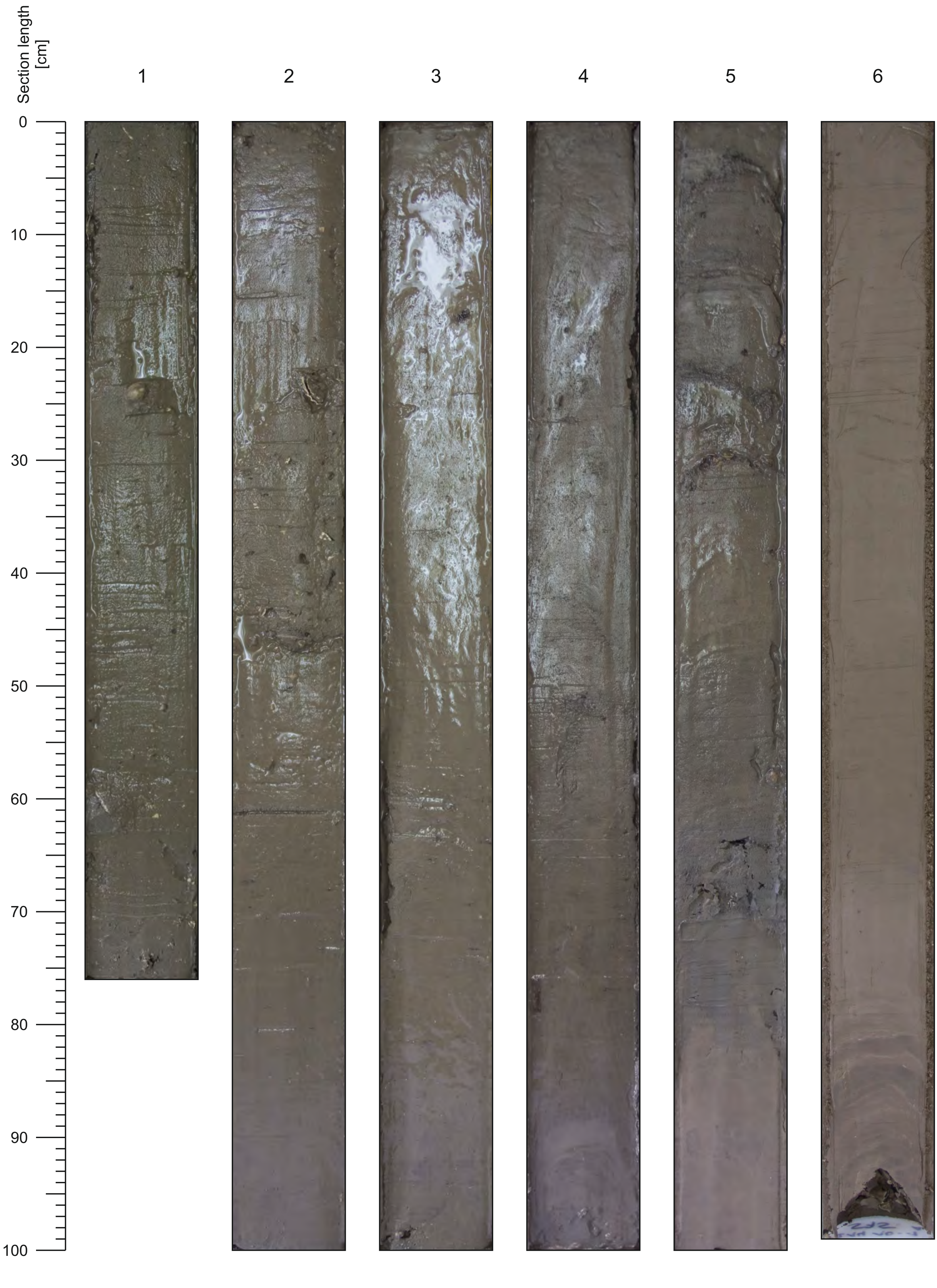
GeoB 21409-1

Latitude: 55°45.024' N | Longitude: 05°10.444' E | Water depth: 52.00 m
Target depth: 5.80 mbsf | Sample depth: 5.71 m | Recovery: 98.5%



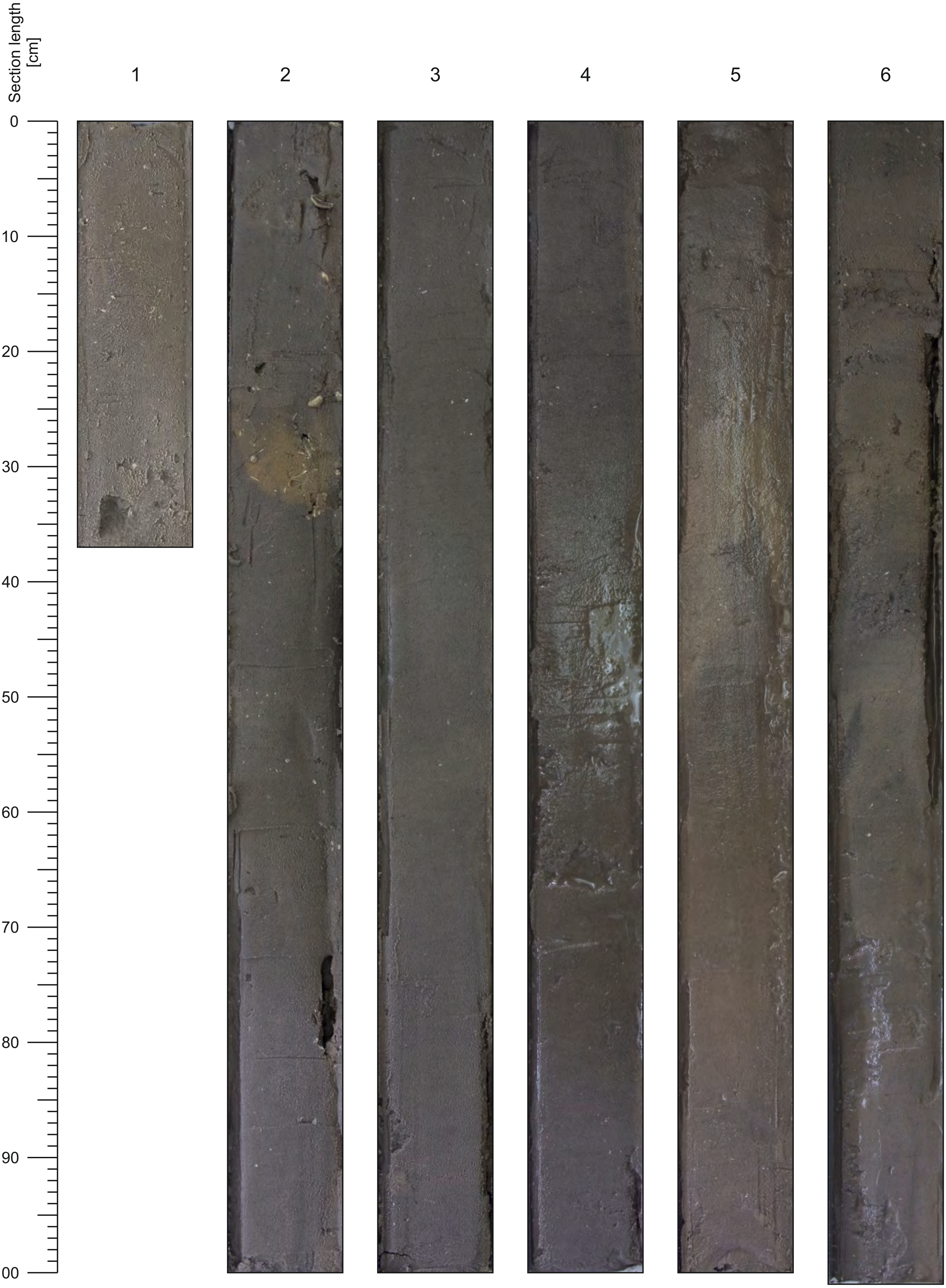
GeoB 21410-1

Latitude: 55°41.505' N | Longitude: 05°04.599' E | Water depth: 47.60 m
Target depth: 5.80 mbsf | Sample depth: 5.75 m | Recovery: 99.1%



GeoB 21411-1

Latitude: 55°34.211' N | Longitude: 04°52.273' E | Water depth: 36.50 m
Target depth: 5.80 mbsf | Sample depth: 5.38 m | Recovery: 92.8%

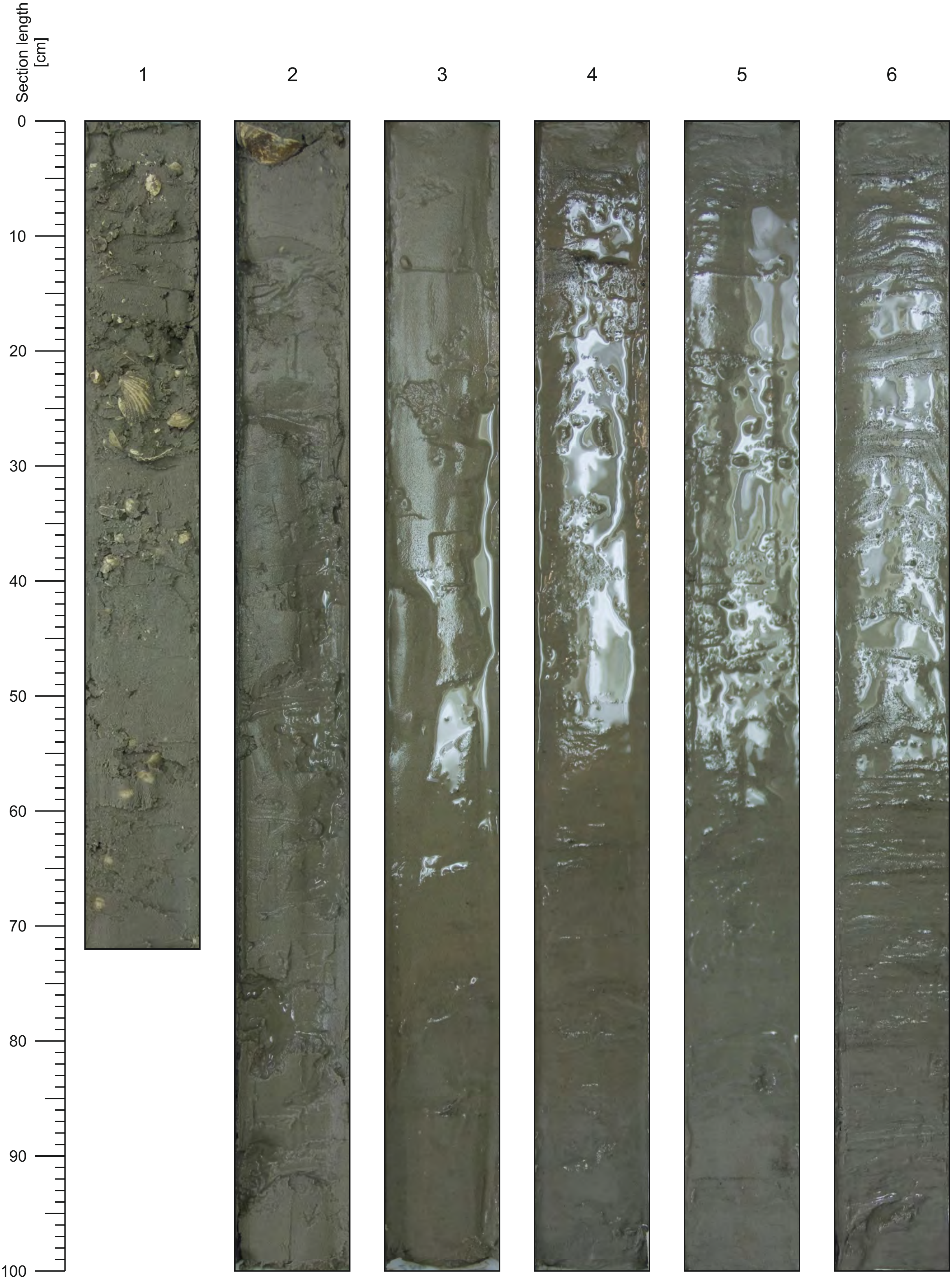


GeoB 21412-1

Latitude: 55°31.419' N
Target depth: 5.80 mbsf

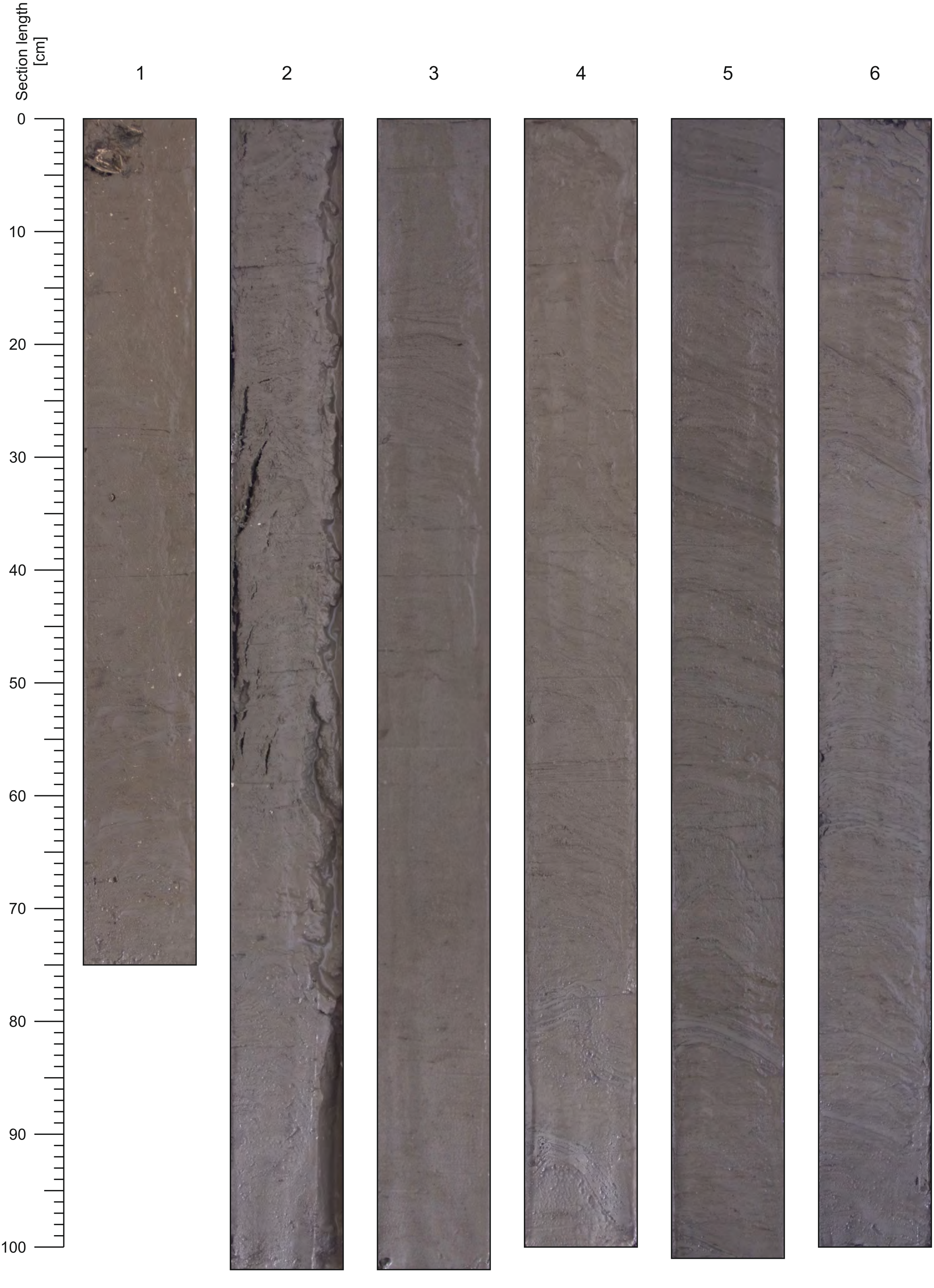
Longitude: 04°47.728' E
Sample depth: 5.72 m

Water depth: 40.90 m
Recovery: 98.6%



GeoB 21418-1

Latitude: 55°19.009' N | Longitude: 04°57.682' E | Water depth: 47.90 m
Target depth: 5.80 mbsf | Sample depth: 5.80 m | Recovery: 100.0%



Core standard graphic report legend

Lithology

Siliclastics:

- Clay
- Silt
- Fine sand
- Medium sand
- Coarse sand

Biogenics:

- Peat
- Shelly deposit

Additional symbols:

- Lost core

Sedimentary structures

Contacts:

- Gradational
- Sharp

Bedding features:

- Horizontal stratification
- Laminated
- Black organic laminae
- Nodules
- Clasts

Lithologic accessories:

- Bivalve
- Gastropod
- Rare shell fragments
- Common shell fragments
- Rare plant fragments
- Common plant fragments
- Isolated pebble
- Py Pyritic
- Charcoal
- Mc Micaceous

Bioturbation

- Slight
- Moderate
- Heavy

Coreing disturbance

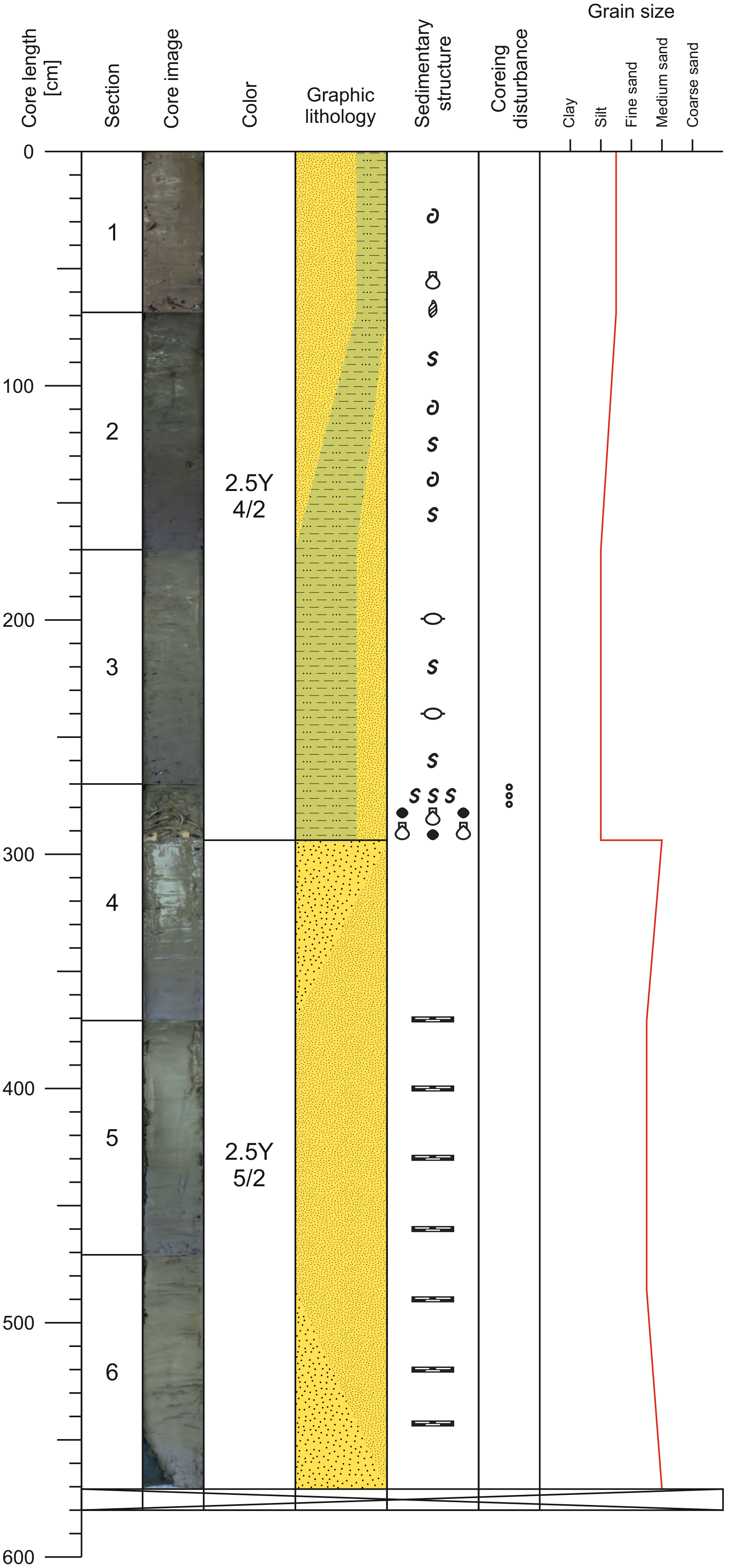
- Soupy
- Deformed strata
- Fractured/cracked
- Voids/gaps
- Upward distortion
- Downward distortion

Intensity of distubance:

- Slightly disturbed
- Heavily disturbed

GeoB 21403-1

Latitude: 56°02.207' N | Longitude: 05°48.868' E | Water depth: 50.70 m
Target depth: 5.80 mbsf | Sample depth: 5.71 m | Recovery: 98.5%

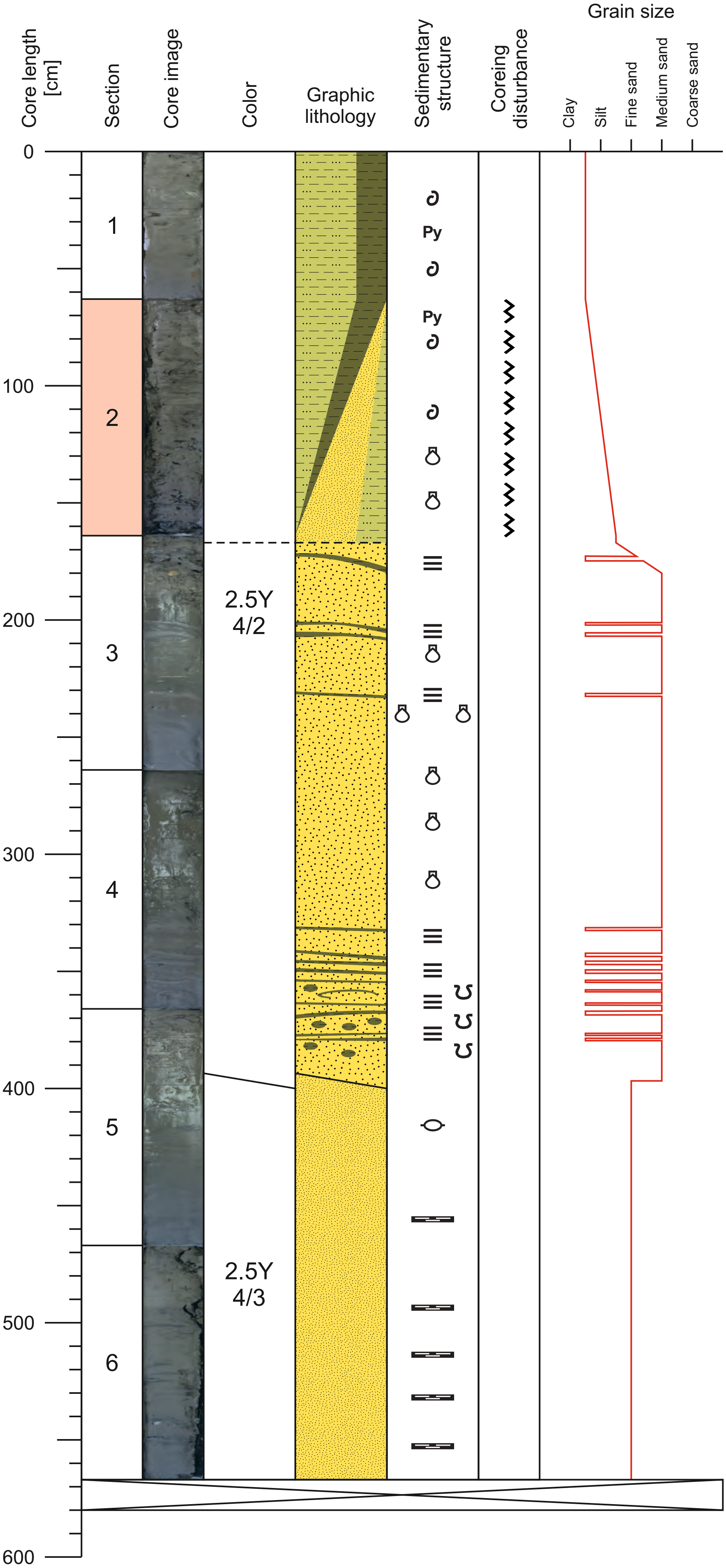


0–294 cm
Dark grayish brown; silty fine sand to sandy silt, fining downward, slight bioturbation
0–69 cm: silty fine sand (90–125 µm)
22–69 cm: rare shell fragments (2–3 mm)
at 55 cm: single bivalve (Cardiidae; 30 mm)
at 67 cm: gastropod (10 mm)
69–189 cm: fining downward to fine sandy silt; very rare shell fragments (2–3 mm)
189–280 cm: sandy silt; rare shell fragments; lenses (fine to medium sand, 180–355 µm; bioturbation?)
273–280 cm: soupy, heavy bioturbated
280–294 cm: layer of well preserved bivalves (*Arctica islandica*?, autochton, 70 mm), mixed with high to low spheric and subangular to subrounded medium gravel (10–20 mm) and a few fragments of various shells
at 294 cm: sharp contact in color and lithology

294–371 cm
Grayish brown; medium sand (250–355 µm) to fine sand (180–250 µm), fining downward
at 298, 323 and 333 cm: isolated high to low spheric, and subangular to subrounded medium gravel (10–20 mm) and
at 340 cm: isolated gastropod (5 mm), all artificially displaced?
370–543 cm: black organic laminae (2–3 mm thick; bioturbation?)
371–486 cm: fine sand (180–250 µm), bare of shell fragments
486–571 cm: coarsening downward from fine sand (180–250 µm) to medium sand (250–355 µm); bare of shell fragments

GeoB 21404-1

Latitude: 55°57.810' N | Longitude: 05°38.211' E | Water depth: 52.40 m
Target depth: 5.80 mbsf | Sample depth: 5.67 m | Recovery: 97.8%



0–170 cm
Dark grayish brown; clayey silt with fine sand to silty fine sand, coarsening downward; rare shell fragments (5–20 mm)
0–63 cm: clayey silt with fine sand (180–250 µm)
at 13.5, 25.5 and 53 cm: pyritic inclusions (dark gray, oxidized to reddish brown)
63–164 cm: coarsening downward from clayey silt with fine sand (180–250 µm) to silty fine sand (180–250 µm)
at 73 cm: pyritic layer (5 mm thick)
at 136 and 149 cm: bivalves
161–170 cm: silty fine sand (180–250 µm)
at 170 cm: gradational change in color and lithology

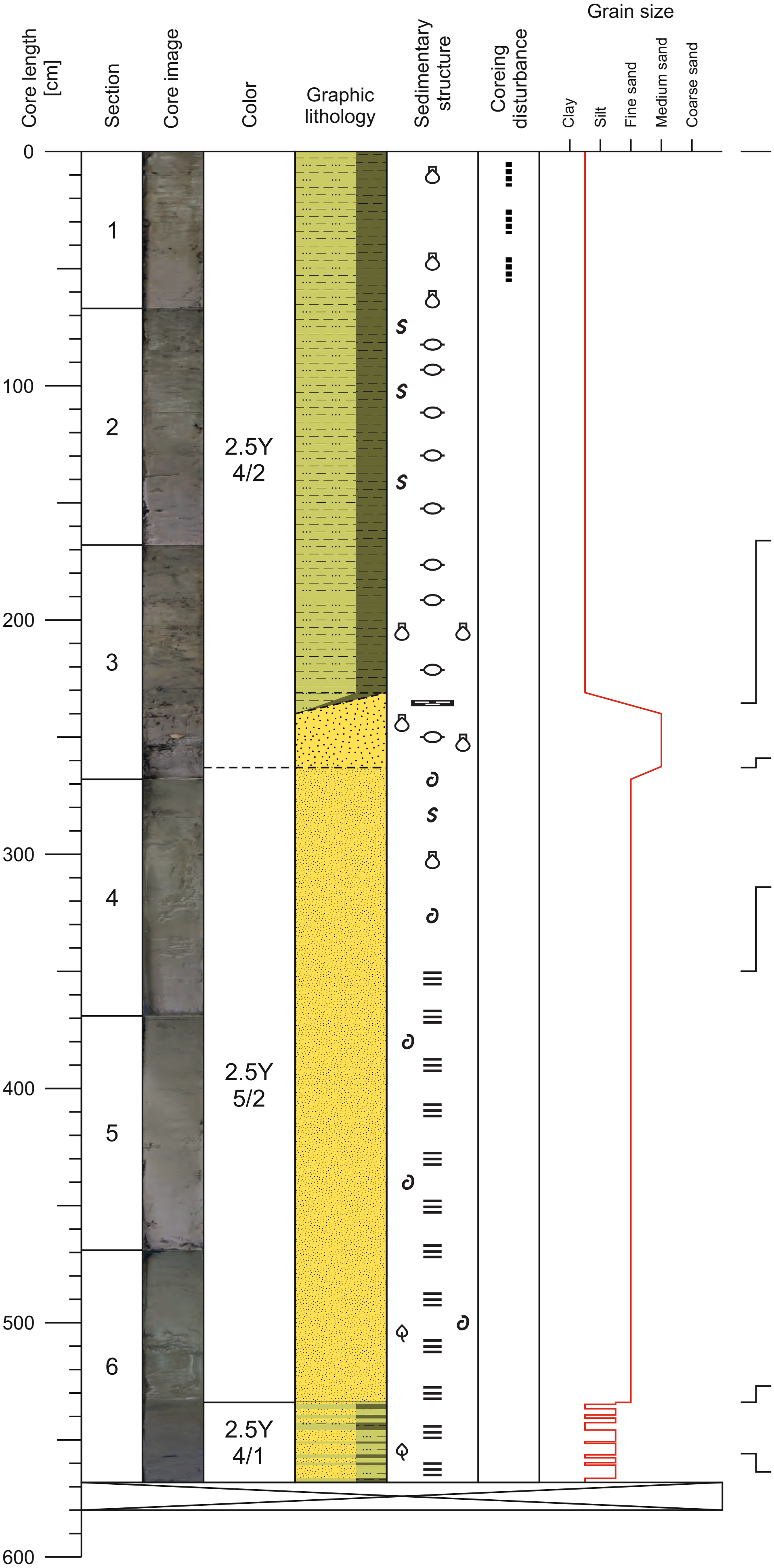
170–400 cm
Olive brown; medium sand (250–355 µm) with layers (partially reworked) and spheric clasts of silty clay; rare to common shell fragments)
172–179 cm: inclined layer of silty clay (20 mm thick) with sharp contacts
179–186 cm: several well preserved bivalves (amongst others: *Cardiidae*, 10–30 mm)
at 201, 205 and 230.5 cm: layers of silty clay (15–20 mm thick) with sharp contacts
at 236 cm: Layer with well preserved bivalves (*Cardiidae*, 10–30 mm)
264–292 cm: well preserved bivalves (amongst others: *Cardiidae*, 10–30 mm)
341–389 cm: several layers (5–15 mm thick; partially reworked) and clasts (10–20 mm) of silty clay with sharp contacts
393.5–400 cm: sharp inclined contact

400–567 cm
Gray; fine sand (125–180 µm); rare shell fragments
400–485 cm: rare shell fragments (1–5 mm)
at 417 cm: dark lens of clayey silt (20 mm)
452–457 cm: darker organic layers (5–10 mm thick)
485–567 cm: bare of shell fragments
at 542 cm: isolated bivalve (13 mm)
494–555 cm: darker organic layers (5–10 mm thick)

Remark on section 2:
The physical property of the sediment was very soft and cohesive during core splitting, which caused a heavy disturbance of the sediment in the whole section. Be careful with any interpretation of sediment structures in this section!

GeoB 21405-1

Latitude: 55°55.298' N | Longitude: 05°32.232' E | Water depth: 53.40 m
Target depth: 5.80 mbsf | Sample depth: 5.68 m | Recovery: 97.9%



0–263 cm
Dark grayish brown; clayey silt with fine sand (180–250 µm); rare shell fragments (1–2 mm)
at 10, 48 and 67 cm: bivalves (5 mm)
67–231 cm: sandy or dark organic lenses (5 mm, bioturbation?)
168–231 cm: bivalves and shell fragments (1–5 mm)
203–206 cm: nodule of molluscs and gastropods in sandy lense
at 231 cm: gradational change from medium sand to fine sand

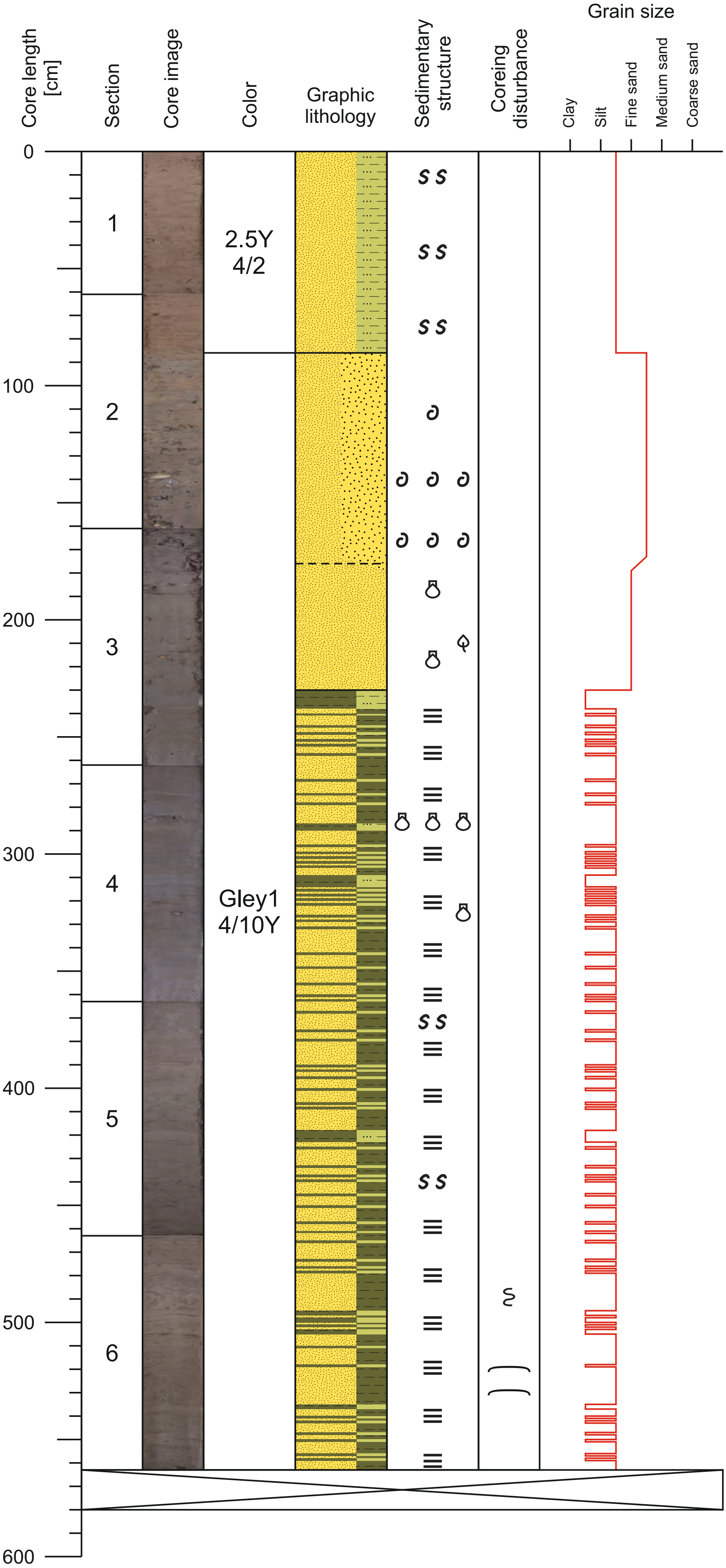
231–263 cm
Dark grayish brown; medium sand (250–355 µm)
231–238 cm: dark organic rich interval
238–256 cm: bivalves (Cardiidae, autochthon, 20–30 mm)
248–251 cm: lens of clayey silt
at 263 cm: gradational change in color and lithology

263–533.5 cm
Grayish brown; fine sand (180–250 µm); rare shell fragments (1–3 mm)
268–285 cm: slight bioturbation
at 296 cm: bivalve (Cardiidae, 13 mm, displaced?)
351–533.5 cm: fine dark layers (4 mm thickness and spacing); downward decrease in rare shell fragments
497–533.5 cm: several shell layers (3–5 mm thick)
at 506–507 cm: two pieces of wood (7 mm and 15 mm)
at 533.5 cm: sharp change in color and lithology

533.5–568 cm
Dark gray; irregular stratification of layers (5–10 mm thick) of clayey silt and silty fine sand (90–125 µm)
at 557.5 cm: piece of wood (horizontal bedded, 30x5 mm)

GeoB 21406-1

Latitude: 55°53.801' N — Longitude: 05°28.629' E — Water depth: 52.81 m
Target depth: 5.80 mbsf — Sample depth: 5.63 m — Recovery: 97.1%



0–86 cm
Dark grayish brown; silty fine sand (125–180 µm); moderate bioturbated (burrows filled with fine sand, 125–180 µm); very rare shell fragments (>1 mm)

at 86 cm: sharp contact in color and lithology (with traces of bioturbation)

86–176 cm
Dark greenish gray; clayey fine to medium sand (180–355 µm); rare shell fragments (2–4 mm)
at 125 cm: well preserved shell (Cardiidae; 10 mm)
at 137–143 cm: layer of well preserved and fragmented shells (Cardiidae, Mactridae; 20–40 mm)
at 147.5 cm: well preserved shell (Cardiidae; 20 mm)
at 158–162 cm: nodule of well preserved shells (Cardiidae; 10–15 mm)

at 176 cm: gradual contact in lithology

176–230 cm
Dark greenish gray; fine sand (180–250 µm)
at 182 and 217 cm: well preserved shells (Cardiidae; 10–15 mm)
at 209–*212 cm*: wood fragments (30 mm)

at 230 cm: sharp contact in lithology (partially reworked or bioturbated?)

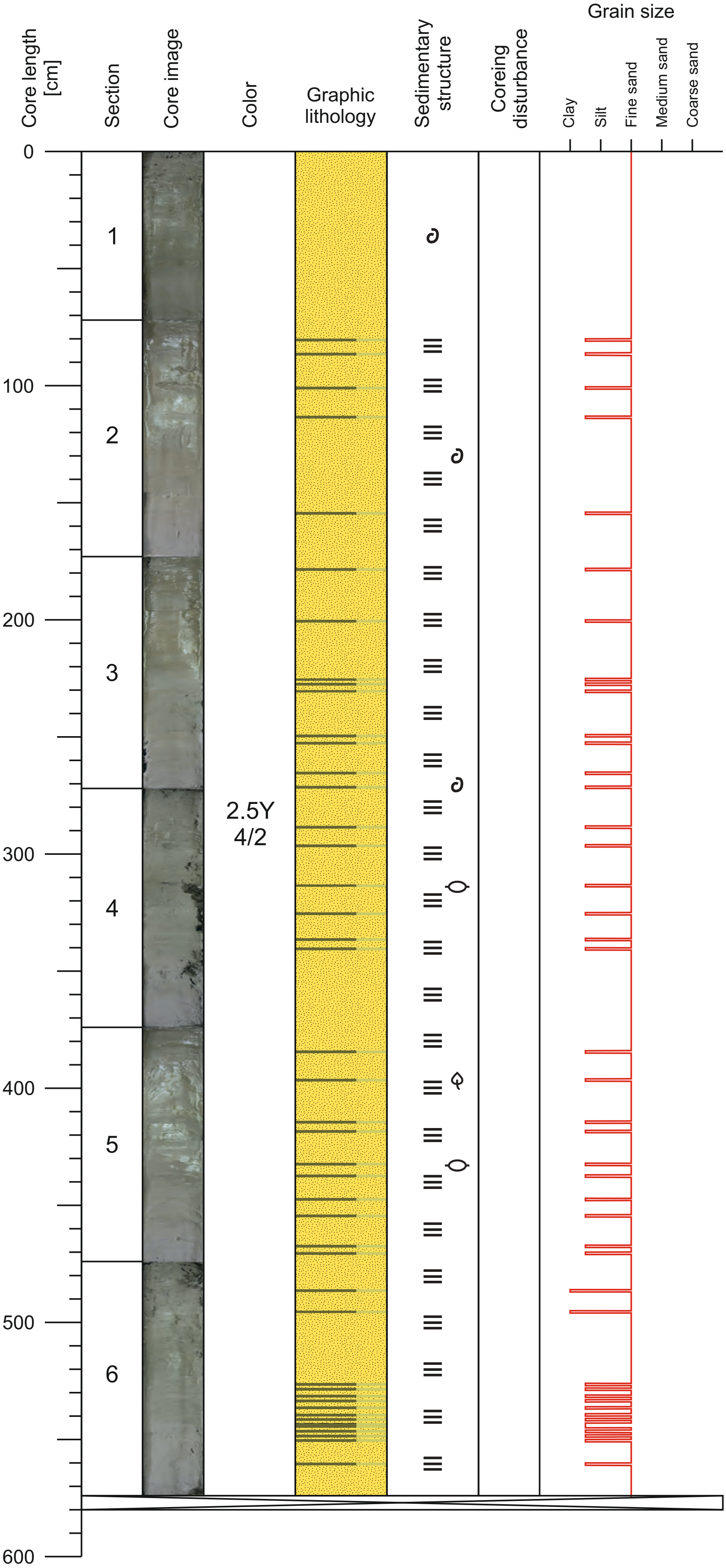
230–503 cm
Dark greenish gray; clayey fine sand (180–250 µm), with layers of silty clay or sandy clay (5–80 mm thick; often with sharp contacts at top and bottom); moderate bioturbated

at 284–286 cm: layer of well preserved shells (Cardiidae; 20–30 mm; in living position?)

at 325 cm: well preserved shell (Cardiidae; 15 mm)

GeoB 21407-1

Latitude: 55°51.778' N | Longitude: 05°23.800' E | Water depth: 51.90 m
Target depth: 5.80 mbsf | Sample depth: 5.74 m | Recovery: 99.0%



0–574 cm
Dark grayish brown; fine sand (90–125 µm) with alternating layers of silty clay; very rare shell fragments (<1 mm)

77–575 cm: alternating layers of silty clay (5–10 mm thick); distinct layers of silty clay at: 80, 86, 100.5, 113, 154, 178, 187, 200, 225, 227, 230, 249, 252, 269, 271, 278, 296.5, 313, 325.5, 336, 340, 384, 396, 414, 418.5, 432, 437.5, 447, 454, 467, 470, 486, 495, 526–551 and 569 cm

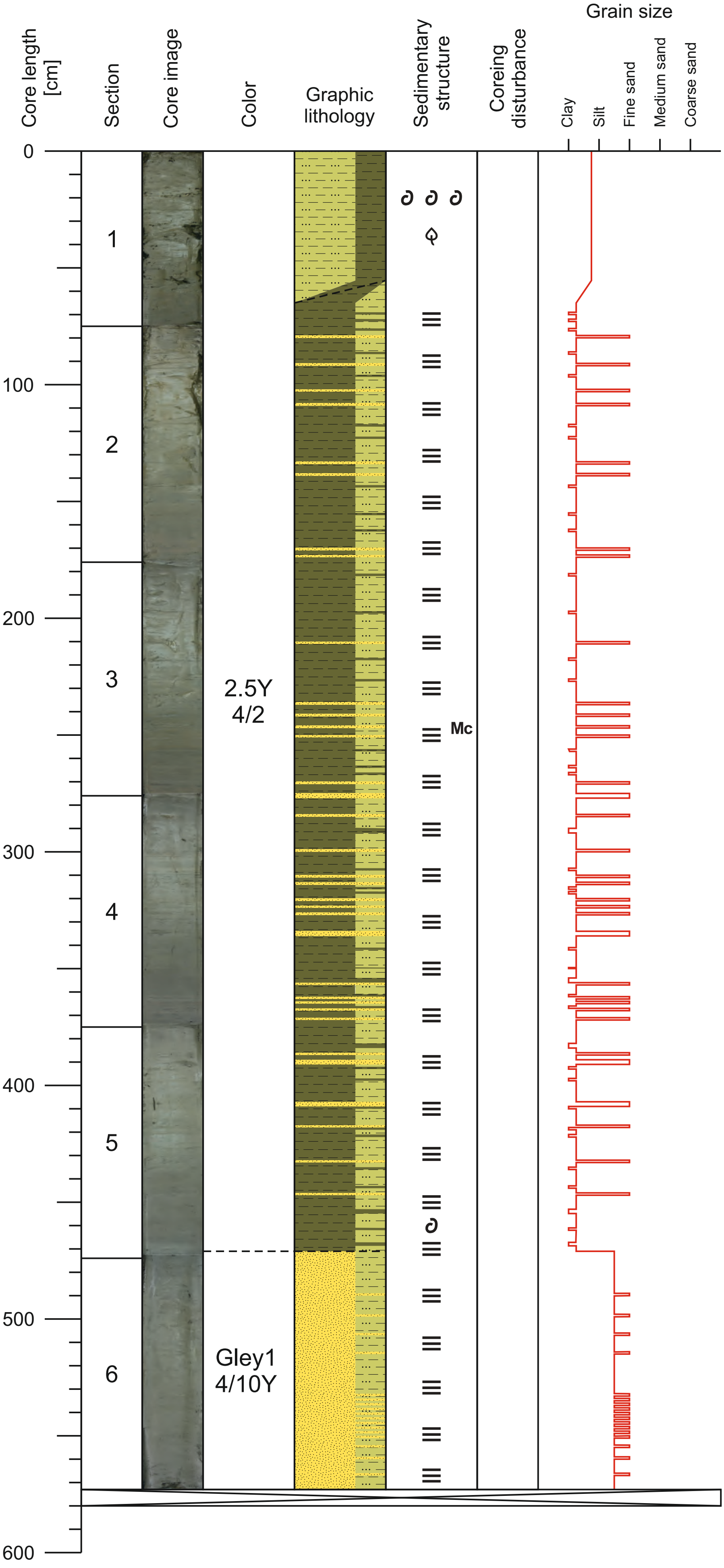
at 314 cm: lens of black organic matter (10 mm thick)

at 397 cm: plant fragment (4x10 mm)

at 433 cm: nodule of black organic matter (10 mm)

GeoB 21408-1

Latitude: 55°48.945' N | Longitude: 05°17.146' E | Water depth: 54.30 m
Target depth: 5.80 mbsf | Sample depth: 5.73 m | Recovery: 98.8%



0–60 cm
Dark grayish brown; clayey silt with fine sand (90–125 µm); common shell fragments (1–4 mm); sandy patches (10 mm)
at 20 cm: layer of shell fragments (1–4 mm)
at 35–38 cm: wooden pieces
at 58 cm: shell fragment (Cardiidae)
55–65 cm: gradual contact in lithology

60–471 cm
Dark grayish brown; silty clay; horizontal stratification with alternating layers (3–10 mm thick; 5–10 mm frequency) of clay, silty clay, very fine sand (63–90 µm) and fine sand (90–125 µm); sandy patches (10 mm); very rare to bare shell fragments

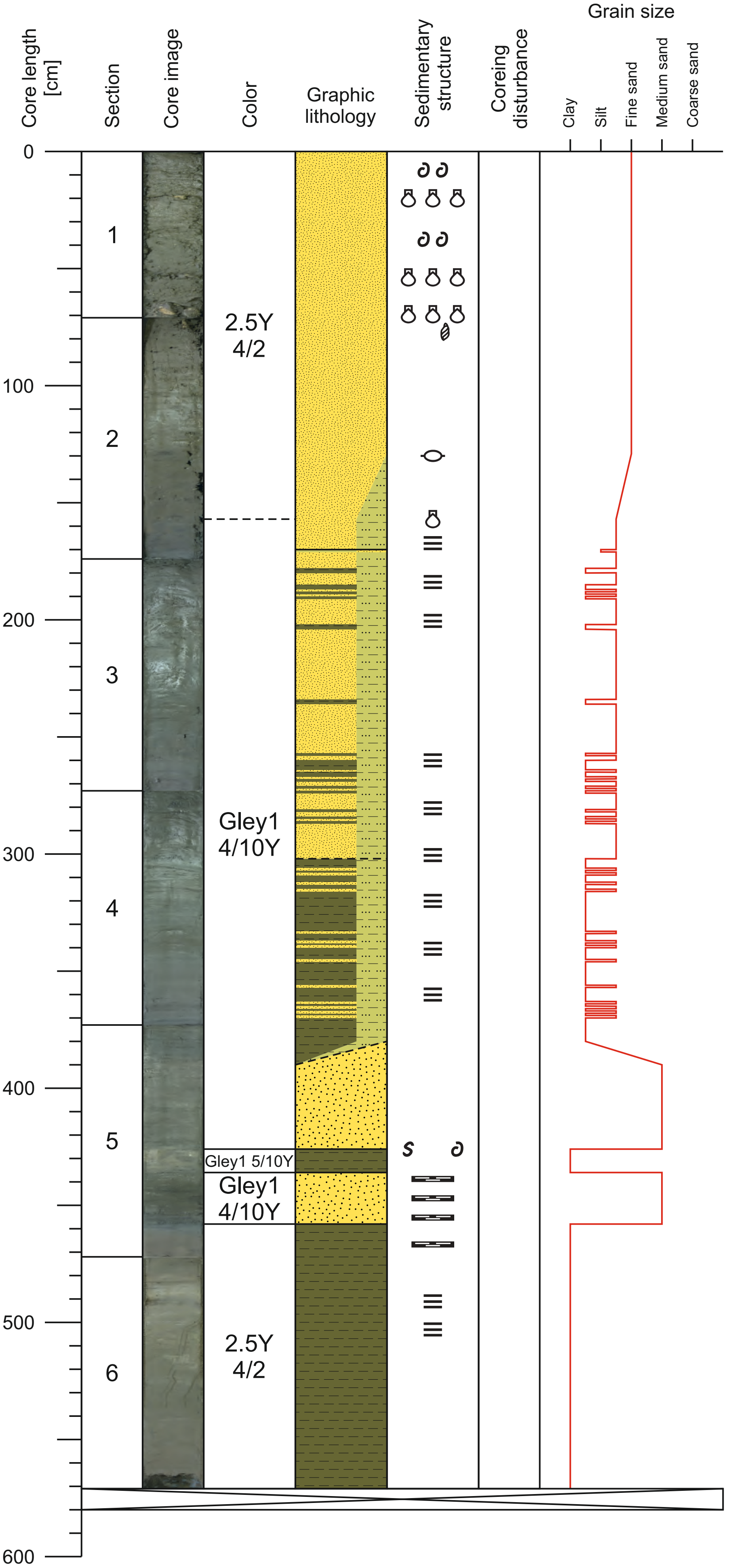
247–255 cm: layers of fine sand with mica

at 471 cm: gradual contact in color and lithology

471–573 cm
Dark greenish gray; silty fine sand (125–180 µm); horizontal stratification with alternating sandy layers

GeoB 21409-1

Latitude: 55°45.024' N | Longitude: 05°10.444' E | Water depth: 52.00 m
Target depth: 5.80 mbsf | Sample depth: 5.71 m | Recovery: 98.5%



0–157 cm
Dark grayish brown; fine sand (180–250 µm); common shell fragments (1–4 mm)
at 20,5 cm: layer of bivalves (autochthon, 20 mm)
at 55 cm: layer of bivalves (autochthon, Cardiidae amongst others, 30 mm)
at 68 cm: layer of bivalves (autochthon, 40–70 mm)
at 77 cm: isolated gastropod (Turritellidae, 30 mm)
129–157 cm: fining downward from fine sand (180–250 µm) to silty fine sand (125–180 µm)
at 130 cm: nodule of black organic matter
at 157 cm: bivalve (10 mm)

157–171 cm
Dark greenish gray; silty fine sand (125–180 µm); hardly observable layers
at 98 cm: sharp contact in lithology

171–303 cm
Dark greenish gray; silty very fine sand (63–90 mm) with layers of silty clay (1–10 mm thick) and black organic matter; rare shell fragments (1–3 mm)
at 178.5, 185, 188, 190, 202, 234, 257–265 and 268, 274, 275, 281, 284, 285, 286, and 301 cm: distinct layers of silty clay
at 303 cm: gradational contact in lithology

303–380 cm
Dark greenish gray; silty clay with layers of very fine sand (63–90 µm; 1–10 mm thick)
at 306, 308, 309, 312, 314, 333, 337, 339, 341, 356, 357, 362, 363, 365, 367, 368, 369, 370 and 373 cm: distinct layers of very fine sand
at 380 cm: gradational contact in lithology

380–426 cm
Dark greenish gray; medium sand (250–500 µm); very rare shell fragments (1–2 mm)
at 426 cm: sharp contact in color and lithology; bioturbation?
at 428 cm: shell fragment

426–436 cm
Greenish gray; clay
at 436 cm: sharp contact in color and lithology

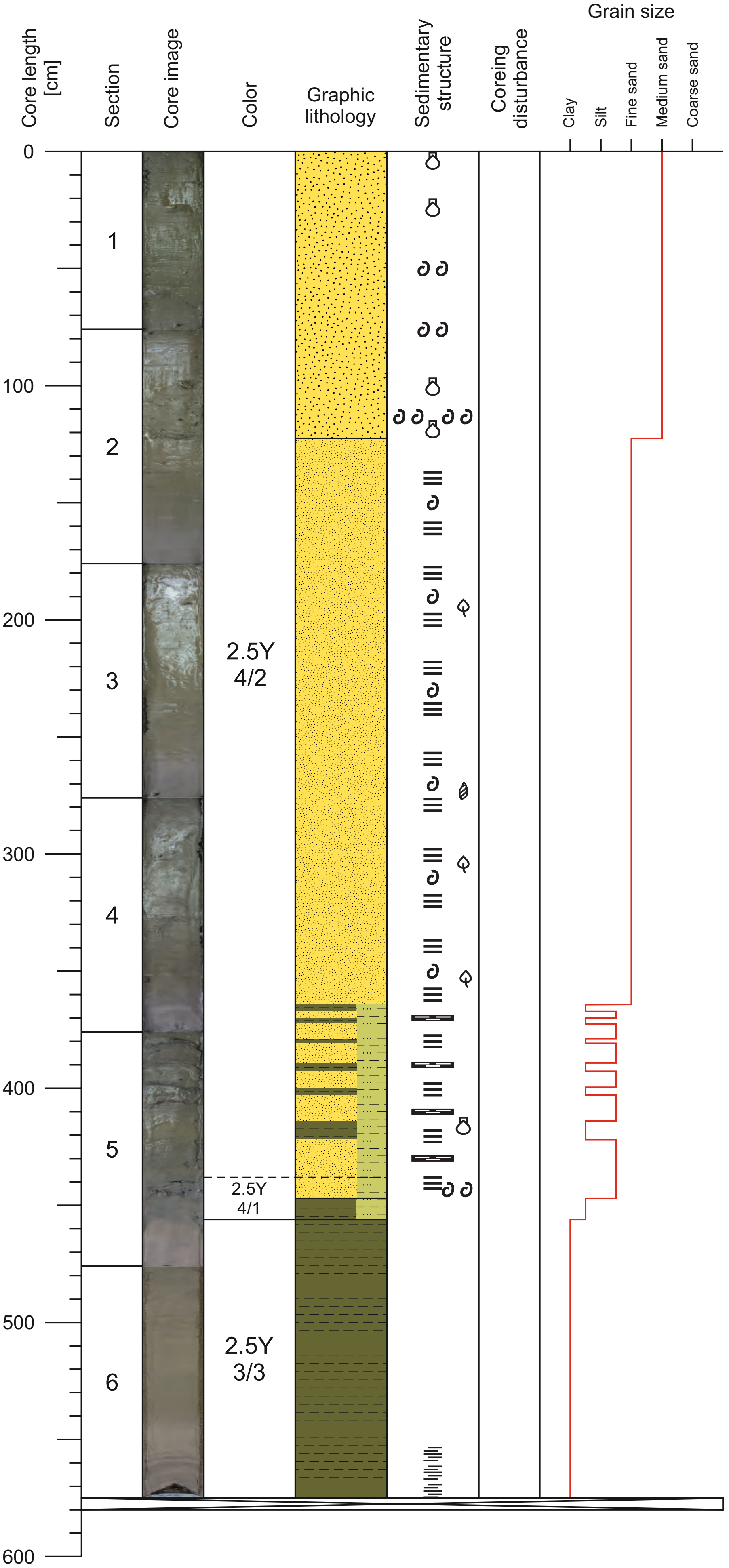
436–458 cm
Dark greenish gray; medium snad (250–355 µm); layers of black organic matter (1–3 mm thick)
454–455 cm: layer of clay
at 458: sharp contact in color and lithology

458–571 cm
Dark grayish brown; clay; black organic matter; soft to stiff consistency (1.25 kg/cm², pocket penetrometer test)
458–491 cm: layers with black organic matter (2-5 mm thick)
491–503 cm: alternating layers of lighter and darker clay
503–545 cm: darker patches (organic matter?; 5–10 mm thick)

Calcium carbonate content (HCl test):
at 497 cm (clay): high

GeoB 21410-1

Latitude: 55°41.505' N | Longitude: 05°04.599' E | Water depth: 47.60 m
Target depth: 5.80 mbsf | Sample depth: 5.75 m | Recovery: 99.1%



0–122.5 cm
Dark grayish brown; medium sand (250–355 µm); common shell fragments (1–4 mm); common dots of black organic matter (<1 mm)
at 1.5 cm: bivalve
at 24.5 cm: bivalve (autochthon)
at 60 cm: large shell fragment (thick-walled, 50 mm)
at 90 cm: two large shell fragments (*Acanthocardia echinata*, 50 mm)
111–122.5 cm: very common shell fragments (5–10 mm)
at 121.5 cm: bivalve (Cardiidae, 35 mm) directly above contact in lithology
at 122.5 cm: sharp contact in lithology

122.5–366.5 cm
Dark grayish brown; fine sand (125–180 µm); rare shell fragments (1–5 mm); common dots of black organic matter (<1 mm); horizontal stratification (hardly distinguishable) with layers of black organic matter (1–2 mm thick)
at 194 cm: piece of wood (10 mm)
at 275 cm: isolated gastropod (10 mm)
293–305 cm and 329–344 cm: nodules of black organic matter
at 303 cm: piece of wood (10 mm)
at 356 cm: piece of wood (30 mm)

366.5–438 cm
Dark grayish brown; alternating sequence (4–20 mm thick) of silty clay and silty very fine sand (63–90 µm) and black organic layers
at 365 and 371.5 cm: distinct layers of silty fine sand (10–20 mm thick)
at 381, 399.5 and 407 cm: distinct layers of black organic matter (4–10 mm thick), one layer is accompanied by bivalves (at 407 cm, Cardiidae, 10 mm)
at 391 and 424 cm: distinct layers of silty clay (5 mm thick)
at 438 cm: gradational change in color and lithology

438–447 cm
Dark gray; silty fine sand (90–125 µm)
at 445.5 cm: nodule of shell fragments
at 447 cm: sharp contact

447–456 cm
Dark gray; silty clay
at 456 cm: sharp contact (reworked or bioturbated)

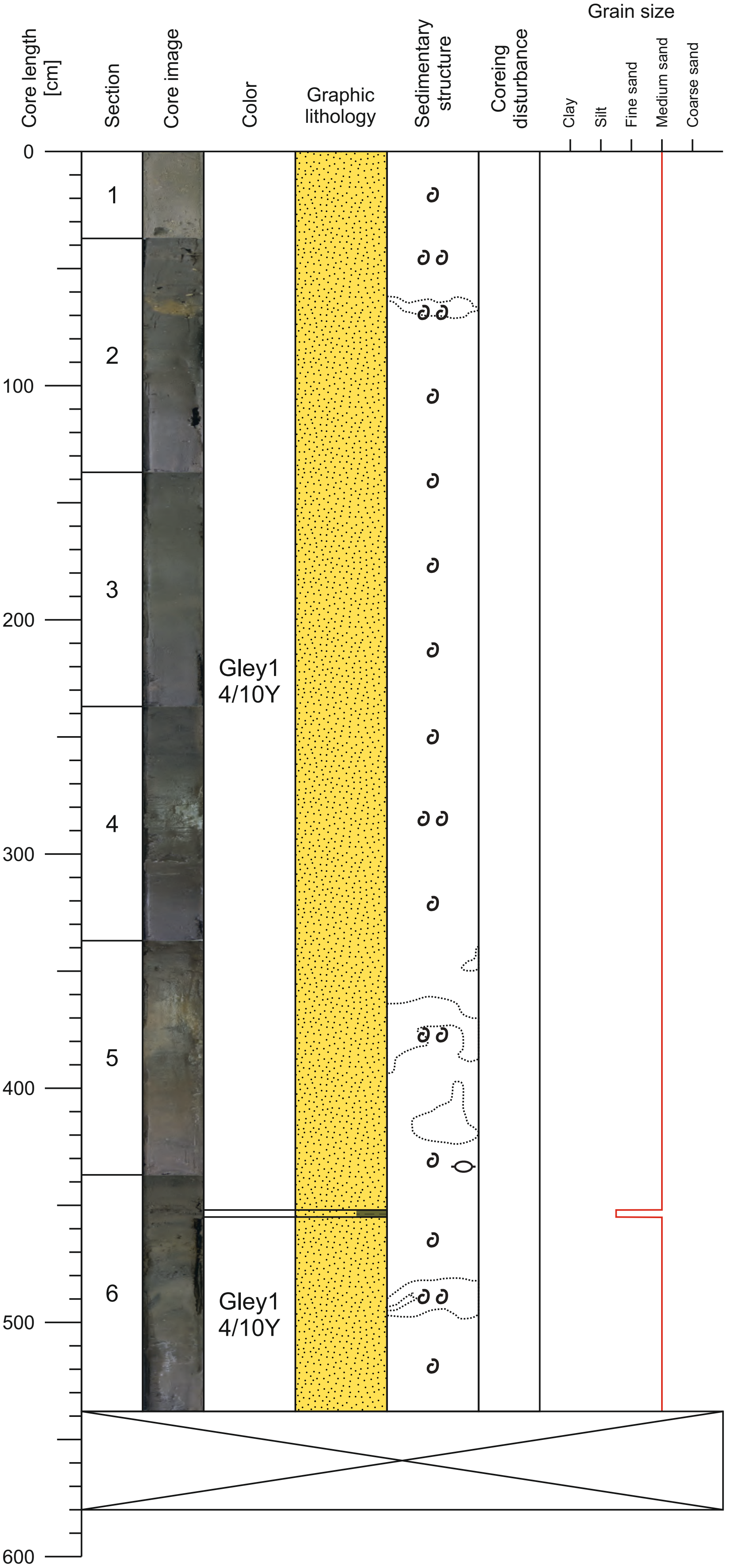
456–555 cm
Dark olive brown; clay; bare of any structures; stiff consistency (2 kg/cm², pocket penetrometer test)

555–575 cm
Dark olive brown; clay; laminated (with darker and lighter layers, 2–20 mm thick); stiff consistency (2 kg/cm², pocket penetrometer test)
at 558.5, 560.5 and 567.5 cm: distinct dark layers

Calcium carbonate content (HCl test):
at 420 cm (silty clay/fine sand): medium
at 443 cm (silty fine sand): low
at 451 cm (silty clay): low
at 473 cm (clay): high

GeoB 21411-1

Latitude: 55°34.211' N | Longitude: 04°52.273' E | Water depth: 36.50 m
Target depth: 5.80 mbsf | Sample depth: 5.38 m | Recovery: 92.8%



0–452 cm
Dark greenish gray; medium sand (250–355 µm); rare shell fragments (1–10 mm)
5–35 cm: common shell fragments (15–20 mm)
at 28–35 cm: irregular discoloration, associated with shell nodules (light yellowish brown, 2.5Y 6/4)
137–177 cm: rare shell fragments (2–5 mm)
177–337 cm: very rare shell fragments (1–3 mm)
284–287 cm: nodules of shell fragments (2–4 mm)
337–538 cm: rare shell fragments (2–4 mm)
344–397 cm: irregular discoloration (10–20 cm thick), often associated with shell nodules (light yellowish brown, 2.5Y 5/2) or with organic matter (darker dark greenish gray)
at 433 cm: clast of silty clay (10 mm)

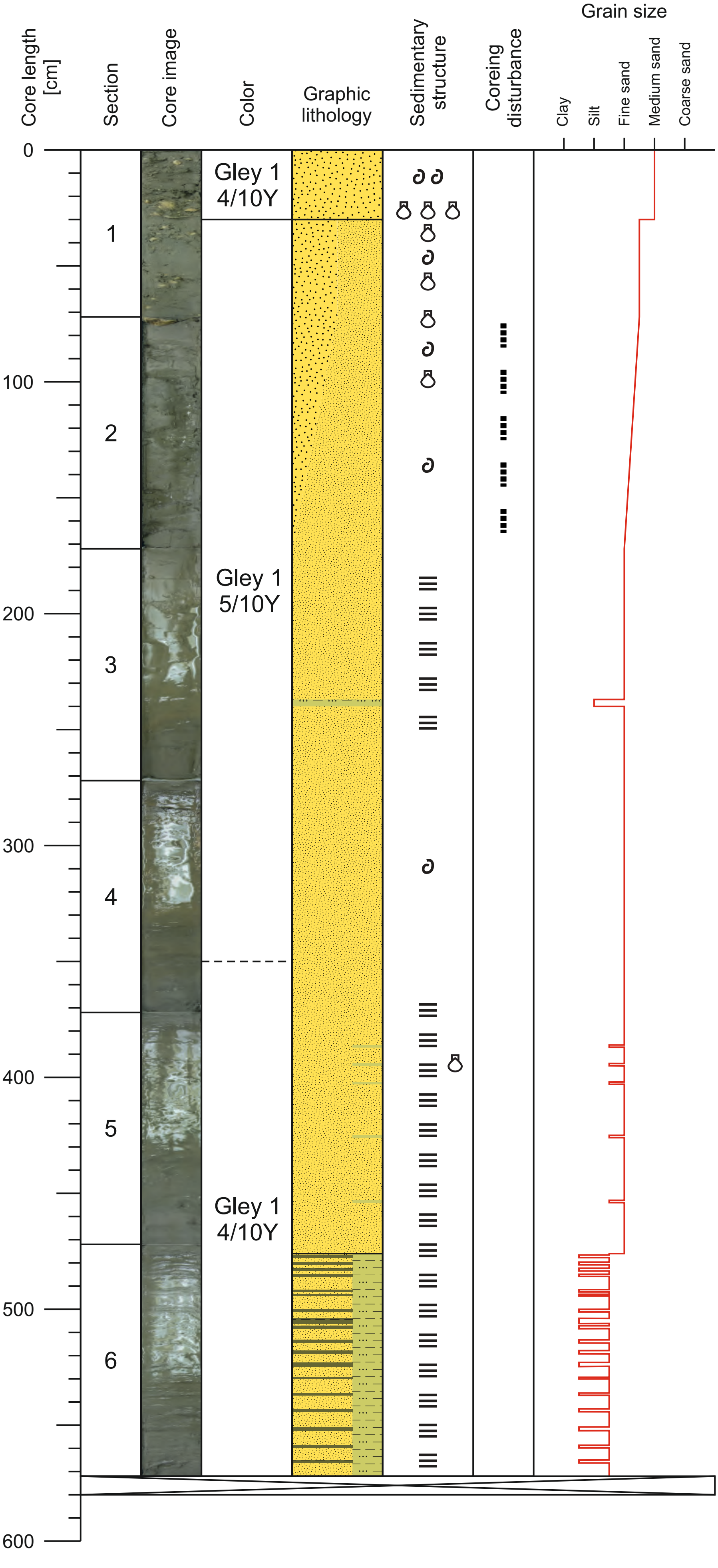
452–455 cm
Dark greenish gray; clayey medium sand (250–355 µm); sharp contacts

455–538 cm
Dark greenish gray; medium sand (250–355 µm); rare shell fragments (2–4 mm)
437–447 and 489–494 cm: darker irregular discoloration (10–20 cm thick) with shell nodule and/or organic matter

Remark on section 2:
The light yellowish brown sediment parts smelled fishy after core splitting

GeoB 21412-1

Latitude: 55°31.419' N | Longitude: 04°47.728' E | Water depth: 40.90 m
Target depth: 5.80 mbsf | Sample depth: 5.72 m | Recovery: 98.6%



0–30 cm
Dark greenish gray; medium sand (250–355 µm); common shell fragments (3–10 mm)
at 4–5 and 10–13 cm: nodules of bivalves (20–50 mm)
at 21–30 cm: layer of bivalves (Cardiidae amongst others, 30–60 cm, autochthon)
at 30 cm: sharp contact in color and lithology

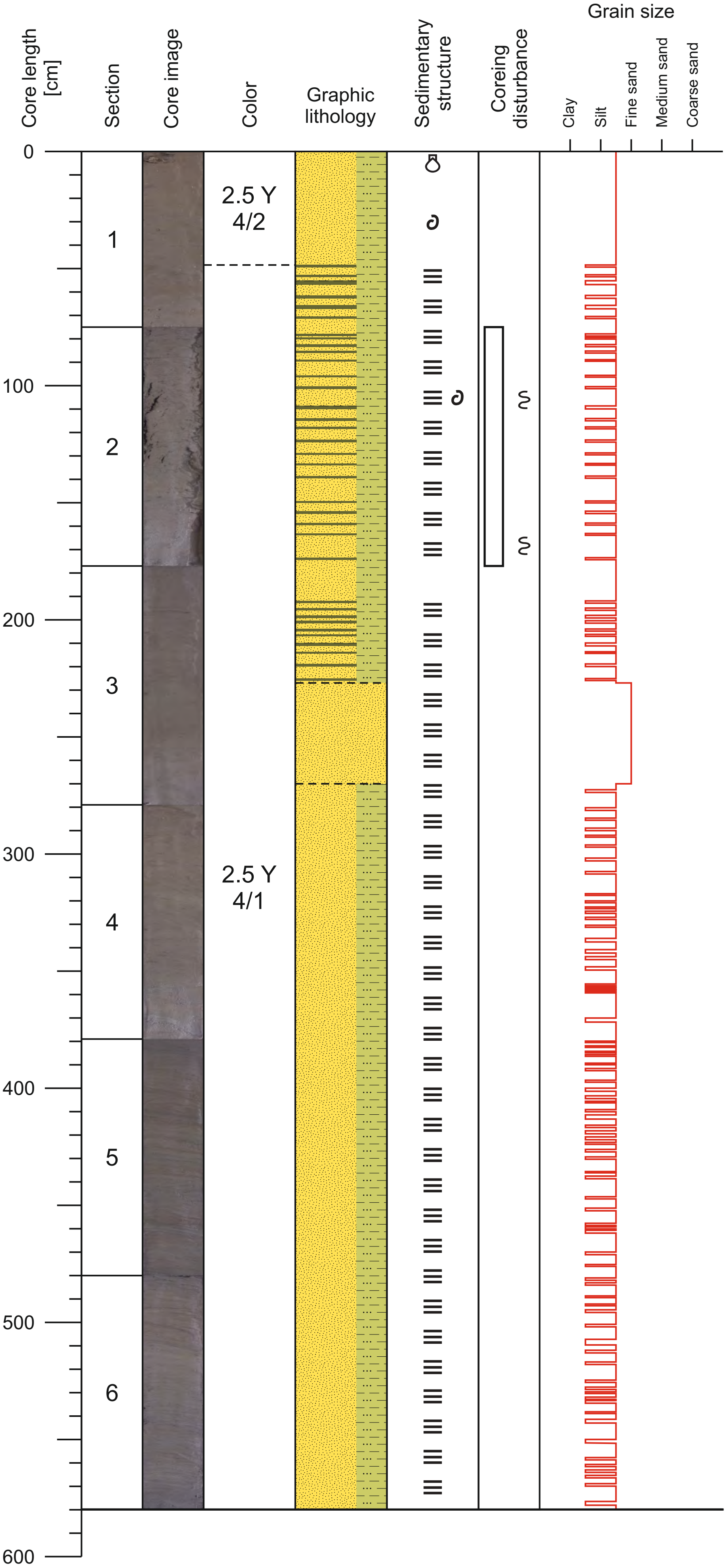
30–350 cm
Greenish gray; fine to medium sand (125–355 µm), rare shell fragments (1–5 mm); dots of black organic matter
at 33–40 and 53–60 cm: nodules of bivalves *(Cardiidae* amongst others, 30–60 mm, autochthon)
at 64 and 68 cm: isolated bivalve (Cardiidae, 10–15 mm)
72–172 cm: fining downward from medium sand (180–355) to fine sand (125–250)
at 100 cm: isolated bivalve (Cardiidae, 10 mm)
172–272 cm: fining downward in fine sand fraction (from 125–250 to 125–180 µm)
at 221, 360 and 284–350 cm: black organic layers (4 mm thick)
at 347 and 348: layers of silt (5 mm thick)
at 350 cm: gradational change in color

350–476 cm
Dark greenish gray; fine (125–180 µm) to very fine sand (63–90 µm), fining downward; very rare shell fragments (1–2 mm); dots of black organic matter
368–472 cm: layers of dark organic matter (2–3 mm)
at 386, 394, 402, 425 and 453 cm: distinct layers of silty fine sand (2–5 mm thick)
at 396.5 cm: bivalve
at 476 cm: sharp contact in lithology

476–572 cm
Dark greenish gray; alternating layers of silty clay and silty very fine sand (63–90 µm), fine sand (90–125 µm) and black organic matter (3–8 mm thick)

GeoB 21418-1

Latitude: 55°19.009' N | Longitude: 04°57.682' E | Water depth: 47.90 m
Target depth: 5.80 mbsf | Sample depth: 5.80 m | Recovery: 100.0%



0–50 cm
Dark grayish brown; silty fine sand (125–180 µm); rare shell fragments (2–5 mm)

at 4–6 cm: nodule of well preserved and fragmented shells (40 mm; Cardiidae and Mactridae)

at 50 cm: gradational contact in color

50–227 cm
Dark gray; silty fine sand (125–180 µm) with layers of silty clay (3–10 mm thick) and black organic matter (<1 mm); rare to bare of shell fragments (2–4 mm)

at 227 cm: gradational contact in lithology

227–270 cm
Dark gray; fine sand (180–250 µm), with very thin layers of dark organic matter (<1 mm); bare of shell fragments

at 270 cm: gradational contact in lithology

270–580 cm
Dark gray; silty fine sand (coarsening downward from 125–180 µm to 180–250 µm), with layers of silty clay and fine sand (3–10 mm thick) and black organic matter (<1 mm); bare of shell fragments

at 394–440, 459–512 and 560–570 cm: inclined layers of silty clay

General
H_2S degassing in core section 6