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2 Research Program

The main working area on this cruise was on the upper and middle continental slope south of Walvis Bay. Investigations were carried out along four transects down the slope (Fig. 2.1).

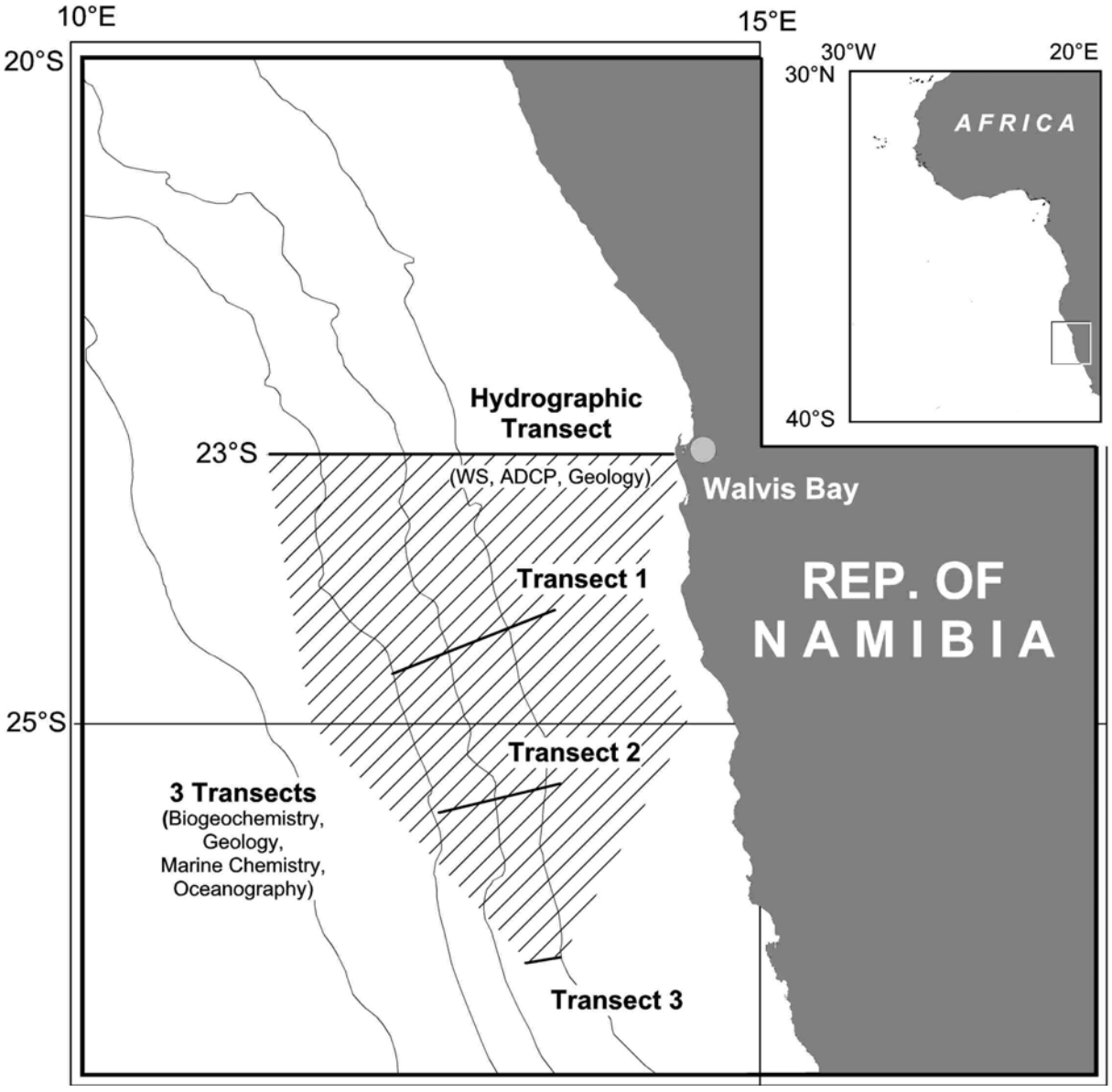


Fig. 2.1 METEOR Cruise M 57/2, area of operation

In addition to their function as sediment deposition sites, continental shelf and upper slope are also source regions for the export of sediment particles to the deep sea. Estimates from geochemical investigations in the SEEP-II (Shelf Edge Exchange Processes) program have shown that up to 15% of the particulate organic carbon from coastal primary productivity is transported over the shelf break and into deep waters. Estimates of a similar order of magnitude also exist for biogenic opal and terrestrially derived material reaching the ocean. A main center of the scientific work during this cruise were biogeochemical investigations close to the sediment-water interface. The primary questions concentrate on the influence of the quantity and quality of lateral transported, biogenic particles on biogeochemical

transformation processes at the sea floor. In this regard, the characterization of suspension load according to provenance and reactivity is also of high significance. The applied interdisciplinary concept will deliver important information about the near-bottom particle transport and the biogeochemical alteration of the particles up to their final burial which should also improve our knowledge on the global cycles of carbon and nutrients.

Additional intentions on this cruise were extensive geochemical, geophysical, marine geological and micropaleotologiocal investigations on sediment samples from this area.

Among others, the aim of the geochemical and geophysical investigations is the detailed examination of the early diagenetic modification of the primary composition and the rock magnetic properties of the sediment within the sulfate/methane transition zone. For this purpose the pore water of the sediments was retrieved to determine the current geochemical zonation as well as the depth position of the sulfate/methane transition zone. The main focus was the high-resolution sampling of the sedimentary solid phase across this important biogeochemical boundary and the adequate storage of the sediment samples for subsequent wet chemical and mineralogical analysis.

Changes in the distribution of solar insolation and atmospheric CO_2 concentration are regarded as major causes for the cyclic occurrence of Northern Hemisphere glaciations during the Quaternary. The glaciation cycles were accompanied by a reconfiguration of the large-scale atmospheric and oceanic circulation that also affected the characteristics of coastal upwelling areas.

Glacial-interglacial changes are natural climate experiments, which enable us to improve our understanding of coastal upwelling and its representation in numerical models. In this regard, the climate archive stored in the Namibia upwelling area is of great importance. On the one hand these sediments offer a high temporal resolution due to large sedimentation rates. On the other hand the Namibia upwelling area is closely related to the global and regional climate through its contribution to biological productivity and the interaction with wind, cloud formation and precipitation. One aim of the geological investigations is therefore to reconstruct changes in the circulation, hydrographic structure and biological production of the Namibia upwelling area during extreme climatic states of the Quaternary, and to represent them in climate models.

To broaden the present knowledge on diversity, spacial distribution and ecology of micororganisms and to improve the validity of these data as proxies, special sub-samples were taken to register diatoms, dinoflagellates, coccolithophorides and benthic foraminifera quantitatively in regard to their species distribution.

The oceanographic investigations permit detailed recording of the water column from surface waters close to the coast line down to the Eastern South Atlantic Central Water (ESACW). One aim here is the description of the temporal and regional variability within the mix layerbetween the ESACW and the South Atlantic Central Water (SACW).

Working Program

The working program can be spitted into two Bereich parts. The first has concentrated on oceanographic/ hydrographic investigations along the hydrographic transects at 23°S. The

second one has enclosed the sampling of sediments and within the water column on four transects between about 23 – 26.5°S and 11.5 – 14.5°E (Figs. 2.1 and 3.1).

During the first part, a high resolution of the current velocity, its spatial distribution, and temporal variability was documented by using LADCP and information from water colum profiles of oxygen and nutrient concentrations. For sampling a CTD-rosette was emploied. All 14 locations along the hydrographic transect was sampled 4 times during this cruise leg.

The biogeochemical and biological investigations have focussed on investigations at and close to the sediment water interface. Beside a CTD-rosette, a bottom water samples equiped with an in-situ pump, ADCP, CTD, and deep-sea cameras was used within the water column. Additionally, in-situ experiments were carried out using a free-falling chamber-lander system. The sampling of surface sediments was done with a multicorer. Sediment cores were used for taken as well solid face samples, as to extract pore water, and to carry out special incubation experiments on board to record temporal changes in the microbial transformation rates.

Geochemical investigantion included the extraction of pore water from multicorer and gravity cores with immediate analyses of Eh, pH, sulfate, sulfide, chloride, alkalinity, ammonium, nitrate, phosphate and silicic acid as well as the preservation of subsamples for later analyses of additional dissolved pore water constituents. Further more, high-resolution sampling and preservation of the sedimentary solid phase for total digestions, sequential extractions, and mineralogical analyses were done.

The primary objective of the geological work was the sampling of Quaternary sediments in water depths shallower than 1500m, especially between 400m and 800m. This material is used to reconstruct changes in vertical temperature and nutrient gradients at the depth levels of the Antarctic Intermediate Water and the South Atlantic Central Water. The sediment sampling was done with gravity and multicorer after a detailed site survey with the onboard systems PARASOUND and HYDROSWEEP.

Hydrographic data (temperature, salinity, oxygen concentration) and water samples were collected at all coring sites with a CTD-rosette equipped with 12 free flow water sample bottles of HYDROBIOS.

3 Summarized Cruise Report

METEOR 57/2 was the second leg out of three of METEOR expedition M57. The program of this cruise were determined by the interests of several research projects. Their general aims were to investigate the water column by different sensors devices, to retrieve water and suspended particle samples, and to recover surface sediments and long sediment cores at the middle and upper continental slope off Namibia between 23° and 27° South. The works concentrated along four down-slope transects within this region (Fig. 3.1). A main scientific objective were biogeochemical investigations close to the sediment-water interface. The primary questions concentrate on the influence of the quantity and quality of lateral transported, biogenic particles on biogeochemical transformation processes at the sea floor. In this regard, the characterization of the suspension load according to provenance and reactivity is also of high significance. The aim of the geochemical and geophysical investigations were detailed examination of the early diagenetic modification of the primary composition and the rock magnetic properties of the sediment within the sulfate/methane transition zone. One aim of the geological investigations were reconstructions of changes in the circulation pattern, in the hydrographic structure of the water column and in the biological production of the Namibia upwelling area during extreme climatic states of the Quaternary, and to represent them in climate models. The major goal of the oceanographic work was the detailed recording of the water column from surface waters close to the coast line down to the Eastern South Atlantic Central Water (ESACW) to describe the temporal and regional variability within the mix layer between the ESACW and the South Atlantic Central Water (SACW).

After one days of uploading and storage of scientific and technical equipment, RV METEOR left Walvis Bay at February 11, with 29 scientists from German research institutes. Unfortunately, our guest from the Namibian National Marine Information and Research Centre (NATMIRC) had to reject his participation just before sailing. The scientific work began four hours after leaving the harbour with the recovery of a mooring which has been deployed two month before by the NATMIRC. All sensors worked fine, giving a high resolution time series of the highly variable and complex composition of the water column and its circulation. After successful tests of the new digital positioning system, installed on board of RV METEOR during the shipyard time one month before in Cape Town, and some preparative scientific works the program was continued with a first transit on the hydrographic transect at 23°S. Water samples, CTD-, and LADCP-profiles were taken at 14 locations from 44 m down to about 2700 m water depth. To optimise the scheduling of this cruise in regard to the short time changes in the current system and the upwelling intensity, SeaWIFS satellite pictures could be used. These information on the distribution patterns of temperature, chlorophyll a, and true colour were transferred to the ship by e-mail with a delay of only one day. Coastal surface water temperatures around 23°C off Walvis Bay at the beginning of this cruise indicated to a temporary intermission of the upwelling process which was supported also by measurements of other water parameters (salinity, oxygen, and nutrient concentrations). At the same time, the permanent Luderiz Cell (at 27°S) exhibited temperatures of about 13°C. This scenario changed over the cruise time, whereas the warm

waters retreated to the north and moderate temperatures of 17° – 18°C prevailed off Walvis Bay.

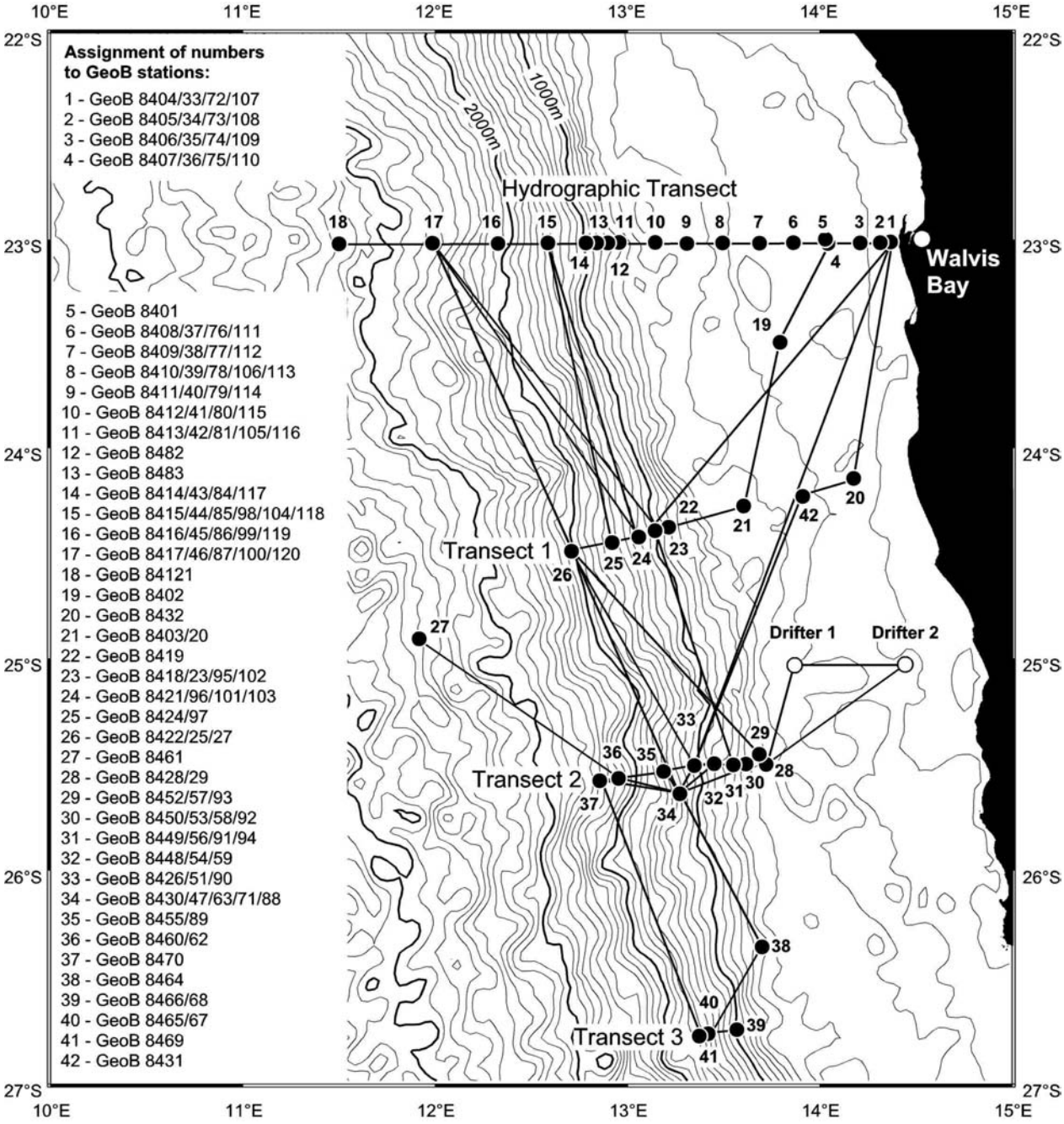


Fig. 3.1 METEOR Cruise M57/2, cruise track with the investigated stations

On the fourth day sampling start on transect 1 between 24,1° and 24,5°S which has been chosen by hydroacoustic surveying with the shipboard systems PARASOUND and HYDROSWEEP already within the first two days on sea. Like to be expected from former cruises the continental slope was relatively steep between water depths of about 400 and 800 m. Showing a lot of outcropping beds, sediment structures exhibited that erosion dominates within this interval. Therefore the seven long sediment cores from this transect originate from the shallower (300 m) or deeper interval (800 – 2000 m). With core length between 3,7 and 10,8 m the total recovery amounted to 50 m. According to a preliminary age

model which is based on geophysical measurements, oldest sediments sequences recovered have been accumulated just before the marine isotope stage (MIS) 5.5, 125.000 year ago. Besides the common type of sediment sampling with gravity corer and multicorer a free-falling Benthic Chamber Lander was deployed three times on transect 1. The long operating times of this lander system (up to more than 40 hours at the sea floor) and the four investigation-series at the hydrographic transect account for a repeated take up of the works on transects 1 and 2.

The first part of the program on transect 1 took four days and was followed by further surveying towards the south. Promising sediment structures were found between 25,5° and 26°S. In contrast to the northern transect PARASOUND profiles indicated to continuous sedimentation also in the sphere of the immediate water masses. So, seven locations between 400 m and 2500 m water depth were chosen for the deployment of the gravity corer. The total recovery amounted to about 100 m. Although these cores are longer in comparison to those from transect 1 (7,8 – 14 m), apart from the deepest location preliminary results indicated a significant younger age and therefore higher sedimentation rates. The lander system was deployed four times at this transect 2. Interrupted by the exposure of two drifters for the NATMIRC at 25,0°S/13,9°E and 25,0°S/14,5°E, a second set of oceanographic investigations on the hydrographic transect at 23°S, and a deep water station for in situ pumping at 24,9°S/11,9°E, the scientific work on transect 2 took a net time of about five to six days.

At the end of the 17th day the program was continued by acoustic surveying of the continental slope between 25,4°S and 26,8°S. Again the sediment structures gave evidence that this area is unsuitable for the purpose of sediment sampling between water depths of 500 – 900 m. Therefore, only three gravity cores were recovered from 430m, 940m, and 1480 m. Although the third transect is closer to the upwelling cell off Luderiz, sedimentation rates seem to be lower than more to the north, at least during the last 60.000 yrs. First results suggested that the deepest core resolve the last 140.000 yrs. Based on this findings and the acoustic profiles from the beginning of this cruise we made the decision to extend the geological program onto the 23rd latitude. After the third repeat of sampling at the hydrographic transect, works were completed at transect 1 and 2 by deployment of the Bottom Water Sampler (BWS), the CTD-Rosette, the multicorer, and the Benthic Chamber Lander.

During the last four days before the transit back to Walvis Bay, sediments at 23°S were sampled at seven locations between 600 m and 2700 m. The cores length amount about 4 to 11 m. In comparison to the other samples recovered on transects 1, 2, and 3 first shipboard results generally indicate to the lowest sedimentation rates. The completion of a successful cruise were performed by last extensive water column sampling at the hydrographic transect. RV METEOR arrived at March 12, 2003, the end of this second leg of M57.

In total about 3300 nm of hydroacoustic surveys with the shipboard PARASOUND, HYDROSWEEP, and ADCP systems were achieved during M57-2. At 24 locations 28 gravity cores were recovered for further geological, geochemical and geophysical investigations. This set was completed by 40 multicorer deployments. The water column was sampled 94 times with 12 water bottles, CTD, and LADCP at 32 locations, and 10 in situ pump

deployments at 5 locations. The benthic nepheloid layer was sampled at 17 BWS-stations. At seven Benthic Chamber Lander deployments in situ incubations were performed. One mooring was recovered. And last but not least, 17 plankton net hauls and 10 shipboard membrane pump samples from the surface waters were taken.

4 Preliminary Results

4.1 PARASOUND and HYDROSWEEP Surveys

PARASOUND and HYDROSWEEP profiling on M57/2 were carried mainly on sediments from the upper and middel continental margin off Namibia from 23°S down to about 27°S (cf. Fig. 3.1).

The major goal was to identify and select promising coring locations and to obtain detailed site information, especially at the interval between 400 m and 900 m water depth.

4.1.1 Equipment / Instrumentation

During the cruise the onboard PARASOUND and HYDROSWEEP equipment of R/V METEOR was used. The PARASOUND system works both as a high-frequency narrow beam sounder to determine the water depth and as a low-frequency sediment echosounder. It makes use of the parametric effect, which produces additional frequencies through nonlinear acoustic interaction of finite amplitude waves. If two sound waves of the certain frequency (e.g. 18 kHz and 22 kHz) are emitted simultaneously, a signal of the difference (e.g. 4 kHz) frequency is generated. The new signal component is traveling with the emission cone of the original high frequency waves, which are limited to an angle of only 4°. Therefore a footprint size of 7% of the water depth is much smaller than for conventional systems and both vertical and lateral resolutions are significantly improved.

The PARASOUND system is permanently installed on the ship. A hull-mounted transducer array of 128 elements on an area of approximately 1m² requires up to 70kW of electric power due to the low degree of efficiency of the parametric effect. The penetration into the sediments varied between about 1 to 120m depending on their physical properties. The system is controlled by the PARADIGMA program (MTU – University Bremen).

During the survey online paper plots were produced in order to get material for scientific discussions and site information. The data was digitally stored on removable hard discs and stored on CD-ROMS and digital tape.

The HYDROSWEEP system is a multibeam echosounder system operating at a frequency of 15.5 kHz. 59 pre-formed beams are emitted with at an opening angle of 90°. Since data quality partly depends on course, heading, and weather conditions HYDROSWEEP recordings during the hydroacoustic surveys were good on some lines and worse on others, although the system works generally very well. HYDROSWEEP data was primarily used to get a better depth control and to get an idea of the surrounding seafloor morphology. It was stored on the onboard LINUX workstation and backed up by the system manager of the vessel.

4.1.2 Preliminary Results

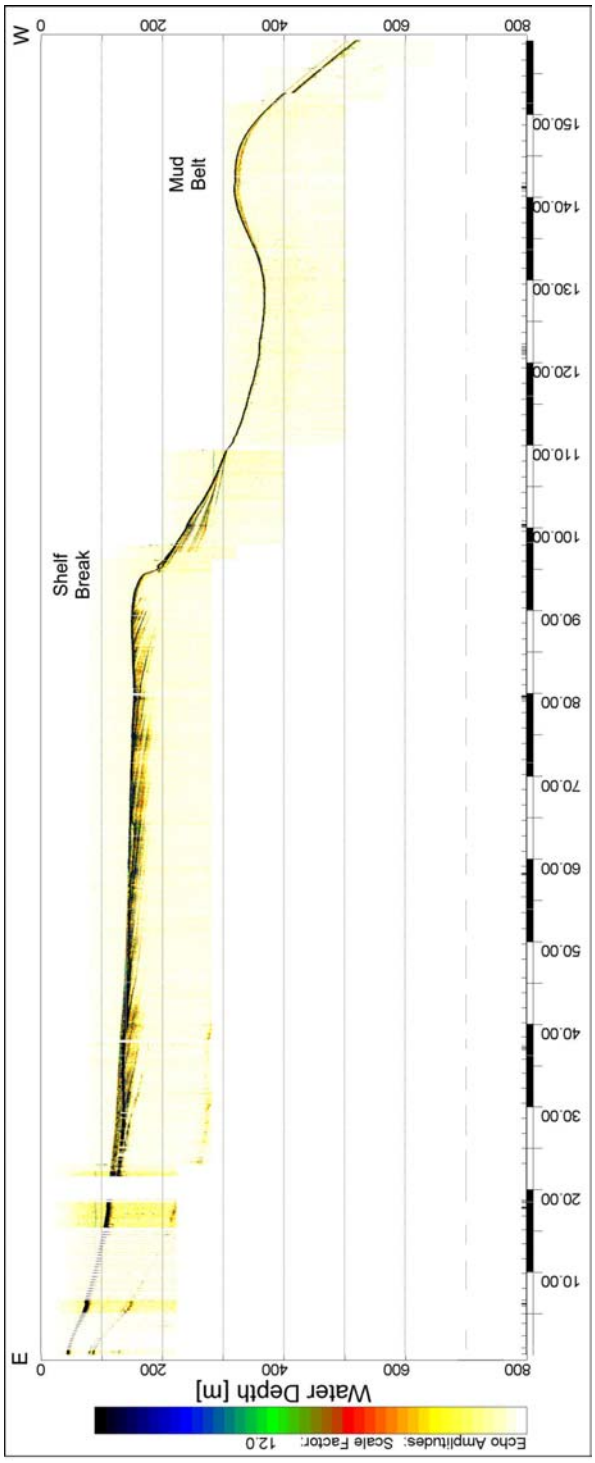


Fig. 4.1.1 Digital PARASOUND profile showing the shallow section (50m to 500m water depth) of the hydrographic transect at 23°S (cf. Fig. 3.1). The section is annotated with distance in km, water depth for a sound velocity of 1500 m/s.

While investigations within the water column and close to the sea floor were nearly independent on the underlying sediment structures, a prerequisite for the geological program are continuously sedimented, undisturbed deposites. On account of one of the scientific goals (the description of the temporal variability of the Central Water masses; cf. Chap. 2) the water depth interval between 400m and 800m were of major interest.

Like to be expected from former cruises the continental slope was relatively steep at this interval, showing a lot of outcropping beds exhibiting that erosion is a dominating process. So, no suitable core locations could be identify along the most sections along the upper continantal slope (e.g. transect 1; see Figs. 4.1.3 and 4.1.4). Sediment structures at the hydrographic transect are hard to interpret because of the low penetration depth of the acoustic signal (Fig. 4.1.2). Anyway, sedimentation rates decrease with decreasing water depth, but profiles give no clear indication if single layers are eroded.

Promising sediment structures were found along transect 2 (Figs. 4.1.5 and 4.1.6). PARASOUND profiles indicate to continuous sedimentation also in the sphere of the Central and Immediate Water masses. So, 7 locations were chosen for the deployment of the gravity corer (cf. Tab. 4.2.1).

Along transect 3 (not shown) PARASOUND surveys gave evidence that this area is also unsuitable for the purpose of sediment sampling between water depths of 500 – 900 m.

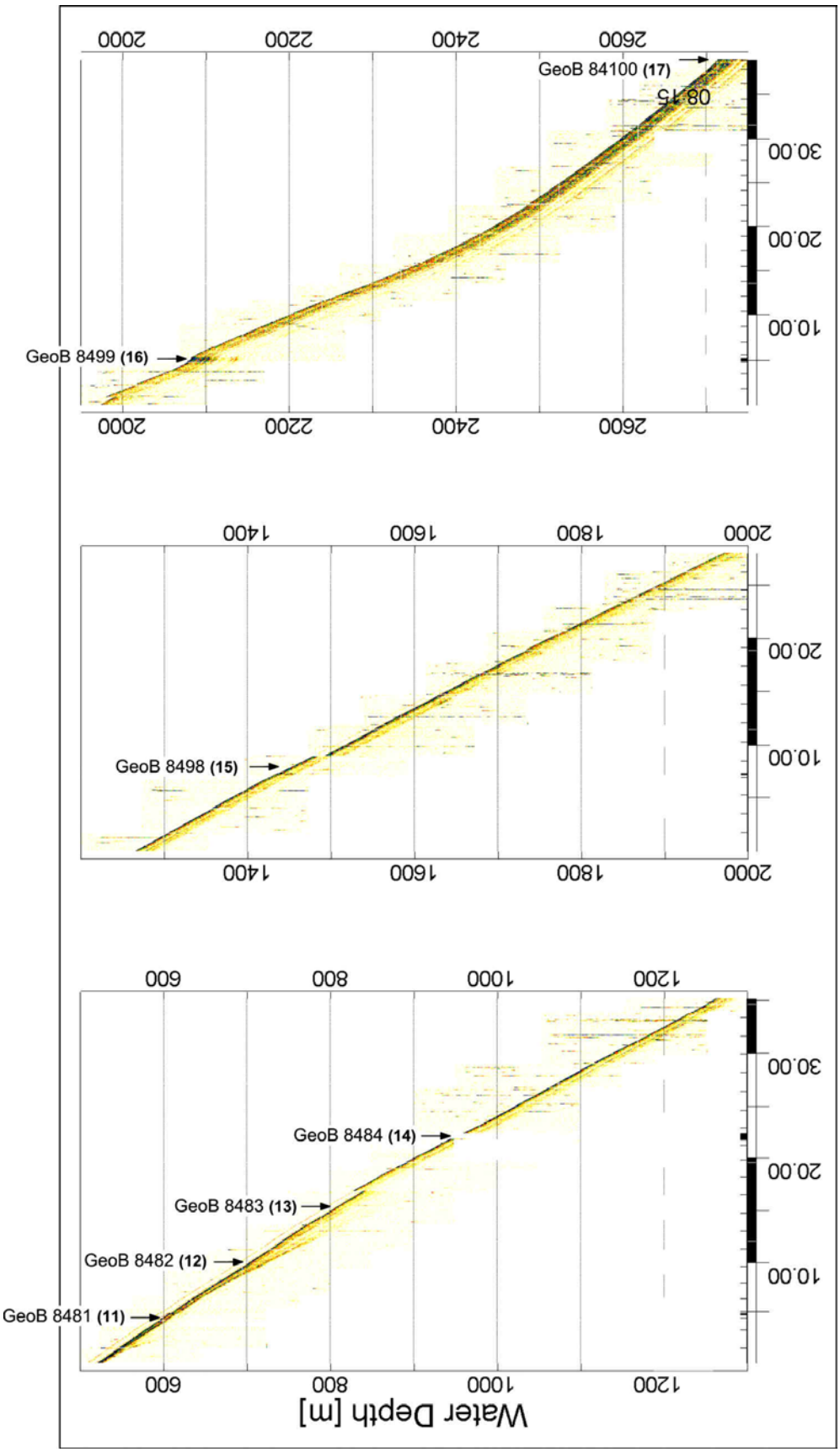


Fig. 4.1.2 Digital PARASOUND profile showing the deeper section of the hydrographic transect at 23°S (cf. Fig. 3.1). Additionally, core locations are given. For further explanations see Figure 4.1.1.

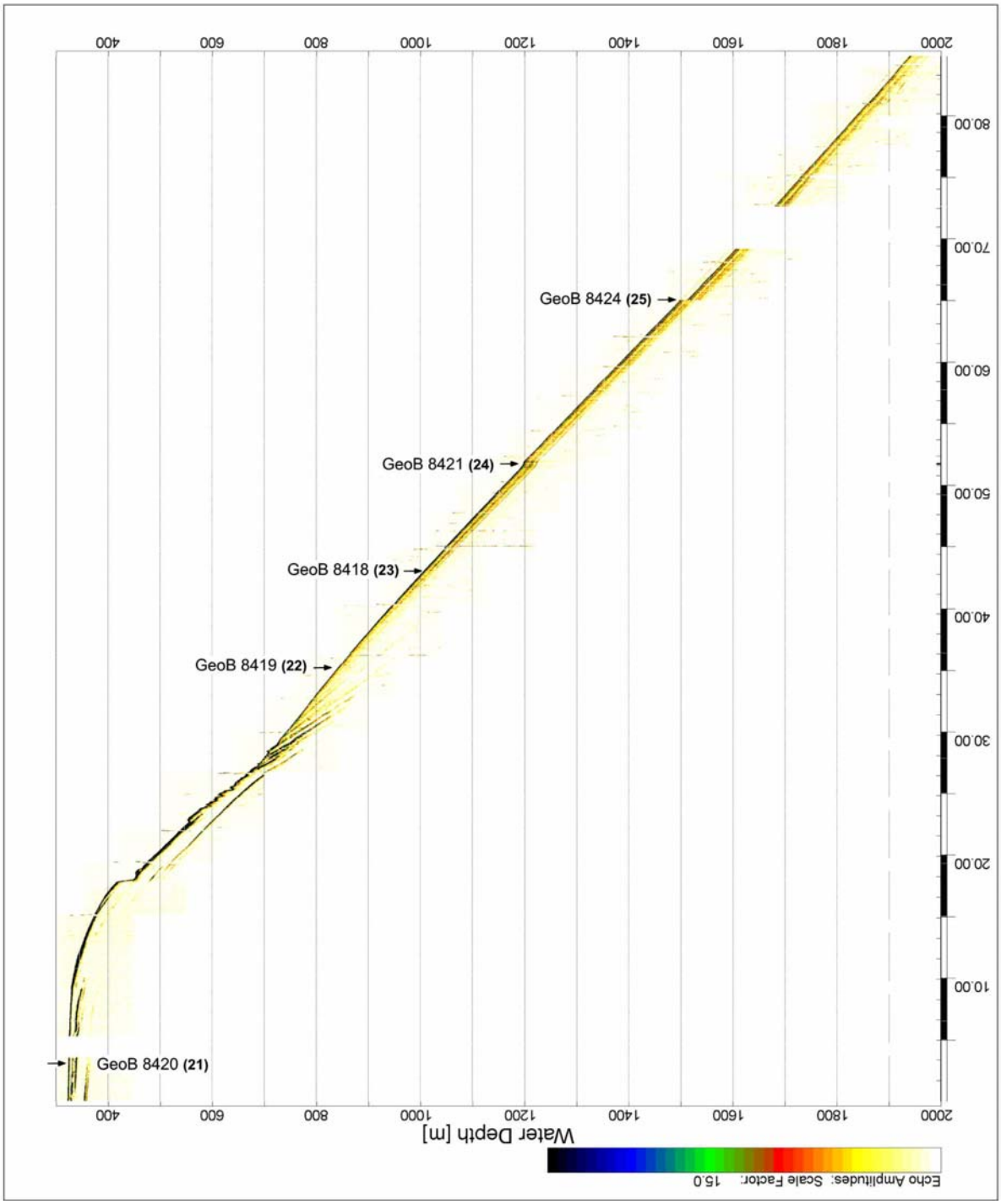


Fig. 4.1.3 Digital PARASOUND profile showing transect 1 between 24°15'S/13°37'E and 24°28'S/12°43'E (cf. Fig. 3.1). Additionally, core locations are given. For further explanations see Figure 4.1.1.

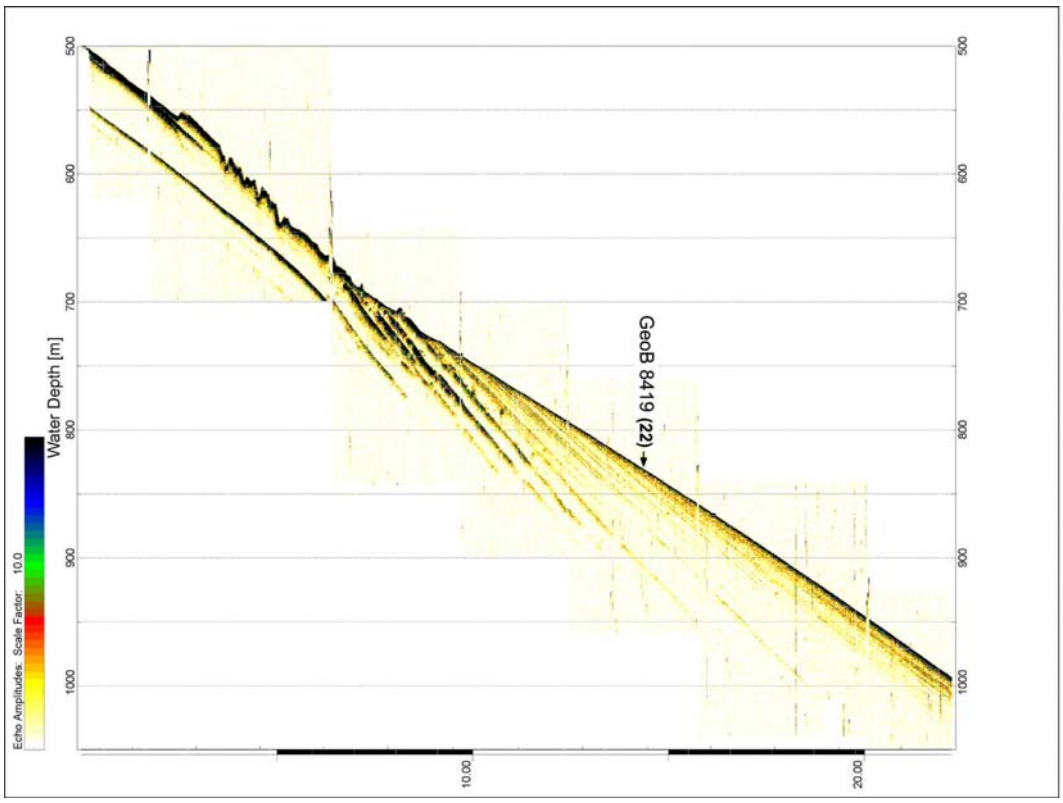


Fig. 4.1.4 Digital PARASOUND profile showing the 500m to 1000m water depth interval of transect 1 in detail (cf. Figs. 3.1 and 4.1.3). For further explanations see Figure 4.1.1.

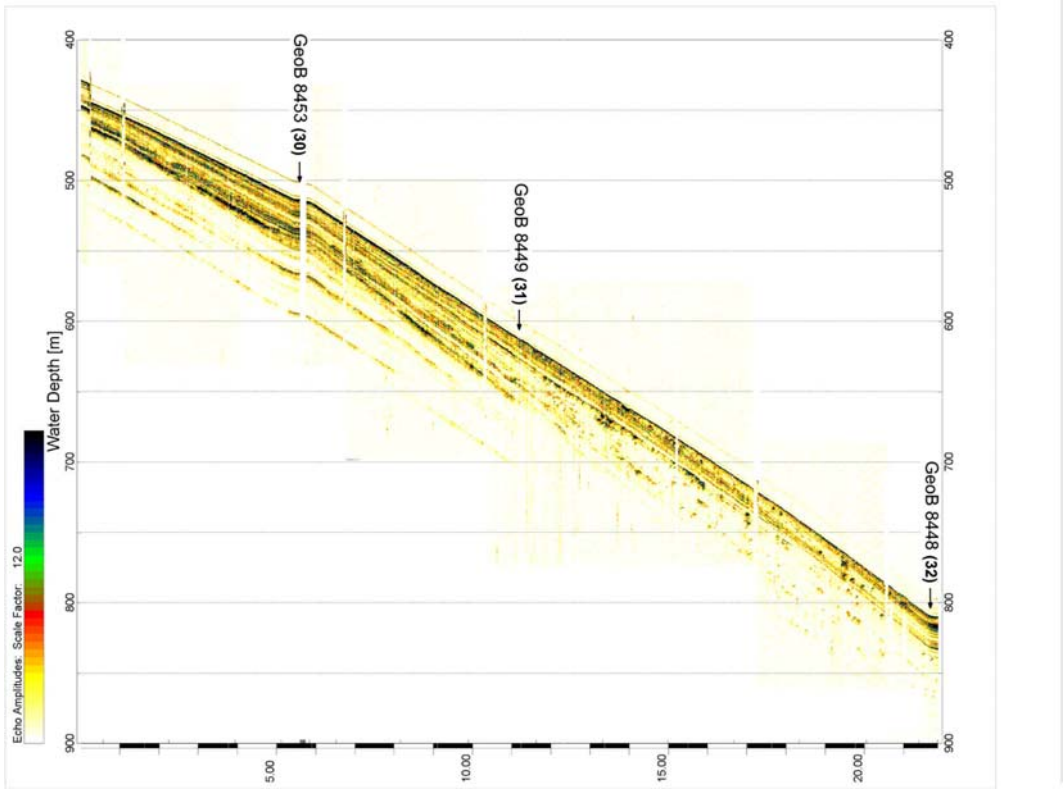


Fig. 4.1.5 Digital PARASOUND profile showing transect 2 between 25°27'S/13°40'E and 25°29'S/13°27'E (cf. Fig. 3.1). Additionally, core locations are given.For further explanations see Figure 4.1.1

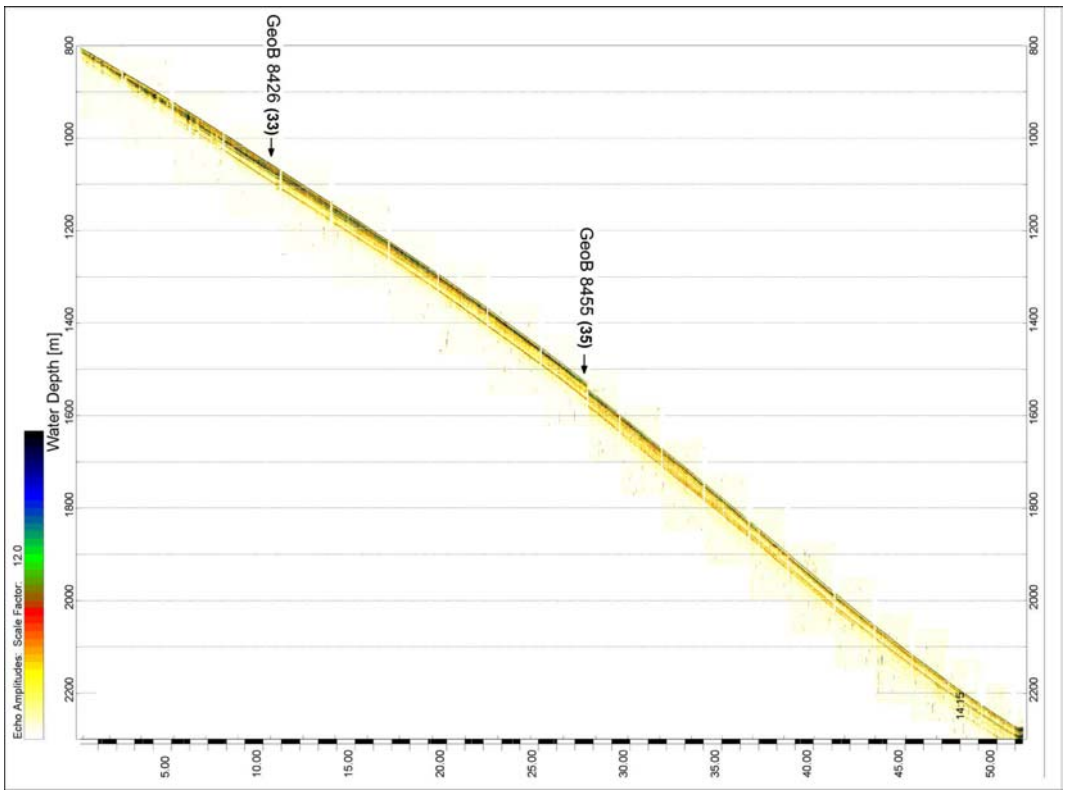


Fig. 4.1.6 Digital PARASOUND profile showing the lower section of transect 2 (cf. Fig. 3.1 and 4.1.5). Additionally, core locations are given. For further explanations see Figure 4.1.1.

4.2 Sampling

During the cruise a couple of different devices were used to recover the sample material. On account of temporal constraints, especially by the employment of the free-falling lander system, most of the 42 investigated locations were visited several times on different days. Following the chronology of the cruise track, we decided to give more than one internal GeoB station number to those locations (s. Fig. 3.1). To make the finding and assignment of single stations more easy, tables also contain the inofficial 42 station numbers in correspondence to Figure 1.

4.2.1 Sediment Sampling with the Gravity Corer

(A. Eberwein, U. Holzwarth, S. Mulitza, A. Paul, S. Rathmann, O. Romero, R. Schäfer, A. Wülbers)

To recover older sediment sequences, a gravity corer with pipe lengths of either 6, 12 m or 18 m, and a weight of 2.5 tons was deployed at 25 stations. A total of 28 cores were retrieved with recoveries between 2.20 and 13.96 m (Tab. 4.2.1). At four deployments the core tube returned empty while at two stations the tube was bent. About 224 m of sediment were recovered with the gravity corer during Cruise M57-2. In order to retain the relative orientation of the core, all liners used had been marked lengthwise with a straight line. On board, the sediment core was cut into 1-meter sections, closed up with caps on both ends and labeled according to a standard scheme (Fig. 4.2.1).

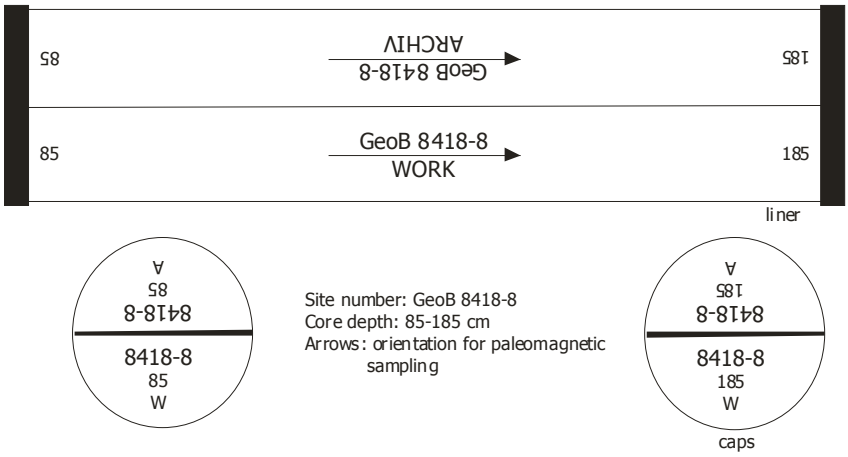


Fig. 4.2.1 Scheme of the inscription of gravity core segments.

Core segments were cut into "archive" and "work" halves. The "archive" half was used for core description, smear slide sampling, core photography, and scanning of light reflectance. The "work" half was sampled with two series of 10-ml syringes for geochemical and foraminiferal analysis at 5 cm intervals.

Table 4.2.1: Gravity corer sampling during M57-2
(Station numbers in brackets correspond to Fig. 3.1)

GeoB	Location		Water depth	Recovery	Remarks
	Latitude (S)	Longitude (E)	(m)	(cm)	
8418-8 (**23**)	24° 21.9	13° 08.2	1007	417	Geochemistry
8418-9 (**23**)	24° 21.9	13° 08.2	1007	---	No recovery
8418-10 (**23**)	24° 21.9	13° 08.2	1008	452	
8419-1 (**22**)	24° 21.2	13° 13.1	830	530	
8420-3 (**21**)	24° 15.1	13° 36.5	315	371	
8421-3 (**24**)	24° 23.5	13° 03.3	1208	220	
8422-3 (**26**)	24° 27.5	12° 42.8	1992	1030	
8424-4 (**25**)	24° 25.3	12° 55.5	1516	595	
8425-2 (**26**)	24° 28.2	12° 42.8	1998	---	No recovery
8425-7 (**26**)	24° 27.6	12° 41.1	2015	1080	Geochemistry
8426-1 (**33**)	25° 28.9	13° 21.3	1039	---	overpenetration, not sampled
8426-2 (**33**)	25° 28.9	13° 21.2	1045	1396	
8426-3 (**33**)	25° 28.9	13° 21.1	1045	1366	Geochemistry
8448-1 (**32**)	25° 28.5	13° 27.0	803	1130	
8449-2 (**31**)	25° 28.5	13° 33.2	606	---	tube bent, not sampled
8449-3 (**31**)	25° 28.5	13° 33.2	607	993	Upper 5 cm lost
8452-2 (**29**)	25° 27.5	13° 41.0	387	784	
8453-1 (**30**)	25° 28.4	13° 36.5	505	1115	
8455-2 (**35**)	25° 30.4	13° 11.0	1503	1058	Geochemistry
8455-3 (**35**)	25° 30.4	13° 11.0	1515	1049	
8464-4 (**38**)	26° 20.2	13° 41.9	430	658	
8466-1 (**39**)	26° 43.7	13° 34.4	930	---	tube bent, not sampled
8468-1 (**39**)	26° 43.7	13° 34.2	941	313	
8469-1 (**41**)	26° 45.6	13° 22.8	1480	1002	
8470-4 (**37**)	25° 32.7	12° 51.6	2470	1126	Geochemistry
8481-3 (**11**)	23° 00.0	12° 57.0	596	563	overpenetration
8481-4 (**11**)	23° 00.0	12° 57.0	598	429	
8482-1 (**12**)	23° 00.0	12° 53.5	704	522	
8483-2 (**13**)	22° 59.9	12° 50.6	803	612	
8484-1 (**14**)	23° 00.0	12° 46.9	951	---	no recovery
8484-2 (**14**)	23° 00.0	12° 46.9	951	386	
8498-1 (**15**)	23° 00.0	12° 34.9	1442	1077	
8499-2 (**16**)	23° 00.0	12° 20.0	2080	1087	
84100-1 (**17**)	22° 59.9	11° 59.9	2725	1034	

4.2.2 Sediment Surface Sampling with the Multicorer

(A. Eberwein, U. Holzwarth, S. Mulitza, A. Paul, S. Rathmann, O. Romero, R. Schäfer, A. Wülbers)

The coring device suited best for the sampling of undisturbed surface sediments including overlying bottom water is the multicorer (MUC). The MUC used during the cruise was equipped with eight large and four small plastic tubes, each of 60 cm length and 10 and 6 cm in diameter, respectively. Depending on the sediment composition, the recovery of the multicorer varied between 10 and 60 cm.

Depending on the purpose of each Multicorer, the sediment was shared for the following studies:

-2 large tubes, cut in 1-cm slices, stained with rose bengal, for foraminiferal studies
-1 large tube, cut in 1-cm slices, frozen, for organic geochemistry
-1 large tube, for geophysical investigations
-1 large tube, cut in 1-cm slices, frozen, for archive
-1 large tubes for pore-water geochemistry
-1 large tubes for Dinoflagellate studies
-1 large tube (uppermost cm only) for Dinoflagellate studies
-1 small tube, frozen, for archive
-1 small tube (uppermost surface sediment), for diatom and for radiolarian studies

On 12 multicorer deployments, all tubes were used for biogeochemical studies (see Tab. 4.2.2 for a detailed sampling list). At all stations, two samples of the overlying bottom water were filled into 30 ml glass bottles for carbon- and oxygen isotope analysis, respectively. The sample for $\delta^{13}C$ was poisoned with 1 ml saturated $HgCl_2$ solution.

Table 4.2.2: Multicorer sampling during M57-2 (Station numbers in brackets correspond to Fig. 3.1)

GeoB	Water depth (m)	Core length (cm)	Foramini-fera large/small	Foramini-fera*	Dino-flagell-ates	Diatoms Radiol.*	Organic Carbon	Geo-physic	(Bio)Geo-chemistry	Reactivity	Fluffy Layer	XRF	BSP	Surface	Archive (frozen)
8402-1 (**19**)	164	10	2/0	–	0/1	–	1/0	–	–	–	–	–	–	–	0/2
8403-1 (**21**)	320	32	2/0	1/0	1/1*	–	1/0	1/0	0/1	–	–	–	–	–	1/1
8404-2 (**1**)	44	56	2/0	–	0/1**	0/1**	1/0	–	0/4	–	–	–	–	–	–
8418-1 (**23**)	1006	23	2/0	–	1/0	–	1/0	1/0	0/2	1/0	–	2/0	0/1	–	0/1
8419-2 (**22**)	834	32	2/0	–	1/0	0/1	1/0	1/0	–	1/0	0/1	–	–	–	1/1
8421-4 (**24**)	1205	18-26	2/0	–	1/1*	0/1	1/0	1/0	–	1/0	0/1	–	–	–	1/1
8422-1 (**26**)	1997	23	2/0	–	1/1	0/1	1/0	1/0	0/1	1/0	–	1/0	–	–	0/1
8422-2 (**26**)	1989	17-22	–	–	–	–	–	–	0/3	8/0	–	–	0/1	–	–
8424-3 (**25**)	1519	23	2/0	–	1/0	0/1	1/0	1/0	–	1/0	0/1	–	–	–	0/1
8425-8 (**26**)	2035	20	–	–	–	–	–	–	0/4	–	–	–	–	–	–
8429-1 (**28**)	362	19	–	–	–	–	–	–	0/3	8/0	–	–	0/1	–	–
8430-2 (**34**)	1330	37	2/0	–	1/0	0/1	1/0	1/0	0/1	–	–	–	–	–	1/1
8447-1 (**34**)	1334	44	2/0	–	–	–	–	–	2/0	–	–	–	0/4	–	–
8448-2 (**32**)	806	37-44	2/0	–	1/0	0/1	1/0	1/0	2/0	1/0	0/1	–	–	–	0/1
8449-1 (31)	605	34	2/0	–	1/0	0/1	1/0	1/0	2/0	1/0	0/1	–	–	–	0/1
8450-1 (**30**)	506	32	2/0	2/0	1/1*	0/1	1/0	1/0	–	–	–	–	–	–	1/1
8451-1 (**33**)	1028	32	2/0	–	1/0	0/1	1/0	1/0	2/0	1/0	0/1	–	–	–	0/1
8452-1 (**29**)	388	36	2/0	–	1/0	0/1	1/0	1/0	–	1/0	0/1	–	–	0/4	1/1
8454-1 (**32**)	803	1	5/0	2/0	–	–	–	–	–	–	–	–	–	–	–

Table 4.2.2: (continued) Multicorer sampling during M57-2 (Station numbers in brackets correspond to Fig. 3.1)

GeoB	Water depth (m)	Core length (cm)	Foramini-fera large/small	Foramini-fera*	Dino-flagell-ates	Diatoms Radiol.*	Organic Carbon	Geo-physic	(Bio)Geo-chemistry	Bacterial Reactivity	Fluffy Layer	XRF	BSP	Surface	Archive (frozen)
8455-1 (**35**)	1503	36	2/0	–	1/0	0/1	1/0	1/0	2/0	1/0	0/2	–	–	–	0/1
8462-2 (**36**)	2289	20	–	1/0	–	–	–	1/0	1/0	1/0	0/1	2/0	0/3	–	1*/1
8462-4 (**36**)	2293	23	2/0	1/0	1/0	0/1	1/0	–	1/0	–	–	–	–	0/1	1/1
8464-2 (**38**)	430	28	2/0	–	1/0	0/1	1/0	1/0	2/0	1/0	0/1	–	–	–	0/1
8465-2 (**40**)	1377	23-27	2/0	–	1/0	0/1	1/0	1/0	2/0	1/0	0/1	–	–	–	0/1
8466-2 (**39**)	940	13-22	2/0	–	1/0	0/1	1/0	1/0	2/0	–	–	–	–	0/1	1/1
8469-3 (**41**)	1480	23-27	2/0	1/0	1/0	0/1	1/0	1/0	–	–	–	–	–	0/1	1/1
8470-1 (**37**)	2470	21	2/0	–	1/0	0/1	1/0	1/0	2/0	1/0	–	–	–	–	0/1
8481-2 (**11**)	597	30	2/0	1/0	***1/0	0/1	1/0	1/0		–	–	–	–	0/1	1/1
8482-2 (**12**)	706	17-26	2/0	1/0	***1/0	0/1	1/0	1/0		–	–	–	–	0/1	1/1
8483-1 (**13**)	805	25	2/0	1/0	***1/0	0/1	1/0	1/0		–	–	–	–	0/1	1/1
8484-3 (**14**)	953	19-26	2/0	1/0	***1/0	0/1	1/0	1/0		–	–	–	–	0/2	1/0
8494-1 (**31**)	602		–	–	–	–	–	–	0/4	1/0	–	8/0	–		
8498-2 (**15**)	1439	23	2/0	1/0	1/0	0/1	1/0	1/0	1/0	–	–	1/0	–	0/2	1/0
8499-1 (**16**)	2080	20	2/0	1/0	***1/0	0/1	1/0	1/0	–	–	–	–	–	0/2	1/1
84100-2 (**17**)	2725	10-20	2/0	1/0	***1/0	0/1	1/0	1/0	–	–	–	–	–	0/2	1/1

large (diameter = 10 cm); small (diameter = 6 cm); * only surface (0-1 cm); ** Shared with Forams; *** Additional surface sample (0-1 cm)

4.2.3 The Benthic Lander System

(T. Ferdelman, J. Langreder, A. Nordhausen, U. Witte)

During cruise M 57-2, seven lander deployments were conducted using a modular benthic lander system (Witte & Pfannkuche 2000; Fig. 4.2.2; for station information see Tab. 4.2.3a). The lander systems was deployed carrying three identical benthic chambers that were used to conduct a series of in situ enrichment experiments. In each deployment, 2 different, ^{13}C-labeled substrates were added to one of the chambers, the third chamber served as a control (Tab. 4.2.3b). A syringe water sampler was attached to each chamber that takes 7 water samples at preset intervals during the incubation. At the end of the incubation the sediment is retrieved by closure of a shutter. For continuous recordings of oxygen concentration, each chamber is equipped with 2 oxygen optodes. All deployments were successful except for the failure of an injection unit during one deployment.

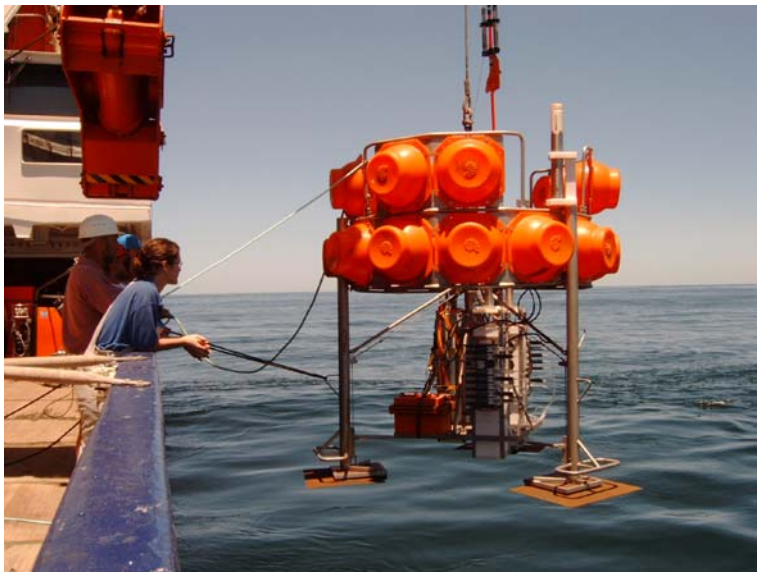


Fig. 4.2.2
Deployment of modular benthic lander system

During two lander deployments (stations GeoB 8460 and GeoB 8495), one benthic chamber was exchanged with the "Orpheus"-module that is designed for in situ measurement of sulfate reduction rates by injection of ^{35}S-labelled SO_4 into three parallel cores. Although, the actual rates of sulfate reduction would have to await further processing in Bremen, we could ascertain the efficiency of injection directly on board using the available scintillation counter. As shown in Figure 4.2.3a, in the first deployment the injection and distribution of radiotracer was poor. In general, we aimed for 100 to 200 kBq per 1cm sediment slice, but the observed amount was usually less than 1 kBq per 1 cm slice. Between 76 and 99% of the radiotracer was found in the overlying water or diffusing into the upper 2 cm of sediment.

Clearly the injector had failed to evenly distribute the radioactivity throughout the length of the core. After determining that no mechanical failures had caused the problem, we altered the injection process. It was hypothesized that a slight underpressure would develop during the coring process (the corer has a piston), thus allowing tracer to leak out of the needles during the initial coring. To avoid this problem, we inserted both the core and needle in a stepwise fashion into the sediment before retrieving the needle.

This approach resulted in an improved distribution of tracer throughout the core during the second deployment (GeoB 8495; Fig. 4.2.3b). In the second deployment, only 23 to 29 % of the tracer remained in the overlying water; the rest was delivered to the core, resulting in 50 to 200 kBq per 1 cm sections (one of the needles failed to operated mechanically and no tracer was injected).

Table 4.2.3a: Lander deployments during M57/2

	Deployment:					Recovery:		Associate GeoB stations
	GeoB station	Longitude (E)	Latitude (S)	Water depth [m]	Date 2003	GeoB station	Date 2003	
BCL I	8418	13,14	24,37	1020	15.02.	8423	17.02.	8495 / 84102
BCL II	8425	12,72	24,46	1990	17.02.	8427	19.02.	
BCL III	8430	13,28	25,61	1330	20.02.	8447	23.02.	8471 / 8488
BCL IV	8449	13,55	25,47	610	23.02.	8456	24.02.	
BCL V	8460	12,95	25,54	2270	25.02.	8462	27.02.	
BCL VI	8471	13,28	25,61	1330	02.03.	8488	05.03.	8430 / 8447
BCL VII	8495	13,13	24,37	1020	06.03.	84102	08.03.	8418 / 8423

Table 4.2.3b: In situ experiments carried out during M57/ 2

	BCL I	BCL II	BCL III	BCL IV	BCL V	BCL VI	BCL VII
K1	control	control	control	Control	SRR	Shelf	SRR
K2	fresh	fresh	control	Fresh	control	2xfresh	shelf
K3	old	Old	old	Old	old	Old	old

Kx: number of the chamber; *control*: injecting no additional organic matter; *fresh*: fresh algae material; *old*: injecting old algae material; *shelf*: Injection of shelf fluff; SSR: development of the ORPHEUS modul for measurements of SSR.

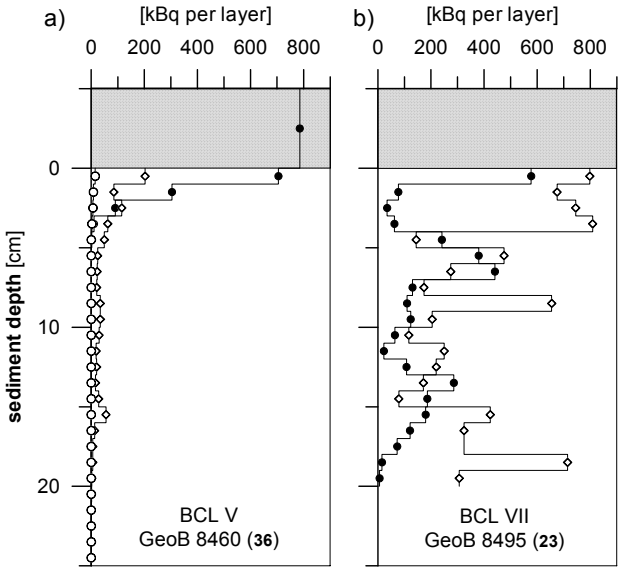


Fig. 4.2.3 Preliminary results of ^{35}S detection in core slides from to locations after in situ injection with the "Orpheus"-module at the benthic chamber lander.

4.2.4 Particle Sampling

(M. Inthorn, O. Wilhelm)

The Bottom Water Sampler (BWS)

The BWS (Fig. 4.2.4) is a new sampling device which was especially designed to collect water samples from different heights above the seafloor which are not in reach of a standard rosette water sampler. It consists of a three-footed frame with an additional central axis which is revolvable against the frame. Five 5-liter Niskin-bottles are horizontally attached to this axis and can be shifted between 10 and 120 cm above ground. The whole device is attached to a rope from the ship via a revolvable connector and both the frame and the inner axis have current-sails which turn the Niskin-bottles directly into the current. This is necessary to avoid any influences of turbulences developing from parts of the frame on the particle-flow. A burn-wire-system connected to a timer which is programmed before deployment closes the Niskin-bottles in a specified time after bottom contact. During the cruise we used a waiting time of 45 minutes to make sure that all the material which was resuspended in succession of the deployment of the device was redeposited or drifted away.

30 m above the BWS a pinger was attached to the rope. The signal of the pinger made it possible to stop the BWS for a couple of minutes at 5 to 10 m (depending on the wave and wind conditions) above the seafloor to give it some time to align with the current conditions close to the seafloor.

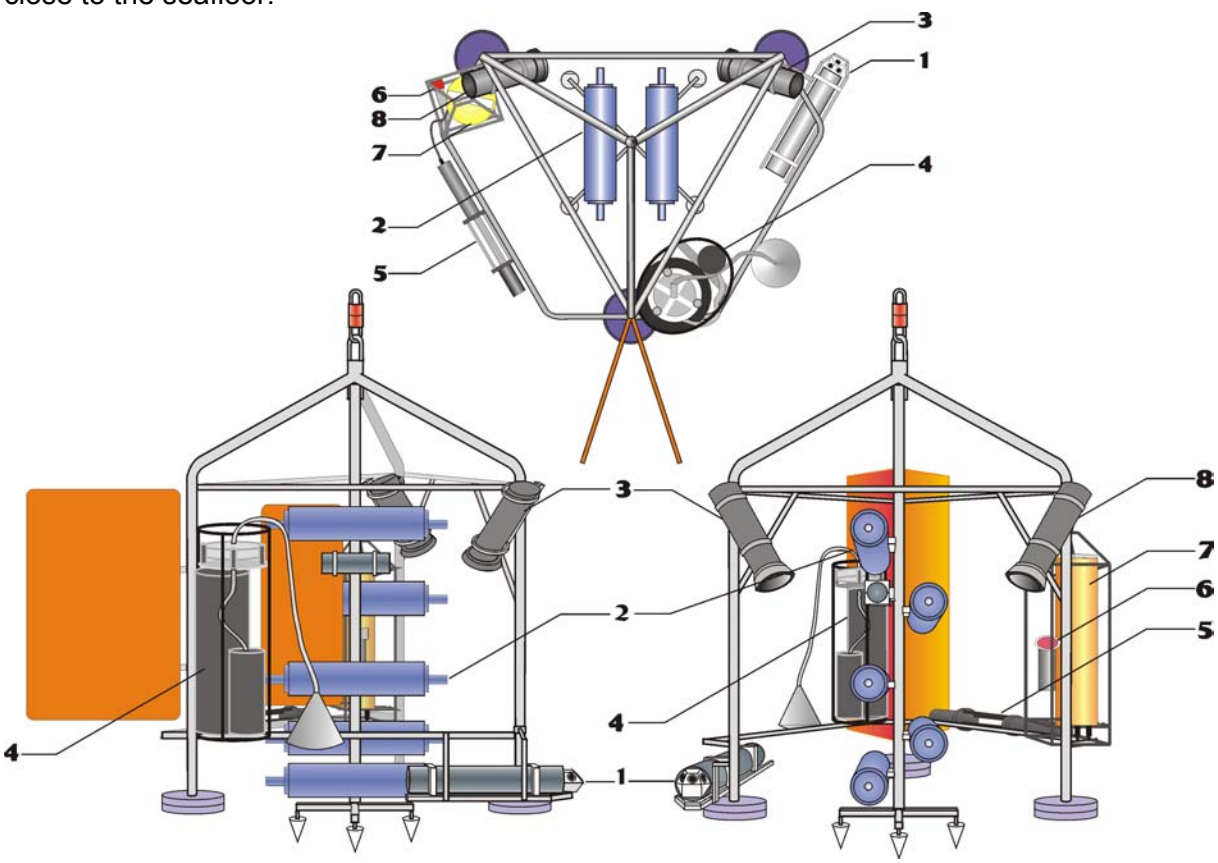


Fig. 4.2.4 Schematic drawing of the bottom water sampler (BWS) in side, top and front view. The stainless-steel tripod is equipped with a current profiler (1), five Niskin-bottles for water-sampling (2), a deep-sea camera (3), an insitu-pump (4), a trans-missometer (5), an oxygen-sensor (6), a CTD (7) and a deep-see flashlight (8).

Another 20 m above the pinger two floats were attached to the rope, which made it possible to let the rope hang loosely in the water without the risk of the slack rope winding around the BWS. By that it is assured that a movement of the ship doesn't directly result in a movement of the BWS which would go along with an artificial resuspension event.

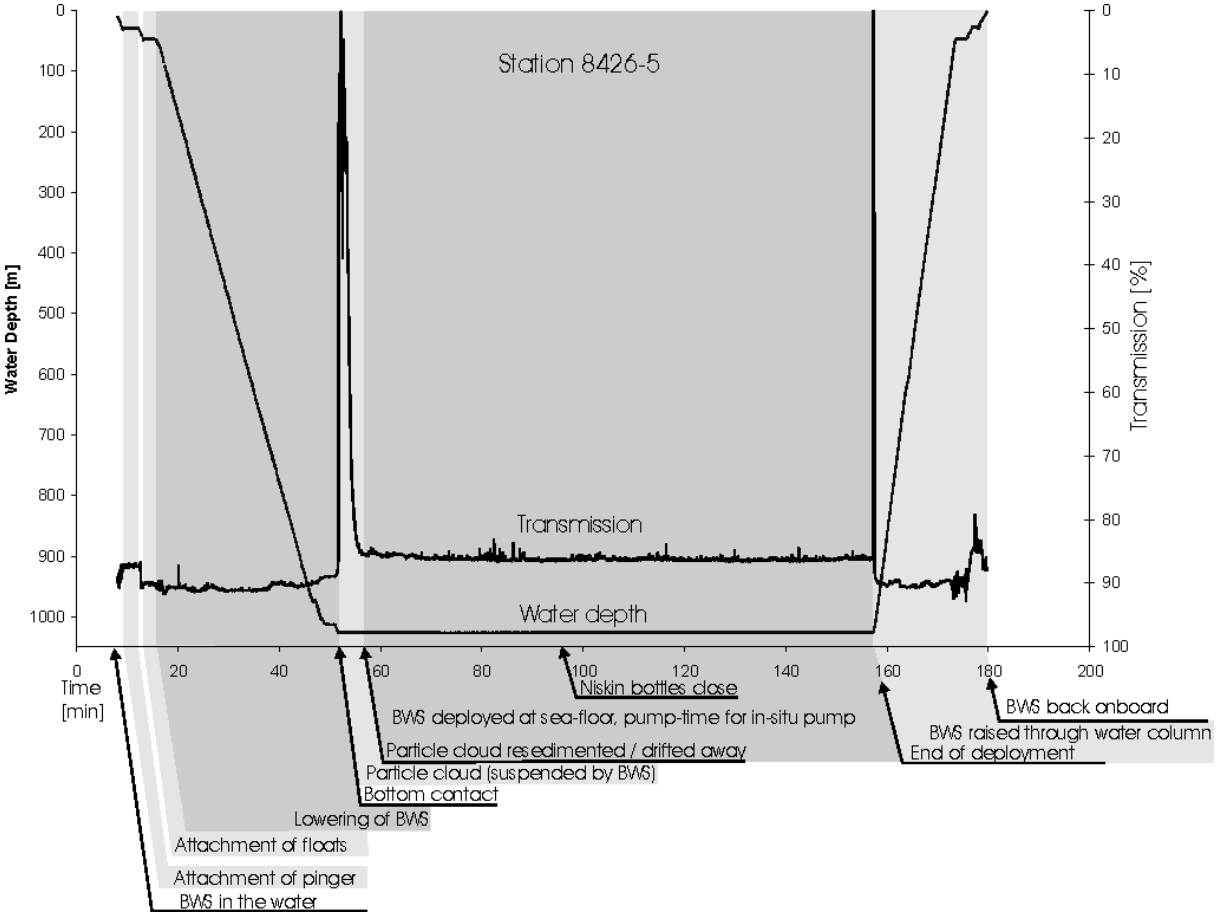


Fig. 4.2.5 Water depth (converted from the pressure data) and transmission data from the BWS deployment at station 8426-5 (1049 m water depth, see Tab. 4.2.4 for details). In this figure the overall process of a BWS deployment is illustrated.

The BWS was additionally equipped with a SEABIRD SBE 19 CTD profiler, a NORTEK AQUADOPP current-profiler, a PHOTOSEA 1000 photo-camera system and a MCLANE insitu-pump (Fig. 4.2.4). The position of the CTD was about 50 cm above the seafloor. Aside of the pressure-, temperature- and salinity-sensor there were also an oxygen- and a SEATECH transmissometer connected to the CTD. Figure 4.2.5 shows the depth (converted from the pressure data) and transmission data over the whole duration of a BWS deployment and illustrates the overall process. The transmissometer was attached to the frame of the BWS about 25 cm above the ground. Beam transmission is a measure of the percentage attenuation of a light signal along its 0.25 m long way from the emitter to a sensor. It operates with light at 660 nm (red) wavelength. The light transmission is directly linked to the particle content of the water. Light transmission in perfectly clean water is 91.3 % for this instrument (information given by the manufacturer). The relative measurements of the transmission cannot be compared directly between different deployments. They will be empirically calibrated by the particle content on the filters later on. But the information is

Table 4.2.4: CTD and BWS stations (M57-2) (Station numbers in brackets correspond to Fig. 3.1)

GeoB No.	Date 2003	Sampling Device	Time of Employment (UTC)	Location Latitude (S)	Location Longitude (E)	Water Depth [m]	Number of Water samples	Number of GFF-Filters / Nuclepore-Filters	In Situ Pump (GFF filter) / Nuclepore-Filters	Remarks
8418-5 (**23**)	15.02.	Rosette	07:57	24°21,7’	13°08,4	998	12	13 / 0	0 / 0	
8418-6 (**23**)	15.02.	BWS	09:33	24°21.7’	13°08,2	1001	5	13 / 0	1 / 0	
8419-4 (**22**)	15.02.	Rosette	17:21	24°21.2’	13°13.1	834	10	12 / 0	0 / 0	2 bottles almost empty
8421-1 (**24**)	16.02.	Rosette	10:40	24°23.6’	13°03.3	1205	11	13 / 0	0 / 0	1 bottle empty
8422-5 (**26**)	16.02.	Rosette	21:13	24°27.4’	12°43.0	1979	12	15 / 0	0 / 0	
8424-1 (**25**)	17.02.	Rosette	09:45	24°25.3’	12°55.4	1518	11	15 / 0	0 / 0	1 bottle missing...
8425-2 (**26**)	17.02.	BWS	16:52	24°28.2’	12°42.8	1998	5	14 / 0	1 / 0	
8426-5 (**33**)	18.02.	BWS	22:29	25°29.0’	13°21.1	1049	5	17 / 0	1 / 0	
8440-1 (**9**)	21.02.	Rosette	18:26	22°59.9’	13°18.8	355	11	14 / 0	0 / 0	1 bottle empty
8442-1 (**11**)	21.02.	Rosette	21:36	23°00.0’	12°57.0	596	11	13 / 0	0 / 0	1 bottle empty
8443-1 (**14**)	22.02.	Rosette	01:26	23°00.0’	12°47.0	951	12	16 / 0	0 / 0	
8444-1 (**15**)	22.02.	Rosette	03:26	23°00.0’	12°35.0	1439	12	14 / 0	0 / 0	
8445-1 (**16**)	22.02.	Rosette	05:57	23°00.0’	12°19.8	2085	12	14 / 0	0 / 0	
8446-1 (**17**)	22.02.	Rosette	09:20	23°00.0’	12°00.0	2724	12	14 / 0	0 / 0	
8448-4 (**32**)	23.02.	Rosette	09:17	25°28.4’	13°26.9	806	11	12 / 0	0 / 0	1 bottle empty
8456-2 (**31**)	24.02.	Rosette	19:12	25°28.5’	13°32.3	630	12	16 / 0	0 / 0	
8457-1 (**29**)	24.02.	BWS	22:40	25°25.8’	13°41.1	390	5	12 / 0	1 / 0	
8457-2 (**29**)	25.02.	Rosette	01:07	25°25.8’	13°41.1	390	12	15 / 0	0 / 0	
8458-1 (**30**)	25.02.	Rosette	02:42	25°28.6’	13°36.6	500	12	14 / 0	0 / 0	
8458-2 (**30**)	25.02.	BWS	03:52	25°28.5’	13°36.6	500	5	13 / 0	1 / 0	
8459-1 (**32**)	25.02.	BWS	09:30	25°28.5’	13°27.0	801	5	14 / 0	1 / 0	
8462-1 (**36**)	27.02.	BWS	05:33	25°32.1’	12°56.4	2280	5	7 / 0	1 / 0	

Table 4.2.4: (continued) CTD and BWS stations (M57-2) (Station numbers in brackets correspond to Fig. 3.1)

GeoB No.	Date 2003	Sampling Device	Time of Employment (UTC)	Location Latitude (S)	Location Longitude (E)	Water Depth [m]	Number of Water samples	Number of GFF-Filters / Nuclepore-Filters	In Situ Pump (GFF filter) / Nuclepore-Filters	Remarks
8462-3 (**36**)	27.02.	Rosette	10:35	25°31.9’	12°56.1	2290	12	14 / 0	0 / 0	
8463-1 (**34**)	27.02.	Rosette	16:34	25°36.7’	13°16.9	1328	0	0 / 3	0 / 0	Thorium-Analysis
8463-3 (**34**)	27.02.	BWS	19:05	25°36.4’	13°16.5	1341	0	0 / 5	0 / 1	Thorium-Analysis
8464-1 (**38**)	28.02.	Rosette	07:45	26°20.2’	13°41.9	430	12	14 / 0	0 / 0	
8465-1 (**40**)	28.02.	Rosette	15:54	26°45.2’	13°25.6	1350	12	14 / 0	0 / 0	
8466-3 (**39**)	28.02.	Rosette	20:55	26°43.7’	13°34.3	940	11	11 / 0	0 / 0	
8467-1 (**40**)	01.03.	Rosette	08:22	26°44.8’	13°25.3	1353	0	0 / 3	0 / 0	Thorium-Analysis
8467-2 (**40**)	01.03.	BWS	10:37	26°44.8’	13°25.4	1356	0	0 / 5	0 / 1	Thorium-Analysis
8489-1 (**35**)	05.03.	Rosette	07:47	25°30.4’	13°10.8	1510	12	16 / 0	0 / 0	
8489-2 (**35**)	05.03.	BWS	10:01	25°30.4’	13°10.9	1522	5	13 / 0	1 / 0	
8490-1 (**33**)	05.03.	BWS	14:53	25°28.9’	13°21.5	1030	5	17 / 0	1 / 0	
8490-2 (**33**)	05.03.	Rosette	18:17	25°28.9’	13°21.4	1030	12	15 / 0	0 / 0	
8491-1 (**31**)	05.03.	Rosette	20:28	25°28.4’	13°33.2	598	12	15 / 0	0 / 0	
8491-2 (**31**)	05.03.	BWS	21:41	25°28.5’	13°33.2	598	5	15 / 0	1 / 0	
8495-1 (**23**)	06.03.	BWS	14:19	24°21.9’	13°08.2	1008	5	8 / 0	1 / 0	
8496-1 (**24**)	06.03.	BWS	20:05	24°23.5’	13°03.3	1195	5	10 / 0	1 / 0	
8497-1 (**25**)	07.03.	BWS	00:12	24°25.3’	12°55.4	1518	5	10 / 0	1 / 0	
84101-1 (**24**)	08.03.	BWS	11:07	24°23.7’	13°03.3	1204	0	0 / 3	0 / 0	Thorium-Analysis
84103-2 (**24**)	08.03.	Rosette	17:50	24°24.0’	13°02.5	1231	0	0 / 5	0 / 1	Thorium-Analysis
84104-1 (**15**)	09.03.	BWS	04:00	23°00.0’	12°35.0	1440	5	12 / 0	1 / 0	
84105-1 (**11**)	09.03.	BWS	09:52	23°00.1’	12°56.7	601	5	14 / 0	1 / 0	deployment aborted because of high swell

sufficient for a first overview and the localization of the nepheloid layers. It was also used to make sure that the artificially resuspended particle-cloud had disappeared before the closing of the Niskin-bottles (cf. Fig. 4.2.5). This cloud usually vanished after 5 to 15 minutes depending on the softness of the seafloor, so that the closing of the Niskin-bottles, 45 minutes after the bottom contact of the BWS, was not affected by this process.

The current-profiler was attached very close to the bottom of the BWS-frame looking upwards into the water column. It can resolve the current-speed and direction in up to 50 cells of 10 cm size, which is important to estimate the transport-velocity of the particles and to calculate the critical shear-velocity which is crucial to estimate the resuspending forces affecting the uppermost sediments. By evaluating the orientation-information from the compass and tilt-sensor of the current-profiler it will be also possible to see if the BWS really turned into the direction of the current while sampling the water. The photo-camera system made up to 30 pictures of the lowermost sampling-bottle of the BWS and the surrounding seafloor. One picture was taken per minute or every second minute from the time the BWS reached the seafloor. These photos will also help us to make sure that the resuspended particle cloud had drifted away before the closing of the bottles. With the pictures of the seafloor-structure the relative importance of macrobenthic activity can be assessed. We will also achieve visual information about the particle environment close to the bottom (e.g. existence of marine snow) and might get a rough estimate on particle-size and quantity of large aggregates. With the in situ-pump, which was equipped with 143 mm glass-fibre or polycarbonate filters, larger amounts of water (up to 250 l) were filtered in one hour of filtration time to achieve higher particle quantities for further analysis in our home laboratory. We used a funnel as aspiration mouth which was positioned 25 cm above the ground. This was approximately the height of the lowermost Niskin-bottle which makes it possible to directly compare the material on the filter with the material in the bottle. By that we make sure that the results from the lowest bottle are not falsified by inswept particles from the artificial particle-cloud after the deployment of the BWS.

We waited about 30 minutes after the bottom contact of the device before we started with the pumping. This waiting and the long filtration time made it necessary that the BWS stood on the bottom of the sea for about 1 ½ to 2 hours (cf. Fig. 4.2.5). The new dynamic positioning system and all the skill of the navigating officers of the RV Meteor were required to make sure that the BWS was not pulled away from its position during that period of time.

During this cruise the BWS was deployed 18 times to sample the benthic nepheloid layer (Tab. 4.2.4). Additionally, suspendet particulate matter (SPM) within the whole water column was filtered from the 5L-HYDROBIOS bottles at 25 deployments of the Kranzwasserschöpfer rosette (Tab. 4.2.4; cf. Section 4.2.5)

In–situ–filtration of SPM for Trace Metal Analysis

The aim of this study is to determine the concentration profiles of selected trace elements, including titanium, zirkonium and hafnium, in the SPM. The ocean chemistry of these metals is not well understood. Since Ti, Zr and Hf have relatively short residence times in the ocean, they have the potential to be used for tracing processes with short time scales and for analysing the sources of the SPM in certain oceanic regions.

Table 4.2.5: Pump stations during M57-2 (Station numbers in brackets correspond to Fig. 3.1)

GeoB 8418-1/2 (**23**); 24°21.8S, 13°08.2E; Water depth 1007m

Pump No	Filter	Depth [m]	Remark	Volume start [L]	Volume end [L]	Volume [L]	Pumping time [sec]	Pumping time [min]	Remarks logfile
9	Ncl 50 Aj	200	Not running	9804,3	9804,3	0	152	2,5	Min flow rate reached
2	GFF 5	210	o.k	7514,7	7789,5	274,8	3352	55,9	Volume reached
3	Ncl 49 Aj	400	o.k	16798,7	16980,2	181,5	3601	60,0	Time Limit
4	GFF 6	410	o.k	14960,5	15913,7	953,2	3452	57,5	Volume reached
5	Ncl 1 Aj	600	Not running	18250,4	18250,4	0	2	0,0	Pump would not start
6	GFF 7	610	o.k	21779,2	22015,7	236,5	3073	51,2	Volume reached
7	Ncl 19 Aj	900	o.k	23689,1	23729,2	40,1	3601	60,0	Time Limit
8	GFF 8	925	o.k	6387,7	6469,3	81,6	3601	60,0	Time Limit
9	Ncl 20 Aj	15	Not running	9804,4	9804,4	0	9	0,2	Low Battery*
2	GFF 1	25	o.k	7499,3	7514,9	15,6	205	3,4	Min flow rate reached
3	Ncl 19 Aj	50	o.k	16559,5	16789,7	230,2	3151	52,5	Min flow rate reached
4	GFF 2	60	o.k	14813,4	14960,6	147,2	3601	60,0	Time Limit
5	Ncl 6 Aj	90	Not running	18250,4	18250,4	0	2	0,0	Pump would not start
6	GFF 3	100	hose coupling was broken	21558,1	21779,2	221,1	3072	51,2	Volume reached
7	Ncl 5 Aj	125	o.k	23455,7	23689,1	233,4	3110	51,8	Min flow rate reached
8	GFF 4	135	o.k	6266	6387,7	121,7	3601	60,0	Time Limit

* Battries were changed before the deployment

GeoB 8425-1/2/3 (**26**); 24°28.1S, 12°42.8E; Water depth 2000m

Pump No	Filter	Depth [m]	Remark	Volume start [L]	Volume end [L]	Volume [L]	Pumping time [sec]	Pumping time [min]	Remarks logfile
2	Ncl Aj9	15	o.k	8202,7	8227	24,3	375	6,3	Min flow rate reached
3	GFF 9	25	o.k	17421,4	17433,8	12,4	202	3,4	Min flow rate reached
4	Ncl Aj40	50	o.k	15387,6	15397,8	10,2	546	9,1	Min flow rate reached
6	GFF 10	60	o.k	23071,5	23117,1	45,6	2580	43,0	Min flow rate reached
7	Ncl Aj48	100	o.k	24193,3	24392,4	199,1	3601	60,0	Time Limit

Table 4.2.5: (continued) Pump stations during M57-2 (Station numbers in brackets correspond to Fig. 3.1)

GeoB 8425-1/2/3 (**26**); 24°28.1S, 12°42.8E; Water depth 2000m

Pump No	Filter	Depth [m]	Remark	Volume start [L]	Volume end [L]	Volume [L]	Pumping time [sec]	Pumping time [min]	Remarks logfile
8	GFF 11	110	o.k	6568,8	6654,3	85,5	3601	60,0	Time Limit
2	Ncl Aj47	250	o.k	8004,2	8202,7	198,5	no data	no data	Laptop goes down
3	GFF 12	260	o.k	17143,7	17421,4	277,7	no data	no data	Laptop goes down
4	Ncl Aj28	450	o.k	15234,1	15387,6	153,5	no data	no data	Laptop goes down
6	GFF 13	460	o.k	22731,8	23071,5	339,7	no data	no data	Laptop goes down
7	Ncl Aj27	950	o.k	23914,8	24193,3	278,5	no data	no data	Laptop goes down
8	GFF 14	960	o.k	6664,5	6668,8	4,3	no data	no data	Laptop goes down
2	Ncl Aj8	1125	o.k	7703	8004,2	301,2	3601	60,0	Time Limit
3	GFF 15	1135	o.k	16913	17143,7	230,7	3141	52,4	Volume reached
4	Ncl Aj7	1800	o.k	14923,7	15234,1	310,4	3601	60,0	Time Limit
6	GFF 16	1810	o.k	22502,4	22731,8	229,4	3072	51,2	Volume reached
7	Ncl Aj21	1920	o.k	23735,3	23914,8	179,5	3601	60,0	Time Limit
8	GFF 17	1930	o.k	6469,3	6664,5	195,2	3572	59,5	Sudden pressure release

GeoB 8461-1/2/3 (**27**); 24°52.6S, 11°54.8E; Water depth 3527m

Pump No	Filter	Depth [m]	Remark	Volume start [L]	Volume end [L]	Volume [L]	Pumping time [sec]	Pumping time [min]	Remarks logfile
2	Ncl Aj13	15	o.k	8574,7	8584	9,3	122	2,0	Min flow rate reached
3	GFF 5b	25	o.k	17922,1	18072	149,9	no data	no data	laptop goes down
4	Ncl Aj18	50	o.k	15714,5	15982,8	268,3	no data	no data	laptop goes down
6	GFF 6b	60	o.k	24566,8	24814	247,2	no data	no data	laptop goes down
7	Ncl Aj17	90	o.k	24600,9	24804,9	204	no data	no data	laptop goes down
8	Ncl Aj22	125	o.k	6760,5	6822	61,5	no data	no data	laptop goes down
2	Ncl Aj29	200	o.k	8454,7	8574,7	120	2576	42,9	Min flow rate reached
3	GFF 3b	210	o.k	17668,8	17922,1	253,3	3248	54,1	Volume reached

Table 4.2.5: (continued) Pump stations during M57-2 (Station numbers in brackets correspond to Fig. 3.1)

GeoB 8461-1/2/3 (**27**); 24°52.6S, 11°54.8E; Water depth 3527m

Pump No	Filter	Depth [m]	Remark	Volume start [L]	Volume end [L]	Volume [L]	Pumping time [sec]	Pumping time [min]	Remarks logfile
4	Ncl Aj30	400	o.k	15559,4	15714,5	155,1	3601	60,0	Time Limit
6	GFF 4b	410	o.k	24327	24566,8	239,8	3073	51,2	Volume reached
7	Ncl Aj26	600	o.k	24443,7	24600,9	157,2	3601	60,0	Time Limit
8	Ncl Aj25	1000	o.k	6658	6760,5	102,5	3601	60,0	Time Limit
2	Ncl Ai19	1500	o.k	8244,4	8454,7	210,3	no data	No data	Laptop goes down
3	GFF 1b	1510	o.k	17444,9	17668,8	223,9	no data	No data	Laptop goes down
4	Ncl Ai20	2000	o.k	15434,6	15559,4	124,8	no data	No data	Laptop goes down
6	GFF 2b	2010	o.k	24113,4	24327	213,6	no data	No data	Laptop goes down
7	Ncl Aj41	3000	o.k	24308,8	24443,7	134,9	no data	No data	Laptop goes down
8	Ncl Aj32	3400	o.k	6654,4	6658	3,6	no data	No data	Laptop goes down

GeoB 8492-1 (**30**); 25°28.4S, 13°36.6E; Water depth 500m

Pump No	Filter	Depth [m]	Remark	Volume start [L]	Volume end [L]	Volume [L]	Pumping time [sec]	Pumping time [min]	Remarks logfile
2	Ncl Al31	15	Low volume	8601,7	8603	1,3	4	0,1	Low Battery*
3	Ncl Al34	50	o.k	18003,6	18182,3	178,7	1374	22,9	Min flow rate reached
4	Ncl Al30	90	o.k	15996,5	16142,1	145,6	3601	60,0	Time Limit
6	Ncl Al33	125	o.k	26104,4	26257,5	153,1	no data	No data	pump can not wake up
7	Ncl Al27	200	o.k	24804,9	25029,8	224,9	3601	60,0	Time Limit
8	Ncl Al28	400	o.k	6822	6947,9	125,9	3601	60,0	Time Limit

* Battries were changed before the deployment

Table 4.2.5: (continued) Pump stations during M57-2 (Station numbers in brackets correspond to Fig. 3.1)

GeoB 84106-1 (**8**); 23°01S, 13°29.9E; Water depth 237m

Pump No	Filter	Depth [m]	Remark	Volume start [L]	Volume end [L]	Volume [L]	Pumping time [sec]	Pumping time [min]	Remarks logfile
3	Ncl Al09	15	o.k	18354,3	18494,9	140,6	1093	18,2	Min flow rate reached
4	Ncl Al08	25	o.k	16144,6	16151,7	7,1	413	6,9	Min flow rate reached
6	Ncl Al07	50	o.k	26258,4	26369,5	111,1	no data	No data	Pump can not wake up
7	Ncl Al10	90	o.k	26206,9	26440,4	233,5	3601	60,0	Time Limit
8	Ncl Al03	125	o.k	6960,9	7073,9	113	3601	60,0	Time Limit
2	Ncl Al04	150	o.k	8603,4	8887,9	284,5	3601	60,0	Time Limit

The probably most important way of the input for these elements is dry and wet deposition from the atmosphere to the ocean surface. Other ways are input by rivers or from the shelf. Scavenging has a strong influence on the distribution of Ti, Zr and Hf in the water column.

Sampling during this cruise was also designed to get information about the seasonal variability, because the same area was already sampled before in the southern spring during a former cruise (M48-4). Furthermore it was intended to determine the percentage of POC in the particles which will be compared with the amount of the particulate Ti, Zr and Hf, that is in excess over their occurrence in the earth crust. To study the fate of Ti, Zr and Hf, samples from top sedimentary layers were taken whose particle composition will be compared with the respective composition in the water column.

Samples were taken at five stations on a transect from the deep sea (3500m) to the shelf (200m). The whole water column was sampled with a focus in the top kilometer of the water column. Seasonal variability was studied by re-occupation of two locations from the former cruise M48/4 (#84106 and #8461, cf. Tab. 4.2.5). After a predetermined pumping time of one hour normally, the in-situ pumps stopped automatically either due to minimal flow rate or because the final volume of 300L was reached.

The further work-up of the sample filters will take place in the labs in Bremen, where the filters will be subjected to a total dissolution procedure. The element concentrations will be analyzed by ICP-MS. Particles on selected filter will be further examined with REM.

4.2.5 CTD-Probe and Water Sampling

(V. Mohrholz, T. Heene)

All 42 stations were occupied using a CTD SBE 911+ with SBE 43 oxygen sensors, 2-channel HAARDT fluorometer, DATASONICS PSA-900 altimeter with a 300 m range for bottom finding together with a HYDROBIOS 12 bottle Kranzwasserschöpfer rosette equipped with 5- litre free flow water sample bottles of HYDROBIOS. Attached to the CTD frame was LADCP consisting of coupled upward and downward looking Workhorse ADCP 300kHz in a 3000dbar pressure case. A special attachment of the CTD-probe to the sea-cable was implemented to minimize the tilt during deployment. The package was weighted by a lead weight in order to avoid looping during lowering. The station list is given in Table 4.2.6.

The wire was a 11 mm single conductor steel cable of the W2 winch. After 3 minutes adjustment of the CTD in a depth of 5 to 10 m it was lowered with 0.5 m/s in the upper 200 m and 1 m/s below this depth. The cast went down from the surface to near the bottom. Bottles were closed automatically on the downward cast, except for the bottom bottle, which was closed by hand at the maximum depth of the cast. During the CTD cast the ship was held on position.

After the cast the rosette was placed on the deck without shelter and secured. Subsequently, water samples were drawn from the water bottles for oxygen, nutrient and salinity analysis. The rosette remained on deck between stations.

The CTD data were passed from the SBE Deck Unit Model 911+ to the CTD client, where data are stored with 24 scans per second. It also permits an on line data visualisation. Over a

local net the actual GPS position, UTC date and time, echo sounding depth and station number have been provided and were added automatically to the CTD header data. The raw data have been processed using Seabird post processing routines (CTD DATA ACQUISITION SOFTWARE, SEASOFT version 4.323, SEA-BIRD ELECTRONICS, INC.).

855 water samples taken on all CTD stations were analysed for oxygen, phosphate, nitrate+nitrite, and silicate. The sampling depths depends on depth and stratification of the water column. Also, at selected stations and depths salinity of water samples was measured by Autosal for intercomparison with the CTD.

Additionally measurements throughout the cruise consisted of temperature and salinity measurements performed continuously in the surface layer by the thermosalinograph of the research vessel. The current profile in the upper 700 m of the ocean was measured by the vessel mounted 75 kHz Ocean Suveyor ADCP manufactured by RDI. In support to the ADCP measurement heading of the ship was measured by ADU II manufactured by Ashtech Inc. and a fiber optical gyro manufactured by C. Plath GmbH and provided information superior to that of the ship's gyro.

The properties of the shelf circulation were detected by the launch of two WOCE type surface drifter. They were released in the coastal branch of the Benguela, one at the 200m isobath and another at the 100m isobath at 25°S.

4.2.6 Water Sampling for Stable Isotopes and Nutrient Analysis

(S. Mulitza, A. Paul)

In paleoceanography, the stable isotopes ^{18}O in seawater and ^{13}C in particulate organic matter play a role similar to temperature and salinity in that they are used to characterize different water masses. Here we want to know whether or not the stable isotopes reflect the variability on a weekly timescale as seen in the classic hydrographic analysis. In particular, if the isotope ratios $\delta^{18}O$ and $\delta^{13}C$ vary in response to the onset and decay of upwelling and changes in the relative abundance of SACW and ESACW, there is hope that the upwelling conditions leave an imprint on the sedimentary record and can be reconstructed from $\delta^{18}O$ and $\delta^{13}C$ in fossil foraminiferal shells.

In order to relate the physical and biological properties of the water column to the sedimentary record, a total of 1604 water samples for stable oxygen and carbon analyses were taken at 86 hydrographic stations (Tab. 4.2.6). Immediately after recovery of the water sampler, two brown 30 ml glass bottles were filled with sea water. Depending on the water depth, four to twelve depth levels were sampled on each station. To prevent bacterial activity, one sample from each free-flow bottle (for ^{13}C analysis) was poisoned with saturated $HgCl_2$ solution. All samples were closed airtight with melted paraffin and stored at 4°C.

At all 86 hydrographic stations, 20 ml of sea water from each free-flow bottle was filled into a scintillation cup for nutrient analyses. For later shore-based silicate and phosphate measurements the remaining water samples were frozen.

Table 4.2.6: Sampling for stable isotopes and nutrients
(Station numbers in brackets correspond to Fig. 3.1)

GeoB No.	Internal IOW No.	Latitude (S)	Longitude (E)	Date 2003, Time (UTC)	Water depth [m]	CTD Mission	Total No. of Bottles	Bottle not sampled	IOW Sample IDs
8401-2 (**5**)	WW23020	22°58.6'	14° 03.1'	11.02., 17:49	130	1	6		0014-0019
8404-1 (**1**)	WW23002	22° 59.9'	14° 22.0'	13.02., 09:23	44	2	4		0026-0029
8405-1 (**2**)	WW23005	23° 00.1'	14° 19.0'	13.02., 10:21	74	3	6		0038-0043
8406-1 (**3**)	WW23010	23° 00.0'	14° 13.0'	13.02., 11:22	110	4	8		0050-0057
8407-1 (**4**)	WW23020	23° 00.0'	14° 03.0'	13.02., 12:44	131	5	8		0062-0069
8408-1 (**6**)	WW23030	23° 00.0'	13° 52.0'	13.02., 14:07	145	6	8		0074-0081
8409-1 (**7**)	WW23040	23° 00.0'	13° 41.1'	13.02., 15:32	152	7	8		0086-0093
8410-1 (**8**)	WW23050	23° 00.0'	13° 30.1'	13.02., 16:58	237	8	9		0098-0106
8411-1 (**9**)	WW23060	23° 00.0'	13° 19.0'	13.02., 18:25	357	9	11	11	0110-0120
8412-1 (**10**)	WW23070	22° 59.9'	13° 09.0'	13.02., 20:00	318	10	11		0122-0132
8413-1 (**11**)	WW23080	22° 59.9'	12° 56.9'	13.02., 21:40	597	11	11		0134-0144
8414-1 (**14**)	WW23090	23° 00.0'	12° 47.0'	13.02., 23:19	946	12	12		0146-0157
8415-1 (**15**)	WW23100	23° 00.0'	12° 35.0'	14.02., 01:21	1435	13	12		0158-0169
8416-1 (**16**)	WW23110	23° 00.0'	12° 20.0'	14.02., 03:45	2075	14	12	12	0170-0181
8417-1 (**17**)	WW23120	22° 59.9'	12° 00.0'	14.02., 06:58	2723	15	12		0182-0193
8418-5 (**23**)		24° 21.8'	13° 08.3'	15.02., 07:34	999	16	12		0194-0205
8419-4 (**22**)		24° 21.3'	13° 13.1'	15.02., 16:50	832	17	12		0206-0214, 0218-0220
8420-1 (**21**)		24° 15.1'	13° 36.7'	16.02., 06:01	315	18	12		0230-0242
8421-1 (**24**)		24° 23.6'	13° 03.3'	16.02., 10:14	1204	19	11		0254-0265
8422-5 (**26**)		24° 27.4'	12° 43.0'	16.02., 20:35	1980	20	12		0266-0277
8424-1 (**25**)		24° 25.3'	12° 55.4'	17.02., 09:14	1520	21	12	12	0278-0289
8428-1 (**28**)		25° 28.1'	13° 43.3'	19.02., 19:52	360	22	11		0290-0300
8430-1 (**34**)		25° 36.6'	13° 16.7'	20.02., 13:04	1322	23	12		0302-0313
8431-1 (**42**)		24° 11.9'	13° 54.1'	21.02., 00:47	257	24	9		0326-0334
8432-1 (**20**)		24° 08.0'	14° 10.0'	21.02., 02:40	136	25	8		0350-0357
8433-1 (**1**)	WW23002	23° 00.0'	14° 22.0'	21.02., 09:22	43	26	4		0374-0377
8434-1 (**2**)	WW23005	23° 00.1'	14° 19.0'	21.02., 10:09	73	27	6		0386-0391
8435-1 (**3**)	WW23010	23° 00.0'	14° 13.0'	21.02., 11:03	109	28	8		0398-0405
8436-1 (**4**)	WW23020	23° 00.0'	14° 03.0'	21.02., 12:18	134	29	8		0422-0429
8437-1 (**6**)	WW23030	23° 00.0'	13° 52.0'	21.02., 13:38	144	30	8		0434-0441
8438-1 (**7**)	WW23040	23° 00.0'	13° 40.9'	21.02., 15:03	152	31	8		0458-0465
8439-1 (**8**)	WW23050	23° 00.0'	13° 29.9'	21.02., 16:30	241	32	9		0482-0490
8440-1 (**9**)	WW23060	23° 00.0'	13° 19.0'	21.02., 18:06	360	33	11		0530-0540
8441-1 (**10**)	WW23070	22° 59.9'	13° 09.0'	21.02., 19:38	318	34	11		0554-0566
8442-1 (**11**)	WW23080	23° 00.0'	12° 57.0'	21.02., 21:15	594	35	11		0590-0600
8443-1 (**14**)	WW23090	23° 00.0'	12° 47.0'	22.02., 00:52	950	36	12		0602-0613
8444-1 (**15**)	WW23100	23° 00.1'	12° 35.1'	22.02., 02:55	1437	37	12		0614-0625
8445-1 (**16**)	WW23110	23° 00.0'	12° 19.8'	22.02., 05:17	2090	38	12		0626-0637
8446-1 (**17**)	WW23120	23° 00.0'	12° 00.0'	22.02., 08:30	2724	39	12		0638-0649
8448-4 (**32**)		25° 28.4'	13° 26.9'	23.02., 08:54	805	40	12	*	0650-0661
8456-2 (**31**)		25° 28.5'	13° 32.3'	24.02., 18:54	629	43	12		0746-0757
8457-2 (**29**)		25° 25.8'	13° 41.1'	25.02., 00:52	390	44	12		0766, 0758-0765,0767,0769,0768

Table 4.2.6: (continued) Sampling for stable isotopes and nutrients
(Station numbers in brackets correspond to Fig. 3.1)

GeoB No.	Inte (**xx**)rnal IOW No.	Latitude (S)	Longitude (E)	Date 2003, Time (UTC)	Water depth [m]	CTD Mission	Total No. of Bottles	Bottle not sampled	IOW Sample IDs
8458-1 (**30**)		25° 28.6'	13° 36.6'	25.02., 02:25	500	45	12		0770-0781
8462-3 (**36**)		25° 31.9'	12° 56.2'	27.02., 09:36	2286	46	12		0794-0805
8463-1 (**34**)		25° 36.7'	13° 16.9'	27.02., 16:00	1329	47	12	**	0826-0821
8464-1 (**38**)		26° 20.2'	13° 41.9'	28.02., 07:32	430	48	12		0842-0854
8465-1 (**40**)		26° 45.2'	13° 25.9'	28.02., 15:23	1341	49	12		0878-0890
8466-3 (**39**)		26° 43.7'	13° 34.3'	28.02., 20:37	942	50	12		0890-0901
8467-1 (**40**)		26° 44.9'	13° 25.3'	01.03., 07:52	1359	51	12	**	0914-0925
8469-4 (**41**)		26° 45.6'	13° 22.8'	01.03., 18:17	1479	52	12		0962-0973
8470-2 (**37**)		25° 32.8'	12° 51.7'	02.03., 05:05	2470	53	12		0974-0985
8472-1 (**1**)	WW23002	22° 59.9'	14° 21.9'	03.03., 02:15	45	54	4		0986-0989
8473-1 (**2**)	WW23005	23° 00.0'	14° 18.8'	03.03., 02:49	76	55	6		0998-1003
8474-1 (**3**)	WW23010	23° 00.0'	14° 12.9'	03.03., 03:35	109	56	8		1010-1017
8475-1 (**4**)	WW23020	23° 00.0'	14° 03.0'	03.03., 04:42	133	57	8		1022-1229
8476-1 (**6**)	WW23030	23° 00.0'	13° 51.9'	03.03., 05:50	145	58	7		1034-1040
8477-1 (**7**)	WW23040	23° 00.0'	13° 40.9'	03.03., 07:11	150	59	8		1046-1053
8478-1 (**8**)	WW23050	23° 00.0'	13° 29.9'	03.03., 08:30	238	60	9		1058-1066
8479-1 (**9**)	WW23060	22° 59.9'	13° 18.9'	03.03., 09:56	358	61	11		1070-1080
8480-1 (**10**)	WW23070	23° 00.0'	13° 08.9'	03.03., 11:22	318	62	11		1082-1092
8481-1 (**11**)	WW23080	23° 00.0'	12° 56.9'	03.03., 12:54	597	63	11		1094-1104
8484-4 (**14**)	WW23090	23° 00.0'	12° 46.9'	03.03., 21:14	951	64	12		1106-1117
8485-1 (**15**)	WW23100	23° 00.0'	12° 34.9'	03.03., 23:07	1444	65	12		1118-1129
8486-1 (**16**)	WW23110	23° 00.0'	12° 20.0'	04.03., 01:31	2076	66	12		1142-1153
8487-1 (**17**)	WW23120	23° 00.0'	12° 00.0'	04.03., 04:32	2719	67	12		1166-1177
8489-1 (**35**)		25° 30.3'	13° 10.8'	05.03., 07:12	1510	68	12		1178-1189
8490-2 (**33**)		25° 28.9'	13° 21.5'	05.03., 17:51	1030	69	12		1190-1201
8491-1 (**31**)		25° 28.5'	13° 33.2'	05.03., 20:09	598	70	12		1202-1213
84103-1 (**24**)		24° 23.9'	13° 02.6'	08.03., 17:22	1231	71	12	**	1214-1225
84107-1 (**1**)	WW23002	23° 00.1'	14° 22.0'	09.03., 21:30	43	72	4		1226-1229
84108-1 (**2**)	WW23005	23° 00.0'	14° 19.0'	09.03., 22:08	72	73	6		1238-1243
84109-1 (**3**)	WW23010	23° 00.0'	14° 13.0'	09.03., 23:00	110	74	8		1262-1269
84110-1 (**4**)	WW23020	23° 00.0'	14° 03.0'	10.03., 00:20	133	75	7	8	1286-1292
84111-1 (**6**)	WW23030	23° 00.0'	13° 52.0'	10.03., 01:38	145	76	8		1298-1305
84112-1 (**7**)	WW23040	23° 00.0'	13° 41.0'	10.03., 02:53	153	77	8		1310-1317
84113-1 (**8**)	WW23050	23° 00.0'	13° 30.0'	10.03., 04:08	237	78	9		1322-1330
84114-1 (**9**)	WW23060	23° 00.0'	13° 18.9'	10.03., 05:27	358	79	11		1334-1344
84115-1 (**10**)	WW23070	22° 59.9'	13° 08.9'	10.03., 06:51	318	80	11		1346-1356
84116-1 (**11**)	WW23080	22° 59.9'	12° 56.9'	10.03., 08:26	600	81	11		1358-1368
84117-1 (**14**)	WW23090	23° 00.0'	12° 47.0'	10.03., 10:00	947	82	12		1370-1381
84118-1 (**15**)	WW23100	23° 00.0'	12° 34.9'	10.03., 11:49	1442	83	12		1382-1393
84119-1 (**16**)	WW23110	23° 00.0'	12° 19.9'	10.03., 14:10	2089	84	11	12	1394-1405
84120-1 (**17**)	WW23120	23° 00.0'	12° 00.0'	10.03., 17:29	2723	85	12		1406-1417
84121-1 (**18**)	WW23160	23° 00.0'	11° 30.0'	10.03., 22:00	3267	86	11		1418-1428

*No CTD values for bottles no. 1 and 2

**Only sampled for Thorium

4.2.7 Sampling of Living Planktonic Foraminifera and Dinoflagellates

(U. Holzwarth, S. Mulitza)

Nine samples were taken from the ships membrane pump (Tab. 4.2.8). Depending on the plankton concentration of the seawater the samples were concentrated to 1l using a filtering system with 100µm and 10µm gauze filters. The water capacity which run through the filters was measured with a water volume counter. The samples were further concentrated to about 25ml with a vacuum-pump using a 5µm polycarbonate filter. After that the samples were stored in 25 ml sterile glass bottles together with the filter, not fixed, in order to get living material. Then they will be transported to the university of Bremen for experimentation.

On 15 stations a 20µm mesh size plankton hand net was used for about 3 minutes (Tab. 4.2.9). Samples were taken from the upper 10m of the water column, fixed with about 8.8ml formaldehyde (37%) and stored in dark 125 ml HDPE NALGENE flasks at + 4°C.

Planktonic foraminifera were collected using a 150 µm-mesh size plankton net (HYDRO-BIOS) on 10 transects (Tab. 4.2.7). Sea-surface water (3.5 m water depth) was constantly pumped for several hours with the help of the vessel's "fire extinguishing pump". Samples were filtered and then dried in an oven at 50°C and then stored in Petri-dishes. Salinity and temperature were measured continuously with the onboard CTD (Tab. 4.2.7). The existing data set - accomplished with the results from this cruise – will be used to calibrate the $\delta^{18}O$ composition of shallow-dwelling planktic foraminifers from surface waters against the present-day surface water hydrography.

Table 4.2.7: Pumping transects for planktonic foraminifera

No.	Date 2003	START					STOP				
		Time (UTC)	Latitude (S)	Longitude (E)	SST [°C]	SSS [‰]	Time (UTC)	Latitude (S)	Longitude (E)	SST [°C]	SSS [‰]
1	04.03.	07:10	23°06.99	12°03.45	21.5	35.3	10:30	23°35.36	12°17.22	20.5	35.2
2	04.03.	14:48	24°07.86	12°33.19	21.3	35.2	-	24°46.28	12°52.03	18.5	35.2
3	05.03.	-	25°33.09	13°13.57	16.7	35.1	09:09	25°30.42	13°10.86	16.9	35.1
4	05.03.	09:10	25°30.42	13°10.86	17.7	35.1	12:03	25°30.42	13°10.86	17.0	35.1
5	05.03.	12:03	25°30.42	13°10.86	17.0	35.1	17:09	25°28.90	13°21.47	16.9	35.1
6	06.03.	07:16	25°28.57	13°32.88	17.5	35.2	11:42	24°41.73	13°15.64	17.8	35.1
7	06.03.	11:42	24°41.73	13°15.65	17.8	35.2	13:45	24°21.92	13°08.19	18.4	35.1
8	06.03.	13:46	24°21.92	13°08.19	18.4	35.1	16:57	24°22.08	13°08.14	18.4	35.1
9	07.03.	06:34	23°39.92	12°44.52	19.5	35.1	13:37	22°59.89	12°22.27	19.9	35.3
10	08.03.	06:13	23°54.98	12°41.59	19.2	35.1	13:12	24°23.70	13°33.30	17.7	35.2

Table 4.2.8: Surface water sampling (membrane pump) for dinoflagellate analysis

Sample No.	Date 2003	START Time (UTC)	Latitude (S)	Longitude (E)	Water depth [m]	Salinity [‰]	STOP Time (UTC)	Latitude (S)	Longitude (E)	Water temp. [°C]	Salinity [‰]	Volume filtered [L]
3/7/a	07.03.	5:30	23°50,98	12°47,61	19,6	35,04	8:30	23°16,31	12°38,88	20,9	35,23	183
3/7/b	07.03.	9:07	23°12,34	12°37,93	20,8	35,26	10:27	23°00,01	12°34,91	20,7	35,24	15
3/8/a	08.03.	6:20	23°56,09	12°42,42	20,0	35,16	9:55	24°22,37	13°30.55	18,5	35,16	15
3/9/a	09.03.	5:35	22°59,96	12°34,97	20,9	35,27	8:50	23°00,00	12°56,96	18,8	35,26	172
3/9/b	09.03.	11:25	23°00,38	12°56,60	19,5	35,19	15:00	23°00,06	13°30,05	21,1	35,21	122
3/10/c	10.03.	13:00	23°00,01	12°34,92	20,9	35,28	14:15	23°00,08	12°19,87	20,7	35,27	81
3/11/a	11.03.	6:10	22°56,50	12°39,58	18,9	35,23	9:15	22°54,82	13°16,68	17,4	35,27	59
3/11/b	11.03.	9:30	22°54,50	13°18,78	17,4	35,27	12:30	22°52,14	13°59,15	17,9	35,27	11
3/11/c	11.03.	13:00	22°51,92	14°04,07			16:00*	22°50,90	14°27,60	20,8	35,27	21

* membrane pump was only working until 14:15

Table 4.2.9: Plankton handnet samples from 0-10 m depth for dinoflagellate analysis (Station numbers in brackets correspond to Fig. 3.1)

GeoB Station	Date 2003	Time	Geographic position		Water depth	Water Temp.	Salinity	Air Temp.	Drainage time
		(UTC)	Latitude (S)	Longitude (E)	[m]	[°C]	[‰]	[°C]	[min]
8418-4 (**23**)	15.2.	7:16	24°24.91	13°08.23	1007	18.7	35.13	18.8	60
8419-3 (**22**)	15.2.	16:35	24°21.26	13°13.14	832			21.7	90
8420-2 (**21**)	16.2.	6:24	23°15.20	13°36.80	317	18.1	35.13	17.1	5
8421-2 (**24**)	16.2.	11:06	24°23.56	13°30.28	1205	20.1	35.14	19.4	60
8422-4 (**26**)	16.2.	20:21	24°27.50	13°43.06	1988	21.0	35.12	20.0	10
8424-2 (**25**)	17.2.	10:17	24°25.38	13°55.46	1518	19.9	35.08	20.0	90
8426-4 (**33**)	18.2.	21:27	25°28.93	13°21.11	1048	19.3	35.19	20.2	10
8447-2 (**34**)	23.2.	4:59	25°35.83	13°16.52	1336	19.4	35.21	19.0	10
8448-3 (**32**)	23.2.	8:44	25°28.50	13°26.96	806	19.1	35.15	18.7	10
8450-2 (**30**)	23.2.	18:15	25°28.51	13°36.56	504	17.4	35.09	19.9	15
8462-5 (**36**)	27.2.	12:45	25°31.97	12°56.19	2290	21.5	35.22	21.4	5
8464-3 (**38**)	28.2.	8:30	26°20.21	13°41.94	430	21.2	35.28	20.8	30
8465-3 (**40**)	28.2.	17:30	26°45.18	13°25.04	1378	21.8	35.36	21.5	20
8469-3 (**41**)	1.3.	17:45	26°45.55	13°22.82	1482	22.1	35.53	21.1	20 *
8470-3 (**37**)	2.3.	6:40	25°32.78	12°51.68	2469	20.4	35.23	20.1	5

net was only at the surface, the current was too strong

4.2.8 Sampling for Suspended Organic Matter and Sr/Ca

(S. Mulitza, S. Rathmann)

At each location 30-1000 l of surface water were sampled with the vessel's membrane pump for the shorebased analyses of alkenones and Sr/Ca ratios (Tab. 4.2.10 and 4.2.11). For Alkenones, the water was passed through glass fibre filters (GMF 5, Sartorius AG) to obtain the suspended particulate matter.

To obtain samples for Sr/Ca analyses, the water was passed through a 22µm gauze and afterwards through polycarbonate filters. The pumping was done with a commercial GARDENA garden pump. After filtering, all samples were stored in Petri dishes at 4°C.

4.2.9 Sampling for Chlorophyll Analysis

(S. Mulitza, S. Rathmann)

For the determination of chlorophyll-a concentrations in surface waters, two samples (0.5 l) of sea water were collected at the positions listed in Table 4.2.12. The water was taken from the ship´s membrane pump (inlet at 3.5 m water depth) and filtered onto glass fibre filters (Whatmann GF/F, ∅ 2.5 cm). The filters were stored in Greiner tubes, wrapped in aluminum foil and frozen at –20 °C. Photometric chlorophyll-a measurements will later be performed at the University of Bremen. They should provide information about regional biomass variations and will be used to calibrate satellite derived chlorophyll data as well.

Table 4.2.10: Locations of samples for alkenone analysis

No.	Date 2003	Start [UTC]	Latitude (S) START	Longitude (E) START	SST [°C]	SSS [‰]	Water-clock START	Stop [UTC]	Latitude (S) STOP	Longitude (E) STOP	SST [°C]	SSS [‰]	Water-clock STOP	Comments
1	11.02.	15:12	22°58.44	14°03.06	18.9	35.1	2.148	16:05	22°58.42	14°03.12	19.5	35.1	2.279	Station GeoB 8401
2	12.02.	06:08	24°12.92	13°44.20	17.4	35.1	2.316	07:04	24°14.62	13°37.53	17.2	35.1	2.476	
3	13.02.	07:25	22°52.04	14°29.27	23.0	35.1	2.494	08:25	22°55.04	14°20.22	23.1	35.3	2.531	
4	14.02.	06:15	22°59.96	12°06.30	20.2	35.2	2.566	07:13	23°00.02	11°59.98	20.5	35.3	2.739	
5	15.02.	06:25	24°21.87	13°08.33	17.9	35.1	2.783	07:25	24°21.86	13°08.35	18.0	35.1	2.842	Station GeoB 8418
6	16.02.	06:13	24°14.97	13°36.63	17.3	35.1	2.858	07:19	24°15.42	13°34.00	17.3	35.2	3.011	Station GeoB 8420
7	17.02.	06:59	24°22.40	13°07.56	19.0	35.1	3.052	08:00	24°25.07	12°56.55	19.5	35.1	3.116	
8	18.02.	06:24	24°27.22	12°42.62	20.1	35.1	3.410	07:15	24°27.63	12°42.23	20.1	35.1	3.579	drain blocked
9	19.02.	07:28	24°50.03	13°03.68	18.4	35.1	3.709	08:24	24°42.53	12°56.46	19.1	35.1	3.903	
10	20.02.	06:59	25°19.54	13°57.20	16.1	35.1	3.977	08:14	25°26.31	13°46.68	16.5	35.1	4.117	
11	21.02.	07:04	23°23.00	14°17.98	14.7	35.3	4.200	07:59	23°12.62	14°19.80	14.7	35.3	4.310	
12	22.02.	07:45	22°59.95	12°07.40	20.6	35.2	4.439	08:48	23°00.01	12°00.04	20.8	35.2	4.711	
13	23.02.	09:04	25°28.47	13°26.96	18.4	35.2	4.739	11:04	25°28.52	13°33.20	17.4	35.1	4.944	
14	24.02.	07:36	25°26.16	13°40.38	17.1	35.0	4.969	08:56	25°28.33	13°36.47	17.8	35.2	5.114	
15	25.02.	06:00	25°28.50	13°36.59	17.2	34.9	5.600	07:54	25°28.52	13°29.13	17.3	34.9	5.762	
16	26.02.	07:22	24°52.51	11°54.82	20.7	35.2	5.882	08:23	24°52.44	11°54.83	20.8	35.2	6.067	
17	27.02.	07:09	25°32.05	12°56.41	20.5	35.3	6.082	08:18	25°31.98	12°56.35	20.5	35.3	6.295	
18	28.02.	06:28	26°15.79	13°35.05	20.3	35.2	6.326	07:28	26°20.26	13°41.90	20.4	35.3	6.549	
19	01.03.	06:30	26°46.73	13°17.63	21.7	35.5	6.554	07:57	26°45.12	13°24.75	21.0	35.5	6.794	
20	02.03.	07:49	25°32.79	12°51.67	19.7	35.2	6.820	08:52	25°32.96	12°57.42	19.1	35.2	7.007	
21	03.03.	06:53	22°59.94	13°43.26	16.8	35.2	7.017	08:52	23°00.05	13°29.97	17.1	35.2	7.166	
22	04.03.	07:18	23°08.48	12°04.12	20.7	35.3	7.290	10:12	23°32.71	12°15.88	20.3	35.2	7.666	
23	05.03.	06:52	25°30.85	13°11.67	16.7	35.1	7.700	07:45	25°30.43	13°10.85	16.8	35.1	7.757	
24	06.03.	07:03	25°28.47	13°33.26	17.5	35.2	7.788	08:20	25°17.34	13°28.96	16.3	35.2	7.987	
25	07.03.	08:40	23°17.09	12°39.06	20.2	35.2	8.022	10:07	23°01.59	12°35.16	20.1	35.3	8.320	
26	08.03.	07:06	24°00.88	12°46.11	18.6	35.1	8.321	10:23	24°23.63	13°03.23	17.6	35.2	8.506	
27	09.03.	04:39	22°59.95	12°34.99	.20.2	35.3	8.551.	05:27	22°59.97	12°34.99	20.1	35.3	8.718	

Table 4.2.11: Locations of samples for Sr/Ca analysis

No.	Date 2003	Start [UTC]	Latitude (S) START	Longitude (E) START	SST [°C]	SSS [‰]	Water-clock START	Stop [UTC]	Latitude (S) STOP	Longitude (E) STOP	SST [°C]	SSS [‰]	Water-clock STOP	Comments
1	11.02.	16:25	22°58.42	14°03.12	18.7	35.1	2.279	16:57	22°59.30	14°02.64	20.2	35.2	2.283	Station GeoB 8401
2	12.02.	07:25	24°15.02	13°36.69	17.2	35.1	2.476	08:04	24°15.10	13°36.71	17.2	35.1	2.479	
3	13.02.	08:33	22°56.68	14°20.44	22.9	35.2	2.531	09:15	22°59.98	14°22.01	22.5	35.3	2.552	
4	14.02.	07:18	23°00.01	11°59.99	20.5	35.3	2.739	08:19	23°00.01	11°59.18	20.5	35.3	2.768	
5	15.02.	07:29	24°21.84	13°08.36	18.0	35.1	2.842	08:26	24°21.73	13°08.35	18.1	35.1	2.851	Station GeoB 8418
6	16.02.	07:27	24°15.88	13°32.53	17.5	35.2	3.011	08:31	24°19.05	13°20.91	18.3	35.1	3.029	Station GeoB 8420
7	17.02.	06:15	24°21.32	13°08.16	19.0	35.1	3.050	06:56	24°22.17	13°07.75	19.0	35.1	3.052	no gauze
8	18.02.	08:39	24°27.54	12°41.92	19.9	35.1	3.579	10:06	24°27.24	12°41.48	20.1	35.1	3.592	
9	19.02.	06:24	24°59.09	13°12.34	18.4	35.1	3.701	07:24	24°50.52	13°04.16	18.3	35.1	3.709	
10	20.02.	06:15	25°16.49	14°01.74	16.2	35.1	3.975	06:55	25°19.14	13°57.76	16.1	35.1	3.977	
11	21.02.	06:33	23°28.67	14°16.98	15.4	35.3	4.199	07:00	23°23.58	14°17.86	14.7	35.3	4.200	
12	22.02.	06:48	23°00.40	12°19.00	20.1	35.2	4.410	07:42	22°59.94	12°08.06	20.5	35.2	4.439	
13	23.02.	11:11	25°28.52	13°33.20	18.2	35.1	4.944	13:46	25°28.54	13°33.20	18.0	35.1	4.946	
14	24.02.	06:12	25°25.79	13°41.21	16.5	35.2	4.963	07:33	25°25.83	13°40.85	17.2	35.1	4.969	
15	25.02.	07:57	25°28.51	13°28.78	17.4	34.9	5.762	08:57	25°28.51	13°27.10	18.4	35.0	5.772	
16	26.02.	06:15	24°52.61	11°54.75	20.9	35.2	5.879	07:18	24°52.50	11°54.83	20.7	35.1	5.882	
17	27.02.	06:05	25°32.06	12°56.41	20.5	35.3	6.072	07:05	25°32.04	12°56.41	20.5	35.3	6.082	
18	28.02.	05:26	26°13.99	13°42.60	19.5	35.2	6.312	06:25	26°15.68	13°34.79	20.3	35.2	6.326	
19	01.03.	05:23	26°38.87	13°17.35	21.6	35.5	6.553	06:27	26°46.70	13°17.31	21.7	35.5	6.554	
20	02.03.	06:47	25°32.74	12°51.70	19.6	35.2	6.802	07:46	25°32.78	12°51.67	19.6	35.2	6.820	
21	03.03.	08:53	23°00.11	13°29.95	17.1	35.2	7.166	09:18	22°59.97	13°25.01	17.3	35.2	7.166	
22	04.03.	06:15	23°00.04	12°00.10	20.9	35.2	7.288	07:14	23°07.88	12°03.85	20.8	35.3	7.290	
23	05.03.	07:51	25°30.42	13°10.85	16.8	35.1	7.757	08:46	25°30.43	13°10.83	16.8	35.1	7.760	
24	06.03.	06:08	25°27.94	13°34.63	17.4	35.2	7.787	06:59	25°28.48	13°33.26	17.5	35.2	7.788	
25	07.03.	05:56	23°47.00	12°46.19	19.5	35.1	8.021	07:09	23°33.67	12°43.02	19.3	35.1	8.022	
26	08.03.	06:05	23°55.23	12°41.77	19.2	35.1	8.319	07:03	24°00.48	12°45.79	18.6	35.1	8.321	
27	09.03.	05:28	22°59.97	12°34.99	20.2	35.3	8.718	06:09	22°59.94	12°34.94	20.1	35.3	8.730	

Table 4.2.12: List of surface water samples for chloropyhall-a measurements

No.	Date	Time (UTC)	Latitude (S)	Longitude (E)	Water depth [m]	Sal. [‰]	Temp. [°C]
1	12.02.2003	07:15	24°14.62´	13°37.55´	N.C.	35.1	17.2
2	12.02.2003	11:56	24°16.81´	13°28.85´	327	35.1	17.2
3	12.02.2003	17:07	24°22.35´	13°06.26´	1080	35.1	18.3
4	13.02.2003	07:25	22°52.04´	14°29.27´	30	35.1	23.0
5	13.02.2003	12:02	23°00.01´	14°09.27´	121	35.1	21.9
6	13.02.2003	17:52	22°59.89´	13°24.13´	319	35.3	18.8
7	14.02.2003	06:11	22°59.96´	12°07.07´	2560	35.2	19.9
8	14.02.2003	11:59	23°04.82´	12°04.02´	2614	35.2	20.0
9	14.02.2003	18:07	23°56.67´	12°47.28´	1562	35.1	20.2
10	15.02.2003	06:08	24°21.86´	13°08.33´	1001	35.1	17.9
11	15.02.2003	11:13	24°21.70´	13°08.29´	1002	35.2	18.1
12	15.02.2003	18:06	24°21.65´	13°11.19´	899	35.1	19.0
13	16.02.2003	06:09	24°15.00´	13°36.02´	316	35.1	17.3
14	16.02.2003	09:48	24°22.66´	13°06.65´	1066	35.1	19.0
15	16.02.2003	16:55	24°27.70´	12°42.82´	1991	35.1	20.2
16	17.02.2003	06:04	24°21.36´	13°08.22´	1002	35.1	18.9
17	17.02.2003	09:55	24°25.33´	12°55.48´	1518	35.1	19.5
18	17.02.2003	18:04	24°28.15´	12°42.76´	1996	35.1	20.4
19	18.02.2003	06:20	24°27.27´	12°42.63´	1991	35.1	20.1
20	18.02.2003	11:26	24°34.42´	12°46.00´	2043	35.1	19.6
21	18.02.2003	18:08	25°28.90´	13°21.43´	1036	35.2	18.5
22	19.02.2003	06:21	24°59.61´	13°12.83´	1350	35.1	18.3
23	19.02.2003	10:44	24°27.45´	12°42.72´	1989	35.1	19.9
24	19.02.2003	17:32	25°14.14	13°29,16	825	35.1	17.9
25	20.02.2003	06:11	25°16.16	14°02.24	232	35.1	16.1
26	20.02.2003	10:18	25°28.22	13°43.04	364	35.1	16.9
27	20.02.2003	16:38	25°36.60	13°16.79	1333	35.1	18.9
28	21.02.2003	06:30	23°29.27	14°16.87	108	35.3	15.5
29	21.02.2003	11:31	23°00.00	14°11.06	115	35.2	16.4
30	21.02.2003	17:07	23°00.03	13°29.14	263	35.3	19.1
31	22.02.2003	06:44	23°00.40	12°19.51	2096	35.2	20.1
32	22.02.2003	10:13	23°00.01	12°00.01	2723	35.2	20.8
33	22.02.2003	14:47	23°42.87	12°20.94	2205	35.2	20.2
34	23.02.2003	08:59	25°28.49	13°26.96	806	35.1	18.4
35	23.02.2003	16:17	25°28.35	13°32.74	621	35.2	17.5
36	23.02.2003	19:50	25°28.66	13°24.42	904	35.2	19.2
37	24.02.2003	06:08	25°25.81	13°41.90	388	35.1	17.3
38	24.02.2003	11:20	25°29.67	13°16.91	1230	35.1	19.0
39	24.02.2003	16:31	25°29.45	13°21.41	1038	35.2	19.7

Table 4.2.12: (continued) List of surface water samples for chloropyhall-a measurements

No.	Date	Time (UTC)	Latitude (S)	Longitude (E)	Water depth [m]	Sal. [‰]	Temp. [°C]
40	25.02.2003	05:49	25°28.51	13°36.59	540	34.9	17.2
41	25.02.2003	11:20	25°25.52	13°27.10	801	35.0	18.9
42	25.02.2003	18:14	25°24.38	12°44.38	2633	35.2	20.2
43	26.02.2003	06:13	24°52.61	11°54.75	3529	35.2	20.9
44	26.02.2003	10:46	24°52.47	11°54.89	3526	35.2	20.9
45	26.02.2003	16:17	24°52.51	11°54.91	3526	35.1	21.3
46	27.02.2003	06:02:	25°32.06	12°56.41	2280	35.3	20.6
47	27.02.2003	10:08	25°31.86	12°56.13	2291	35.2	20.7
48	27.02.2003	16:08	25°35.74	13°16.89	1328	35.2	20.1
49	28.02.2003	05:23	26°13.86	13°43.13	445	35.2	19.5
50	28.02.2003	10:20	26°27.44	13°44.26	458	35.3	21.1
51	28.02.2003	16:05	26°45.20	13°25.56	1354	35.5	21.7
52	01.03.2003	05:19	26°38.40	13°17.35	1685	35.5	21.6
53	01.03.2003	10:08	26°44.77	13°25.43	1444	35.3	20.5
54	01.03.2003	16:59	26°45.56	13°22.81	1481	35.5	21.2
55	02.03.2003	06:43	25°32.77	12°51.70	2470	35.2	19.6
56	02.03.2003	11:02	25°36.61	13°16.72	1331	35.1	17.5
57	02.03.2003	16:08	24°52.17	13°35.51	475	35.1	17.6
58	03.03.2003	06:43	22°59.97	13°45.45	147	35.2	16.8
59	03.03.2003	10:24	23°00.00	13°19.04	357	35.2	17.8
60	03.03.2003	20:31	23°00.02	12°46.91	950	35.2	20.0
61	04.03.2003	06:11	23°00.03	12°00.06	2724	35.2	20.9
62	04.03.2003	10:26	23°34.52	12°16.77	2298	35.2	20.3
63	04.03.2003	17:23	24°28.77	12°43.29	1978	35.1	19.7
64	05.03.2003	06:43	25°31.57	13°12.26	1459	35.1	16.7
65	05.03.2003	10:24:	25°30.42	13°10.87	1511	35.1	16.9
66	05.03.2003	14:43	25°28.90	13°21.48	1030	35.1	16.5
67	06.03.2003	06:04	25°27.71	13°35.29	539	35.1	17.4
68	06.03.2003	10:37	24°53.60	13°20.07	960	35.1	17.4
69	06.03.2003	19:27	24°23.59	13°03.36	1000	35.1	18.6
70	07.03.2003	05:52	23°47.69	12°46.35	1546	35.1	19.5
71	07.03.2003	11:31	23°00.04	12°34.99	1438	35.2	20.0
72	07.03.2003	14.49	22°59.89	12°20.10	2078	35.3	19.9
73	08.03.2003	06:10	23°54.65	12°41.31	1805	35.1	19.2
74	08.03.2003	10:44	24°23.69	13°03.22	1207	35.1	17.6
75	08.03.2003	18:05	24°24.13	13°02.48	1239	35.2	17.8

4.3 Visual Core Description and Smear Slide Analysis

(A. Eberwein, C. Franke, D. Heslop, S. Mulitza, A. Paul, S. Rathmann, O. Romero, T. v.Dobeneck)

4.3.1 Methods

The core description, carried out on the archive half of all gravity core segments, serves to summarize the most important sediment features. The major objective of macroscopic core description is the identification of sediment structures, such as unconformities, discontinuities, turbidites and bioturbation. Core descriptions follows the ODP nomenclature. The visible color classification was determined by comparison with the MUNSEL soil color chart.

The lithologic observation is supported by smear slide analysis. In each core segment at least one sample was taken depending on the heterogeneity of the sediment and the occurrence of conspicuous lithologies. In some cases, the position of smear slides was determined by changes in color. For smear slides sediment was taken using a toothpick. The sample was placed on a clean glass microscope slide and smeared with water. Smear slides were prepared using NORLAND OPTICAL ADHESIVE as a mounting medium and dried with UV light for at least one hour. The samples were investigated using an OLYMPUS light microscope at 400 and 1000 X. The sediment composition was described also according to the ODP nomenclature. A total of 175 smear slides were analyzed.

Each visual core description is completed by the results of the physical properties measurements (reflectance, redblue ratio, porosity and magnetic susceptibility). The physical background and experimental techniques are described in section 4.4.1.

On the following sides detailed information from preliminary investigations on all gravity cores cores recovered and opened were given (Figs. 4.3.1 to 4.3.28).

4.3.2 Shipboard Results

During the cruise M57/2, 27 sediment cores were retrieved from water depths ranging from 315 to 2725 m (Tab. 4.2.1). Core stations are located along 4 transects from almost west to east, off Namibia. Core recovery was generally very good. All cores were opened and described on board.

Oceanographic Transect (23°S)

At the northernmost transect of the working area, 8 gravity cores at 7 stations were retrieved from depths ranging between ca. 600 and 2800 m depth. The core length varies between ~3.9 and 11.8 m. The deepest cores are the longest and lightest in color. An extreme downcore color change is observed at the deepest stations. Very narrow shell fragment and sandy layers occurred at some cores at some depths.

The sediment is mostly composed by biogenic material, predominantly carbonaceous, till approximately 1400 m water depth, mainly delivered by coccolithophorids and foraminifera. At 1400 m water depth some diatoms appear for the first time at this transect. At both deepest stations, diatoms have the highest contribution for the transect, although without becoming dominant. Bioturbation occur almost throughout: except at GeoB8484-2, all cores

GeoB 8418-08 Date: 15.02.03 Position: 24° 21.9' S 13° 08.2' E
Water Depth: 1007 m Core Length: 4.17 m

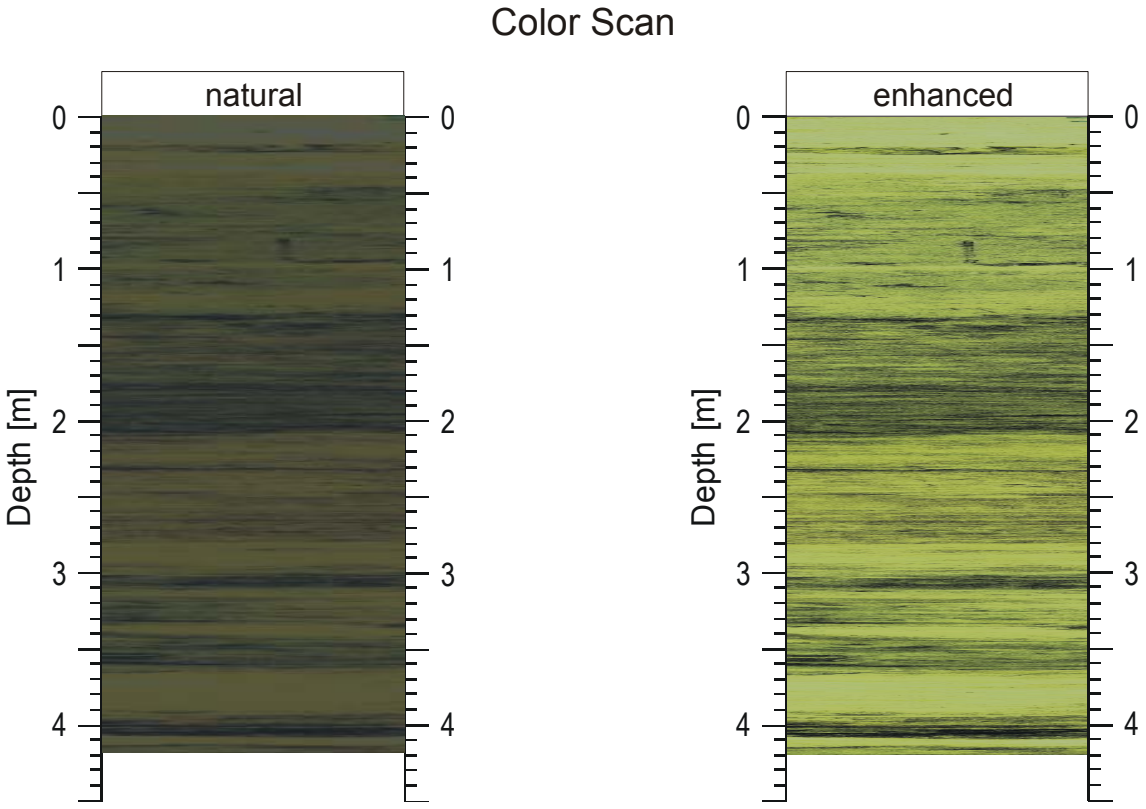


Fig. 4.3.1a Color scan of gravity core GeoB 8418-8 (for geochemical investigations) The difference between natural and enhanced colar is described in section 4.4.1.

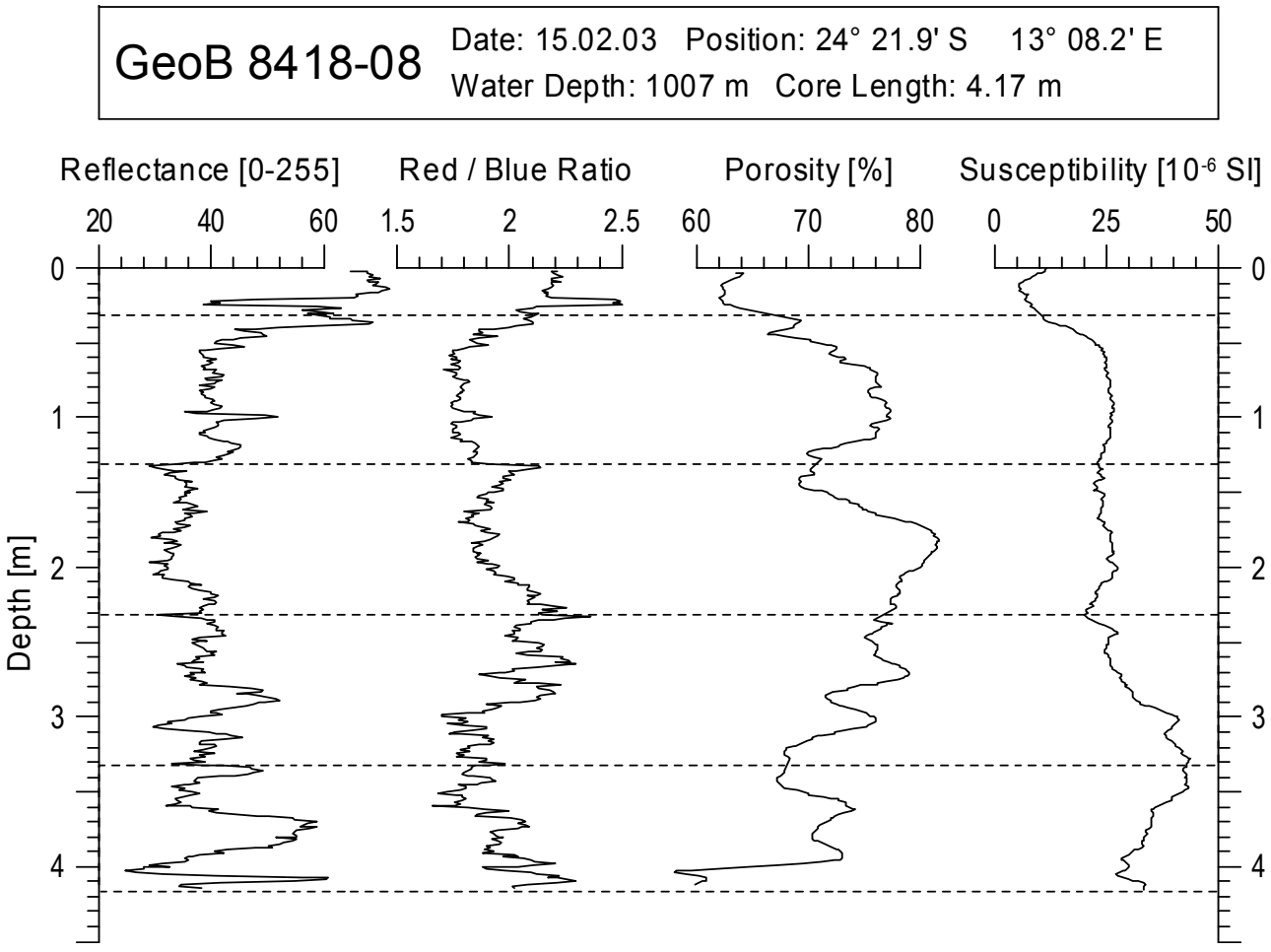


Fig. 4.3.1b Physical properties of gravity core GeoB 8418-10. The dashed lines indicate the ends of the 1m sections of the core.

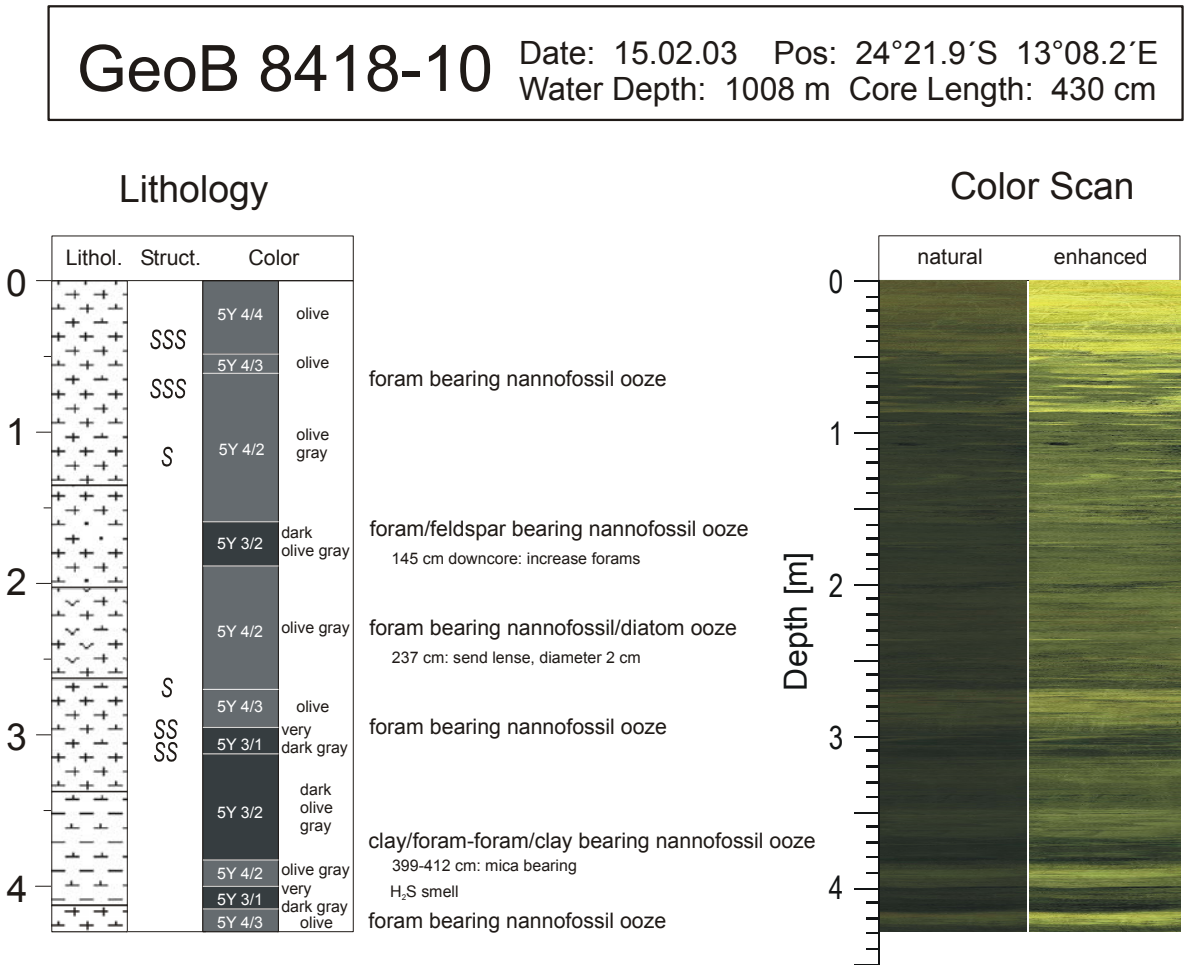


Fig. 4.3.2a Visual description of gravity core GeoB 8418-10.

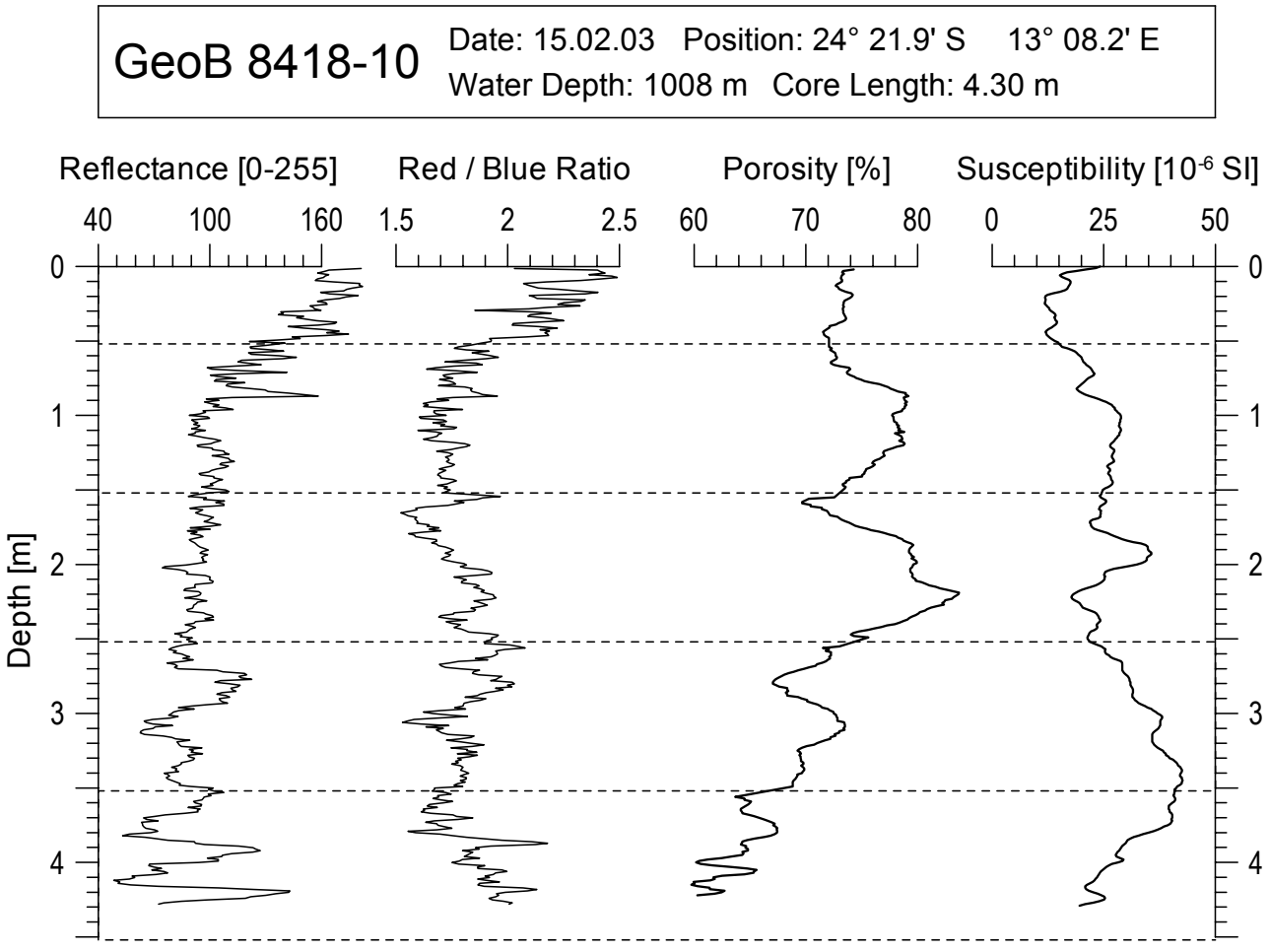


Fig. 4.3.2b Physical properties of gravity core GeoB 8418-10. The dashed lines indicate the ends of the 1m sections of the core.

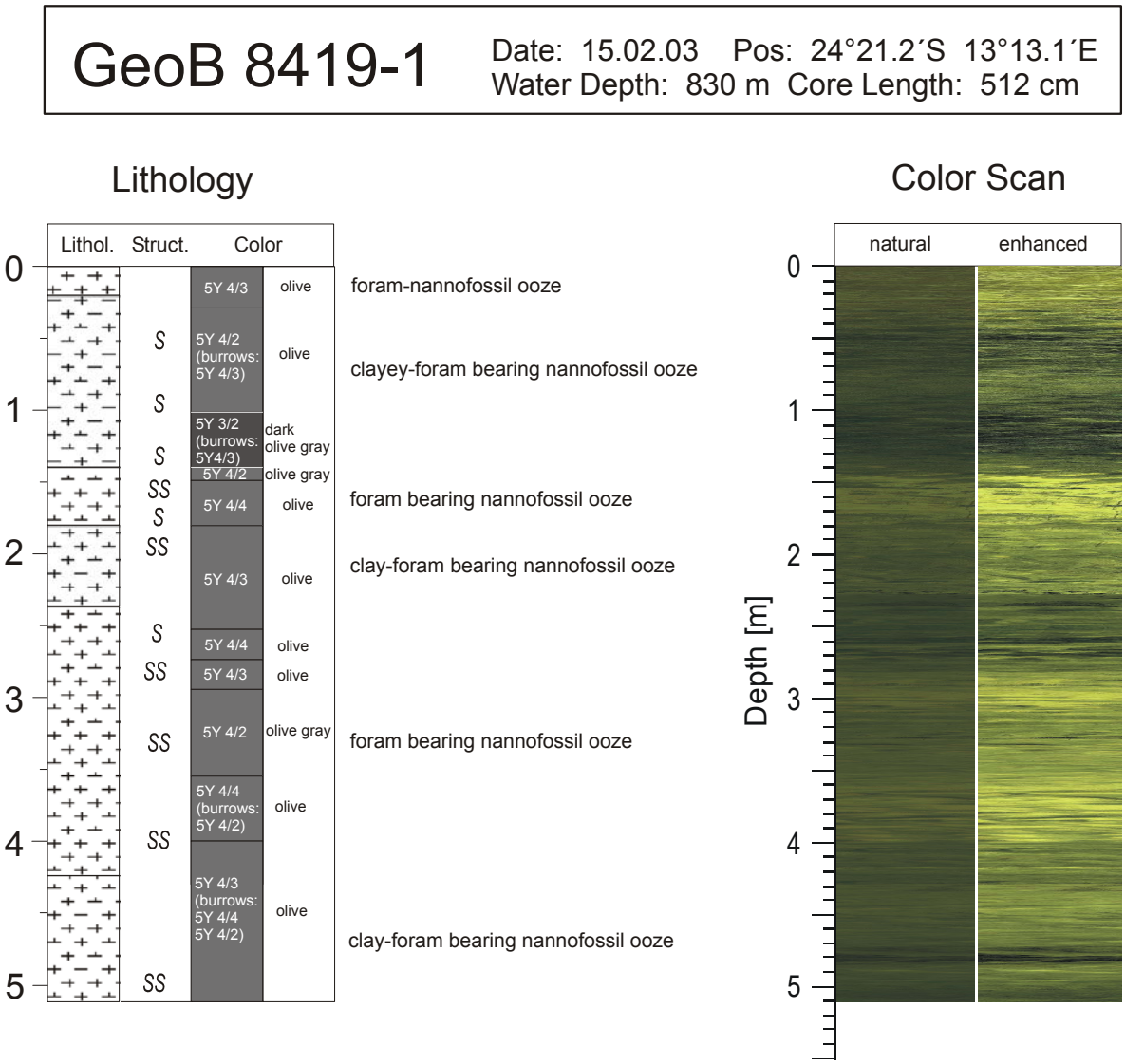


Fig. 4.3.3a Visual description of gravity core GeoB 8419-1.

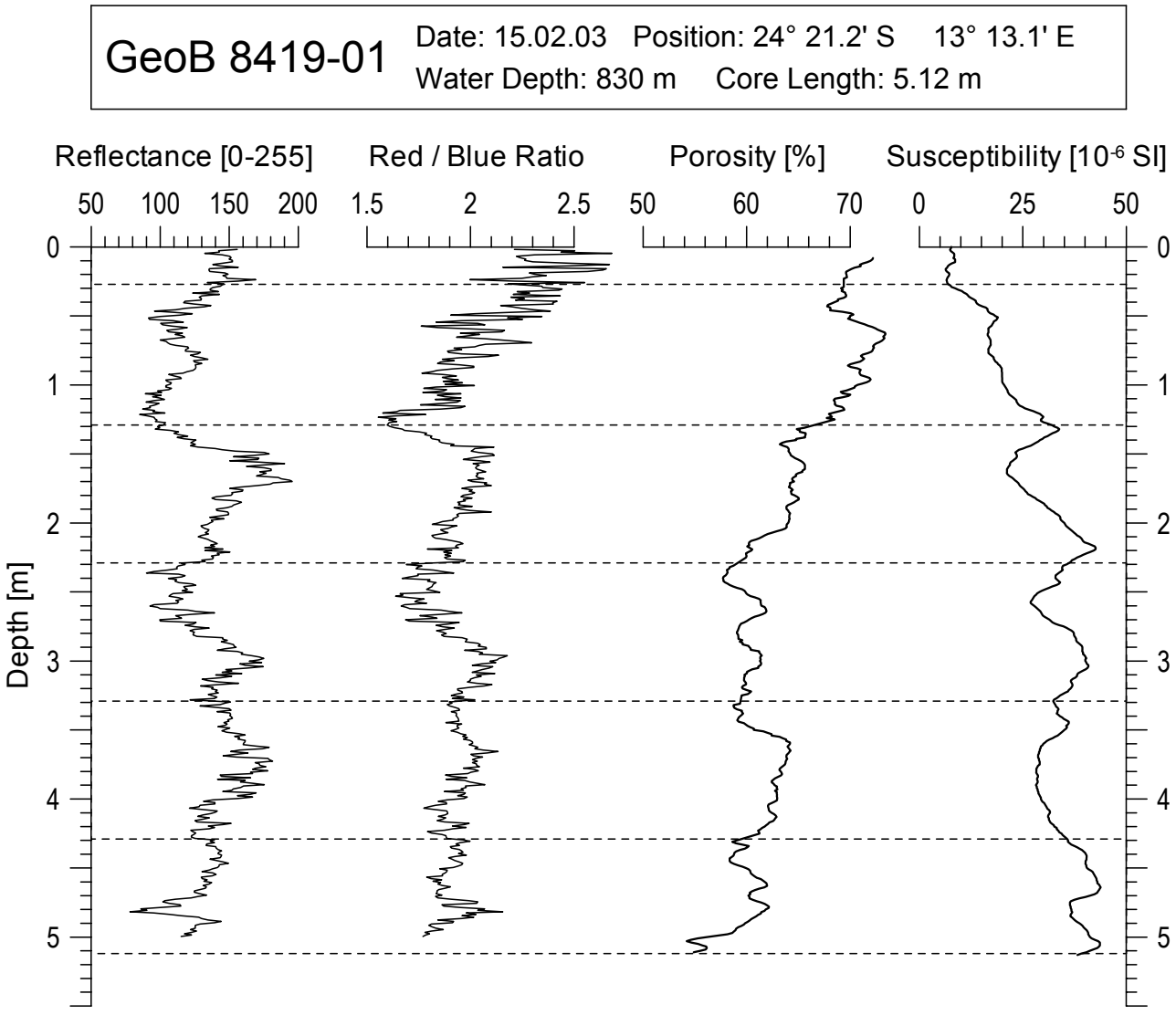


Fig. 4.3.3b Physical properties of gravity core GeoB 8419-1. The dashed lines indicate the ends of the 1m sections of the core.

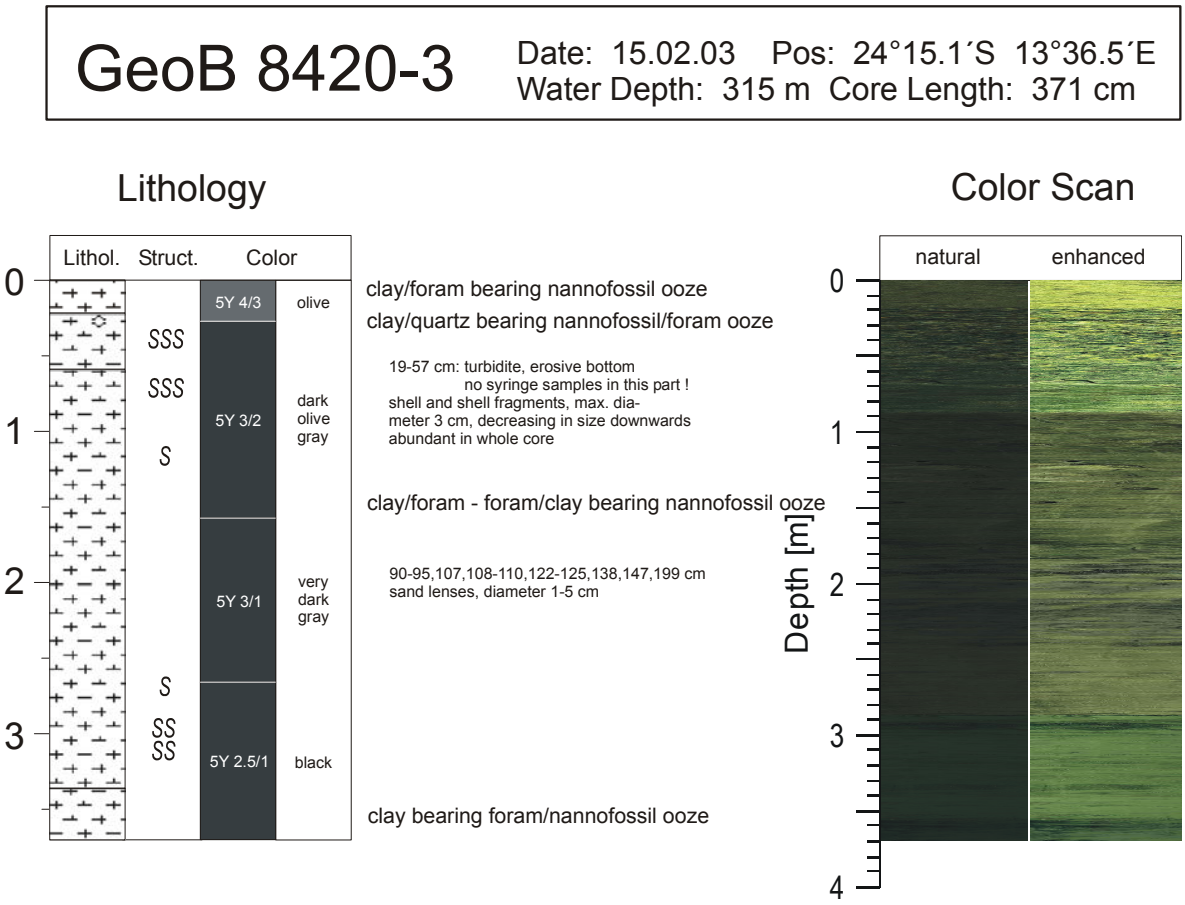


Fig. 4.3.4a Visual description of gravity core GeoB 8420-3.

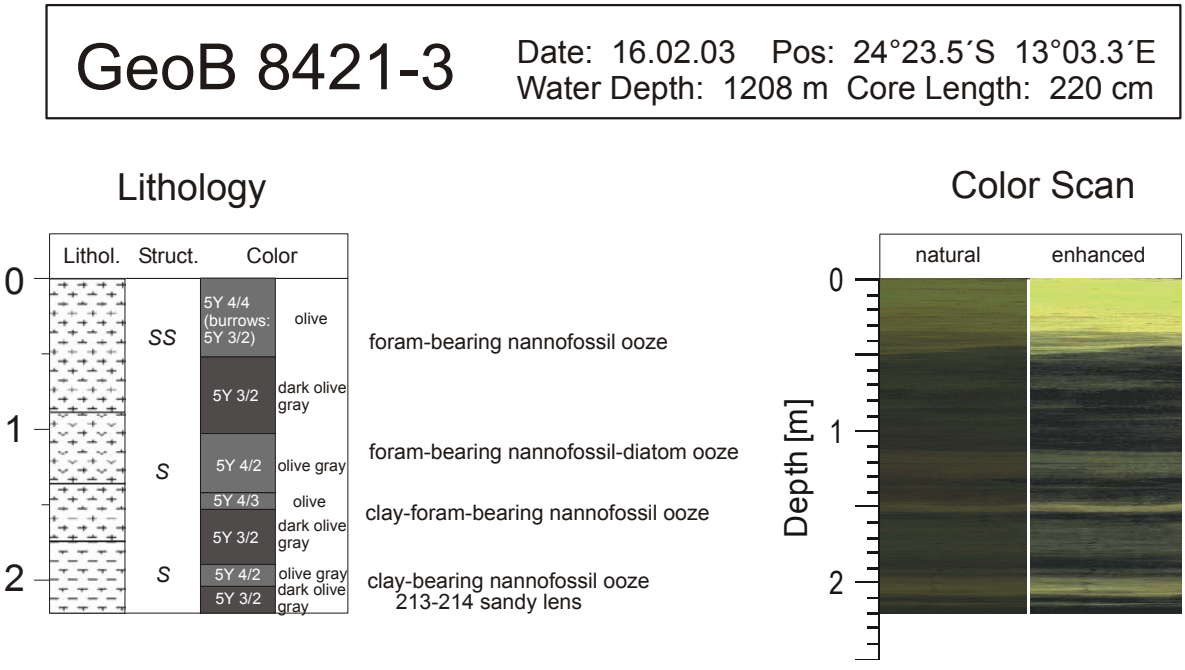


Fig. 4.3.5a Visual description of gravity core GeoB 8421-3.

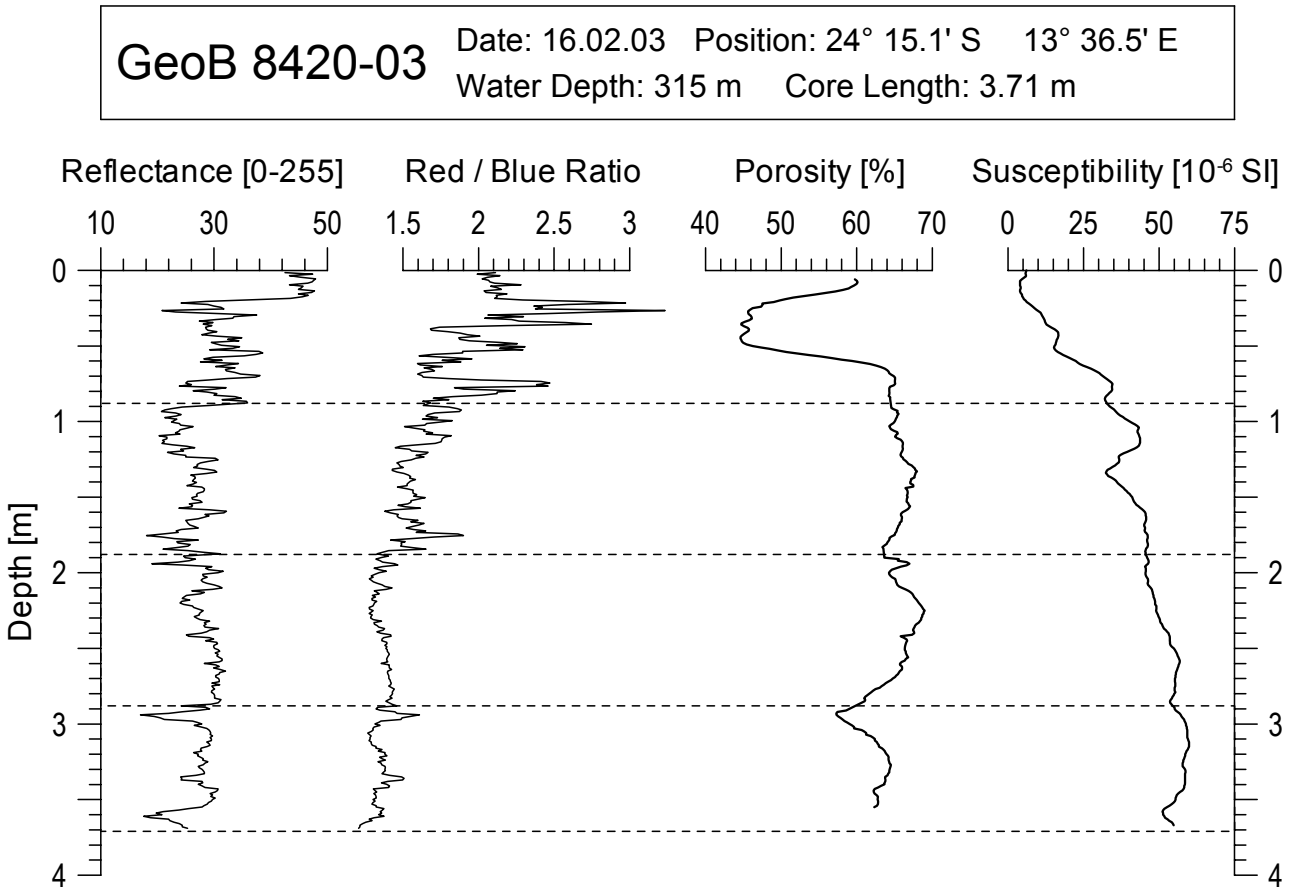


Fig. 4.3.4b Physical properties of gravity core GeoB 8420-3. The dashed lines indicate the ends of the 1m sections of the core.

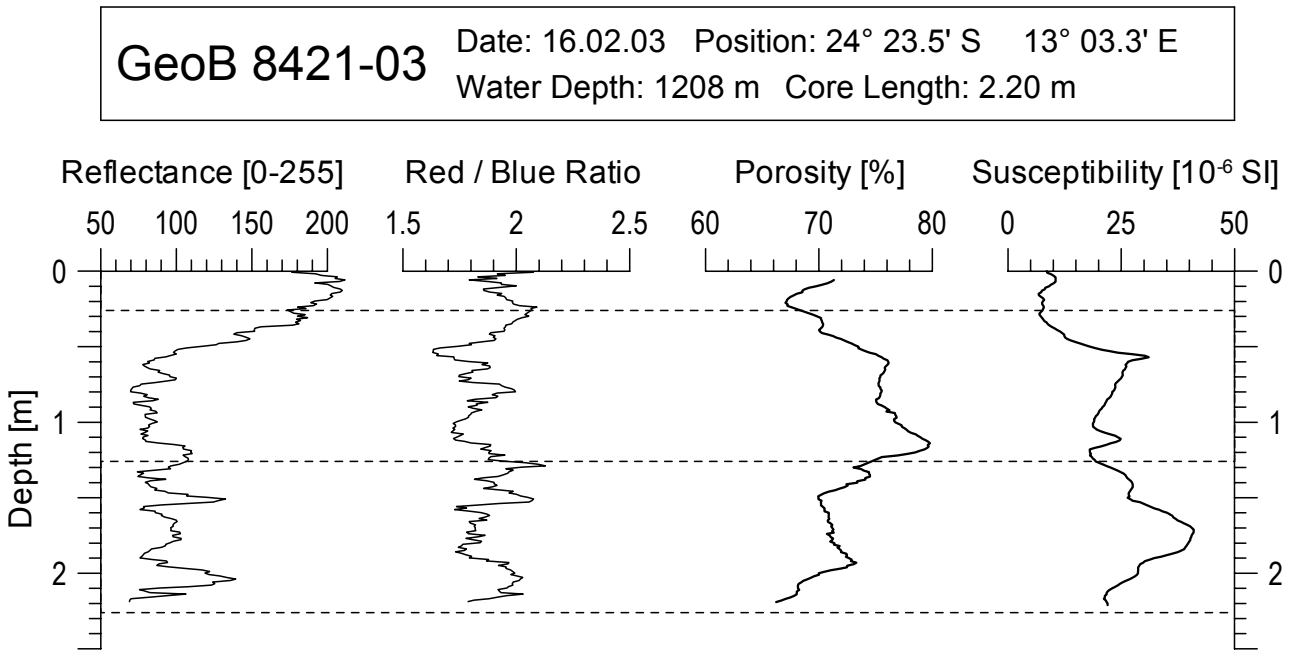


Fig. 4.3.5b Physical properties of gravity core GeoB 8421-3. The dashed lines indicate the ends of the 1m sections of the core.

GeoB 8422-3

Date: 16.02.03 Pos: 24°27.5´S 12°42.8´E
Water Depth: 1992 m Core Length: 1030 cm

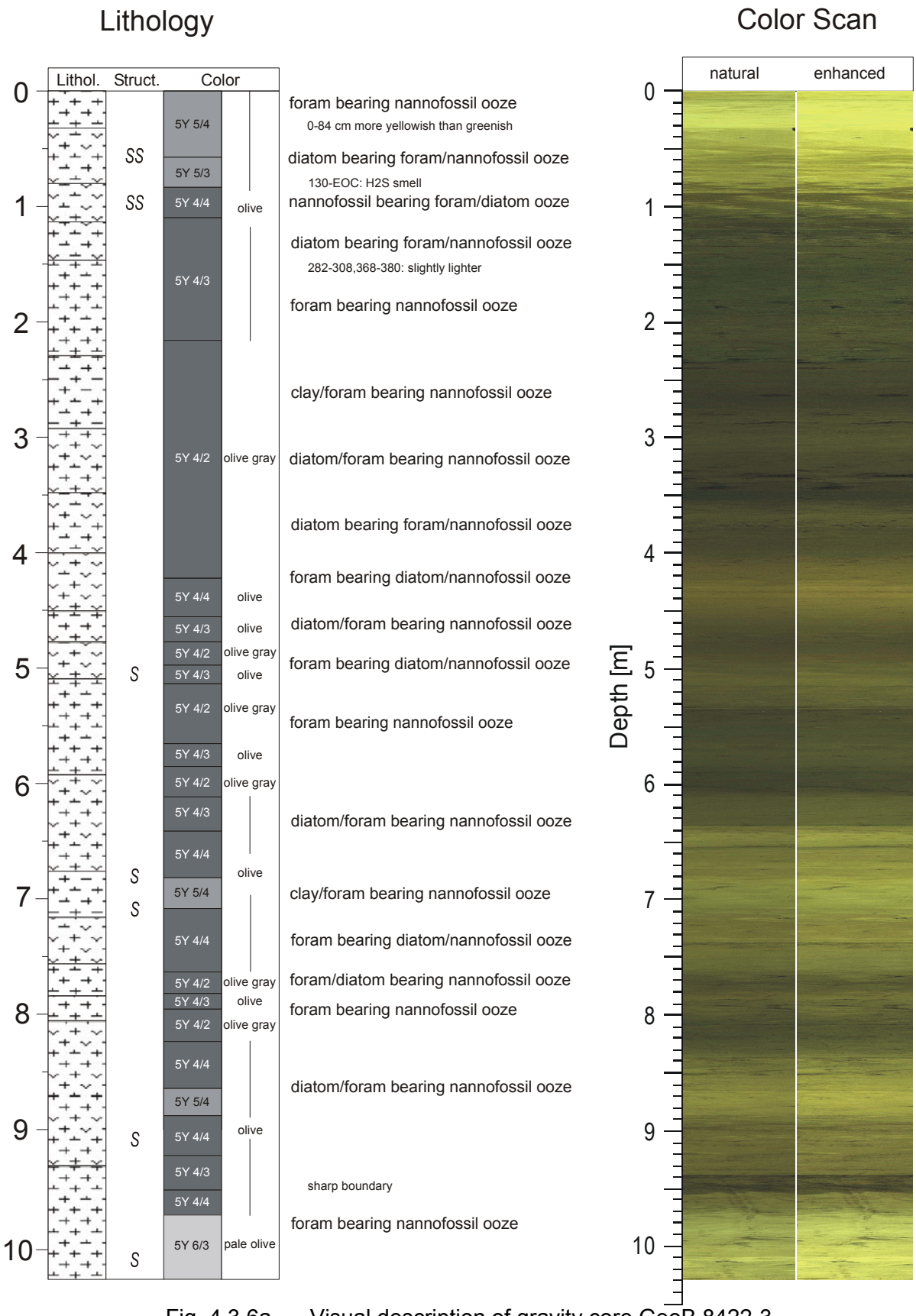


Fig. 4.3.6a Visual description of gravity core GeoB 8422-3.

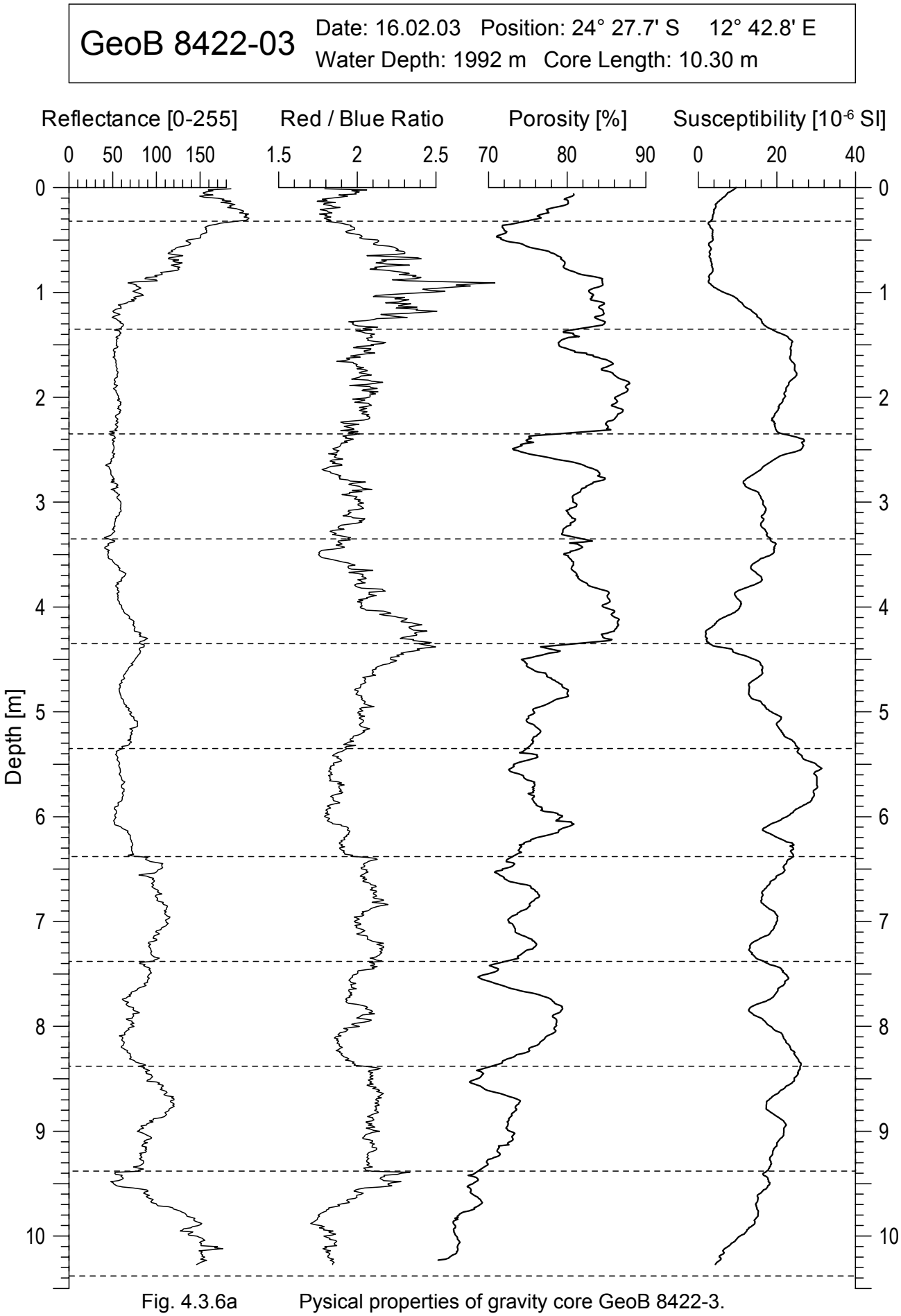


Fig. 4.3.6a Pysical properties of gravity core GeoB 8422-3.

GeoB 8424-4

Date: 17.02.03 Pos: 24°25.3´S 12°55.5´E
Water Depth: 1516 m Core Length: 595 cm

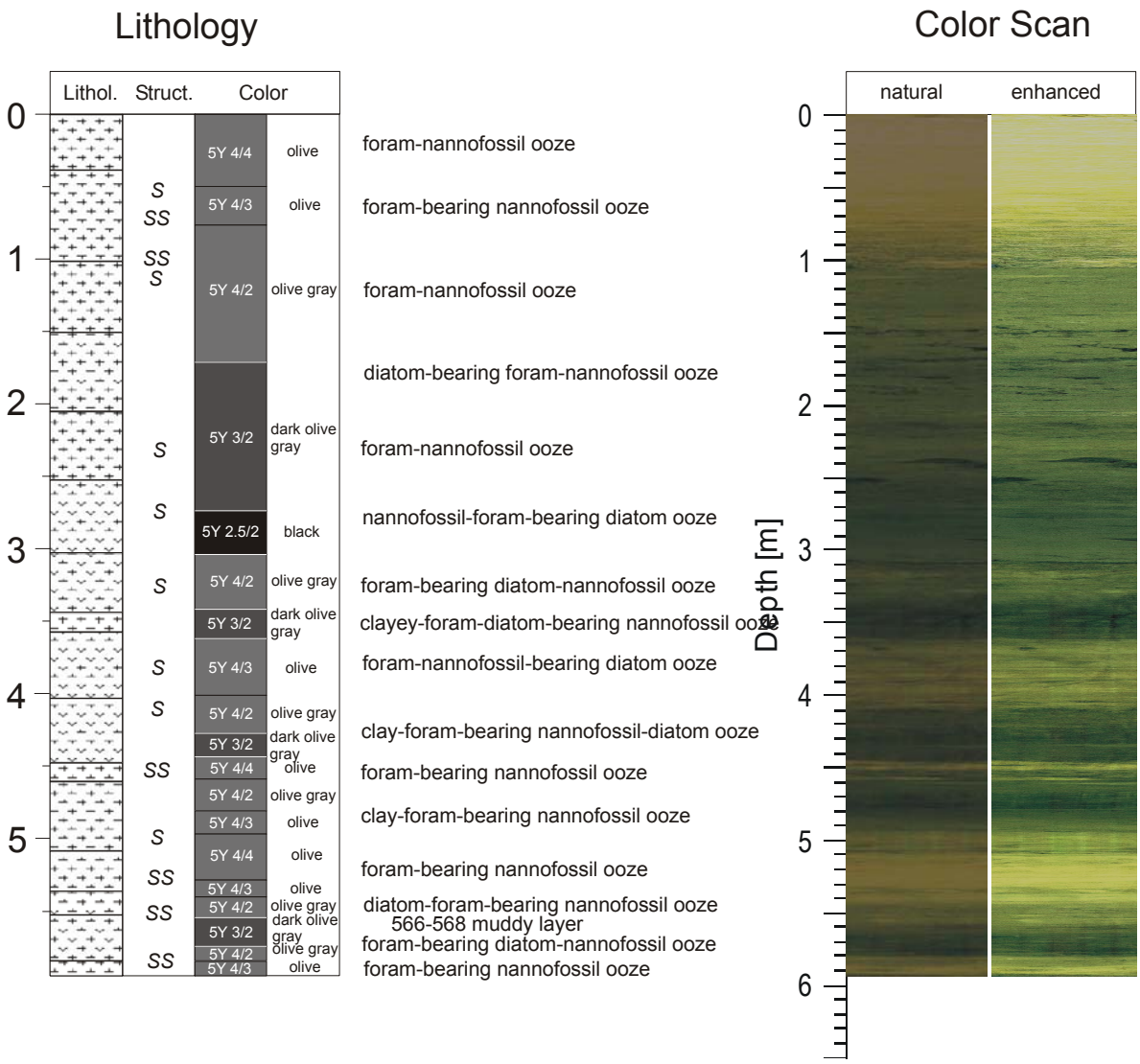


Fig. 4.3.7a Visual description of gravity core GeoB 8424-4.

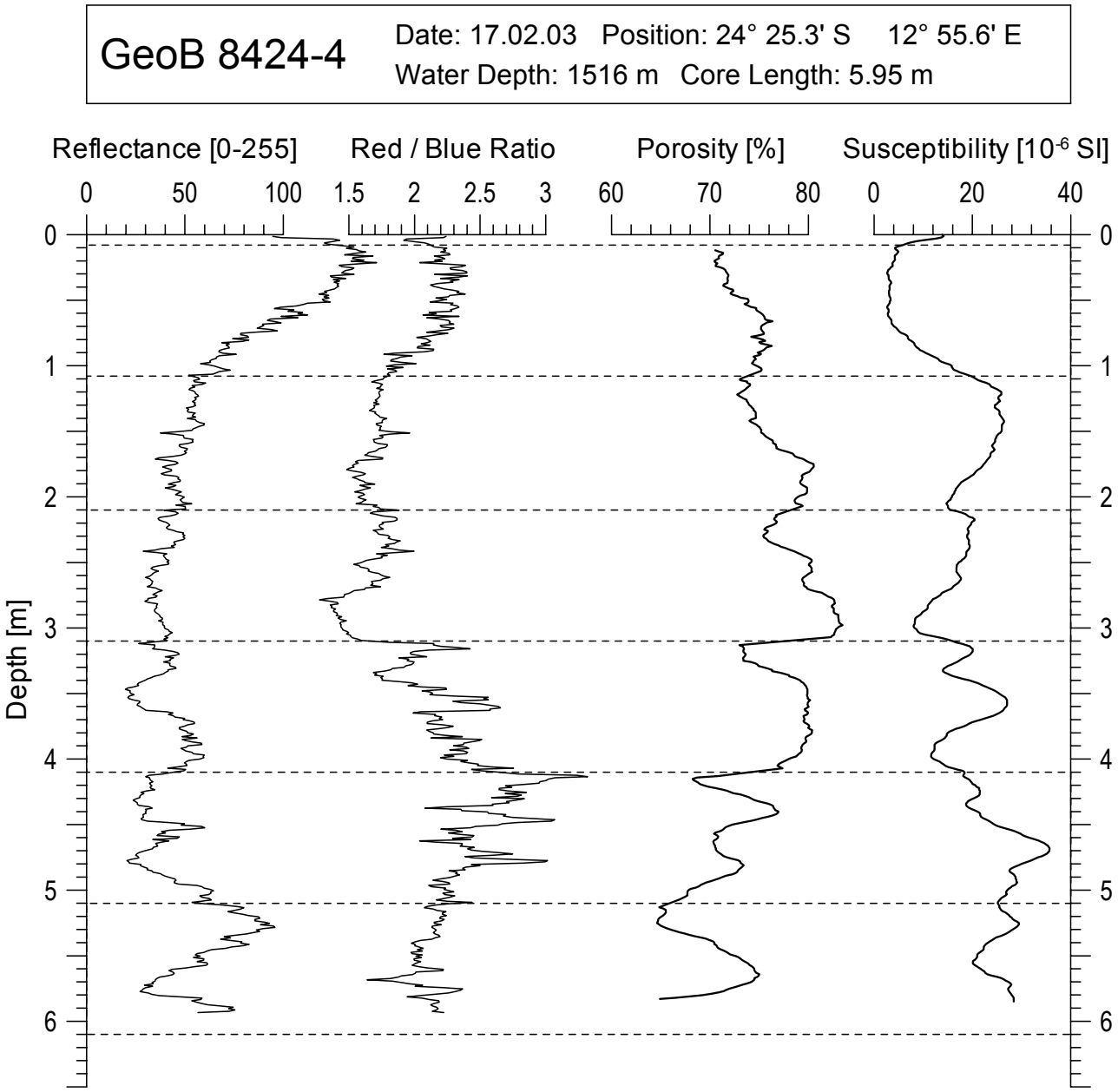


Fig. 4.3.7b Physical properties of gravity core GeoB 8424-4. The dashed lines indicate the ends of the 1m sections of the core.

GeoB 8425-07 Date: 18.02.03 Position: 24° 27.6' S 12° 42.1' E
Water Depth: 2015 m Core Length: 10.90 m

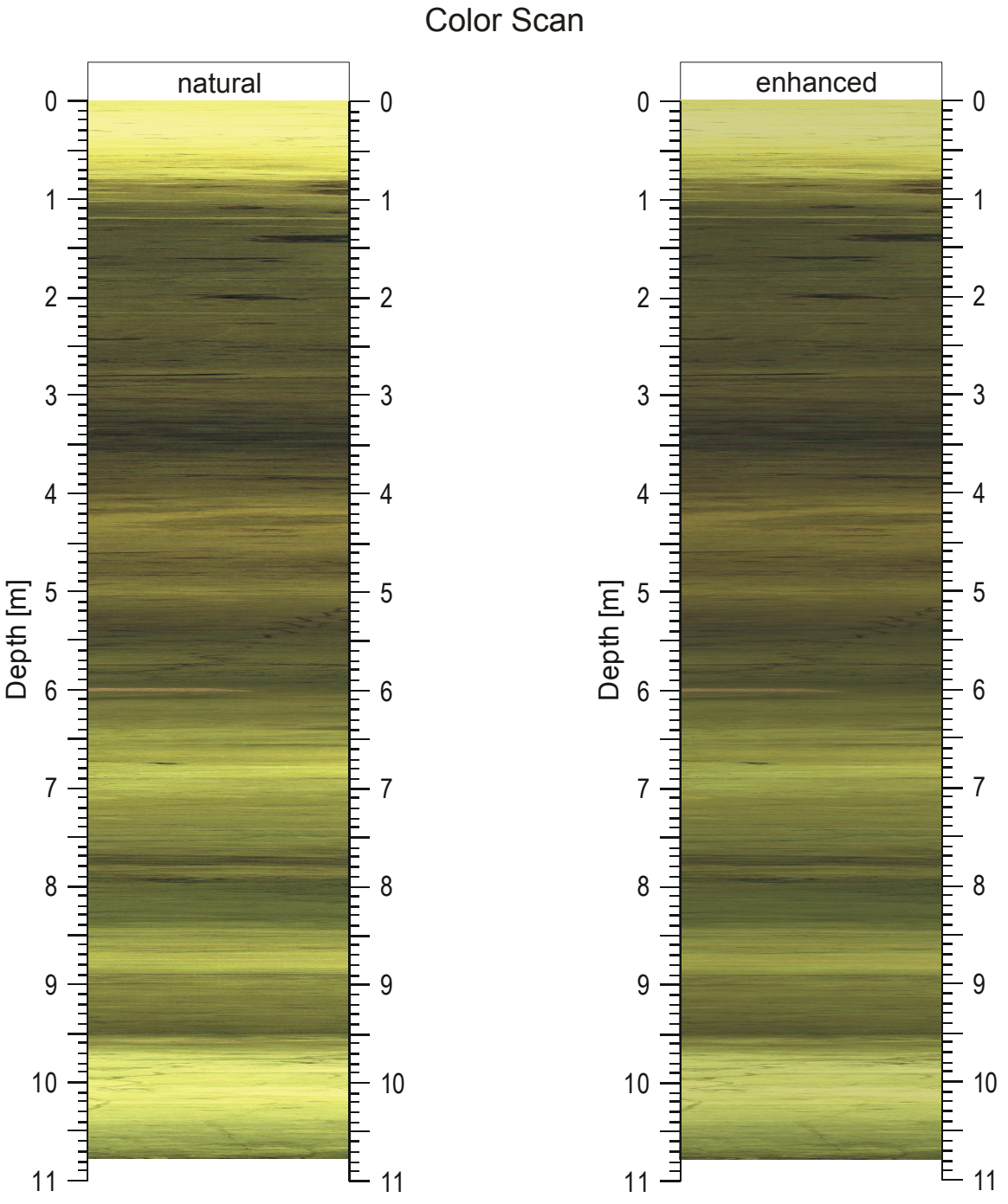


Fig. 4.3.8a Color scan of gravity core GeoB 8425-7 (for geochemical investigations)

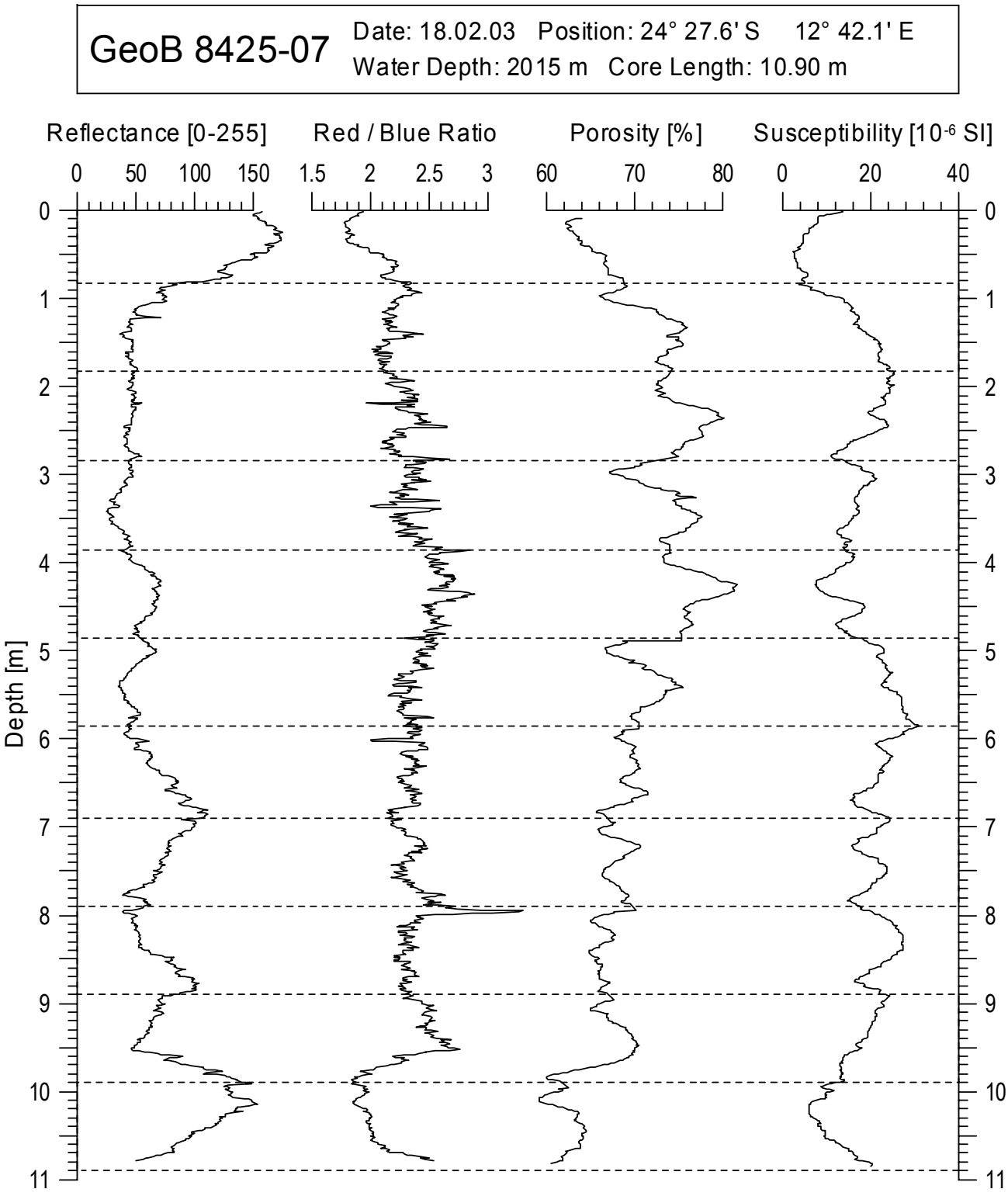


Fig. 4.3.8b Physical properties of gravity core GeoB 8425-7. The dashed lines indicate the ends of the 1m sections of the core.

GeoB 8426-2

Date: 18.02.03 Pos: 25°28.9´S 13°21.2´E
Water Depth: 1045 m Core Length: 1396 cm

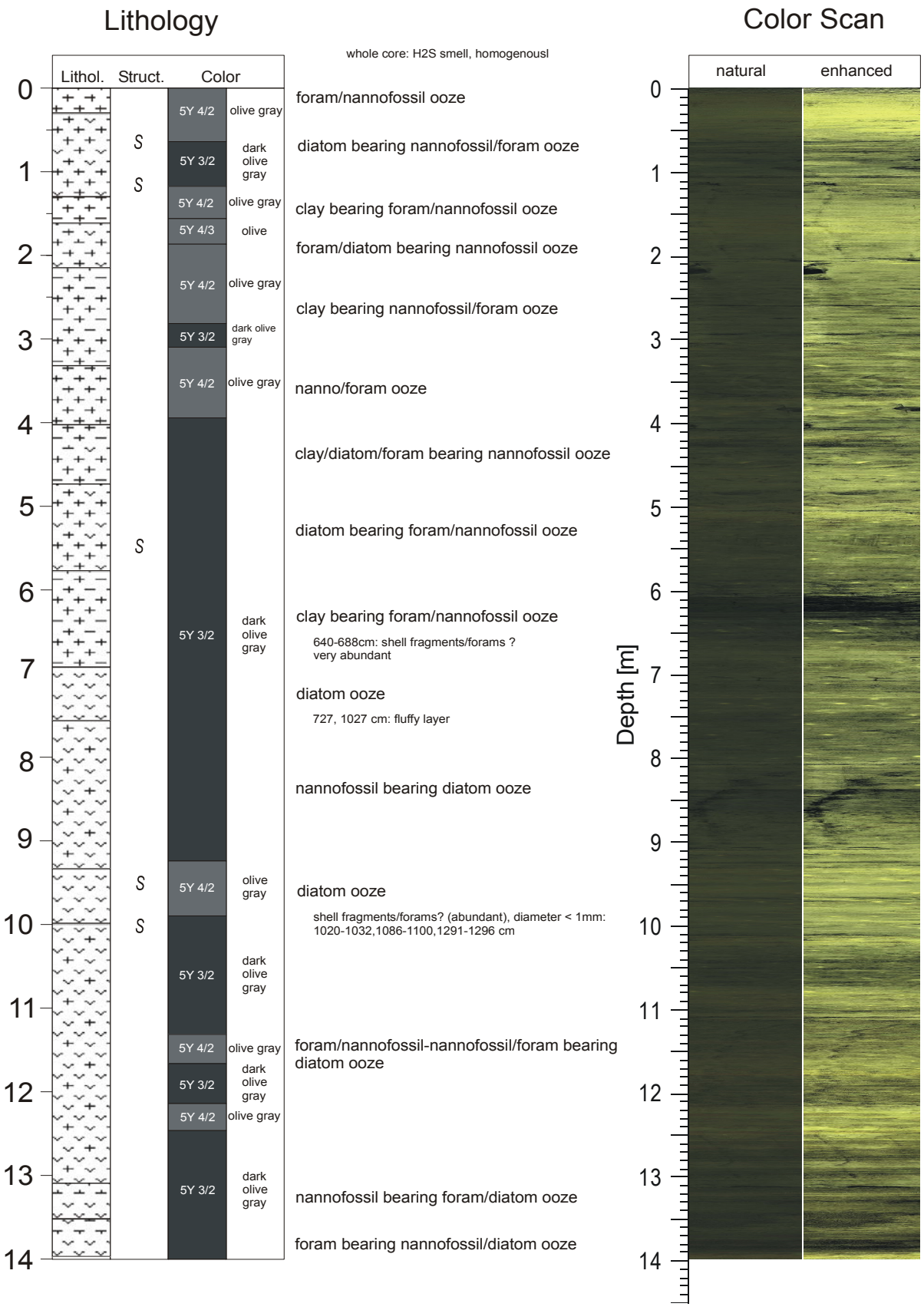


Fig. 4.3.9a Visual description of gravity core GeoB 8426-2.

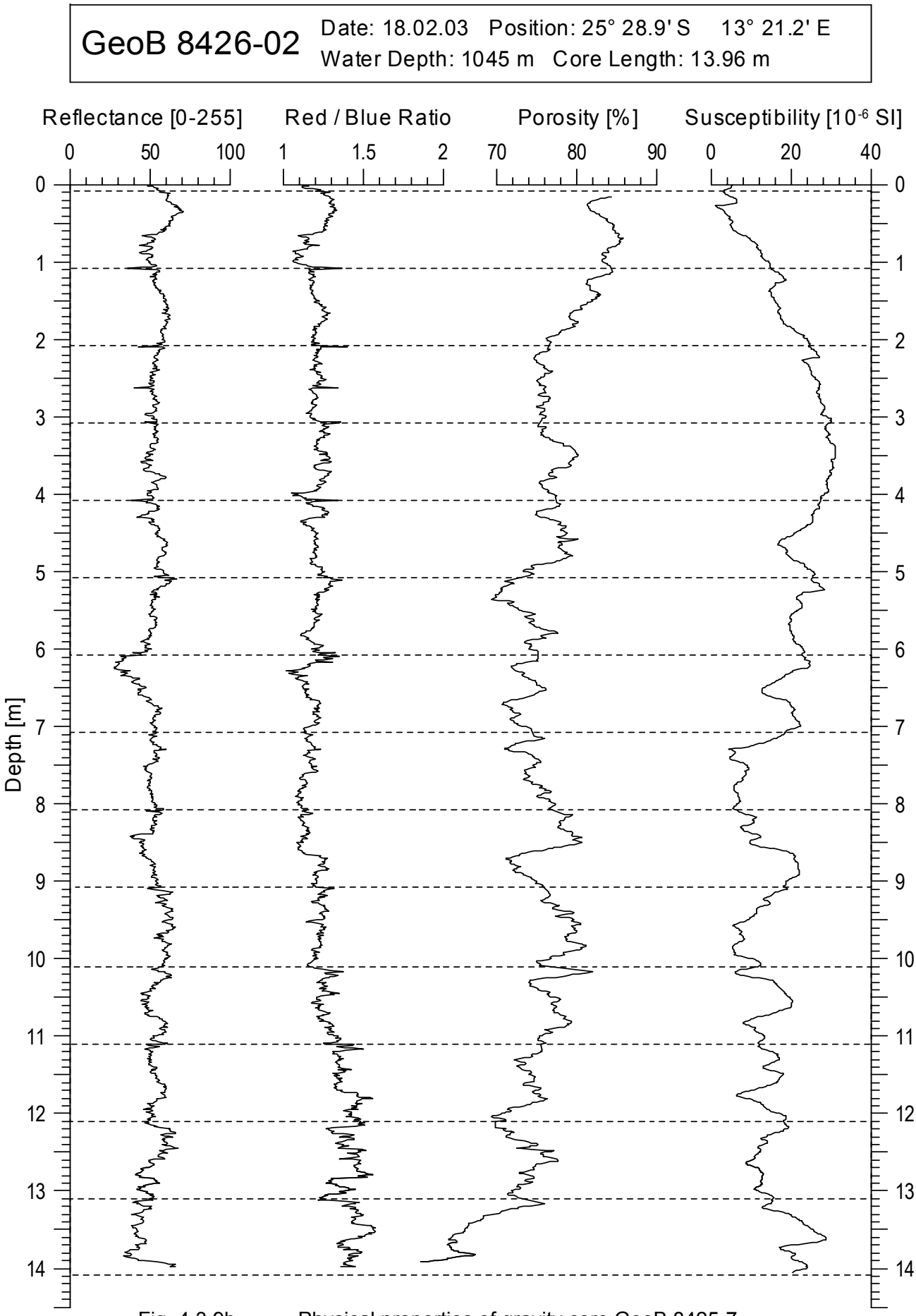


Fig. 4.3.9b Physical properties of gravity core GeoB 8425-7.

GeoB 8426-03 Date: 18.02.03 Position: 25° 28.9' S 13° 21.1' E
Water Depth: 1045 m Core Length: 13.66 m

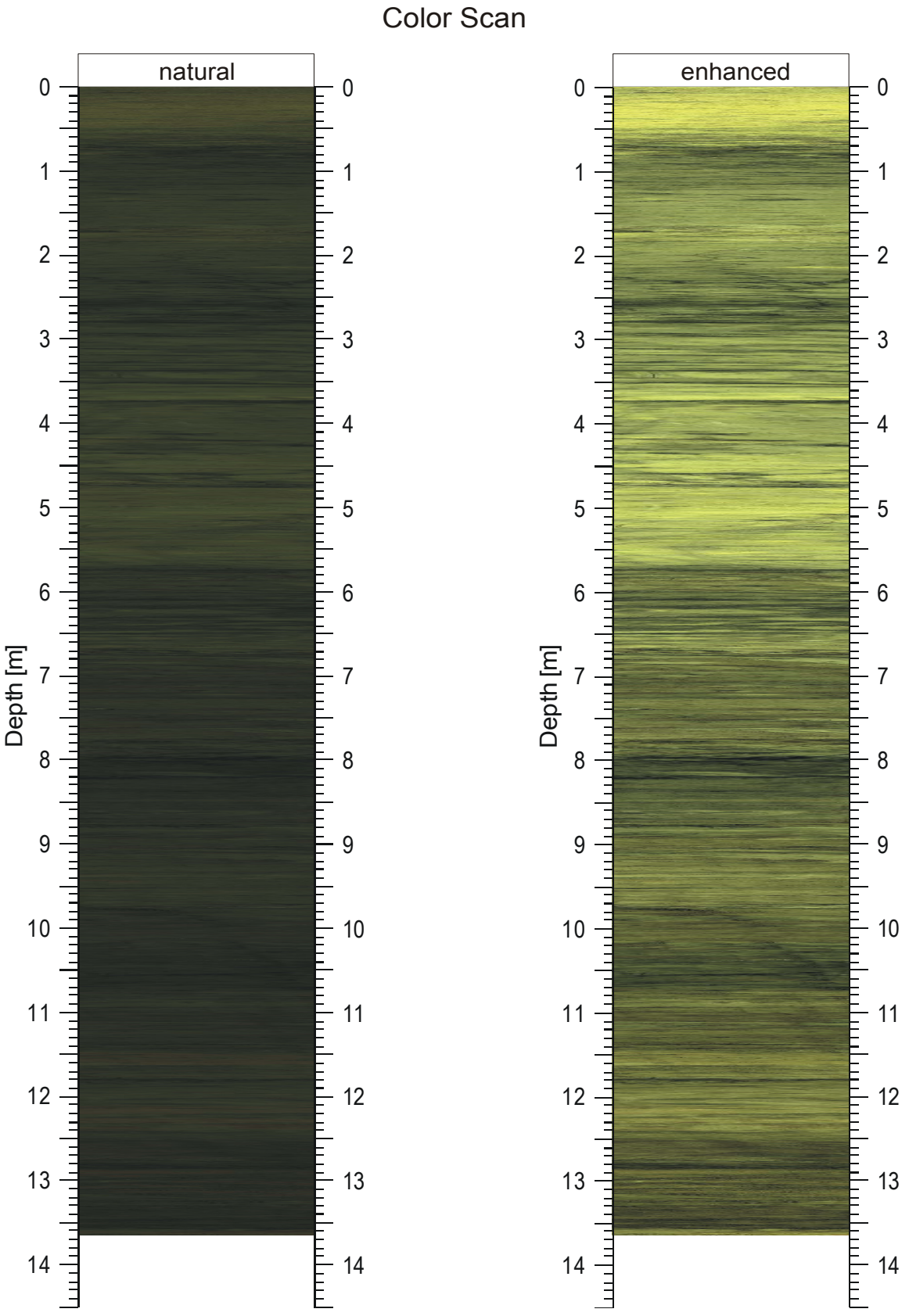


Fig. 4.3.10a Color scan of gravity core GeoB 8426-3 (for geochemical investigations)

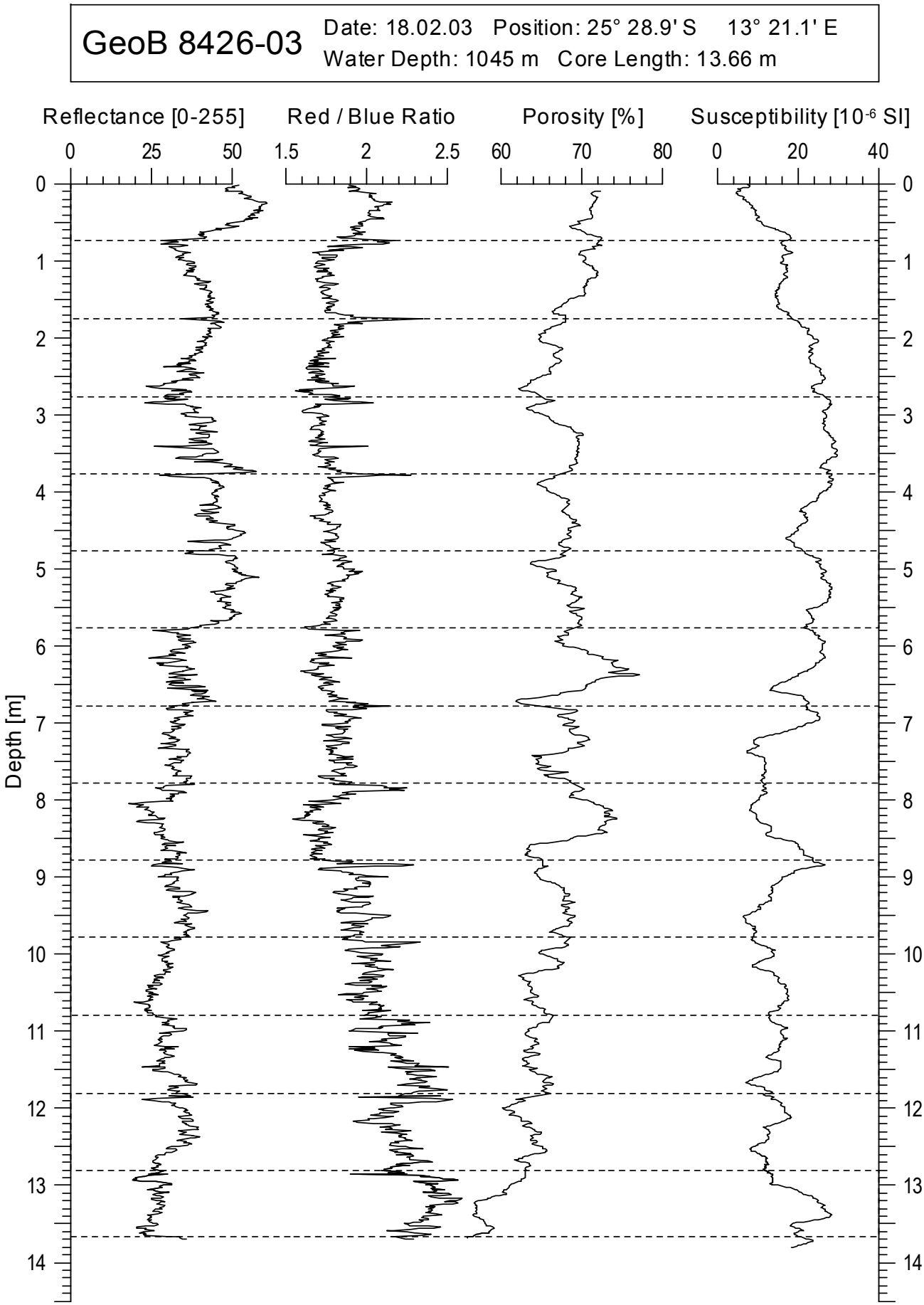


Fig. 4.3.10b Physical properties of gravity core GeoB 8426-3.

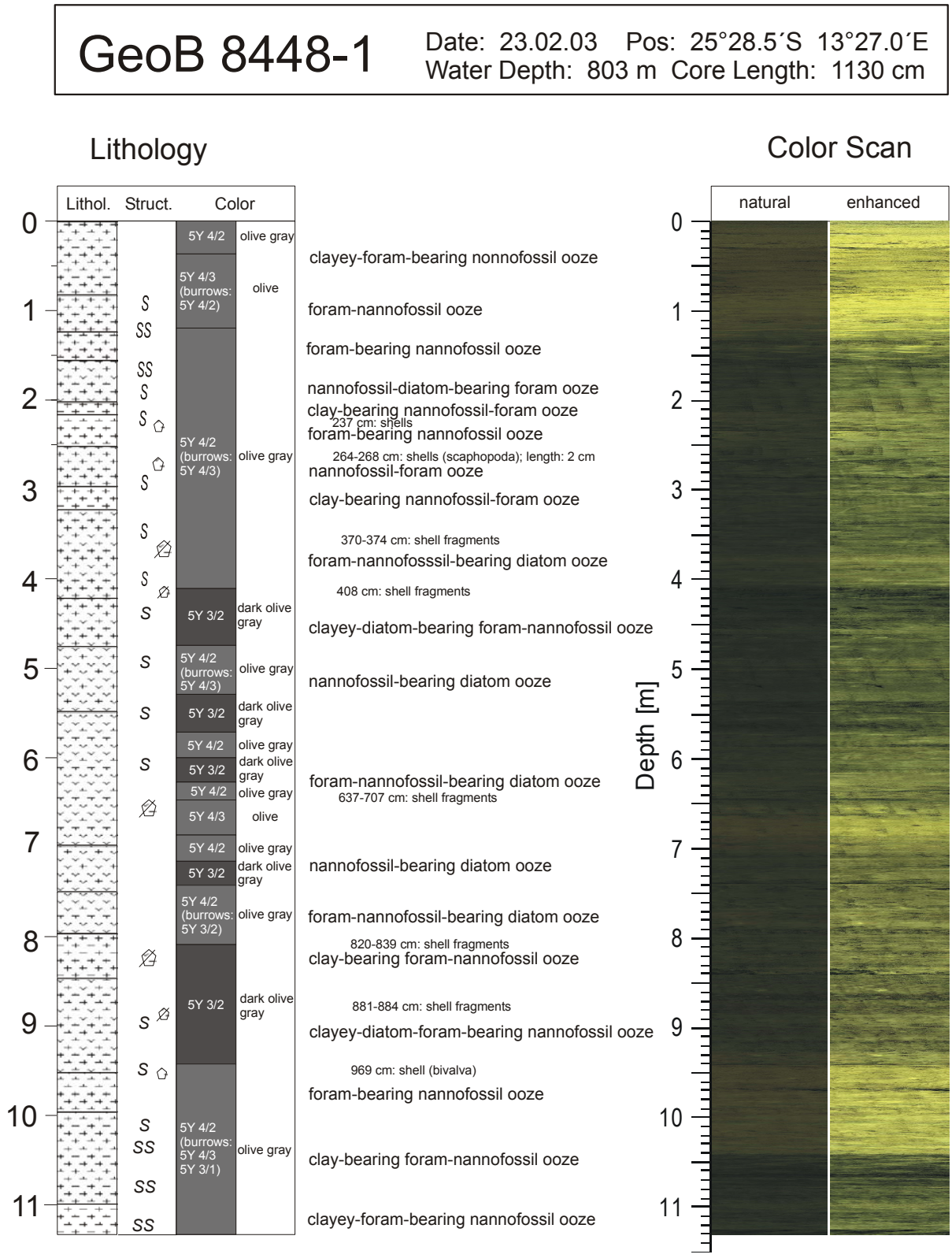


Fig. 4.3.11a Visual description of gravity core GeoB 8448-1.

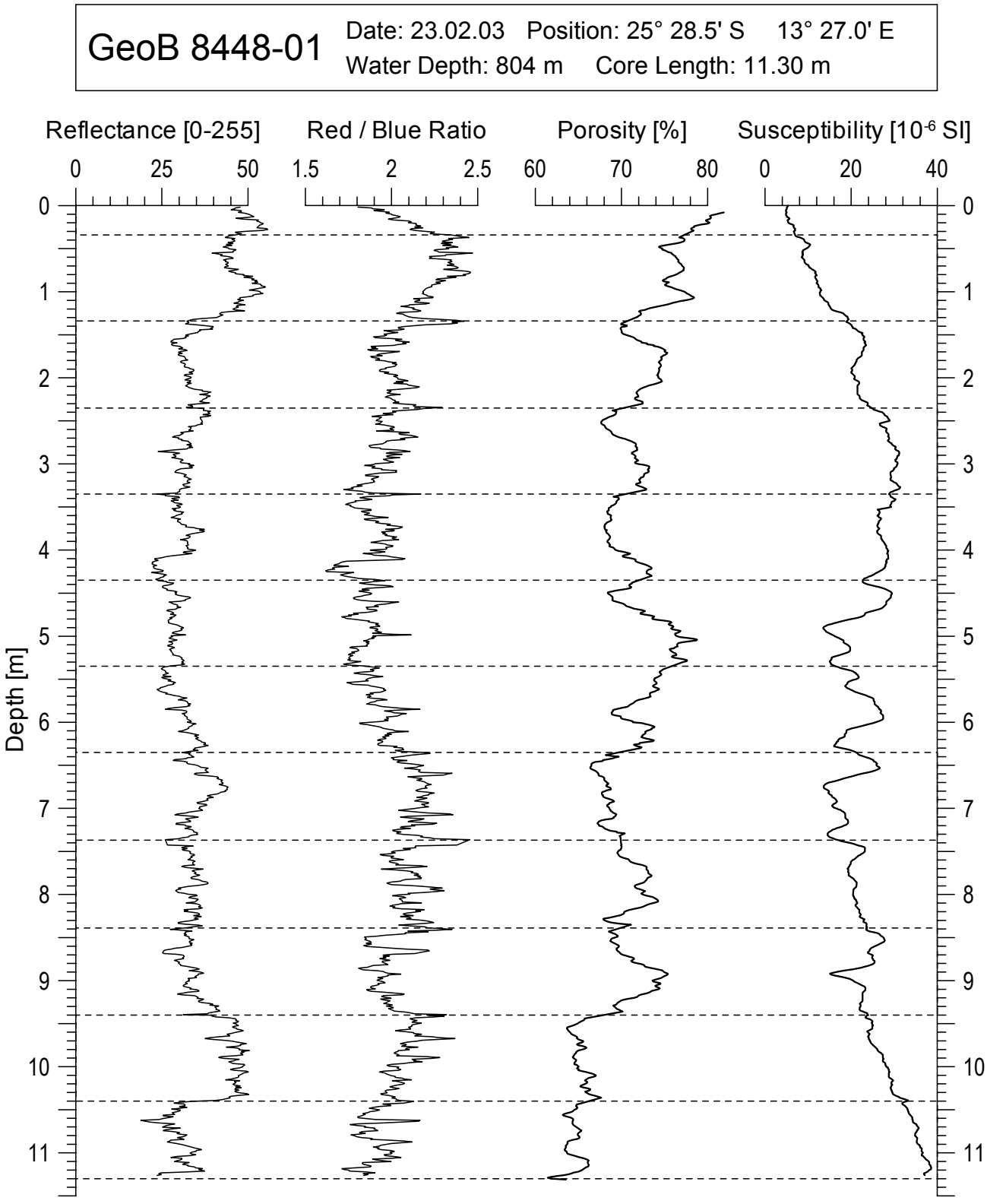


Fig. 4.3.11b Physical properties of gravity core GeoB 8448-1. The dashed lines indicate the ends of the 1m sections of the core.

GeoB 8449-03	Date: 23.02.03 Position: 25° 28.54' S 13° 33.2' E Water Depth: 607 m Core Length: 9.93 m

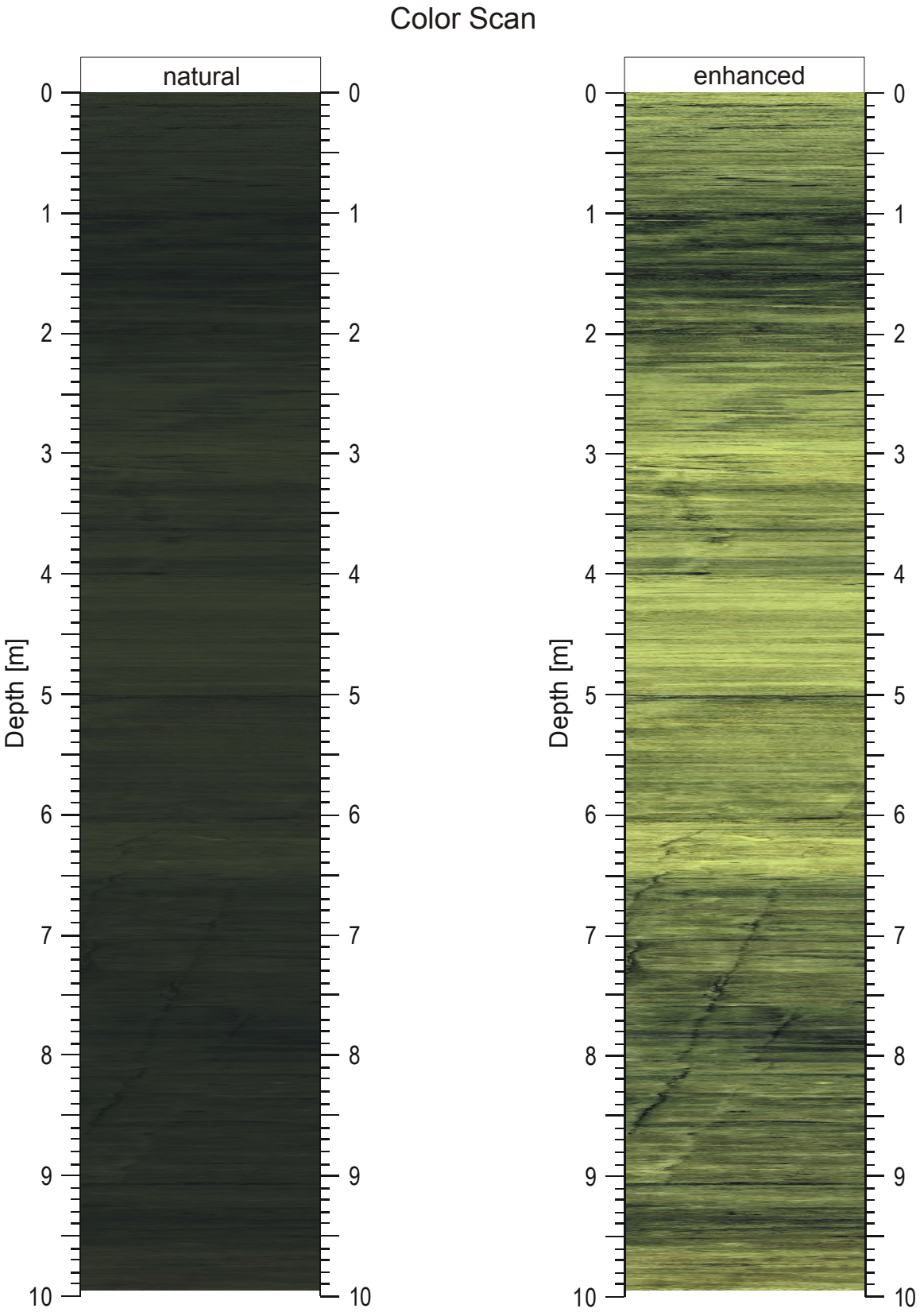


Fig. 4.3.12a Color scan of gravity core GeoB 8449-3 (upper 5 cm lost)

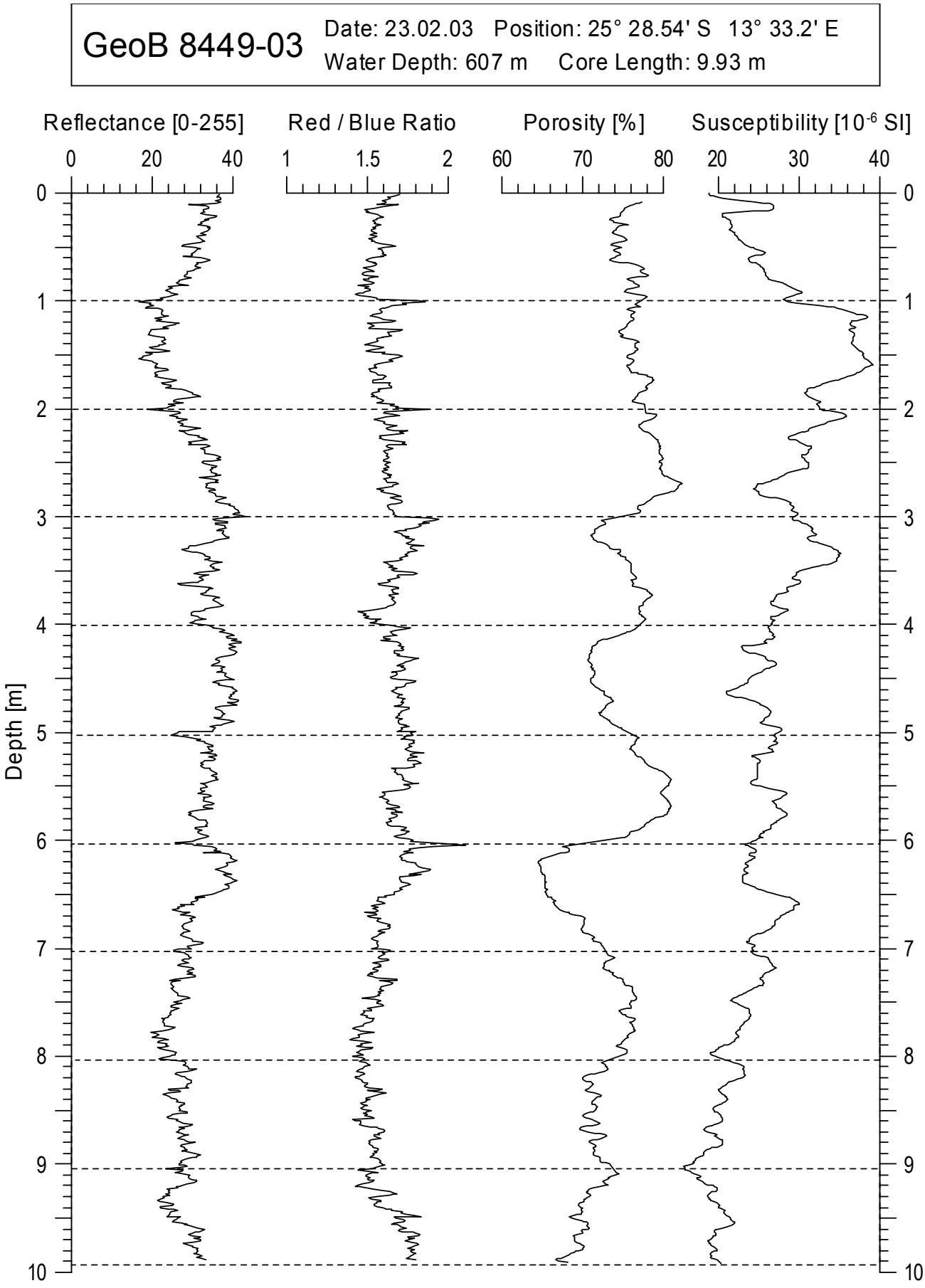


Fig. 4.3.12b Physical properties of gravity core GeoB 8449-3. The dashed lines indicate the ends of the 1m sections of the core.

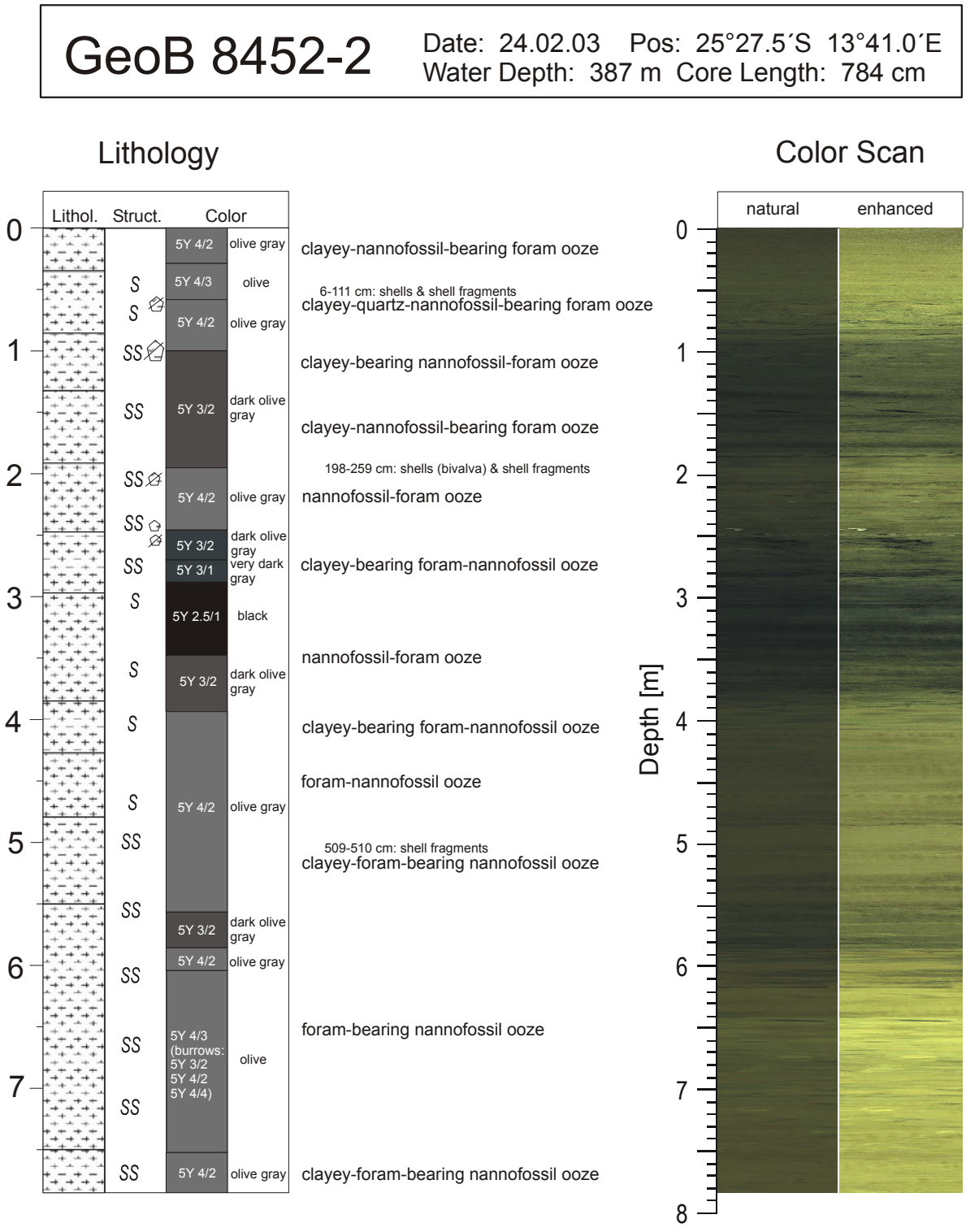


Fig. 4.3.13a Visual description of gravity core GeoB 8452-2.

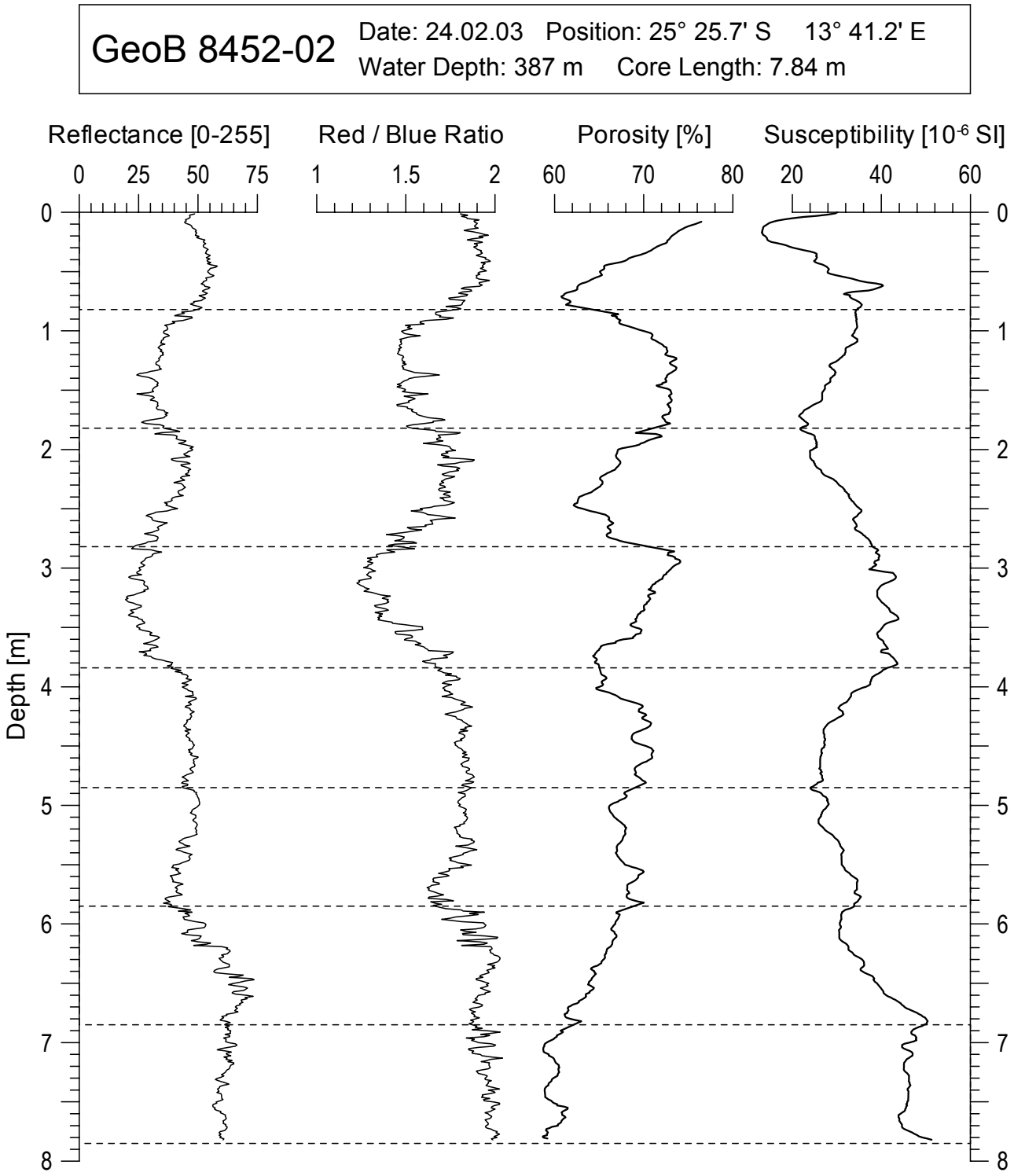


Fig. 4.3.13b Physical properties of gravity core GeoB 8452-2. The dashed lines indicate the ends of the 1m sections of the core.

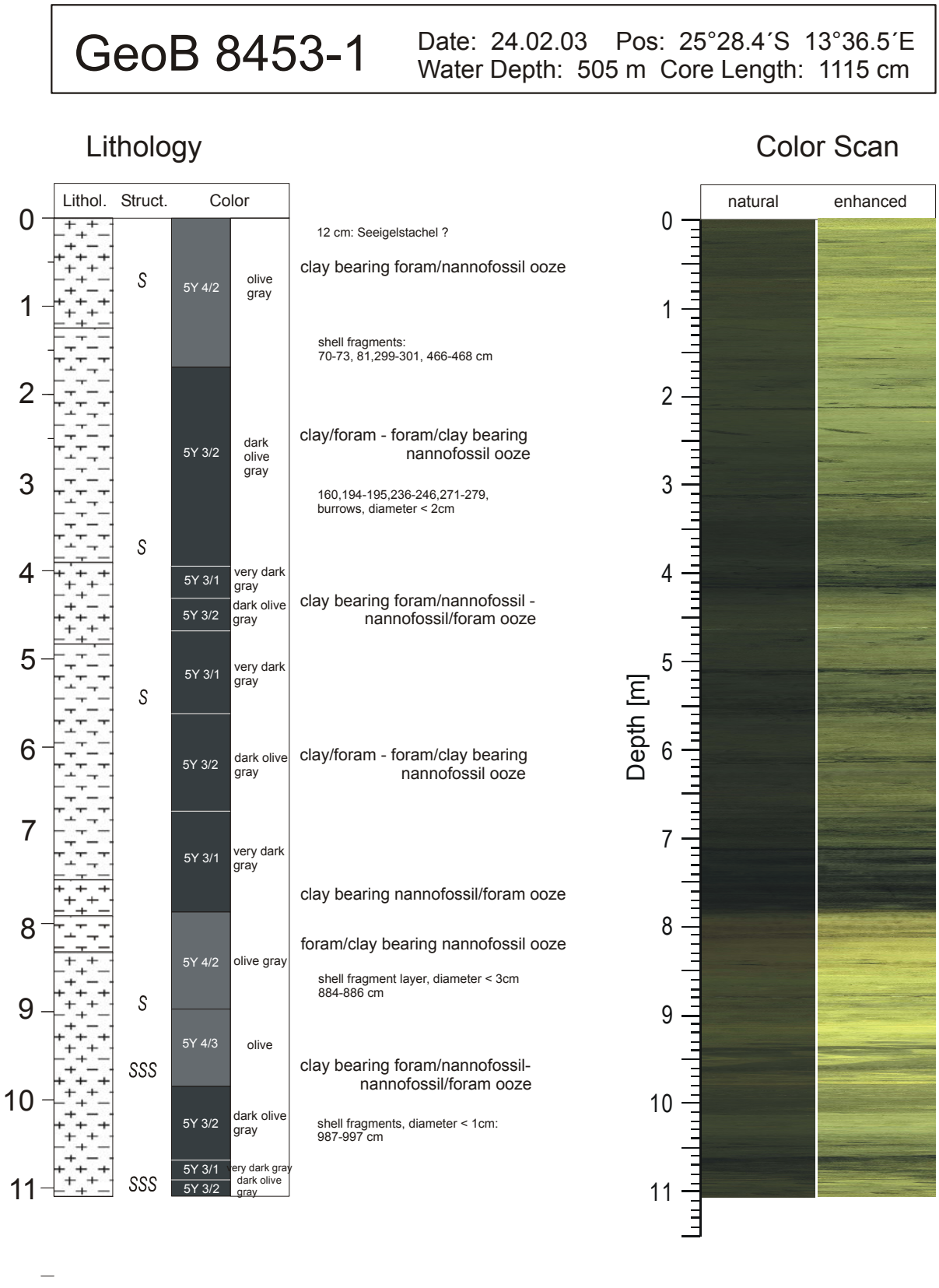


Fig. 4.3.14a Visual description of gravity core GeoB 8453-1.

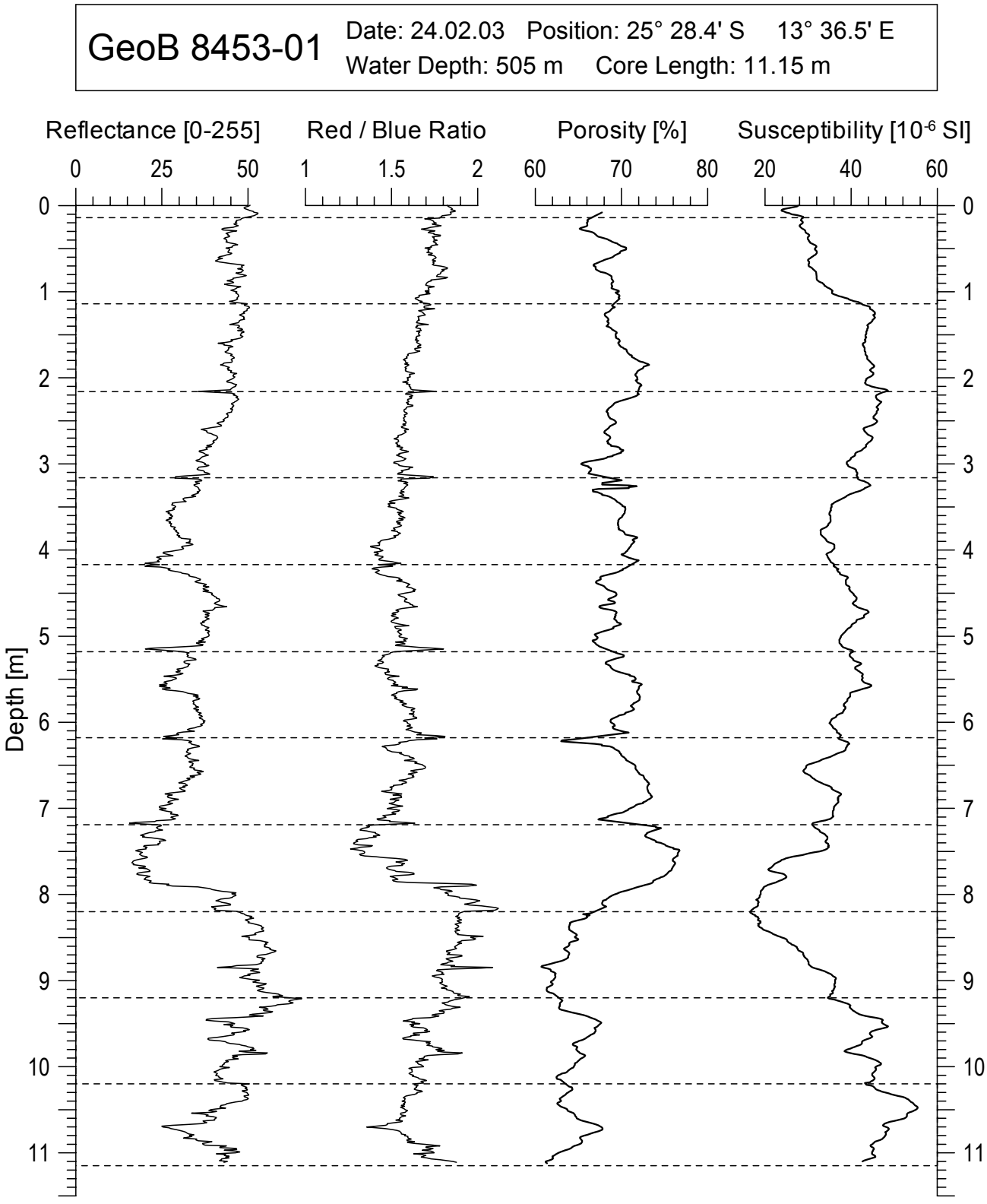


Fig. 4.3.14b Physical properties of gravity core GeoB 8453-1. The dashed lines indicate the ends of the 1m sections of the core.

GeoB 8455-02 Date: 24.02.03 Position: 25° 30.4' S 13° 11.0' E
Water Depth: 1502 m Core Length: 10.58 m

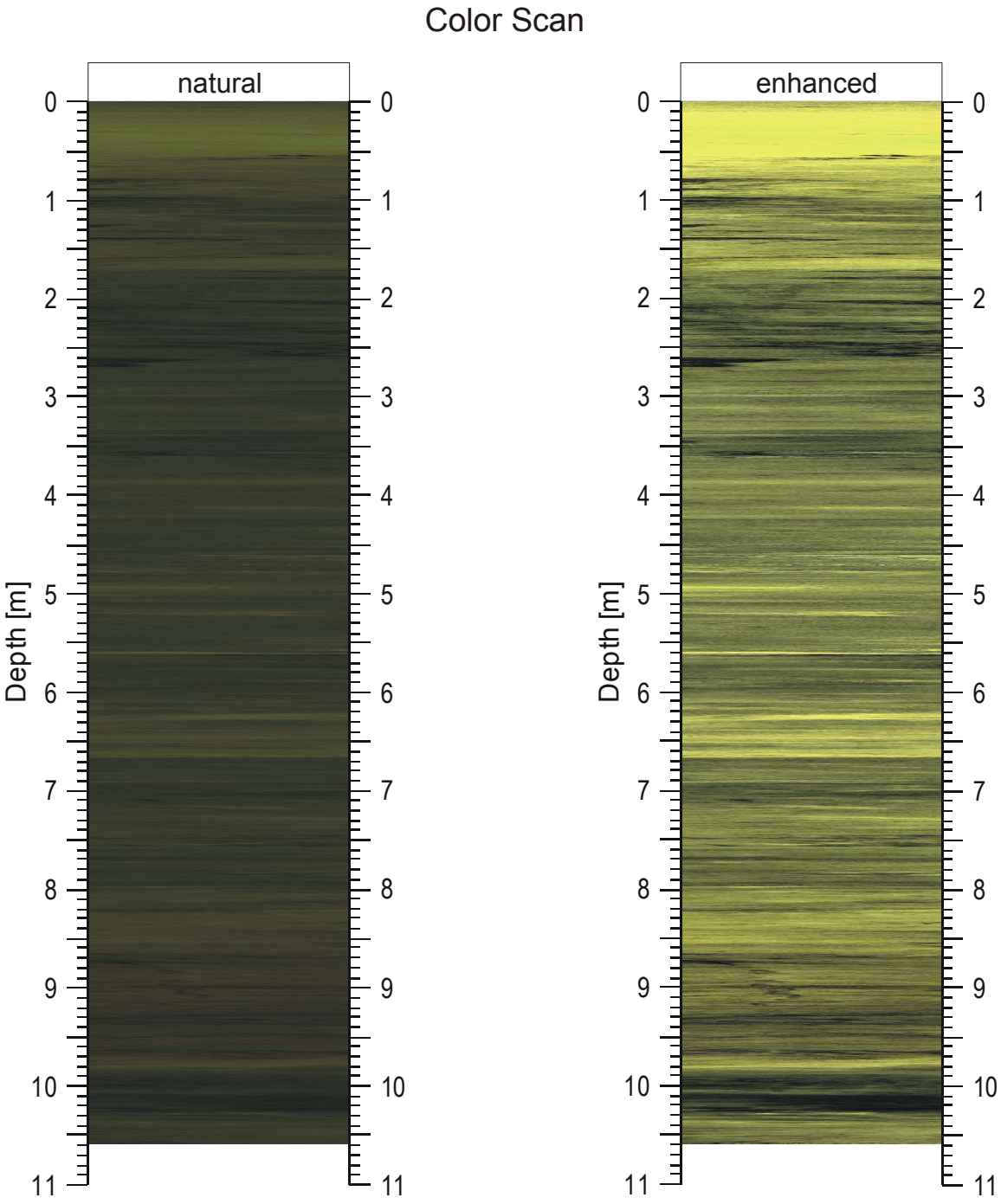


Fig. 4.3.15a Color scan of gravity core GeoB 8455-2 (for geochemical investigations)

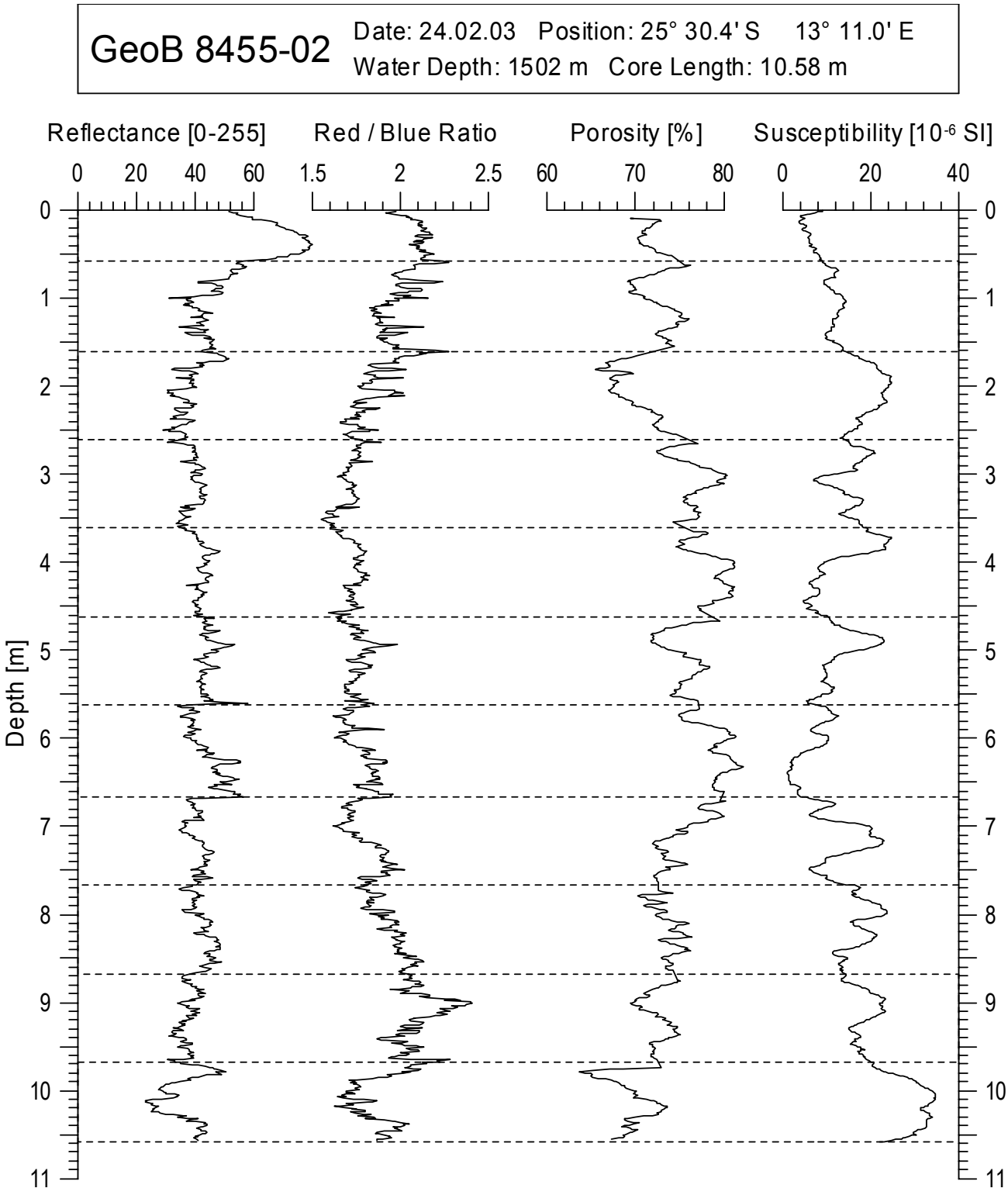


Fig. 4.3.15b Physical properties of gravity core GeoB 8455-2. The dashed lines indicate the ends of the 1m sections of the core.

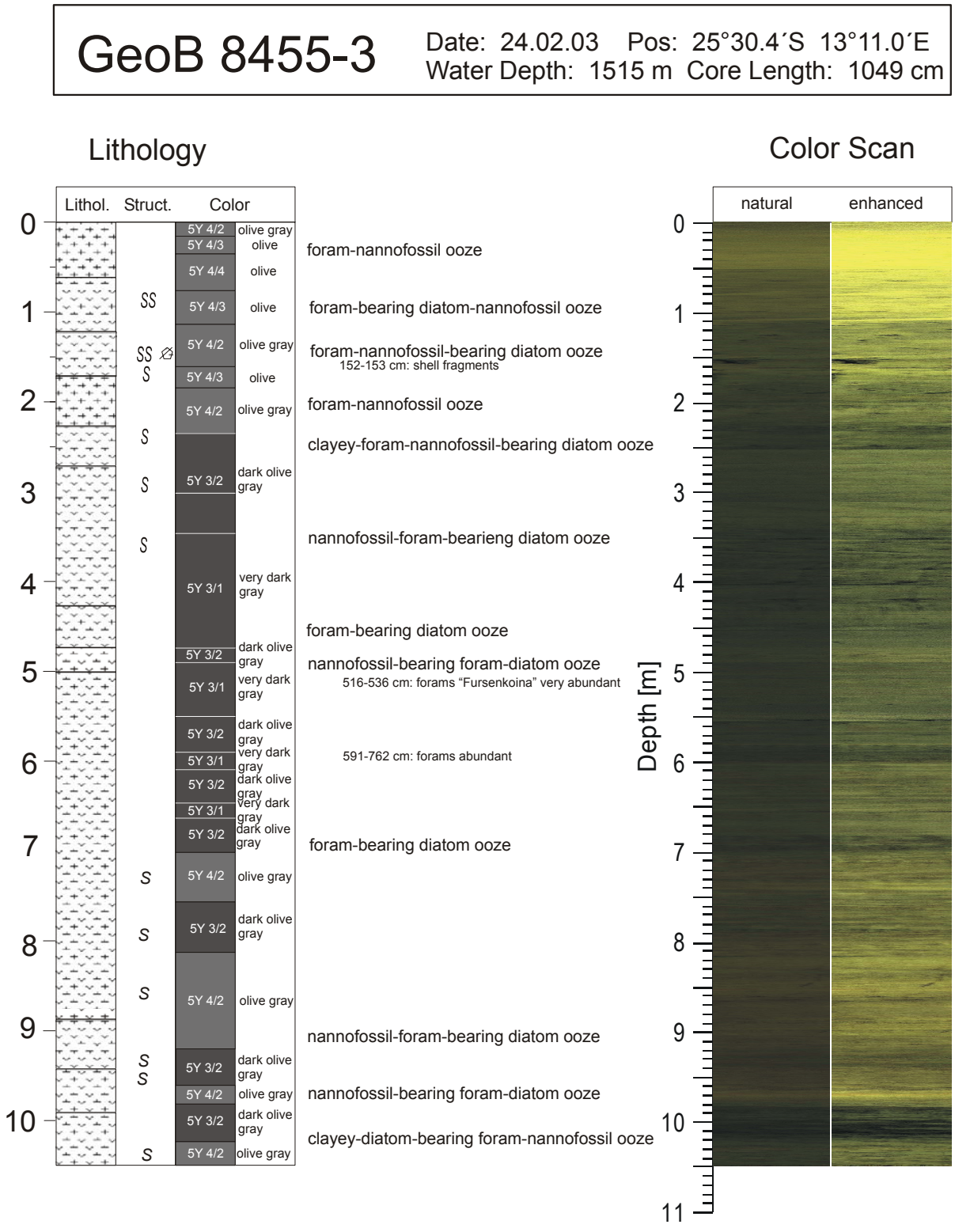


Fig. 4.3.16a Visual description of gravity core GeoB 8455-2.

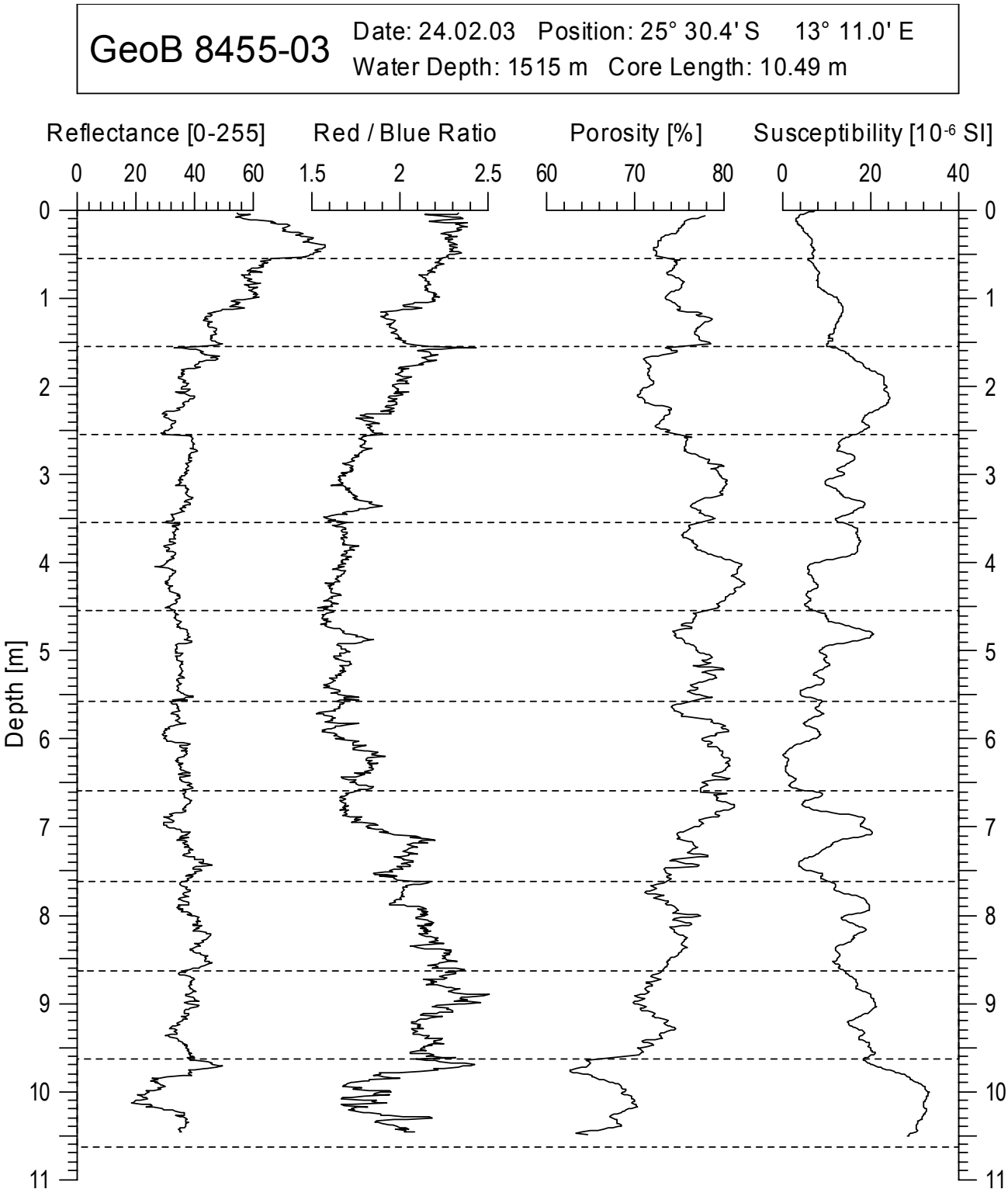


Fig. 4.3.16b Physical properties of gravity core GeoB 8455-3. The dashed lines indicate the ends of the 1m sections of the core.

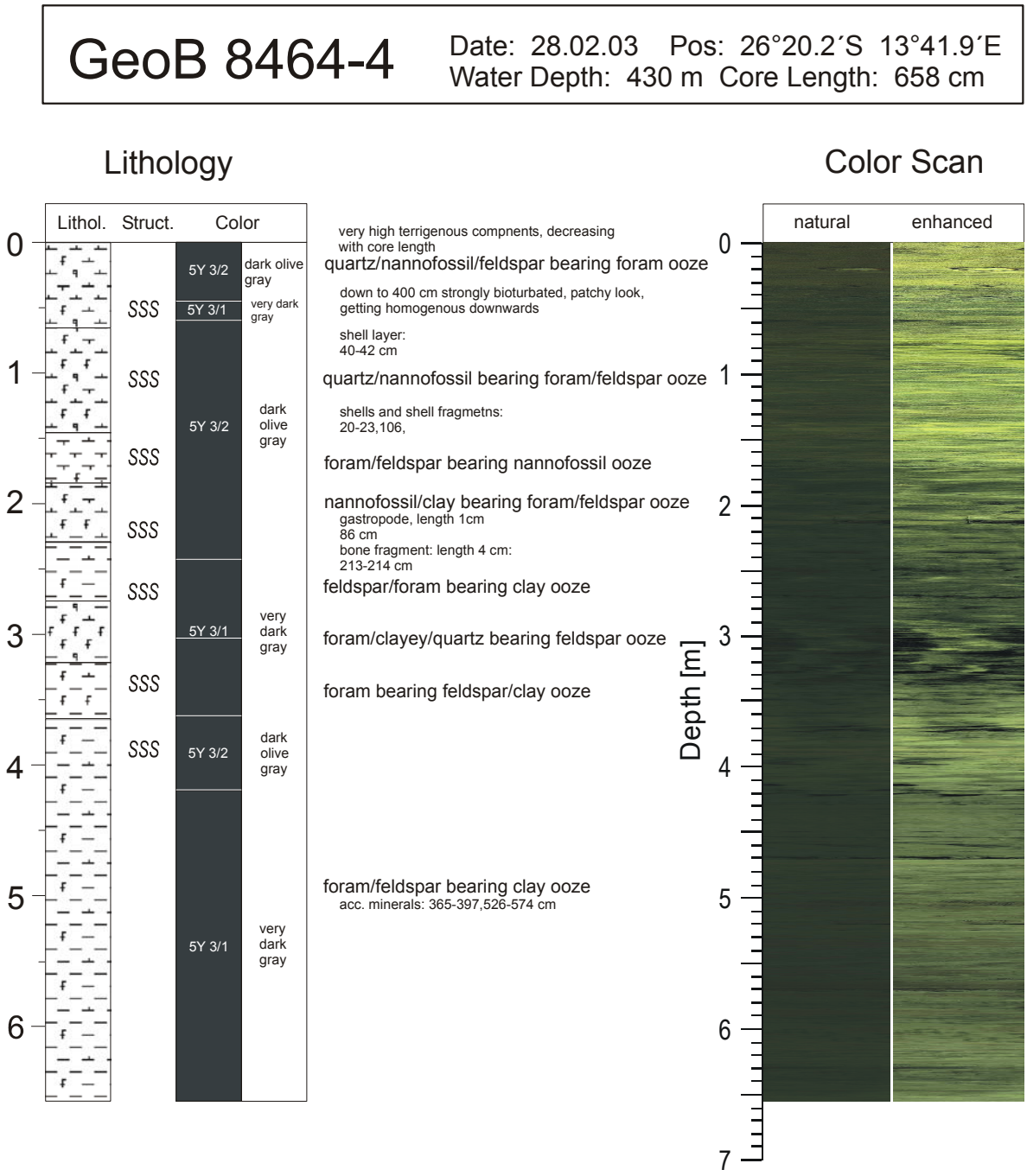


Fig. 4.3.17a Visual description of gravity core GeoB 8464-4.

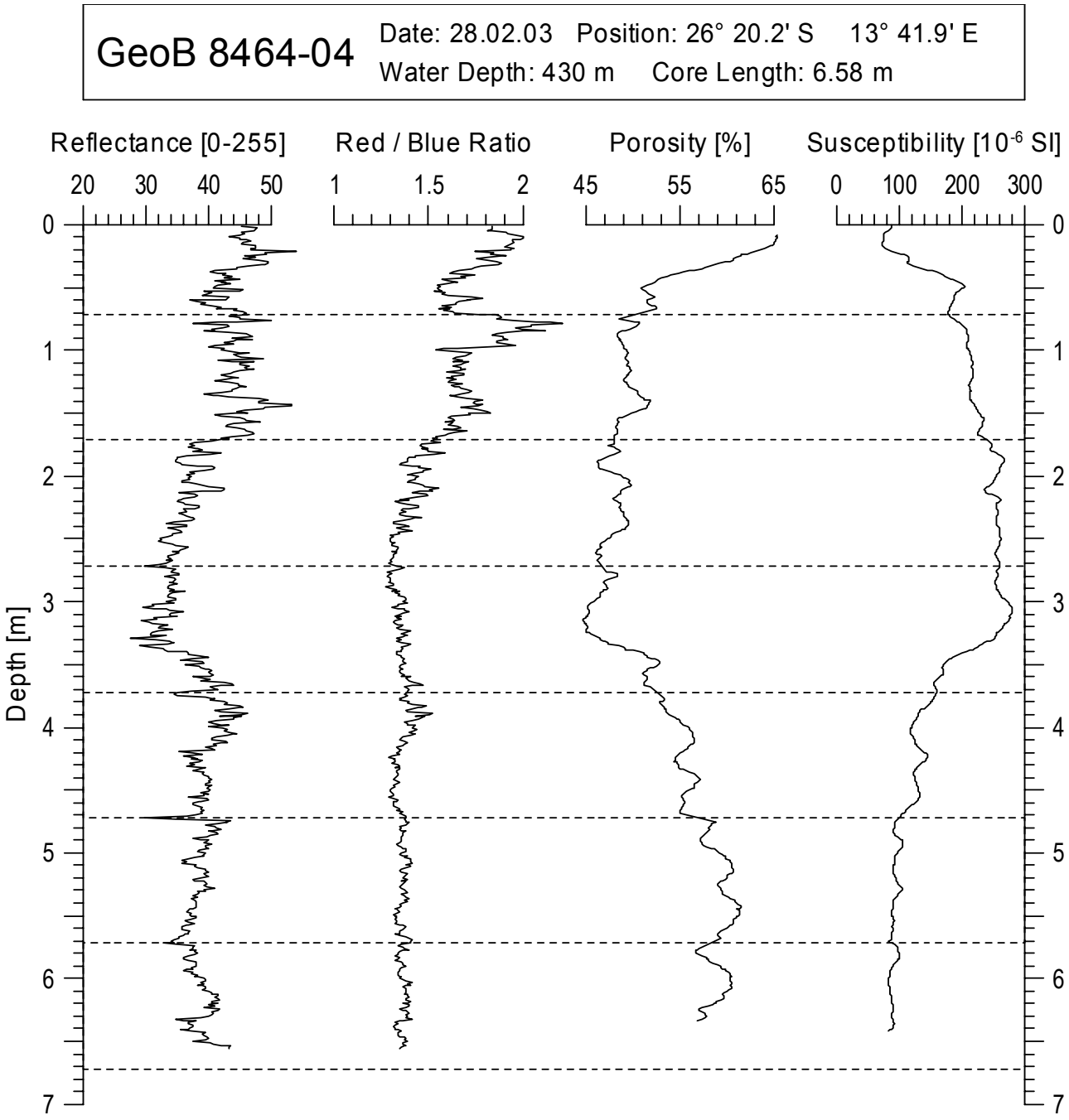


Fig. 4.3.17b Physical properties of gravity core GeoB 8464-4. The dashed lines indicate the ends of the 1m sections of the core.

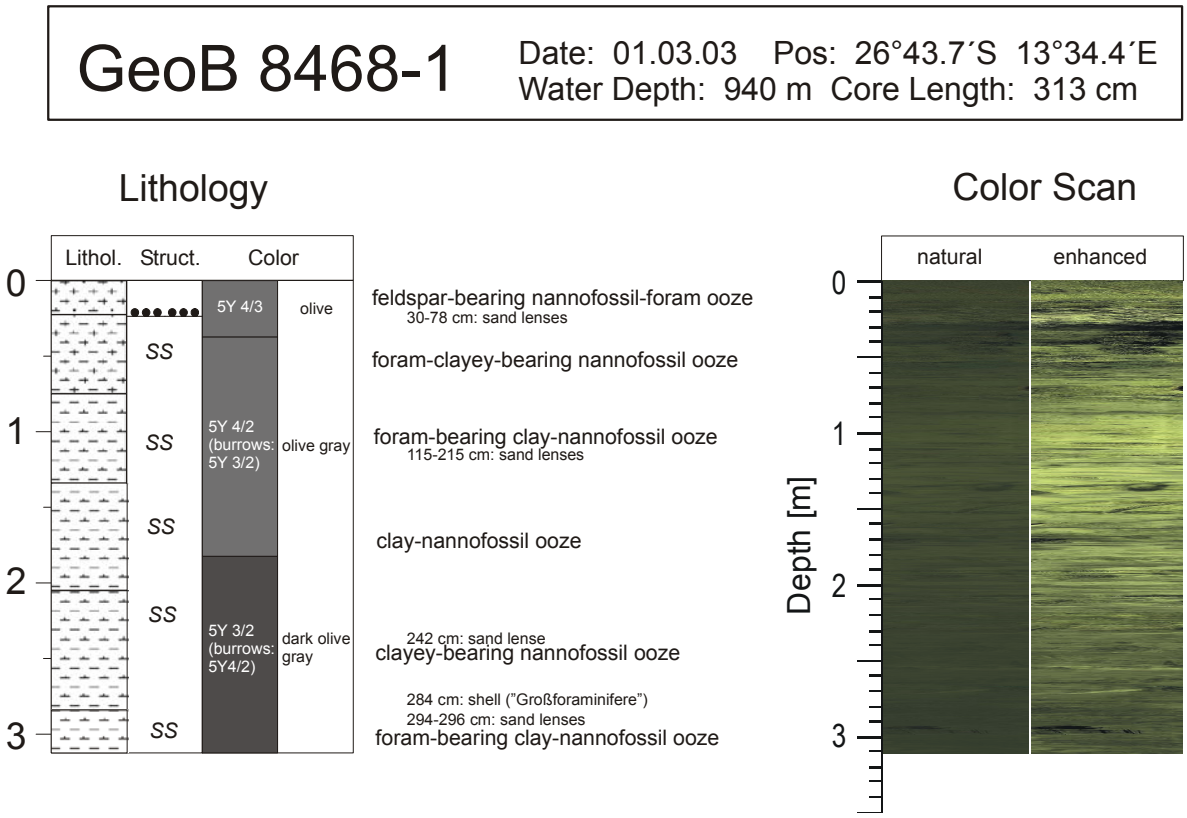


Fig. 4.3.18a Visual description of gravity core GeoB 8468-1.

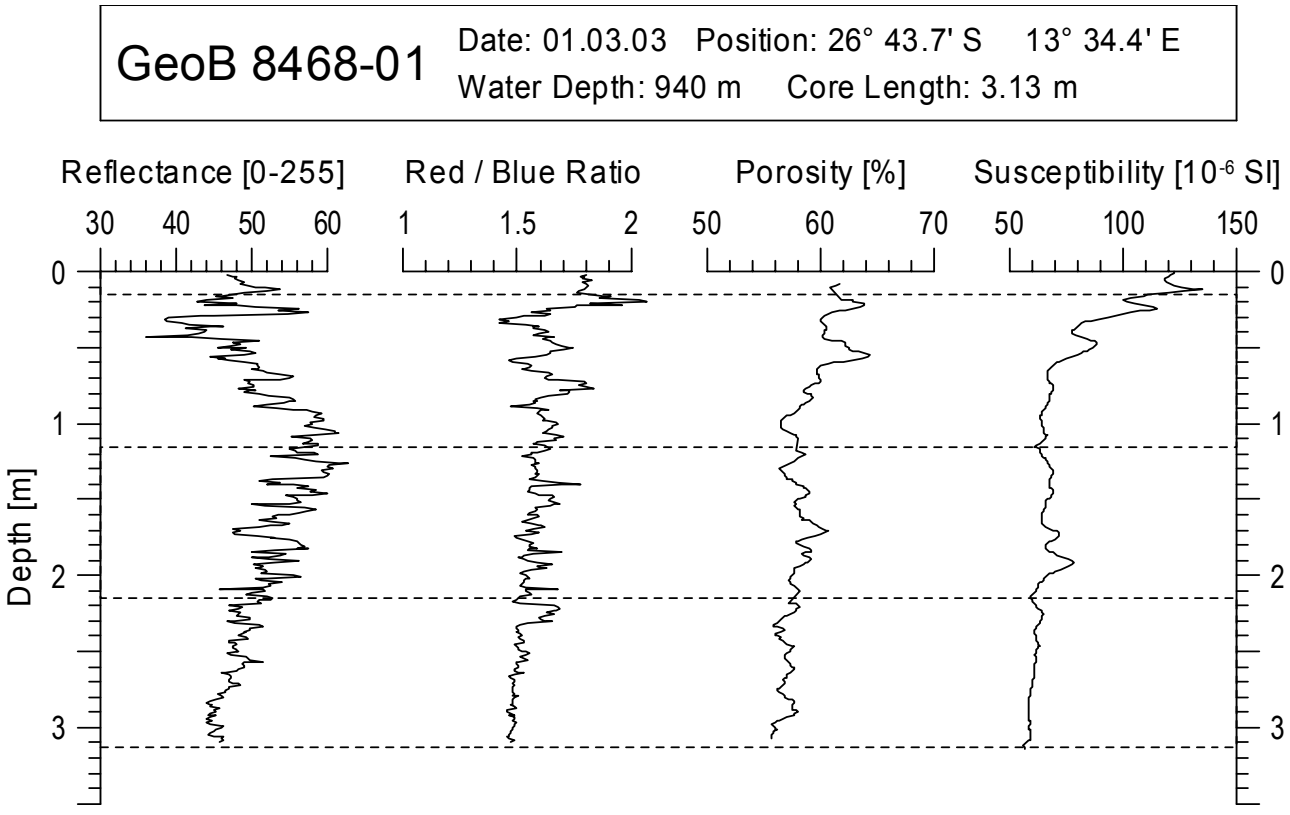


Fig. 4.3.18b Physical properties of gravity core GeoB 8468-1. The dashed lines indicate the ends of the 1m sections of the core.

GeoB 8469-1

Date: 01.03.03 Pos: 26°45.6´S 13°22.8´E
Water Depth: 1480 m Core Length: 1002 cm

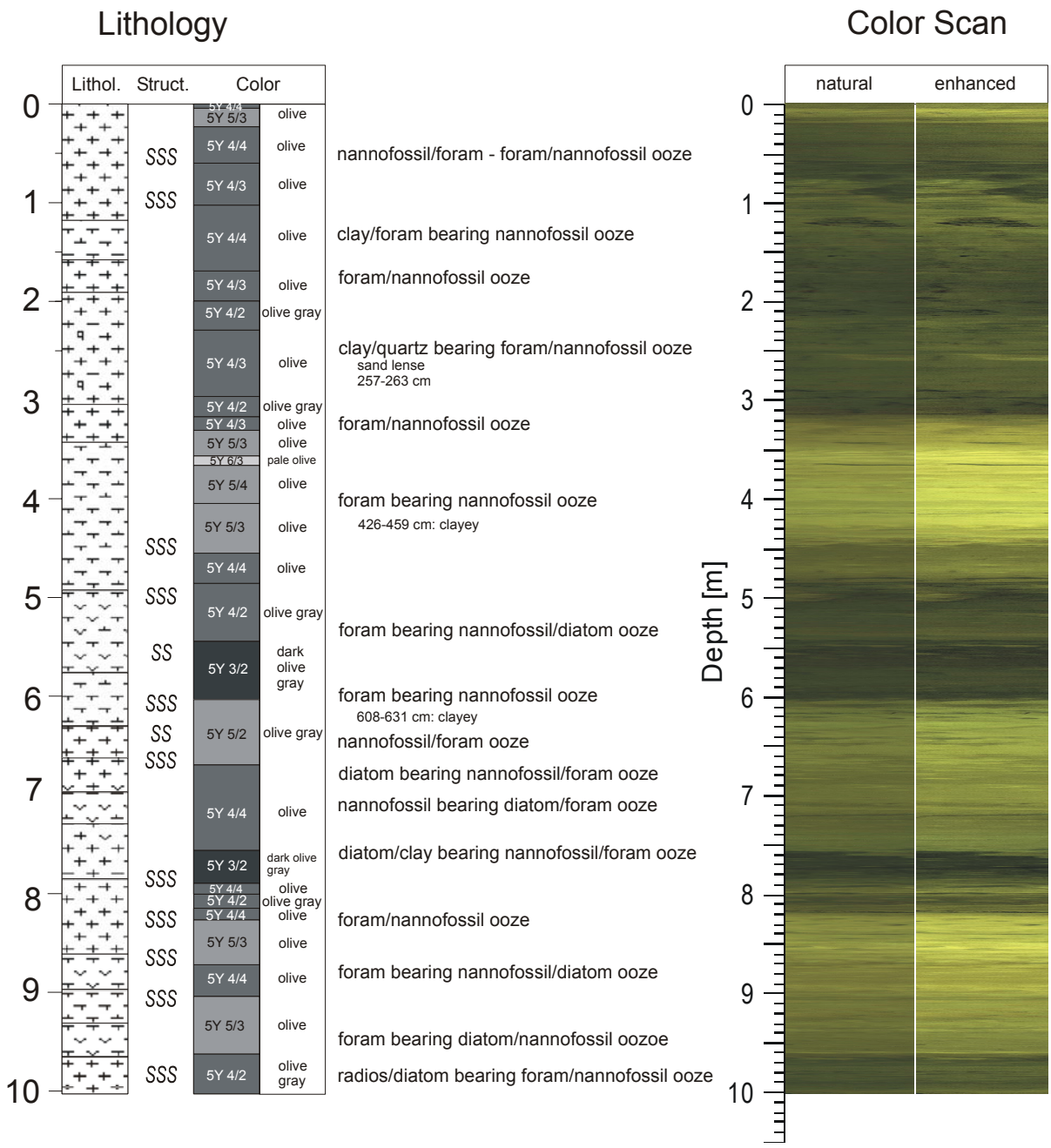


Fig. 4.3.19a Visual description of gravity core GeoB 8469-1.

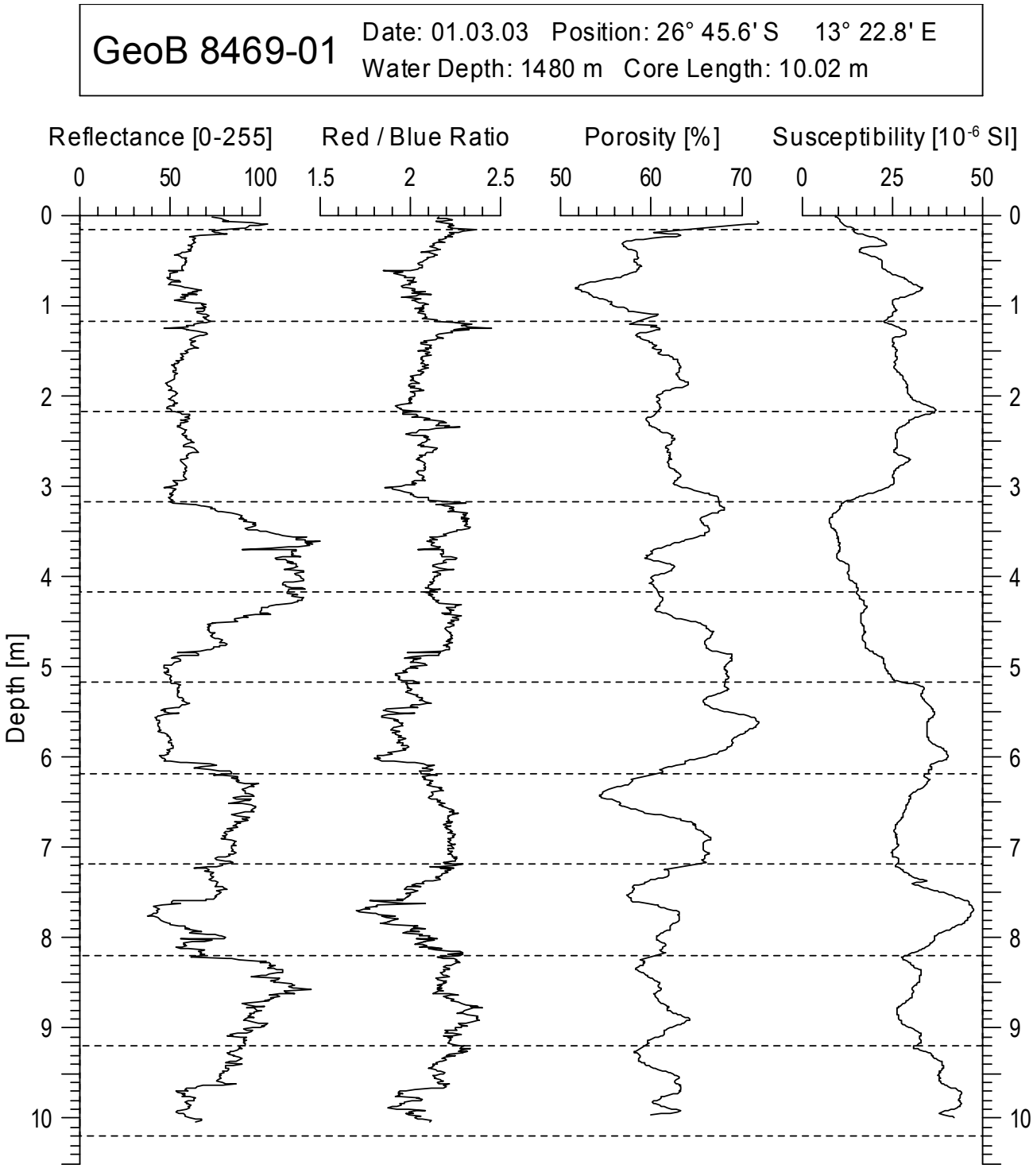


Fig. 4.3.19b Physical properties of gravity core GeoB 8469-1. The dashed lines indicate the ends of the 1m sections of the core.

GeoB 8470-04

Date: 02.03.03 Position: 25° 32.77' S 12° 51.67' E
Water Depth: 2469 m Core Length: 11.26 m

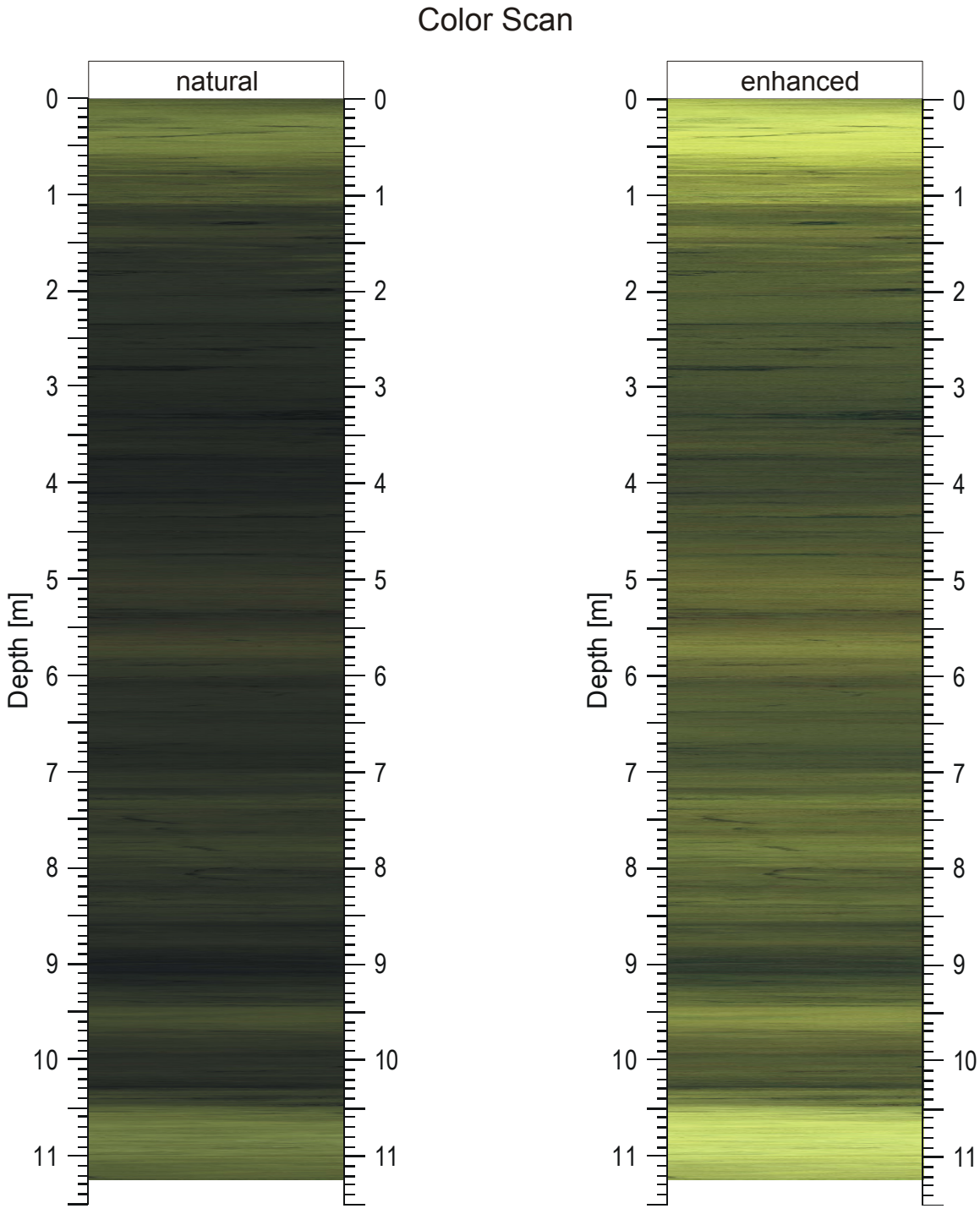


Fig. 4.3.20a Color scan of gravity core GeoB 8470-4 (for geochemical investigations)

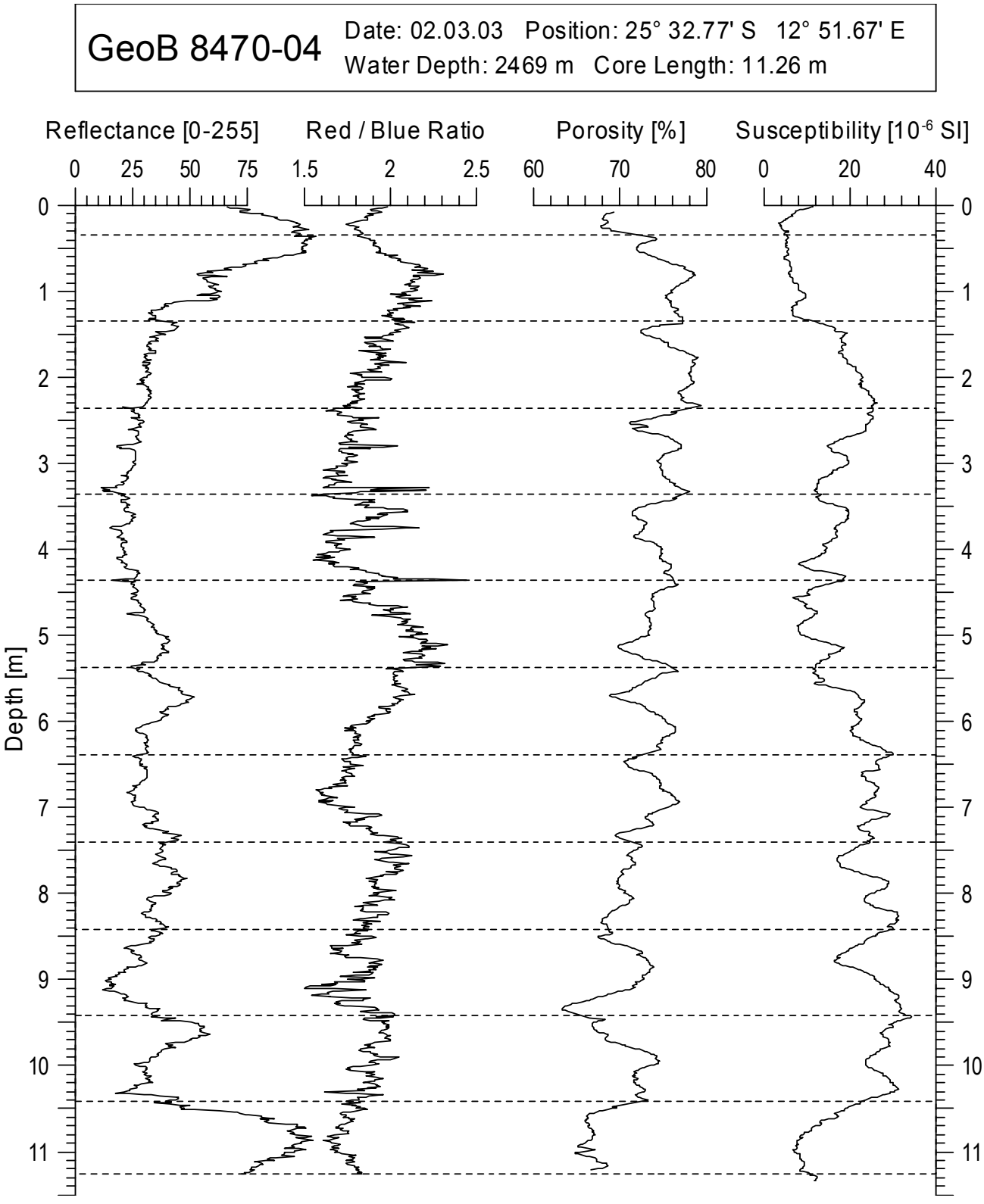


Fig. 4.3.20b Physical properties of gravity core GeoB 8470-4. The dashed lines indicate the ends of the 1m sections of the core.

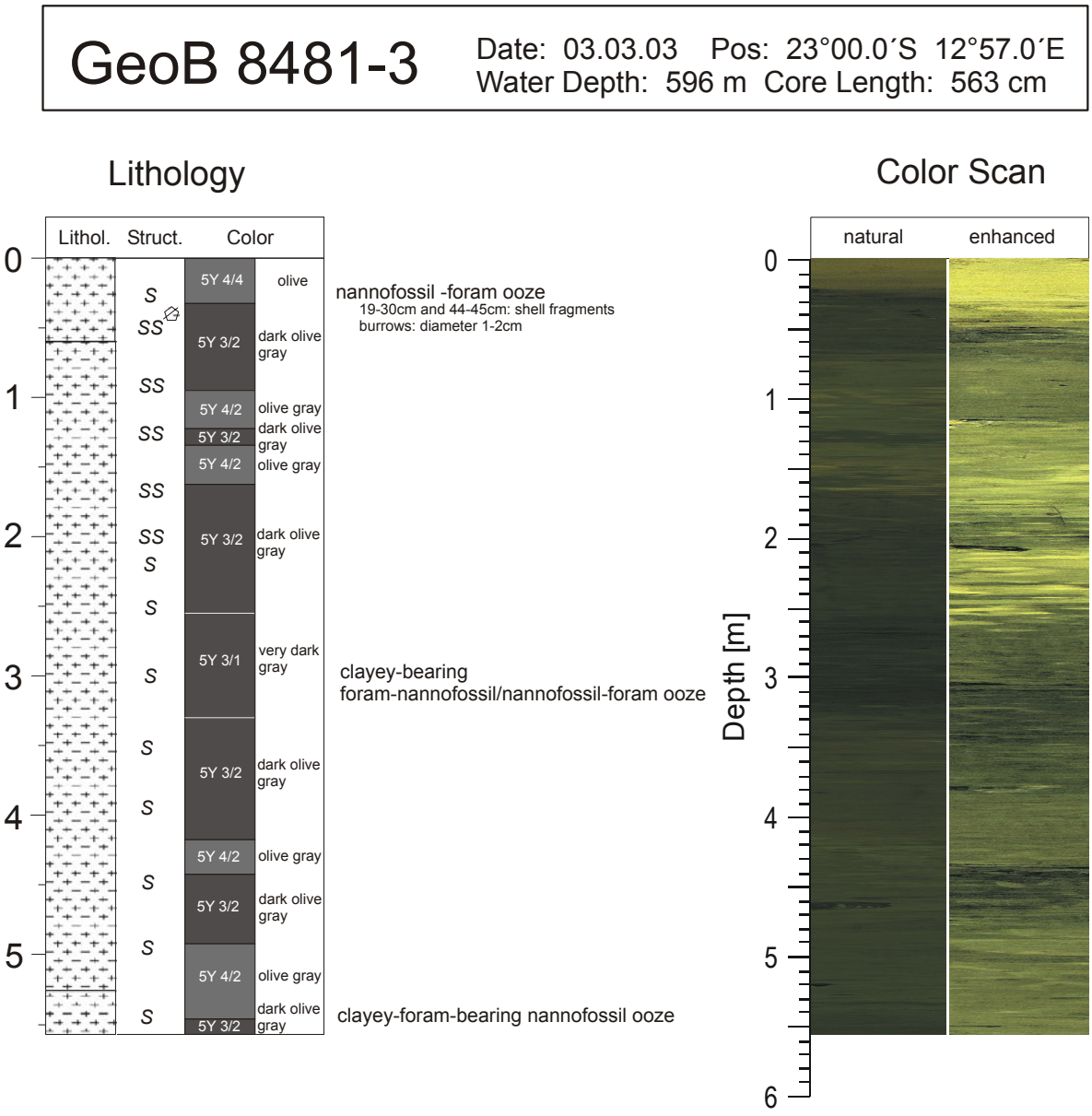


Fig. 4.3.21a Visual description of gravity core GeoB 8481-3

.

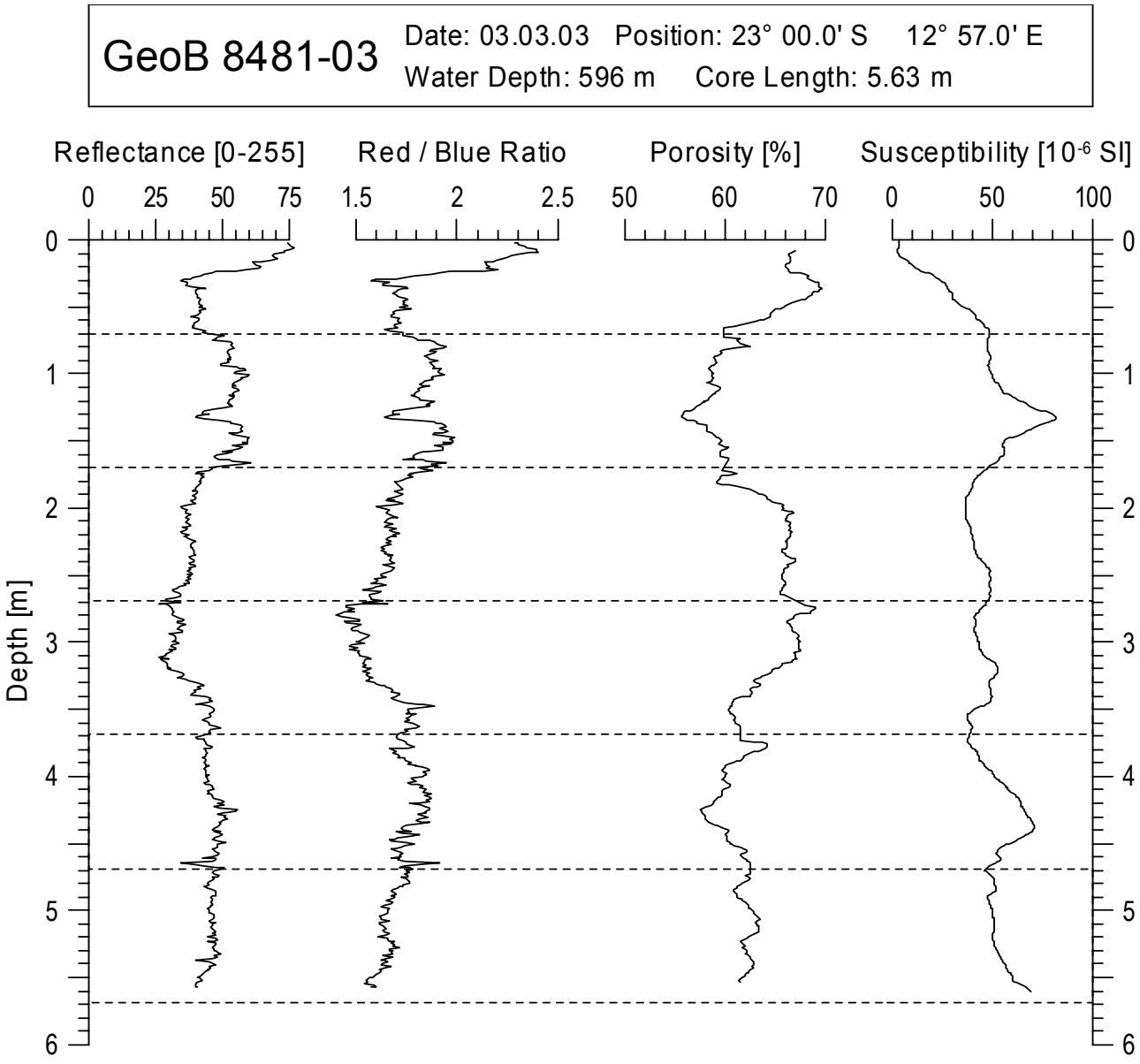


Fig. 4.3.21b Physical properties of gravity core GeoB 8481-3. The dashed lines indicate the ends of the 1m sections of the core.

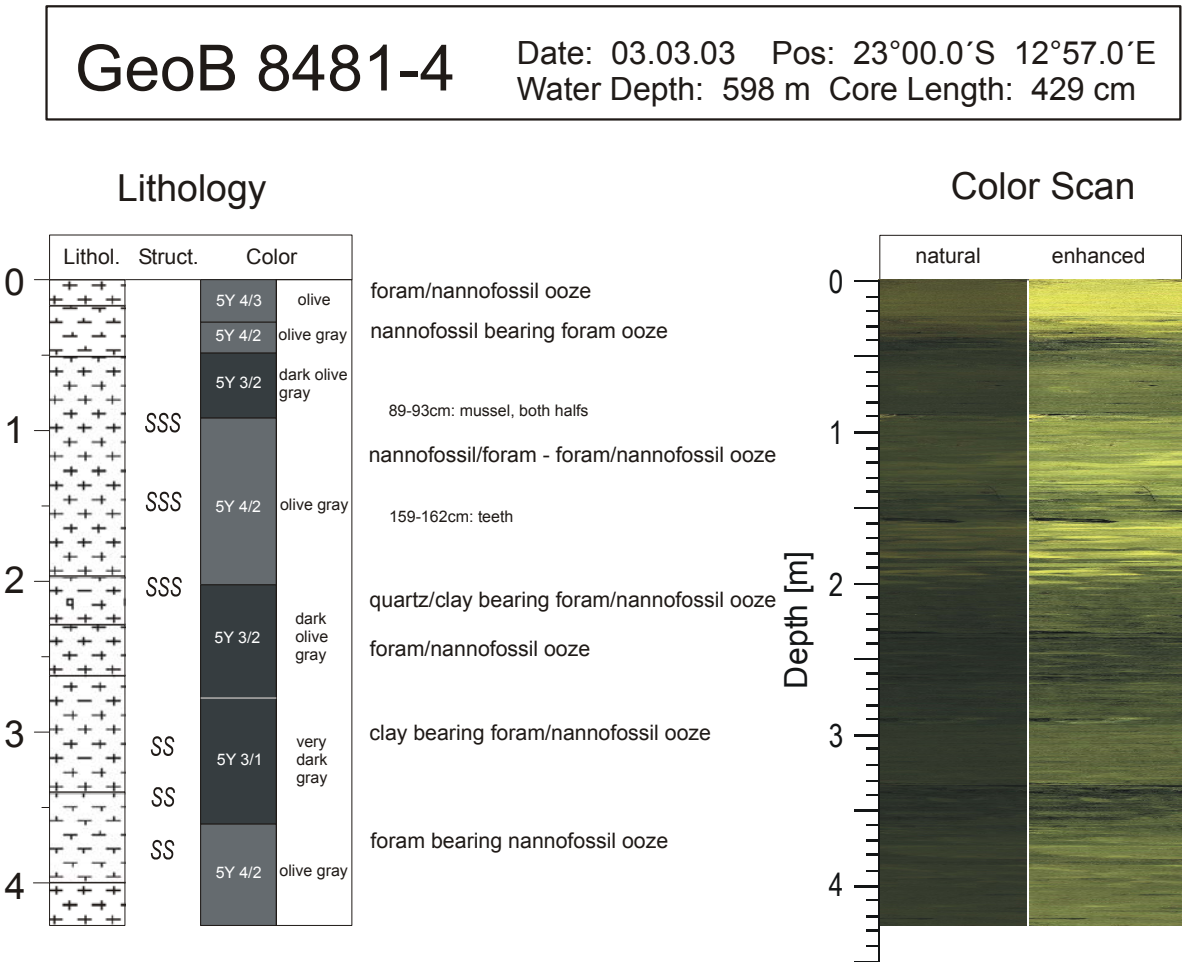


Fig. 4.3.22a Visual description of gravity core GeoB 8481-4.

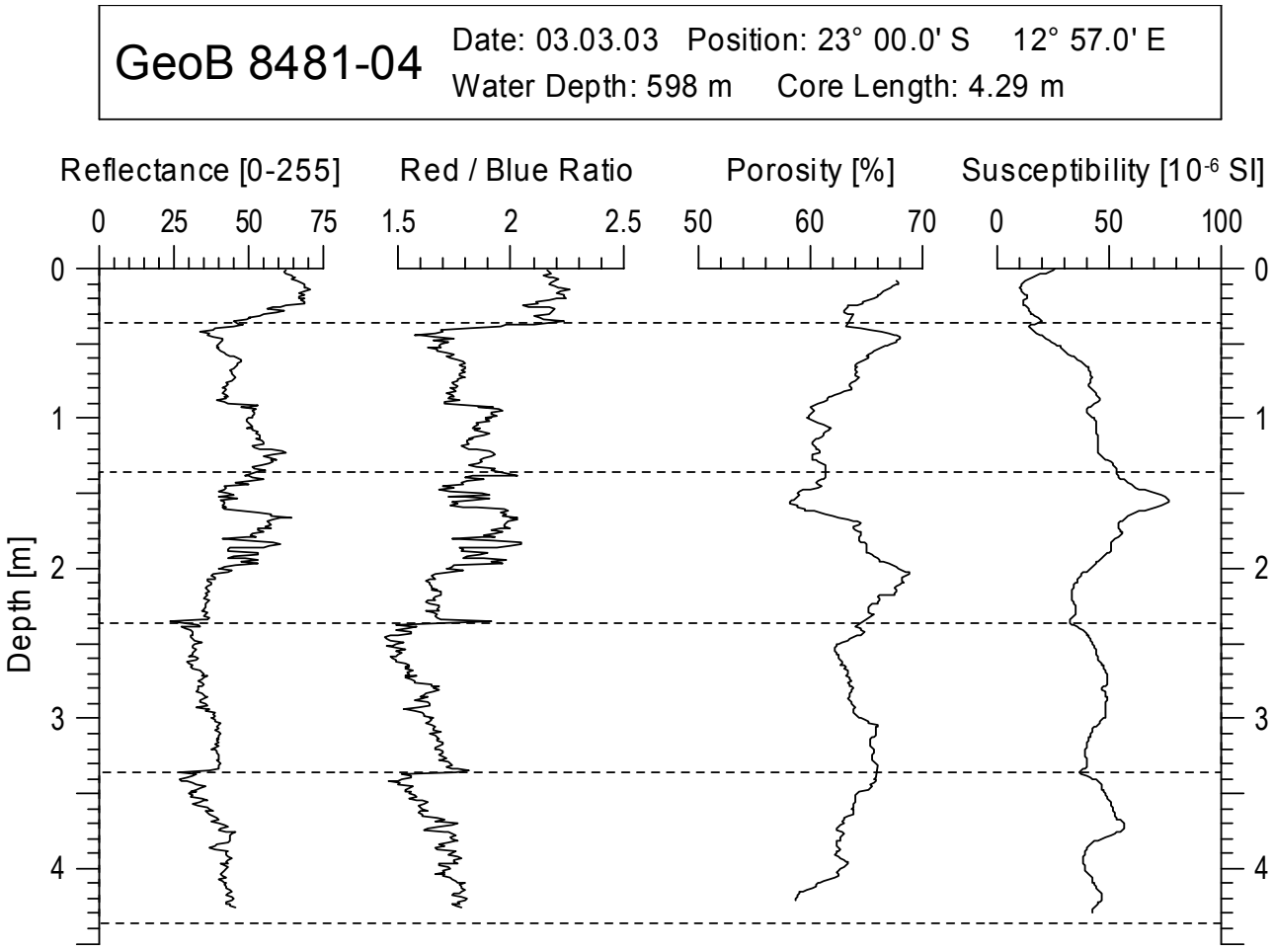


Fig. 4.3.22b Physical properties of gravity core GeoB 8481-4. The dashed lines indicate the ends of the 1m sections of the core.

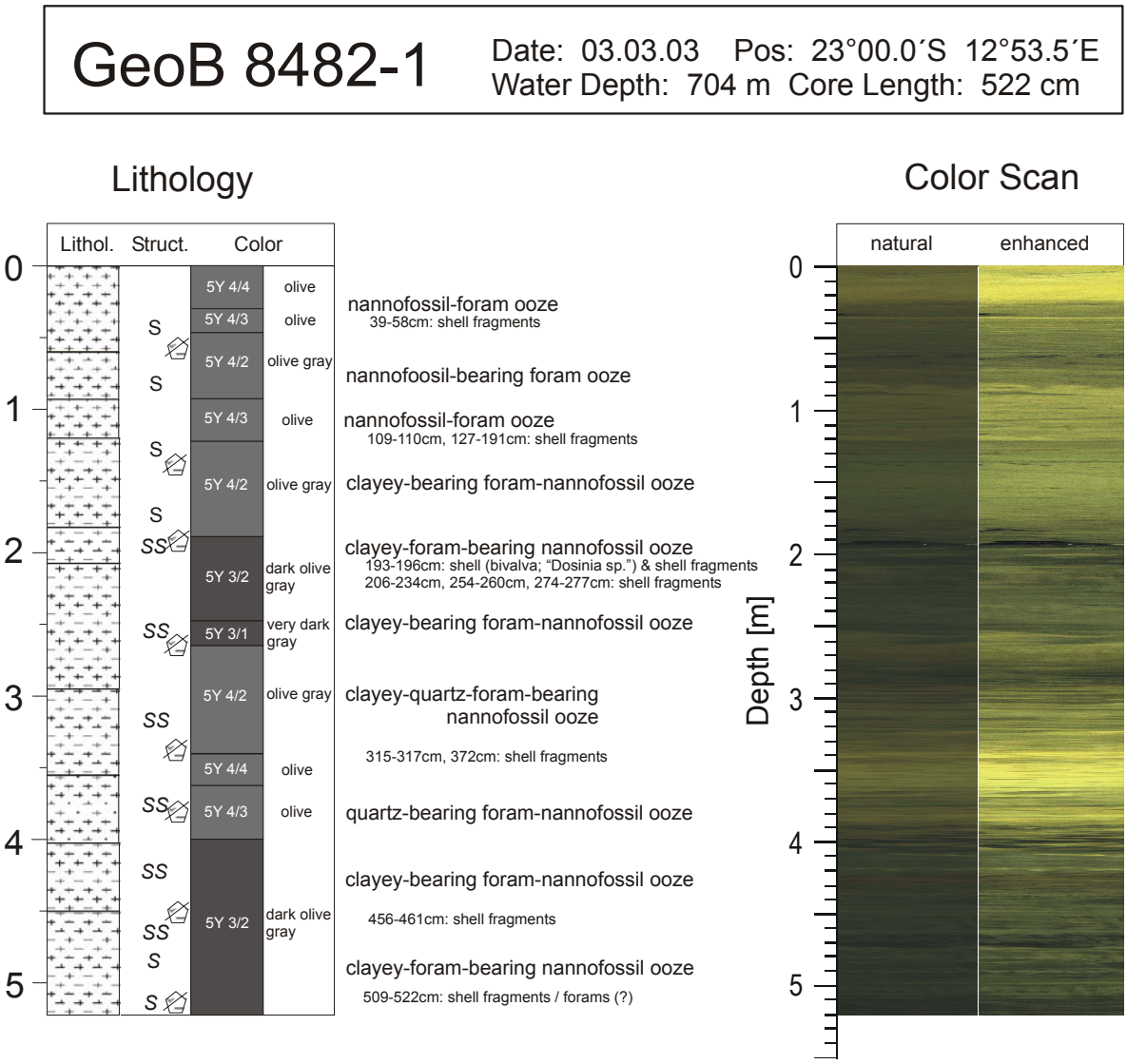


Fig. 4.3.23a Visual description of gravity core GeoB 8482-1.

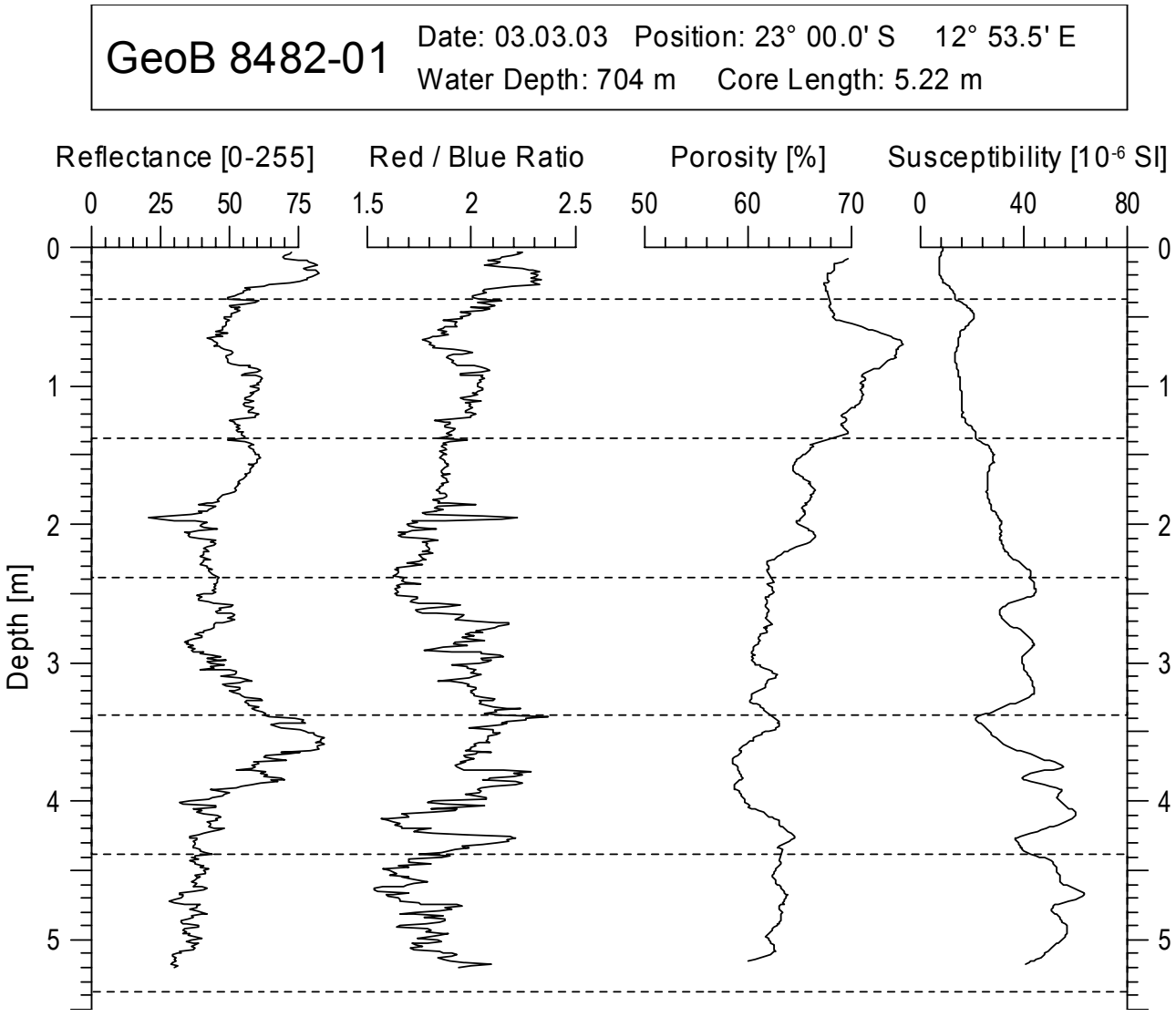


Fig. 4.3.23b Physical properties of gravity core GeoB 8482-1. The dashed lines indicate the ends of the 1m sections of the core.

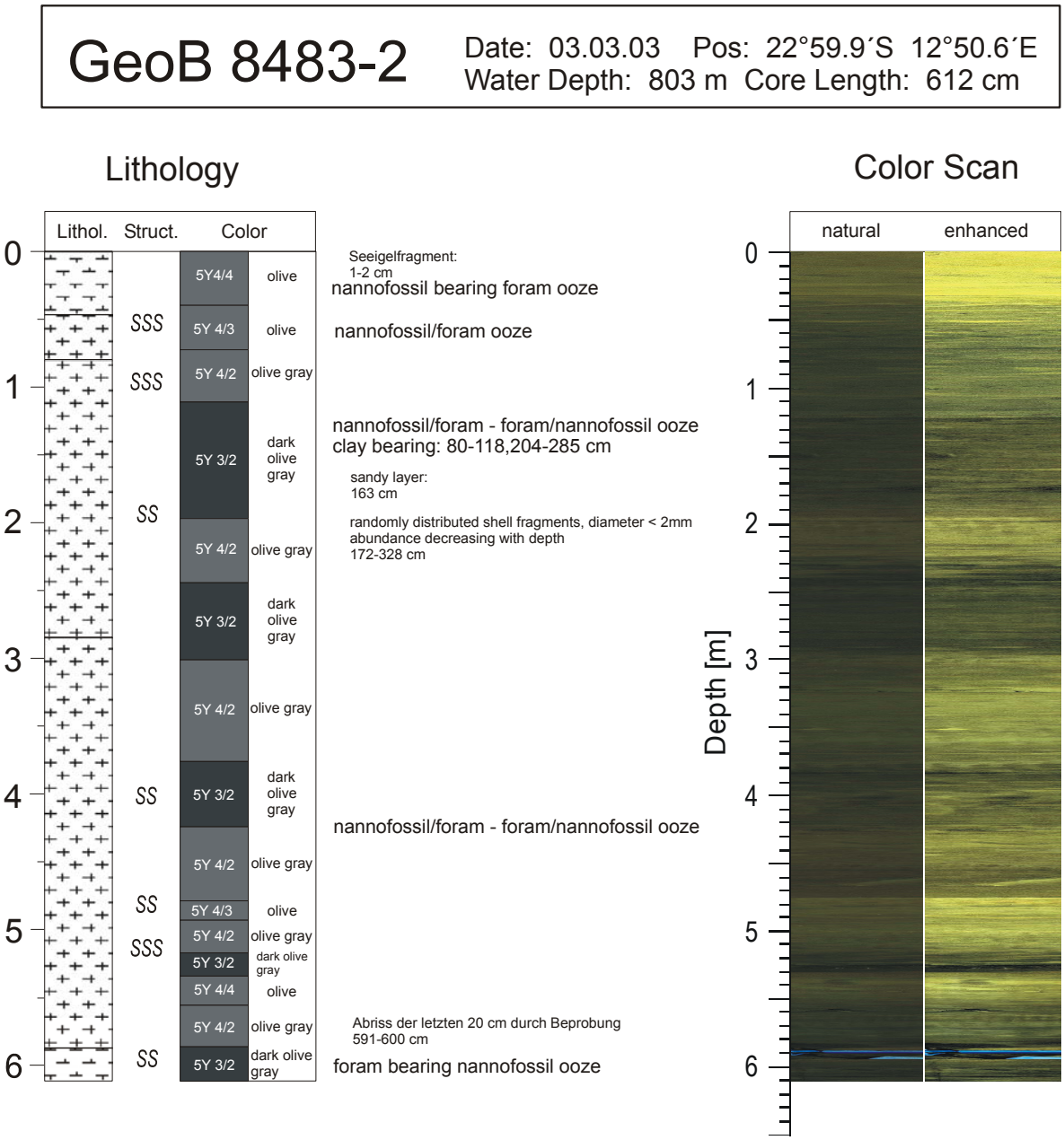


Fig. 4.3.24a Visual description of gravity core GeoB 8483-2.

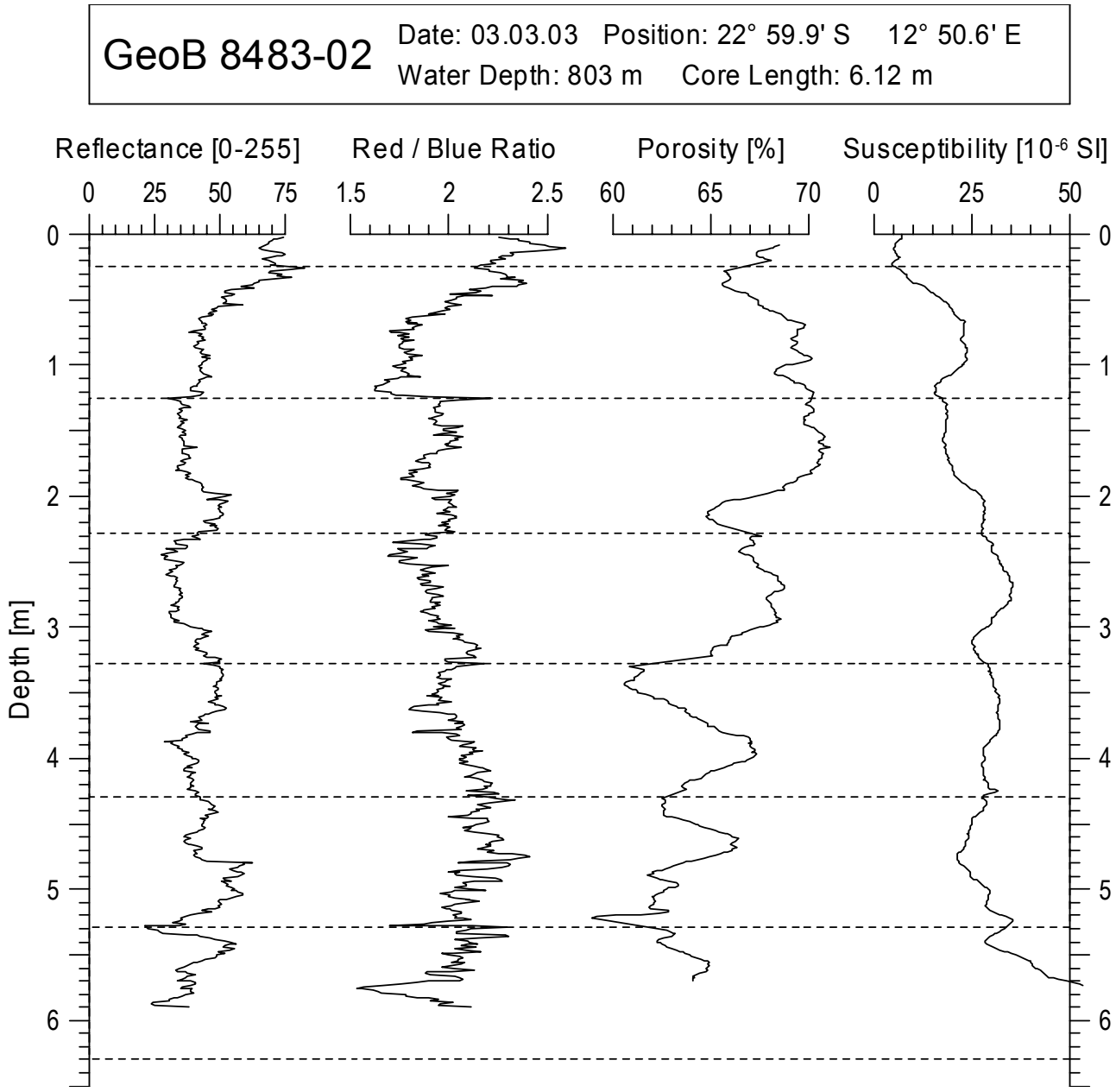


Fig. 4.3.24b Physical properties of gravity core GeoB 8483-2. The dashed lines indicate the ends of the 1m sections of the core.

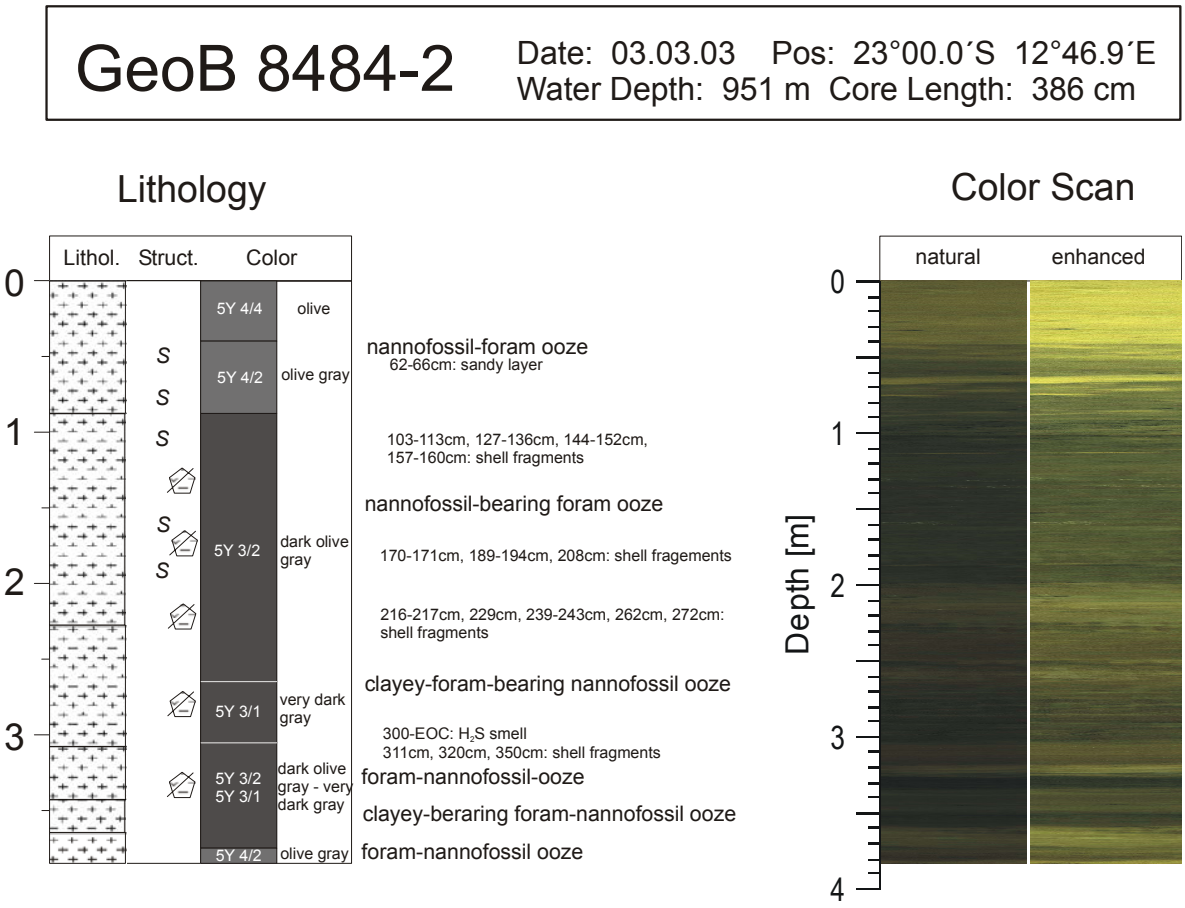


Fig. 4.3.25a Visual description of gravity core GeoB 8484-2.

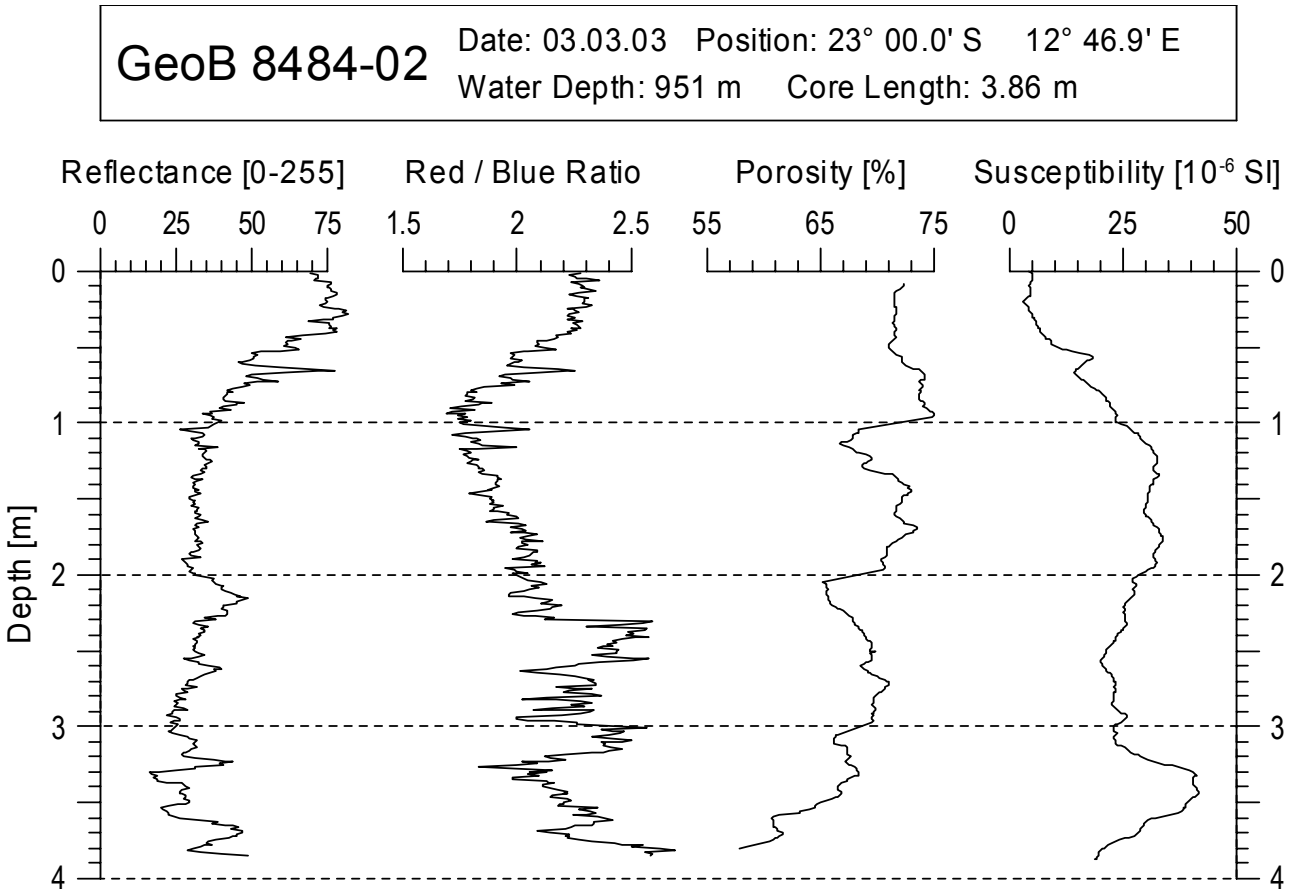


Fig. 4.3.25b Physical properties of gravity core GeoB 8484-2. The dashed lines indicate the ends of the 1m sections of the core.

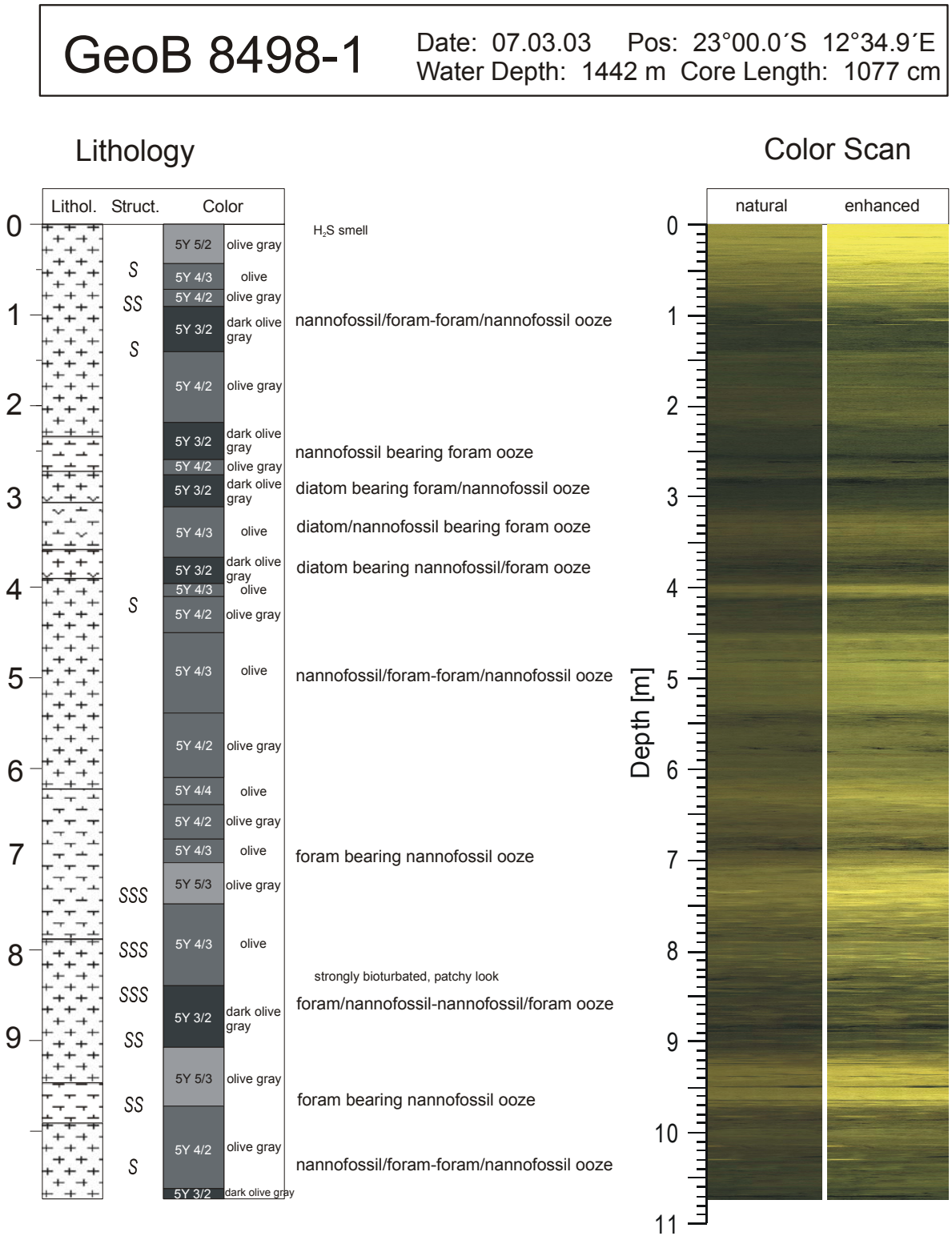


Fig. 4.3.26a Visual description of gravity core GeoB 8498-1.

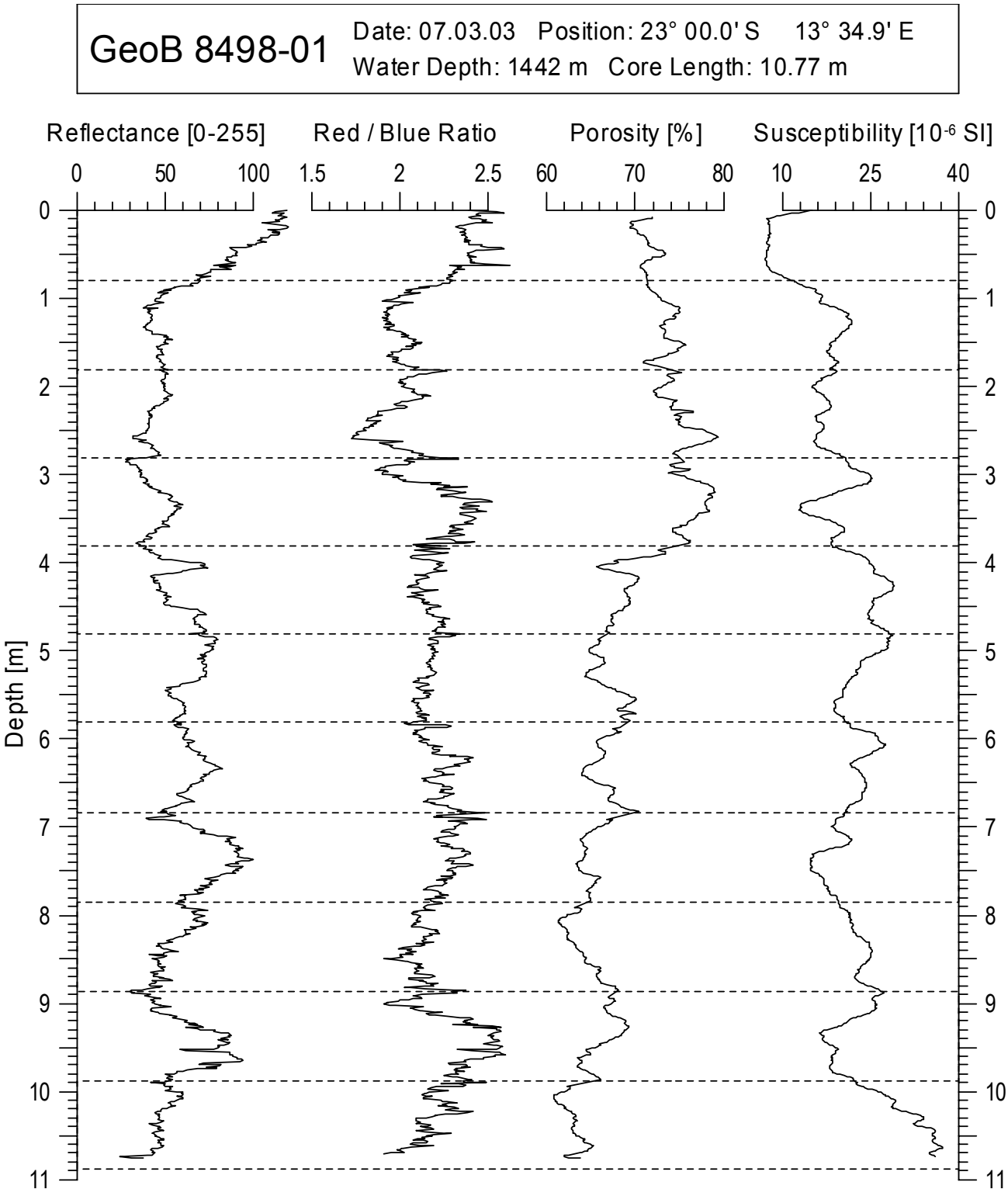


Fig. 4.3.26b Physical properties of gravity core GeoB 8498-1. The dashed lines indicate the ends of the 1m sections of the core.

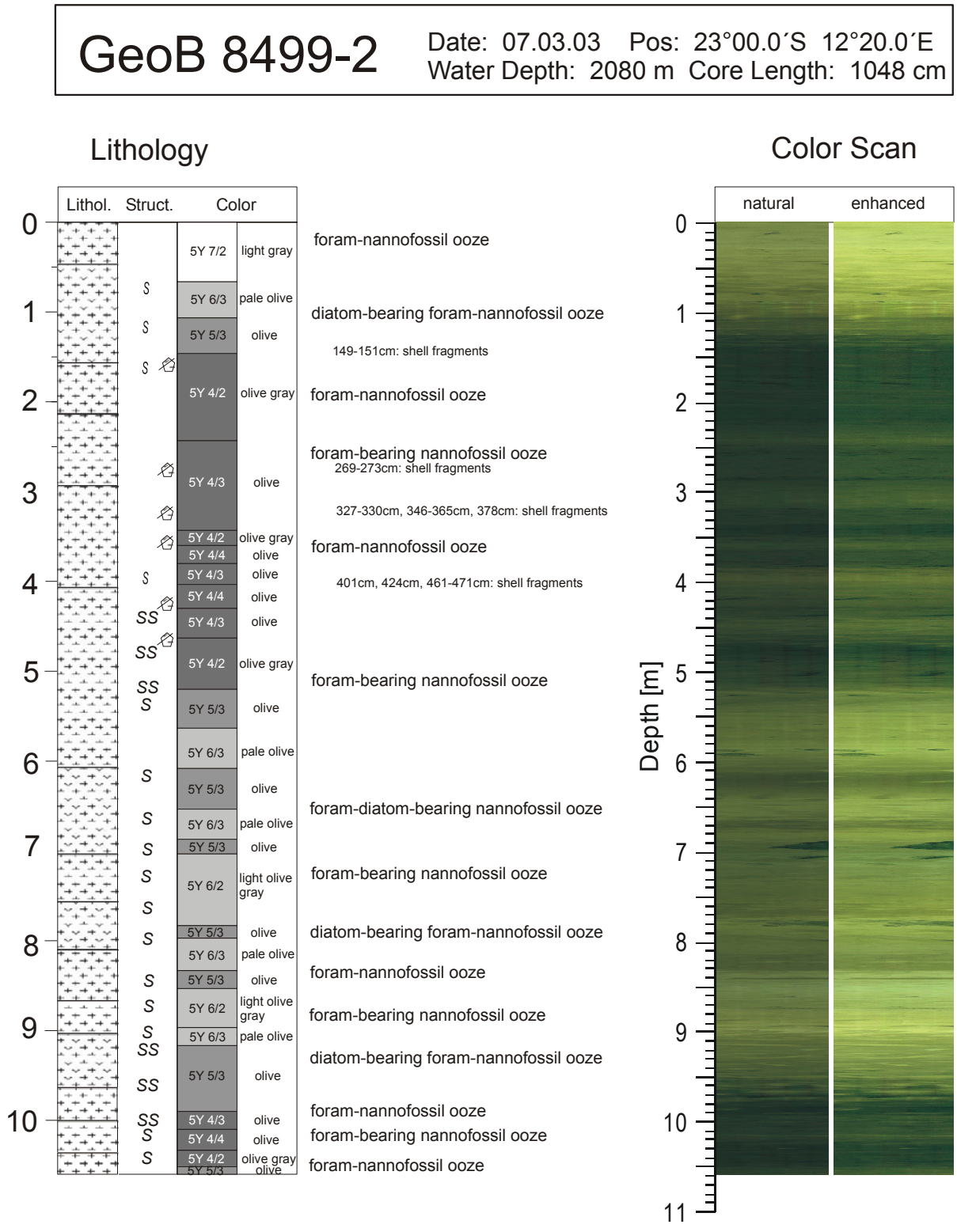


Fig. 4.3.27a Visual description of gravity core GeoB 8499-1.

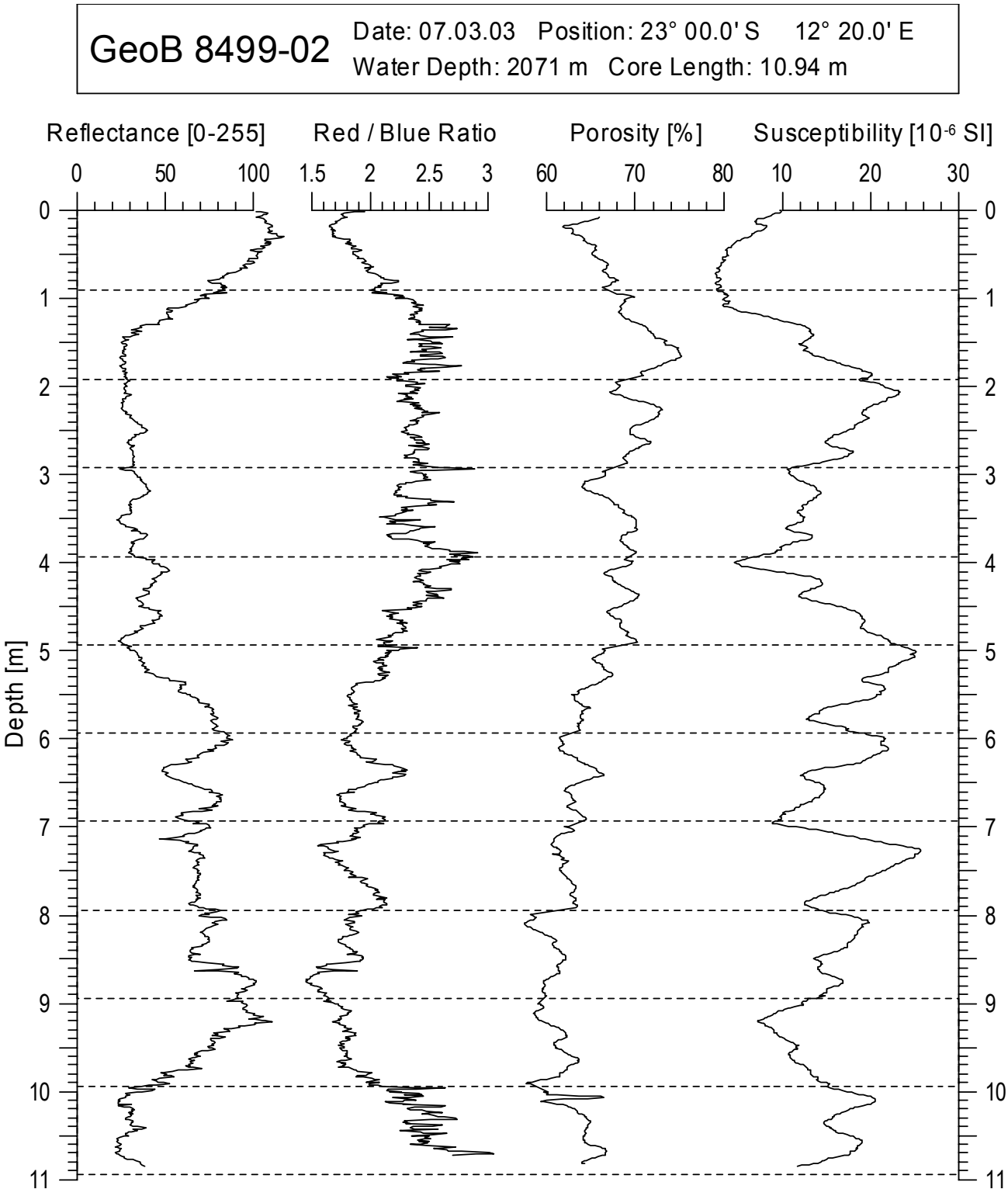


Fig. 4.3.27b Physical properties of gravity core GeoB 8499-2. The dashed lines indicate the ends of the 1m sections of the core.

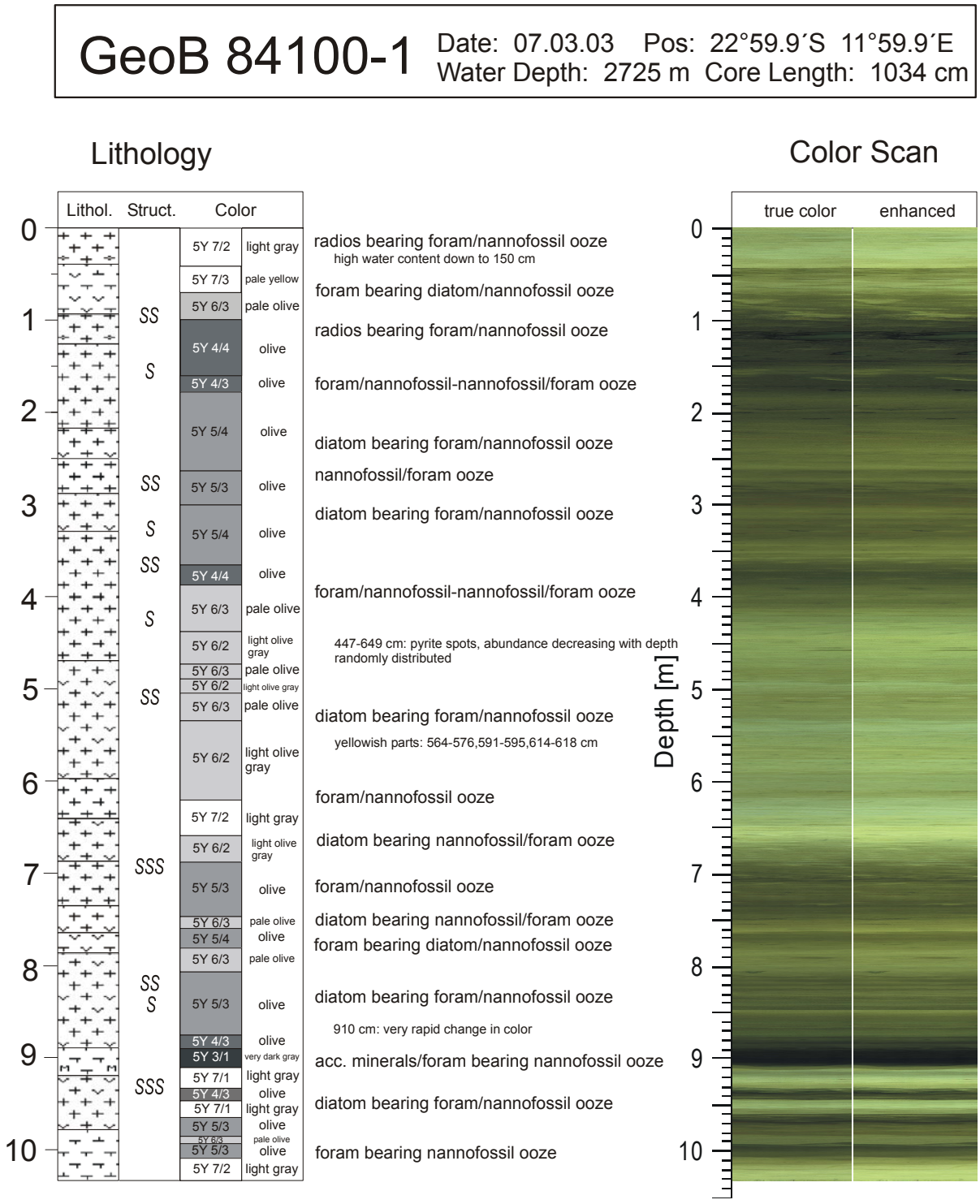


Fig. 4.3.28a Visual description of gravity core GeoB 84100-1.

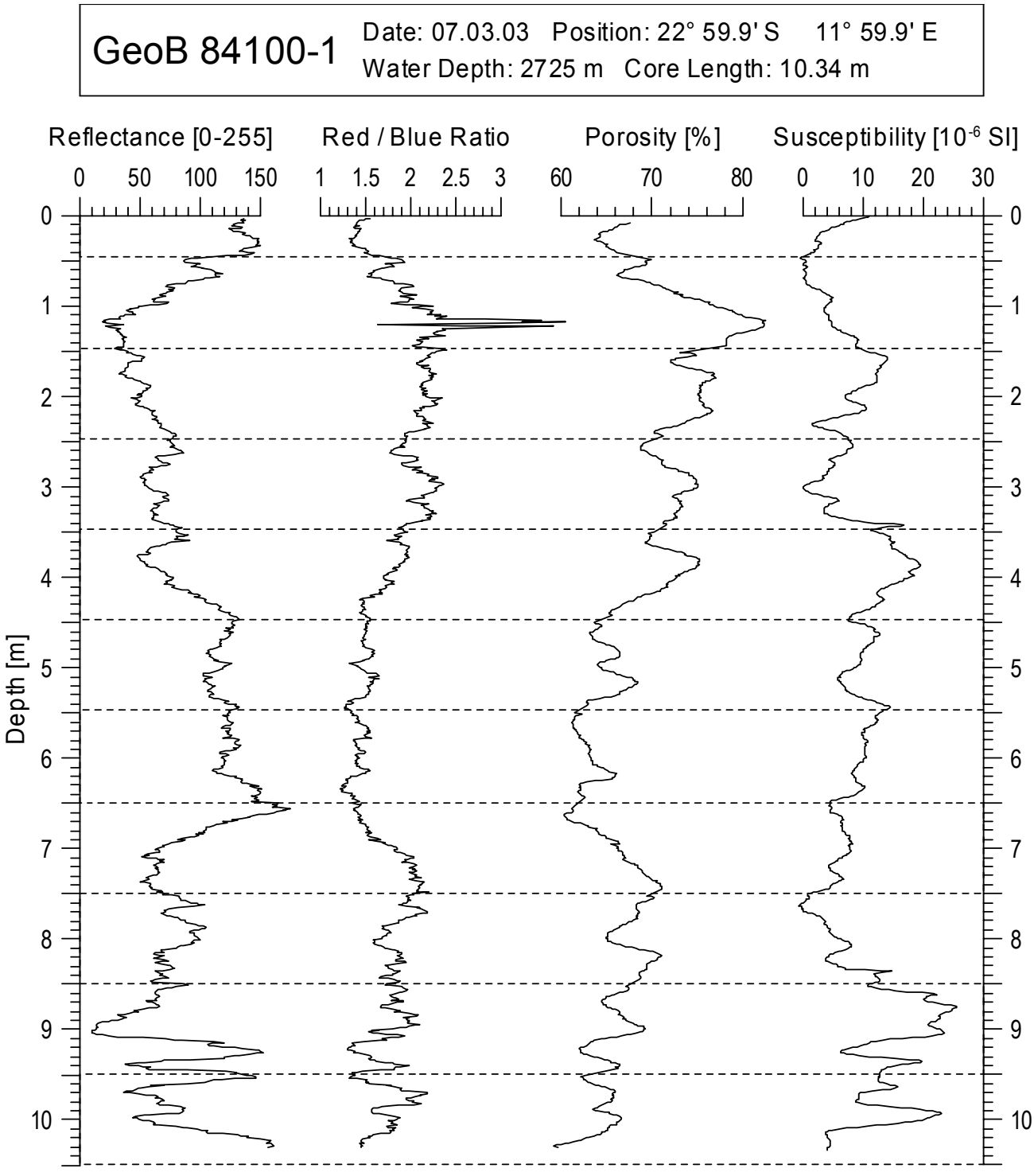


Fig. 4.3.28b Physical properties of gravity core GeoB 84100-1. The dashed lines indicate the ends of the 1m sections of the core.

are almost throughout bioturbated. No differences are recognized between the shallowest and the deepest stations. H_2S smell was detected all downcore at Geo8498-1 and from 3 m downcore at GeoB8484-2.

Transect 1 (24°S)

In the northern part of the working area, six gravity cores were retrieved along a transect between ca. 12°-14°E, 24°S off Namibia (Fig. 3.1). Water depths range from 315 to 1992 m. Recovery varied between 2.20 m and 10.30 m. The cores have throughout very fine material. Nannofossils (coccolithophorids) dominates the carbonate-rich sediments from water depth up to 1200 m, while foraminifera are secondary components. At the deepest positions (GeoB 8424-4 and GeoB 8422-3) diatoms occur either as primary or secondary contributors to the sediment composition. Between 300 and 1500 m depth, all cores are strongly bioturbated. The most common color is olive to dark-olive gray, almost throughout the cores at all positions. Very dark gray and black layer occur seldom. One turbidite layers observed only at GeoB 8920-3 between 19 and 57 cm. Additionally, sandy lenses are observed at some depths in cores between 1200 and 300 m water depth.

Transect 2 (25°S)

In the middle part of the working area, six gravity cores were retrieved along a transect between ca. 12°-14°E, 25°S off Namibia (Fig. 3.1). Water depths range from 387 to 1595m. The shortest core was 7.90 m length, and the longest core 14 m. Biogenic components dominate with a change between calcareous und siliceous oozes. Main calcareous contributors are coccolithophorids and foraminifera. Diatom contribution increases toward deeper positions. Strong bioturbation is only recognized at shallower cores (GeoB 8452-2 and GeoB 8453-1). Otherwise, only slight bioturbation is observed. Dark olive gray is the predominant color almost throughout. Some color trend is recognized in the deeper cores: these tend to be somehow lighter than the shallower positions. Strong H_2S smell characterizes each core almost at each depth. Turbidites (shell fragments) are present at each location with irregular downcore distribution.

Transect 3 (26°S)

At the southernmost transect of the working area, 3 gravity cores were retrieved from depths ranging between ca. 430 and 1500 m depth (Fig. 3.1). The core length varies between ~3.1 and 10 m. At the shallowest stations the sediment is darkest, at the deepest only the upper part of the downcore sediment column is darker than the lower part. Strongly bioturbation occurs almost throughout, no significant differences between shallower and deeper stations are observed. Lithogenics component are much more important than in the northern profiles, and its contribution decreases toward the deepest stations. Main biogenic components are coccolithophorids and foraminifera. Diatoms appear only in the deepest station from 5 m depth downcore.

4.4 Physical Properties Studies

(C. Franke, D. Heslop, T. v.Dobeneck)

All sediment series recovered during METEOR Cruise M57/2 by gravity coring were subject to routine geophysical shipboard measurements. These were performed on closed full cores (geology) or on open half cores (geochemistry) and comprised three basic parameters:

- magnetic volume susceptibility κ,
- electric resistivity R_s as a measure of porosity and density), and,
- spectral light reflectance

These properties are closely related to sediment lithology and provide high-resolution core logs with a standard spacing of 1 cm for electric resistivity and magnetic susceptibility and 0.01 cm for light reflectance. They were measured with a customized GEOTEK Multi-Sensor Core Logger (MSCL) utilizing a stepper motor to convey core segments along a track and through a series of sensors. Positions and lengths are automatically detected. The separate logging measurements are controlled and rapidly collated by the systems computer terminal.

In addition, oriented cube samples for shore based rock and paleomagnetic studies were taken at 5 cm intervals.

4.4.1 Physical Background and Experimental Techniques

Magnetic Susceptibility

The magnetic volume susceptibility κ is defined by the equations

$$B = \mu_0 \cdot \mu_r \cdot H = \mu_0 \cdot (1 + \kappa) \cdot H = \mu_0 \cdot H + \mu_0 \cdot \kappa \cdot H = B_0 + M$$

with magnetic induction B, absolute and relative permeabilities μ_0 and μ_r, magnetizing field H, magnetic volume susceptibility κ and volume magnetization M. As can be seen from the third term, κ is a dimensionless physical quantity. It records the amount to which a material is magnetized by an external magnetic field.

For marine sediments the magnetic susceptibility may vary from an absolute minimum value of $-15 \cdot 10^{-6}$ (diamagnetic minerals such as pure carbonate or silicate) to a maximum of some $10.000 \cdot 10^{-6}$ for basaltic debris rich in (titano-) magnetite. In most cases κ is primarily determined by the concentration of ferrimagnetic minerals, while paramagnetic matrix components such as clays are of minor importance. Enhanced susceptibilities indicate higher concentrations of lithogenic or authigenic components. This relation may serve for correlating sedimentary sequences deposited under similar global or regional conditions.

The core logger is mounted with a commercial BARTINGTON M.S.2 susceptibility meter with a 125 mm loop sensor. Due to the sensor's size, its sensitivity extends over a core interval of about 8 cm. Consequently, sharp susceptibility changes in the sediment column will appear smoothed in the κ core log and thin layers such as ashes cannot appropriately be resolved. In order to make an accurate end correction at the base of each segment and to assess the drift of the susceptibility meter, a spacer cylinder of 29.5 cm length was placed between each segment during the measurement procedure. The measurements taken at the centre of the

spacer was used to assess and compensate the instrument drift. During post-processing all data related to void sections were removed to provide a continuous composite core log.

Electrical Resistivity and Porosity

The electrical sediment resistivity R_s was determined using an inductive non-contact sensor. The system applies high frequency magnetic fields by a transmitter coil inducing electrical eddy currents in the sediment which are proportional to conductivity. Their secondary field is recorded and yields raw and calibrated values for conductivity and resistivity. Porosity was calculated according to the empirical Archie's equation

$$R_s/R_w = k \cdot \phi^{-m}$$

where the ratio of sediment resistivity R_s and pore water resistivity R_w can be approximated by a power function of porosity ϕ. Following a recommendation by Boyce (1968), suitable for sea water saturated clay-rich sediments, values of 1.30 and 1.45 were used for the constants k and m, respectively. The calculated porosity ϕ is subsequently converted to wet bulk density ρ_{wet} using the equation (Boyce, 1976)

$$\rho_{wet} = \phi \cdot \rho_f + (1 - \phi) \cdot \rho_m$$

with a pore water density ρ_f of 1030 kg/m^3 and a matrix density ρ_m of 2670 kg/m^3. For a uniform treatment of all cores, these empirical coefficients were not adapted to individual sediment lithologies. Yet, relative porosity and density changes should be well documented.

The resistivity sensor averages over approximately 12 cm core length. A platinum thermometer inserted into a segment continuously measures sediment temperature for temperature compensation. Absolute sensor calibrations using a series of saline standards are performed daily. For subsequent drift and segment end correction, 29.5 cm long insulating spacers were placed between segments during logging. Thus, the characteristic decay of the eddy currents nearby the end-caps was separately recorded for each segment and corrected on basis of a model curve. This method provides a continuous composite record, however the first 2-3 data points from each intersection were discarded due to some overshooting. It was only recognized after completing all measurements, that especially long and heavy segments bow under their own weight while sliding over the guide bars and thereby undulate the distance between core and sensor. This leads to systematically reduced porosity values around segment centers discernable in some of the data logs.

Light Reflectance

Spectral light reflectance is a measure of the relative amount of light reflected by a material under incident white light. It is expressed within an absolute range from 0 (minimum) to 255 (maximum) and specified as average value for the red (600-700 nm), green (500-600 nm) and blue (400-500 nm) color band (RGB system). The reflectance properties of sediments relate to their chemistry and structure and are dominated by pigmented trace constituents,, typically Fe and Mn bearing minerals (clays, oxides, sulfides) and organic enrichments. Reflectance logs provide high-resolution records of terrigenous content (total reflectance) and redox state (red/blue ratio). Scanned at high spatial resolution, reflectance images

provide sharp, undistorted, true-color core photographs scarcely affected by undesirable artefacts known from classical core photography (shadows, reflections etc.).

The digital imaging module of the GEOTEK MSCL consists of a camera containing three separate 3*1024 pixel CCD detectors mounted in the focal planes of split light beams ~40 cm above the surface of the sediment and equipped with red, green and blue dichroic filters. This camera captures consecutive, strictly orthogonal line images of the bypassing split core surface. The sediment is illuminated from above by two white fluorescent tubes. Freshly cut archive halves were carefully leveled to prevent shadows from residual surface roughness. All cores were scanned at an axial resolution setting of 100, corresponding to 1 row of pixels for every 100 µm in core depth. The resolution achieved across the core is nearly equivalent. The brightest part of each core was selected to determine the lens aperture value which allows the entire core to be measured on the same setting without saturating any of the color channels. Each reflectance value is calibrated against the range defined by a white tile (white calibration) and a closed lens cap (black calibration). Color test cards were measured before and after each core to determine and linearly correct drift effects of the CCD sensors.

A specialized post-processing software was written on board to perform all necessary image corrections and calculations. The processing starts out by cropping end-cap and cavity sections and by removing spurious color stripes caused by a non-uniform response of individual color channels. This task is efficiently solved by normalizing the means within each down-core column of data to the same mean-core value. The individual segment images are then merged into a full core image and numerically compressed in various ways. The median value of each data row was chosen as representative reflectance value in the depth series of red, green and blue reflectance, total reflectance (mean value of R, G and B) and for the red/blue ratio.

Contrast-enhanced color images were produced to improve the identification of layers, gradients, and textures. For this purpose, the RGB images were transformed to the equivalent hue, saturation and value (HSV) color system. By linearly expanding the data range of the value (intensity) parameter, the available contrast is broadened without shifting hue (dominant wavelength) and saturation (degree of purity) of each color, hence, the specific aspects of mineral color. In the standard processing, the 10% and 90% percentiles of V were determined for each core and linearly rescaled to a value range reaching from 25% to 75% total reflectance.

4.4.2 Shipboard Results

Sampling Sites and Recovery

The gravity coring program of research cruise M57/2 was successful beyond expectations: 28 complete and largely coherent sediment sequences with a cumulative length of 223 m were recovered from 24 sites on the upper Namibian continental slope. These sites form four E/W oriented, parallel and mutually equidistant transects stretching from the shelf break at 300-500 m depth down to hemipelagic depths of 1500-2700 m (upper part of Fig. 4.4.1).

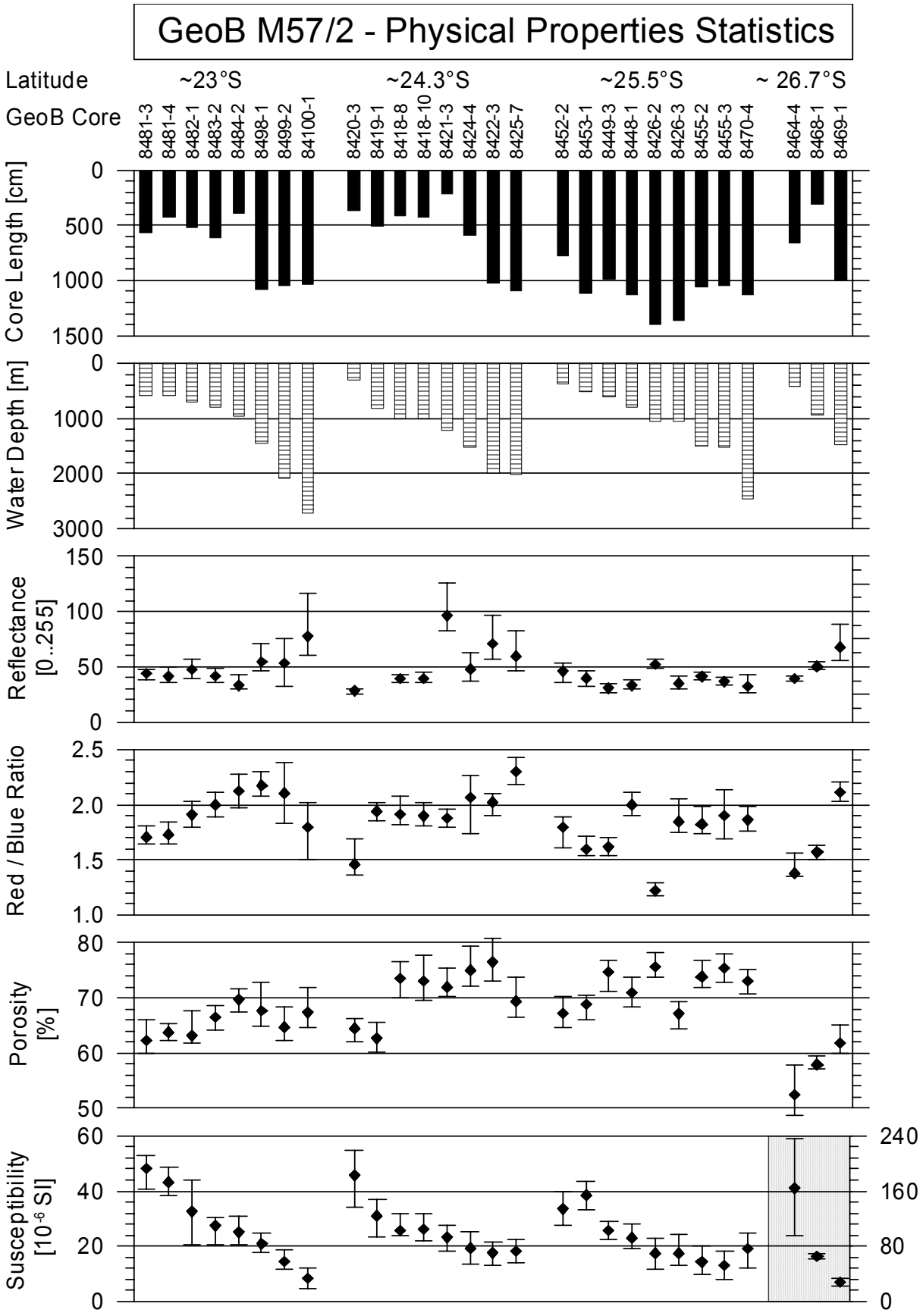


Fig. 4.4.1 Length, water depth, reflectance, red/blue ratio, porosity and susceptibility of M57/2 gravity cores. Diamonds denote median values, vertical bars represent the inter-quartile (25%-75%) range.

The northernmost hydrographic transect (HT: GeoB 8481-3, 8481-4, 8482-1, 8483-2, 8484-2, 8498-1, 8499-2, 84100-1) is located at 23° S west of Walvis Bay (cf. Fig. 3.1). The other three profiles are situated at ~24.3° S (transect 1: GeoB 8420-3, 8419-1, 8418-8, 8418-10, 8421-3, 8424-4, 8422-3, 8425-7), at ~25.5° S (transect 2: GeoB 8452-2, 8453-1, 8449-3, 8448-1, 8426-2, 8426-3, 8455-2, 8455-3, 8470-4) and at ~26.7° S, the approximate latitude of Lüderitz Bay (transect 3: GeoB 8464-4, 8468-1, 8469-1). Along profiles HT, 1 and 3, sediment recovery increases with depth (and, thus, with porosity) from 5 m lengths below 1000 m water depth to 10 m lengths at greater depths. Profile 2 located in the center of the high productivity region was targeted at the most rapidly accumulating and least consolidated sediments, yielding also the longest cores of 10-14 m lengths.

General Results

The measured and processed physical properties logs have been compiled together with the core descriptions and digital core images (Figs. 4.3.1 to 4.3.28). Parallel cores taken for geological and geochemical purposes are presented in a coherent way to facilitate co-processing of their data. As will be later discussed, these multiple logs are highly suitable for the purpose of stratigraphic cross-correlation and age modeling. The statistical analysis depicted in the central and lower parts of Figure 4.4.1 gives an overview of the absolute core characteristics. It clearly shows some differentiation with regard to latitude and depth.

Most cores have total reflectance values below 40 denoting extremely dark sediments. Their brown and olive shades correspond to a grayscale reflectance of over 80% black. This dim color is likely to result from the high organic and terrigenous content, from pyrite and possibly from smectite formation. Climate dependent lithological successions in the sediment columns are most easily observed in the enhanced contrast images and reflectance logs. Calcareous bands representing the warm marine isotope stages of Holocene and Eemian are visibly brighter. Wherever these are present, the frequency distribution of reflectance values is skewed as to be observed by the asymmetric whisker length of the 25% and 75% quartiles. The absolute calibration of reflectance is not fully reliable for some of the first cores measured during this expeditions (e.g. GeoB 8419-1) and subtle differences should therefore not be over-interpreted.

The red-blue ratio is generally assigned to the balance of more reddish ferric and the more greenish or bluish ferrous iron. For most M57/2 cores, this parameter is positively correlated with total reflectance (e.g. GeoB 8452-2). Brighter olive sediment sections tend to be more reddish than the darker olive gray sections, probably because of the influence of organic carbon. For cores with light calcareous, slightly bluish sections (e.g. GeoB 84100-1) an inverse correlation of the red-blue ratio and reflectance is apparent. With several pigments contributing to sediment color, a more detailed spectral analysis seems advised.

The resistivity-derived porosity values give comparably low numbers increasing with water depth and from N to S. This is an indication of bottom current influence. Average median values for transects HT–2 are 65%, 71% and 72% porosity. With only 52-61% porosity, the three cores of transect 3 are extremely dense and consolidated owing to their high, possibly poorly sorted terrigenous content.

The magnetic susceptibilities logs take extremely low numbers for near-continent conditions. There is a strong inverse correlation with water depth and shore distance. At the shelf break, median susceptibilities above $40 \cdot 10^{-6}$ SI are observed, which decrease to below $15 \cdot 10^{-6}$ SI at the deeper stations. As speculated on board and meanwhile verified in the lab, these low, but positive susceptibilitites are primarily attributable to paramagnetic, probably ferrous iron minerals, while the strongly magnetic ferric iron oxides appear to be completely dissolved under the influence of strongly reducing redox conditions. This nearly complete dissolution of magnetite leaves basically simple and well interpretable susceptibility patterns controlled by the ratio of diamagnetic (carbonate, opal) and paramagnetic (clay) constituents. Higher susceptibilitites up to $300 \cdot 10^{-6}$ SI are only observed on transect 3, in particular for core GeoB 8464-4. According to the core description, this sediment is denoted as "feldspar ooze". Feldspars are known to contain internal magnetite crystals protected from diagenesis by the silicate matrix.

Stratigraphic Results

The high similarity of physical property signals within and in between the four core profiles was already observed and discussed on board. Reflectance signals follow the known patterns of marine isotope stages (MIS) controlled by Milankovitch cycles although much more stratigraphic detail is present. These climate patterns are easily recognized when cores reach back to MIS 5.5 such as GeoB 8422-3, 8425-7, 8469-1 and 8470-4 or even further into MIS 6 such as cores GeoB 8498-1, 8499-2 and 84100-1. Resultant average accumulation rates for these cores are in the order of 8-10 cm/kyr. This value is doubled by a number of cores with equal or greater total length which reach only into MIS 4.2 (GeoB 8455-2/3, 8426-2/3, 8448-1, 8449-3, 8453-1).

Unlike as in many other marine environments, the magnetic susceptibility signal plays an own and relatively independent role for pattern correlation. The characteristic features of the susceptibility logs are clearly distinct from the reflectance logs and seem to reflect millennial scale climate variations. There is convincing evidence for an identification of low-pass filtered Dansgaard-Oeschger cyclicity identified in other tropical marine sedimentary environments (von Dobeneck and Schmieder, 1999). A tentative closed age model for nearly all M57/2 has been established on board, but needs further verification.

4.5 Pore Water Chemistry

(S. Hessler, S. Kasten, N. Riedinger, M. Schmidt)

The aim of geochemical investigations carried out during this cruise in the frame of RCOM sub-project C1 was a detailed examination of the early diagenetic modification of the primary composition and the rock magnetic properties of the sediment within the sulfate/methane transition zone. For this purpose the pore water of the sediments was retrieved and analysed to determine the current geochemical zonation as well as the depth position of the sulfate/methane transition zone or the zone of anaerobic oxidation of methane, respectively. The main focus is the high-resolution sampling of the sedimentary solid phase across this important biogeochemical transition and the adequate storage of the sediment samples for subsequent wet chemical and mineralogical analyses.

In addition, we also sampled and/or analysed surface sediments as well as the water column in close co-operation with other groups participating in this cruise (cf. Sects. 4.6, 4.7 and 4.8). The purpose of these analyses was to identify and quantify the relevant biogeochemical processes occurring at and above the sediment surface (cf. Sects. 4.6 and 4.7) and to characterize the water masses in the study area – particularly focussing on the vertical nutrient distribution (cf. Sekt. 4.8).

4.5.1 Methods

To prevent a warming of the sediments on board all cores were transferred into the cooling room or the H_2S container immediately after recovery and maintained at a temperature of about 4°C. The cores from the MUC were processed within a few hours within a glove box under argon atmosphere. Two samples of the supernatant bottom water were taken and filtered for subsequent analyses. The remaining bottom water was carefully removed from the multicorer tube by means of a siphon to avoid destruction of the sediment surface. During subsequent cutting of the core into slices for pressure filtration, pH and Eh measurements were performed with a minimum depth resolution of 0.5 cm. Conductivity and temperature were measured on a second, parallel core to calculate sediment density and porosity.

The gravity cores were cut into 1 m segments on deck and syringe samples were taken from every cut segment surface for methane analysis. Higher resolution sampling for methane was carried out in the H_2S container immediately after storing by sawing 2x4 cm rectangles into the PVC liner. In this way, syringe samples of 5 ml sediment were taken every 30 to 35 cm and injected into 50 ml septum vials containing 20 ml of seawater. After closing and subsequent shaking methane becomes enriched in the headspace of the vial. One replicate was taken and poisoned with a $HgCl_2$ solution for determination of the stable isotopic ratios of carbon and oxygen.

Within one or two days after recovery, gravity cores were cut lengthwise into two halves and processed. PH and Eh were determined on the working halves and sediment samples were taken every 25 cm for pressure filtration. Solid phase samples for total digestions, sequential extractions and mineralogical analyses were taken at 10-cm intervals and kept in gas-tight glass bottles under argon atmosphere. The storage temperature for all sediments was -20°C to avoid dissimilatory oxidation of reduced species.

Table 4.5.1: Sites sampled geochemically during this cruise, including parameters analysed on board as well as aliquots of samples taken and stored for further analyses in Bremen. (Station numbers in brackets correspond to Fig. 3.1)

No.	GeoB No.	Equip.	Alkalinity	NH_4	NO_3	PO_4	Fe^{2+}	H_2S (ZnAc)	SO_4 & Cl (1:20 dilution)	$\delta^{13}C$ of DIC (frozen)	CH_4 (frozen)	$\delta^{13}C$ of CH_4 ($HgCl_2$)	$\delta^{13}C$ of DIC* ($HgCl_2$)
1	8418-1 (**23**)	MUC	X	X	X	X	X	X	X	–	–	–	–
2	8418-8 (**23**)	GC	X	X	–	X	X	–	X	X	X	X	–
3	8422-1 (**26**)	MUC	X	X	X	X	X	–	X	–	–	–	X
4	8425-7 (**26**)	GC	X	X	–	X	X	X	X	X	X	X	–
5	8426-3 (**33**)	GC	X	X	–	X	X	X	X	X	X	X	–
6	8447-1 (**34**)	MUC	X	X	X	X	X	X	X	–	–	–	X
7	8448-2 (**32**)	MUC	X	X	X	X	X	X	X	–	–	–	X
8	8449-1 (**31**)	MUC	X	X	X	X	X	–	X	–	–	–	X
9	8451-1 (**33**)	MUC	X	X	X	X	X	–	X	–	–	–	X
10	8455-1 (**35**)	MUC	X	X	X	X	X	–	X	–	–	–	X
11	8455-2 (**35**)	GC	X	X	–	X	X	X	X	X	X	X	–
12	8462-4 (**36**)	MUC	X	X	X	X	X	–	X	–	–	–	–
13	8464-2 (**38**)	MUC	X	X	X	X	X	X	X	–	–	–	–
14	8465-3 (**40**)	MUC	X	X	X	X	X	–	X	–	–	–	X
15	8466-2 (**39**)	MUC	X	X	X	X	X	–	X	–	–	–	–
16	8470-1 (**37**)	MUC	X	X	X	X	X	X	X	–	–	–	–
17	8470-4 (**37**)	GC	X	X	–	X	X	X	X	X	X	X	–
18	8492-2 (**30**)	MUC	X	X	X	X	X	X	X	–	–	–	–
19	8493-2 (**29**)	MUC	X	X	X	X	X	X	X	–	–	–	–
20	8498-2 (**15**)	MUC	X	X	X	X	X	–	X	–	–	–	X

* samples analysed in the frame of RCOM sub-project A1

All work done on opened liner cores was carried out in the cooling room. For pressure filtration Teflon-squeezers were used. The squeezers were operated with argon at a pressure gradually increasing up to 5 bar. The pore water was retrieved through 0.2 µm cellulose acetate membrane filters. Depending on the porosity and compressibility of the sediments, the amount of pore water recovered ranged between 5 and 20 ml.

Pore water analyses

Pore water analyses of the following parameters were carried out during this cruise: Eh, pH, temperature, ammonium, alkalinity, nitrate, phosphate, and iron (Fe^{2+}).

Eh and pH were determined with electrodes before the sediment structure was disturbed by sampling for pressure filtration. Ammonium was measured using a conductivity method. Alkalinity was calculated from a volumetric analysis by tritration of 1.5 ml of the pore water sample with 0.01, 0.05 or 0.1 M HCl, respectively. Phosphate and nitrate were determined photometrically using a continuous flow system. For the analysis of dissolved iron (Fe^{2+}) sub-samples of 1 ml were taken within the glove box and immediately complexed with 50 µl of "Ferrospectral" and determined photometrically.

For further analyses at the University of Bremen, aliquots of the remaining pore water samples were diluted and acidified with $HNO_{3\ (suprapure)}$ for determination of cations (Ca, Mg, Sr, K, Ba, S, Mn, Si, B, Li) by ICP-AES and AAS. Additionally, 1 ml subsamples of the pore water were added to a ZnAc solution (400 µl) to fix all sulfide present as ZnS for later analysis. Subsamples for sulfate and chloride determinations were diluted 1:20 and stored frozen for ion chromatography (HPLC) analyses at the University of Bremen. For the determination of $\delta^{13}C$ of DIC 5 ml of the pore water were filled into glass vials, sealed and stored at -20°C. A second set of pore-water sub-samples from selected multicorer cores (c.f. Tab. 4.5.1, last column) was also taken and poisoned with $HgCl_2$ for the measurement of $\delta^{13}C$ of DIC. These data will be obtained in the frame of RCOM subproject A1 to investigate the differences between the $\delta^{13}C$ signal of the pore water and infaunal living benthic foraminifera.

4.5.2 Shipboard Results

During this cruise 15 multicorer cores and 5 gravity cores were processed. All sites sampled geochemically, including parameters analysed on board as well as aliquots of pore water samples taken and stored for further analyses in Bremen are listed in Table 4.5.1. Furthermore, the following samples were taken and/or analysed in the frame of cooperations with other participating groups: (1) 126 bottom water samples taken during in-situ incubations with the benthic chamber lander by syringes (cf.Sects. 4.2.3 and 4.6) were analysed for alkalinity and nutrient concentrations; (2) 5 sub-cores from the benthic chamber lander (cf. Sects. 4.2.3 and 4.6) were sampled for pore water and analysed (65 samples) for alkalinity and nutrients; (3) analyses of alkalinity and nutrients of bottom waters (80 samples) and pore waters (90 samples) from incubation experiments of multicorer cores (cf. Sect. 4.6); (4) analyses of nutrients of 90 water samples taken during 18 casts of the bottom water sampler (cf. Sects. 4.2.4, 4.6, and 4.7); (5) 450 water column samples taken by the rosette/CTD water

sampler on three hydrographic transects were analysed for their nitrate and phosphate concentrations (see Sects. 4.2.5 and 4.8).

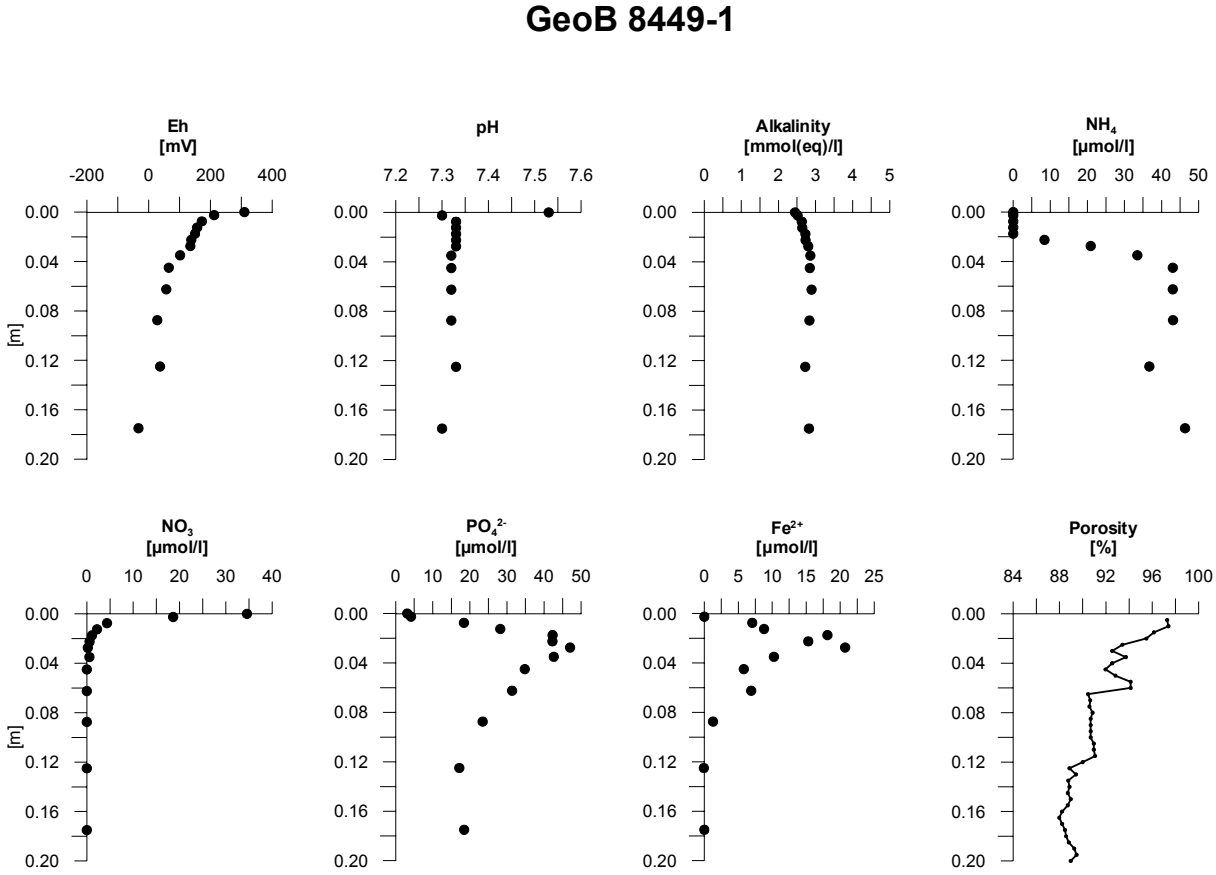


Fig. 4.5.1: Pore water concentration profiles for multicorer core GeoB 8449-1.

Pore water data for the two MC cores from stations GeoB 8449 (Fig. 4.5.1) and 8462 (Fig. 4.5.2) are shown here as typical representatives of the study area. In most of the multicorer cores maximum nitrate concentrations were measured in the bottom waters overlying the sediment and at 0.5 cm sediment depth. Denitrification was more or less complete at 4 to 6 cm. These findings suggest that a large share of the aerobic degradation of organic matter in this area takes place in the bottom waters overlying the sediment surface. As further typical features of these sediments prominent sub-surface maxima in PO_4^{2-} concentrations are generally found around 3 cm sediment depth which coincide with peaks in dissolved iron contents. These concomitant peaks of pore water PO_4^{2-} and Fe^{2+} were also found during RV Meteor cruise M 34/2 in 1996 (Schulz et al. 1996) and are interpreted to result from iron reduction accompanied by liberation of initially adsorbed phosphate into interstitial waters (Steinmetz 1997, unpublished data).

Due to the overall low input of detrital iron minerals to the sediments of the study area, iron reduction is generally restricted to the upper few centimeters and only plays a minor role in the total degradation of organic matter. Highest Fe^{2+} concentrations of up to 22 µmol/l were determined for multicorer core GeoB 8449-1 (Fig. 4.5.1) recovered on Transect 2. Hydrogen sulfide could be detected by smell below the Fe^{2+} containing sediment intervals at most of the sites.

In at least two of the 5 sampled gravity cores (Figs. 4.5.3 to 4.5.7) the sulfate/methane transition has been penetrated as can be deduced from the gradient changes in the alkalinity profiles. In core GeoB 8426-3 (Fig. 4.5.5) a prominent kink in the alkalinity profile is located at 3.7 m sediment depth. At site GeoB 8455 (Fig. 4.5.6) a less pronounced change in the concentration gradient can be observed around 4 m. In none of the examined gravity cores Fe^{2+} dissolved in pore water could be detected, supporting the low-iron environment and the sulfide-dominated setting. Analyses of pore-water sulfate performed in Bremen will reveal the exact location of the sulfate/methane transition in these sediments.

GeoB 8462-4

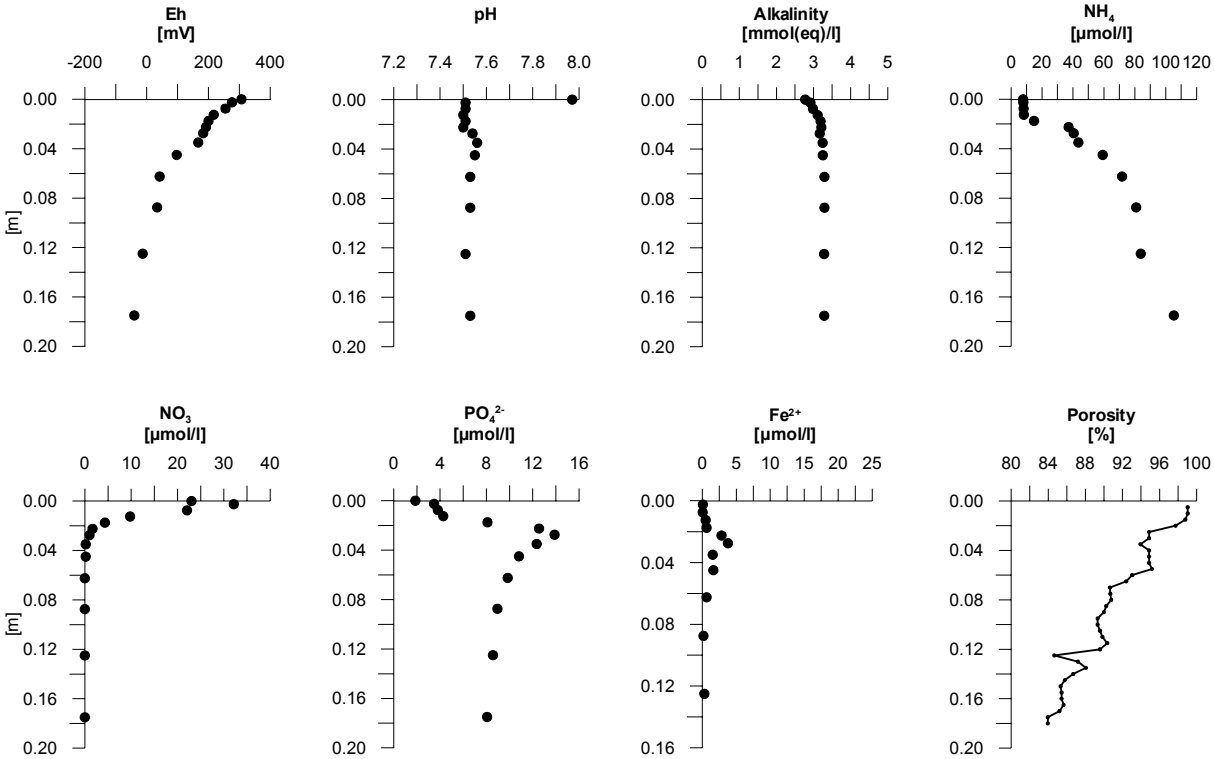


Fig. 4.5.2 Pore water concentration profiles for multicorer core GeoB 8462-4.

GeoB 8418-8 GC

Water depth: 1005 m

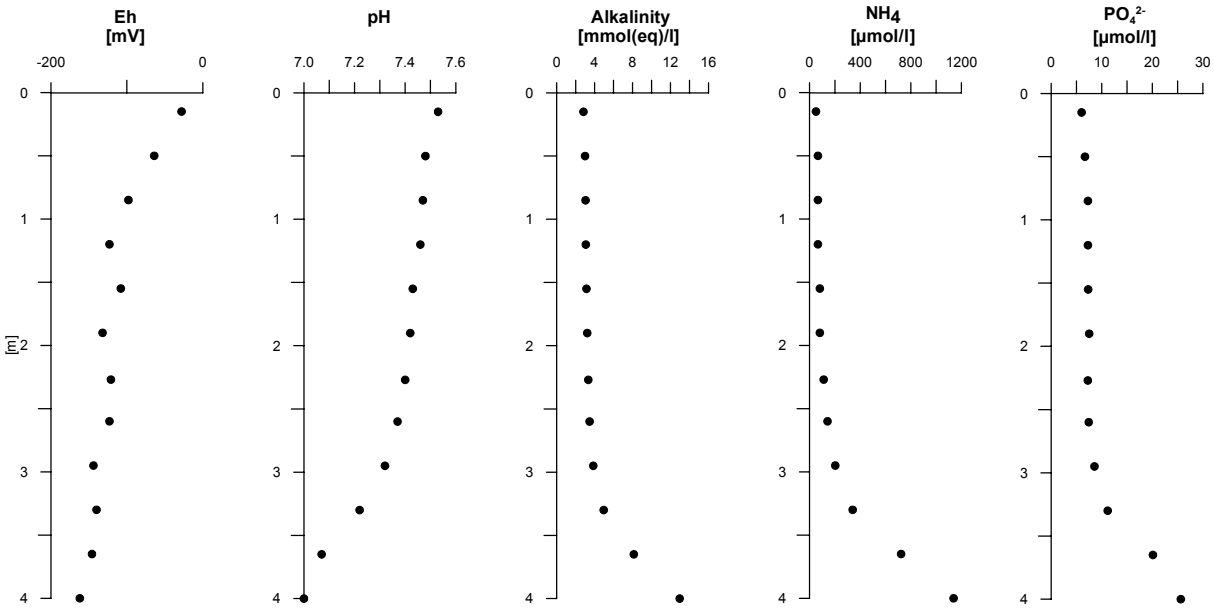


Fig. 4.5.3 Pore water concentration profiles for gravity core GeoB 8418-8.

GeoB 8425-7 GC

Water depth: 2000 m

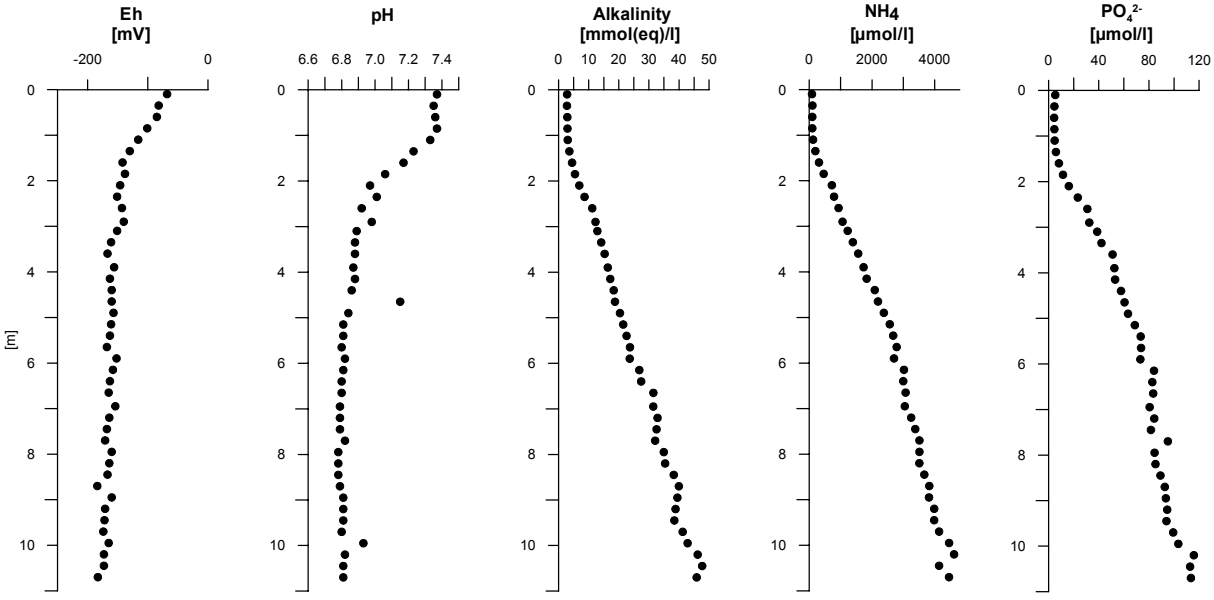


Fig. 4.5.4: Pore water concentration profiles for gravity core GeoB 8425-7.

GeoB 8426-3 GC

Water depth: 1046 m

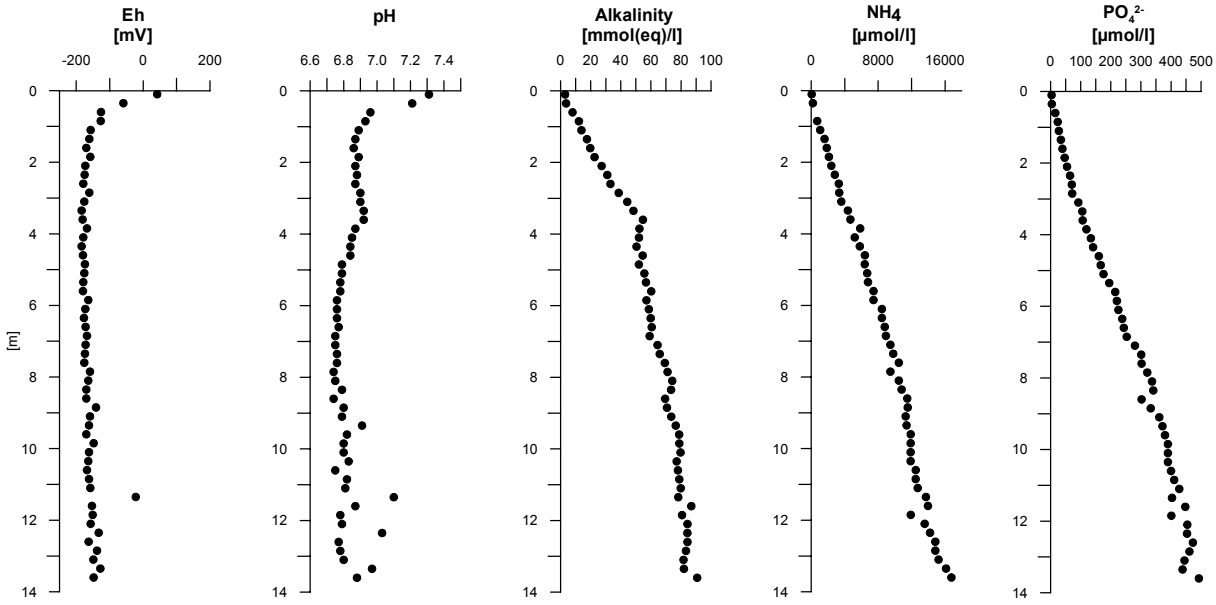


Fig. 4.5.5 Pore water concentration profiles for gravity core GeoB 8426-3.

GeoB 8455-2 GC

Water depth: 1502 m

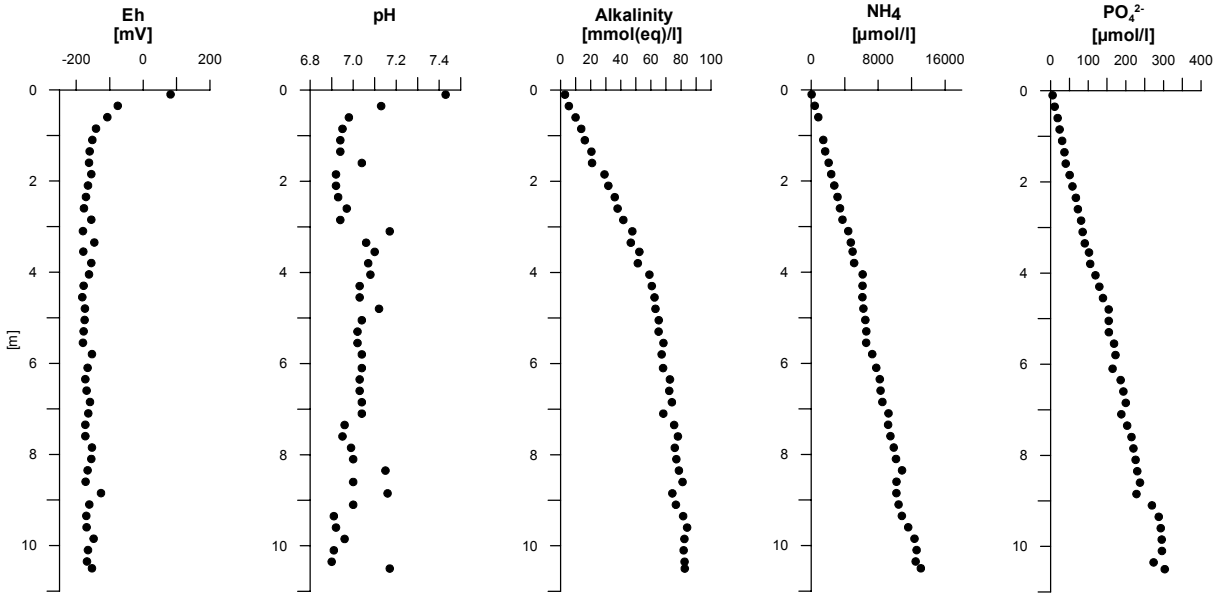


Fig. 4.5.6 Pore water concentration profiles for gravity core GeoB 8455-2.

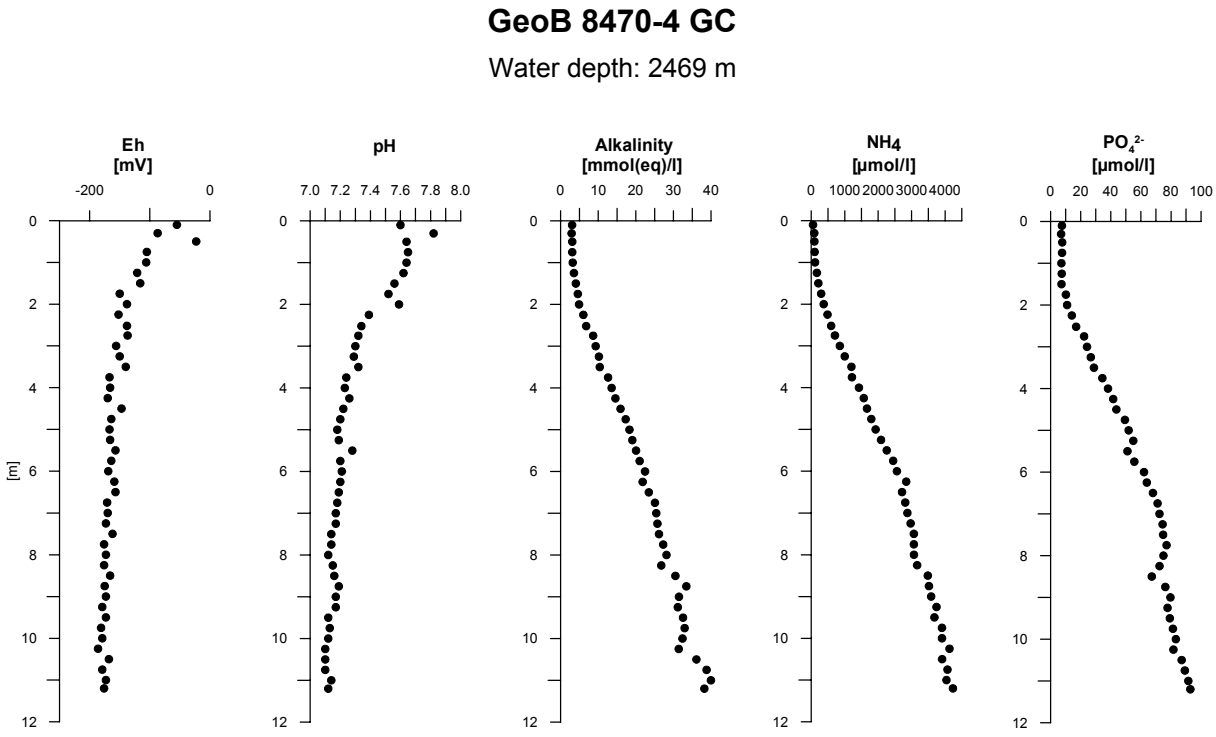


Fig. 4.5.7 Pore water concentration profiles for gravity core GeoB 8470-4.

4.6 Biogeochemical and Biological Studies

(A. Ahke, A. Aspetsberger, T. Ferdelman, U. Witte)

One goal of the biogeochemical survey of the Benguela Upwelling sediment regime was to achieve a better understanding of organic carbon degradation and preservation processes. Of primary interest is not only what drives organic matter degradation during early diagenesis but also the proceeding steps of organic matter transformation and preservation within the upper sediment layer. Total organic carbon (TOC) contents in sediments along the continental slope range from appr. 1 to 10% TOC. TOC concentrations also change vertically as represented by layers of alternating high-low organic carbon contents within the sediments. In order to examine the spatial connection between organic matter amounts, variability, quality and its terrestrial vs. marine origin, two major transects off Walvis Bay down the Namibian continental slope were investigated. The cross-slope transects, close to 24°S and 25 - 26°S, intersected areas of high and low TOC in surficial sediment.

The benthic response to organic matter input is reflected in metabolic activity that is measurable in terms of oxygen consumption. Aerobic respiration is the primary respiratory process of organic matter degradation. Of secondary importance are anaerobic reactions due to heterotrophic micro-organisms using other electron acceptors e.g. sulfate or nitrate. Important rate measurements on board were 1.*in situ* oxygen uptake rates by the sediment community (SCOC Sediment Community Oxygen Consumption) and 2. the determination of Sulfate Reduction Rates (SRR). Together with a geological and chemical characterization of the sediments these measurements should reveal insights in the timescale of local carbon degradation and preservation processes.

Table 4.6.1 List of biogeocemical and biological investigations during M57-2 (Station numbers in brackets correspond to Fig. 3.1)

GeoB station	Long. (E)	Lat. (S)	Water depth [m]	Ass. Lander deploy-ment*	Incu-bation	Reactivity	Bag	SRR	^{210}Pb	Remarks
8404 (**1**)	14,37	23,00	44	–	–	–	–	–	–	shelf material
8418 (**23**)	13,14	24,37	1019	BCL I + BCL VII	–	X	–	MC	X	
8419 (**22**)	13,22	24,35	834	–	–	X	–	–	–	
8421 (**24**)	13,06	24,39	1205	–	–	X	–	–	–	
8422 (**26**)	12,72	24,46	1997	BCL II	X	X	X	MC, Inc.	X	
8424 (**25**)	12,93	24,42	1519	–	–	X	–	–	–	
8425 (**26**)	12,72	24,46	1989	BCL II	–	–	–	MC, GC	–	
8429 (**28**)	13,72	25,47	362	–	X	X	–	MC, Inc.	–	
8447 (**34**)	13,28	25,60	1334	BCL III + BCL VI	–	–	X	MC	X	
8448 (**32**)	13,45	25,48	806	–	–	X	–	–	X	
8449 (**31**)	13,55	25,48	605	BCL IV	–	X	–	–	X	
8451 (**33**)	13,36	25,48	1028	–	–	X	–	–	X	
8452 (**29**)	13,69	25,43	388	–	–	X	–	–	–	
8455 (**35**)	13,18	25,51	1506	–	–	X	–	–	–	
8460 (**36**)	12,95	25,54	2267	BCL V	–	–	–	O, BCL	–	
8462 (**36**)	12,94	25,53	2293	BCL V	–	X	X	–	X	
8463 (**34**)	13,28	25,61	1335	BCL III + BCL VI	X	–	–	MC, Inc.	–	
8464 (**38**)	13,70	26,34	430	–	–	X	–	–	X	
8465 (**40**)	13,42	26,75	1377	–	–	X	X	–	X	
8466 (**39**)	13,57	26,73	941	–	–	–	–	–	X	
8470 (**37**)	12,86	25,55	2470	–	–	X	–	–	X	
8492 (**30**)	13,61	25,47	501	–	–	–	–	MC	X	
8493 (**29**)	13,69	25,43	387	–	–	–	–	–	X	
8494 (**31**)	13,55	25,47	602	BCL IV	–	X	X	MC	–	
8495 (**23**)	13,13	24,37	1015	BCL I + BCL VII	–	–	–	O, BCL	–	
8498 (**15**)	12,58	23,00	1439	–	–	–	–	–	–	

Bag – for anoxic bag incubations, *Inc.* – SRR measurements on incubated Multicorer cores, *MC* – SRR measurements on Multicorer cores, *O* – in situ SRR measurements with the ORPHEUS module; *cf. Tab. 4.2.3

4.6.1 "Reactivity" Analysis and Geochemical Methods

The reactivity or organic carbon is of principal interest in the geochemical survey. Elemental analysis (Total Organic C, N and S contents of the sediment and the derived C/N ratio) will provide basic geological information on the research area within the Benguela Upwelling exhibits highly but they hardly reveal information of organic matter reactivity.

Of central biogeochemical interest is the study of early diagenesis and long-term degradation processes during vertical transport in the water column and in the upper sediment layer, respectively, concerning kinetic organic carbon turnover. Rate measurements of organic carbon degradation underlying varying oxygen regimes that are initiated by organisms of the sediment community are a valuable tool to decipher reaction kinetics of sedimentary degradation processes. Rate measurements are important to understand the kinetics of local organic carbon mineralization. Thus, *on board* and *in situ* measured rates were oxygen uptake by the sediment community and sulfate reduction under anoxic conditions due to the activity of sulfate reducing bacteria. These rates will contribute to set up a time scale for organic matter turn-over, degradation and preservation in these specific sediments.

One major goal is to calibrate molecular degradation indices. Precise information of organic matter reactivity will be drawn from molecular compounds that are revealed using sediment extraction methods. Publications so far propose molecular degradation indices that much more correct define the organic matter degradation state e.g. by means of the molecular transformation of amino acids (Dauwe et al., 1999). This specific index furthermore links compositional features of POM to its degradation dynamics. The major parameter to gain from the retrieved samples - the chlorin index (CI) - has been introduced by C. Schubert et al. (2002). It can be used as a productivity indicator as it relates the present chlorin content of a sediment to its potential chlorin amount. In this context, it is a measure of sediment maturity or grade of reactivity. Schubert et al. (2002) already published data on chlorin contents and the CI in the Benguela Upwelling north of Walvis Bay so that the expected data being retrieved from the Meteor cruise in 2003 will be an important complement.

Rates and pathways of benthic carbon degradation depend on the quality and quantity of carbon flux to the ocean floor. However, descriptive approaches to this question are often hampered by logistic difficulties and the unpredictability of sedimentation events.

These difficulties can be overcome by in-situ experimental approaches. Recent in situ experiments with ^{13}C-labeled diatoms revealed the response time and response pattern of continental slope communities to large amounts of fresh (i.e. highly "reactive") organic carbon (Witte et al. 2003). However, the importance of the quantity, sources, quality and composition of the settling organic material (export production) still needs to be investigated. Organic matter of differing reactivity may be utilised in a very different ways by the sediment community. This context was addressed by two series of experiments during Meteor cruise M57/2.

The work included *in situ* incubation experiments in benthic sediment chambers of a free-falling Lander and i*n situ* incubation experiments in whole sediments cores deploying organic material of different reactivity grades: fresh algae, artificial degenerated algae (both isotopically labelled) and local shelf material. Following the cruise there will be carried out *ex situ* incubation experiments in gas-tight Würgler bags for detailed insights into oxidation types and degradation processes at the MPI.

The following sections gives an overview of the experiments and sample processing with main emphasis on geochemical and reactivity analysis.

4.6.2 Experiments and Rate Measurements

Preparation of ^{13}C and altered algae

In order to track down organism-specific molecular compounds and their degradation dynamics and degradation products, we employed isotopic labelled algae. Local typically occurring diatoms of the genus *Skeletonema costatum* were cultured in 25% ^{13}C and ^{15}N-labelled medium on a 12 hour light:dark cycle. The preparation of altered algae material was done on board by dialysis method.

The dialysis was carried out at 4°C. Freeze-dried fresh *Skeletonema costatum* were soaked in sterile filtered (250 µm) seawater and filled into dialysis tubings (1000 MWCO). The dialysis solution was pre-cooked seawater with pH ~ 7 to prevent bacterial growth during dialysis and to obtain a sterile fluid. The algae were dialysed at a ratio 1:100 - sample : solution for 6 hours in the dark. Subsamples have been taken after two solution exchanges every 2 hours and from the finally “altered” algae. The dialysis extracts were centrifuged at 2500 rpm for 7 min at room temperature. The supernatants were coloured light-yellow and altered algae had a distinct tang. The supernatants and the dialysed “altered” algae were kept deep-frozen and light protected until utilization in the experiments.

Measurements of sulfate reduction rates

The benthic remineralization of organic carbon exerts an important influence on the flux and distribution of carbon and nutrients in continental margin oceans . Anaerobic processes are particularly important in continental margin sediments, and of the anaerobic processes, sulfate reduction dominates. Over the past seven years, a comprehensive map of sulfate reduction rates in the slope and shelf sediments has been assembled by Bremen scientists, including measurements made during the cruises: Meteor M34-2 (continental slope), Petr Kottsov 1997 (selected near-shore sites between Conception Bay to the south and Cape Frio to the north), Poseidon 99 (extensive net of sites south of Walvis Bay), and Meteor M48-2 (an extension of the sampling net to include much of the coast north of Walvis Bay). In contrast to these earlier cruises, measurements of sulfate reduction rates on Meteor 57-2 were undertaken to support the studies and experiments (both in situ and ex situ) of organic carbon reactivity and mineralization at selected sites.

Sulfate reduction rates were determined using the whole-core method, whereby a sub-core of one of the multicores is injected with radio-labelled sulfate (approximately 200 kBq per injection) via silicon-filled ports spaced at 1 cm intervals along the side. After an appropriate incubation period, the samples were sliced in 1 to 2 cm intervals and preserved for further treatment in Bremen. There the reduced radio-labelled sulfide will be distilled, trapped, and counted in order to determine the sulfate reduction rates. Table 4.6.1 shows the location from where samples for sulfate reduction samples were taken. Sulfate reduction rate experiments were also performed on sediment sub-samples taken from the Benthic Chamber Lander deployments. Additionally, two Lander deployments, utilizing the Orpheus in situ sulfate reduction unit were undertaken (see discussion in Section 4.2.3).

^{210}Pb

At selected sites cores were also obtained for determination of mixing and sedimentation rates using the naturally occurring ^{210}Pb distribution. Multi-core samples were first measured for resistivity (for porosity determination) and then sliced into 2 cm sections for storage in plastic petri dishes. These sample will be analyzed using gamma spectroscopy in Bremen (MPI).Table 4.6.1 shows the location of samples taken for gamma spectroscopy.

4.6.3 Microbial Parameters

Bacterial Abundance and Diversity

Sediment samples (0.5 ml) were preserved in paraformaldehyde (PFA) for later quantification of bacterial numbers and community composition by counterstaining with DAPI (4',6-Diamidino-2-phenylindole) and selected FISH-probes (Fluorescent *In Situ* Hybridization).

Water samples (50 ml) were fixed with formaldehyde for later quantification of bacterial numbers and community composition with the same techniques as the sediment samples.

Bacterial Secondary Production

The measurement of incorporation of radioactively labelled (^{3}H, ^{14}C) leucin into protein was developed in planktonic environments and has rarely been used in sediments, especially not in deep sea environments. It is physiologically based on the bacterial synthesis of protein, which can be measured without evaluating bacterial numbers in an environment. It doesn't measure cell division but biomass increase and can thereby be used to investigate community as well as individual growth, which is of special importance in partly limited systems, where "unbalanced growth" (increase in storage compounds, when energy and carbon are available in excess but inorganic nutrients like phosphorous or nitrogen are limiting) may be significant. The method is relatively insensitive to against disturbances in the sediments, allowing for preparation of slurries for easier sample handling.

Sediment (3–5 ml) was incubated with 20 µM ^{14}C-leucine (Amersham Biosciences) in glass syringes under anoxic conditions at *in situ*-temperature in the dark. Surface sediment was additionally incubated under oxic conditions. After 8 hrs the reaction was stopped with TCA (Tricloracetic acid, 5 % final conc.). Immediately after addition of the ^{14}C-leucine, 500 µl of sediment were transferred into a cryovial and killed with TCA. Subsequently, samples were either stored deep frozen (-20°C), or washed with a combination of centrifugation and filtration steps. The applied extraction method closely followed a protocol suggested by Buesing and Gessner (2003), which was developed for muddy sediments of high organic content. Extraction was carried out in a water bath of 80°C for 2 hours, a subsample placed in Scintillation Cocktail and measured in the Scintillation Counter (Packard).

Preceding experiments were carried out on board to estimate sediment quenching, substrate saturation concentrations, linearity of leucin-incorporation and isotope dilution. It showed that tracer concentrations suggested in the literature were appropriate for the sediment samples, and a tracer concentration of 20 µM and incubation time of 8 hrs lay was used for all incubations (Fig. 4.6.1).

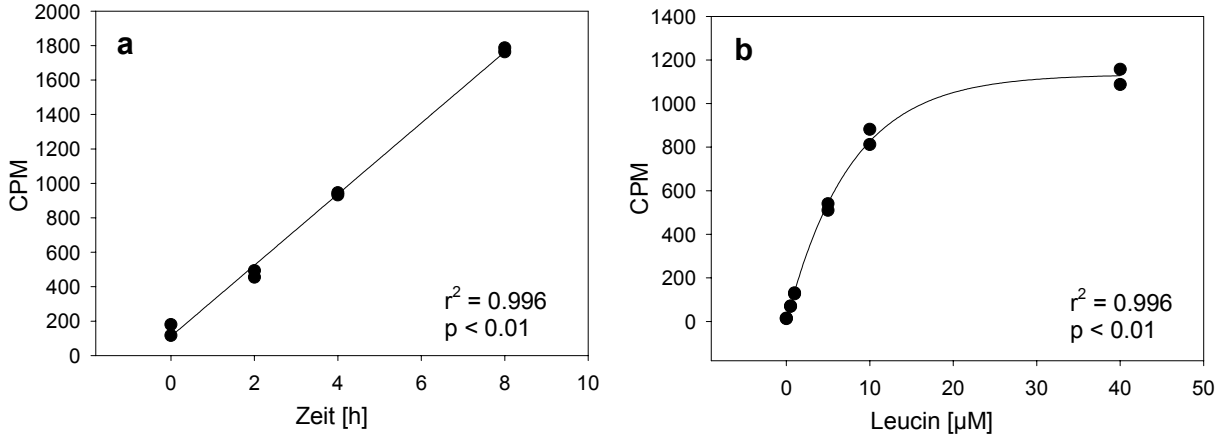


Fig. 4.6.1 (a) Experiment for linearity of [^{14}C]-leucine incorporation at 20µM [^{14}C]-leucine. (b) Substrate saturation curves of [^{14}C]-leucine incorporation at an incubation time of 8 hours.

4.6.4 *In situ* Experiments

Experimental setup

During the cruise, seven deployments of a free falling Benthic Chamber Lander (BCL) (cf. Sect. 4.2.4) have been carried out on stations on transect 1 and 2 (GeoB 8418, 8425, 8447, 8456, 8460, 8471, 8495). The stations cover a range of depth (605–2267m) and TOC content (2.74–8.09 % TOC).

During most deployments, the Lander was operated with three benthic chambers for *in situ* experiments. Only at stations GeoB 8460 and GeoB 8495, one chamber was replaced by the ORPHEUS module that is capable of measuring *in situ* Sulfate Reduction Rates (Tab. 4.6.1). The benthic chambers were used to carry out *in situ* pulse chase experiments with isotopically (^{13}C and ^{15}N) labelled organic matter of different quality. Three types of substrate were used: local shelf material (which was not labelled), “fresh” algal material and “altered” algal material.

Prior to the deployment, subsamples from each substrate were taken and kept deep-frozen and in the dark for detailed and accurate characterization in the lab. An average Lander experiment took 36 hrs and provided he following parameters:

1. Chamber water (sampled regularly):
   - Oxygen
   - DI^{13}C
   - Nutrients (phosphate, nitrite+nitrate, ammonium, alkalinity)
   - Bromide
2. Sediment:
   - CNS, TO^{13}C
   - Lipid (bacterial lipids) and Reactivity Analysis
   - FISH and BSP
   - SRR
   - macrofauna

3. Porewater:
   - Nutrients (phosphate, nitrite+nitrate, ammonium, alkalinity)
   - Bromide
   - $DI^{13}C$

During the experiment, chamber water subsamples were taken at regular intervals. After the experiment those were subsampled at *in situ* temperature (4°C). From the chamber sediments, subcores (diameter 9 cm) were taken for subsequent slicing and sampling. The remaining sediment in the chambers was collected in three layers (0–2, 2–5, 5–10 cm) and sieved immediately for collection of macrofauna organisms. These were fixed in formaldehyde for later identification and ^{13}C-analysis.

The processing of the sediment subcores proceeded at 4°C under anoxic conditions (Argon saturated atmosphere). The core was sectioned into 1cm slices for the upper 3 cm, then into 2 cm slices from 3–7 cm. The slices were transferred into clean plastic dishes and slurried. After subsampling for all investigated sediment parameters (TOC, FISH, BSP, Sulfate Reduction Rates [BCLV,VI,VII] and lipid/chlorin analysis), the remaining sediment was centrifuged at room temperature and 4000 rpm x 15 min and filtered through 0.2 µm Minisart disposable plastic filters for pore water analysis. The gain was about 20–30 ml per 50 ml sediment.

Pore water was sampled for $DI^{13}C$ analysis (fixed with 3.5% $HgCl_2$ solution), bromide and nutrient analysis and stored cool.

Preliminary results

Initial oxygen concentrations in the benthic chambers varied between 100–120 µmol l^{-1}. Background sediment community oxygen consumption (SCOC) ranged from 0.90 mmol m^{-2} d^{-1} to 8.5 mmol m^{-2} d^{-1}. Conspicuous differences in SCOC were found between the different treatments, indicating that SCOC may depend on the quality of the material settling at the deep sea floor. However, in order to obtain a more complete picture of rates and pathways of benthic carbon degradation, the SCOC data need to be combined with results from the $DI^{13}C$ and $TO^{13}C$ analysis as well as bacterial and macrofaunal ^{13}C-signatures.

Nutrients have been measured in bottom water of each benthic chamber during the Lander experiment and in pore water of the respective sediment cores. Nutrient data include phosphate, nitrate + nitrite, ammonium and alkalinity concentrations. Selected examples represent phosphate data.

Phosphate bottom water concentrations during all *in situ*-experiments showed site-dependent variations within a range of 0–2 mg l^{-1}. Chambers injected with fresh algal material always revealed much higher phosphate concentrations than those injected with altered algae, shelf material and the control chambers. In BCL VI (GeoB 8471, 1372m) shelf material, double amount of fresh and altered algae have been deployed (Fig. 4.6.2a). Phosphate concentrations in the chamber water with fresh algae were on average 5 times those from the shelf-injection. Altered algae induced 1.5 times higher phosphate concentrations than shelf material. All three show an increase in concentration for the first 12

hours. High phosphate values by fresh algae may have been due to residual phosphate from the algae medium.

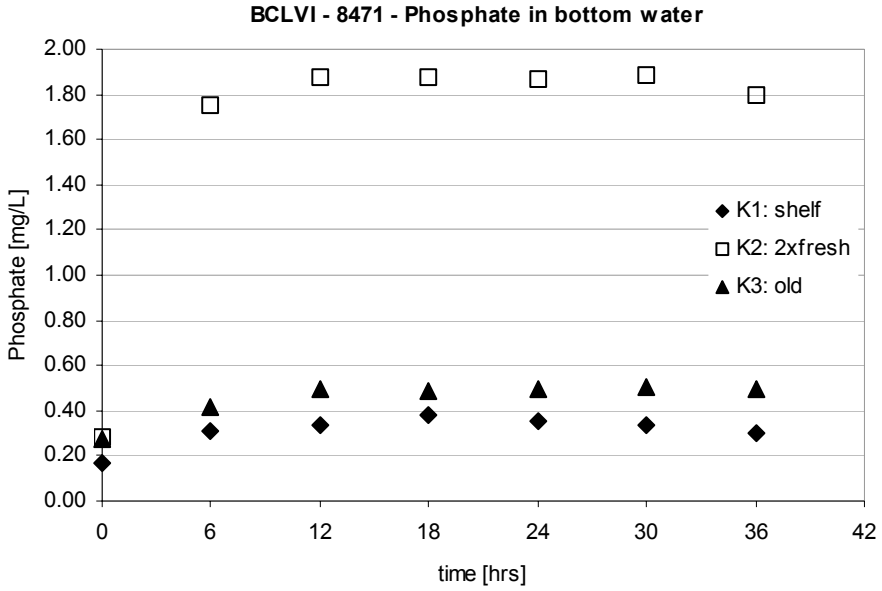


Fig. 4.6.2a Phosphate in bottom water of chamber 1-3 (K1-3) during BCL VI

Pore water phosphate concentrations show a wider range (0–3 mg l^{-1}) and tend to have maximum values in 1–2 cm sediment depth. Again, fresh algae result in higher concentrations than old algae and shelf material in BCL VI (Fig. 4.6.2b). They were 1.3 times higher than shelf induced phosphate values and 2 times higher than phosphate concentrations from the chambers receiving altered material.

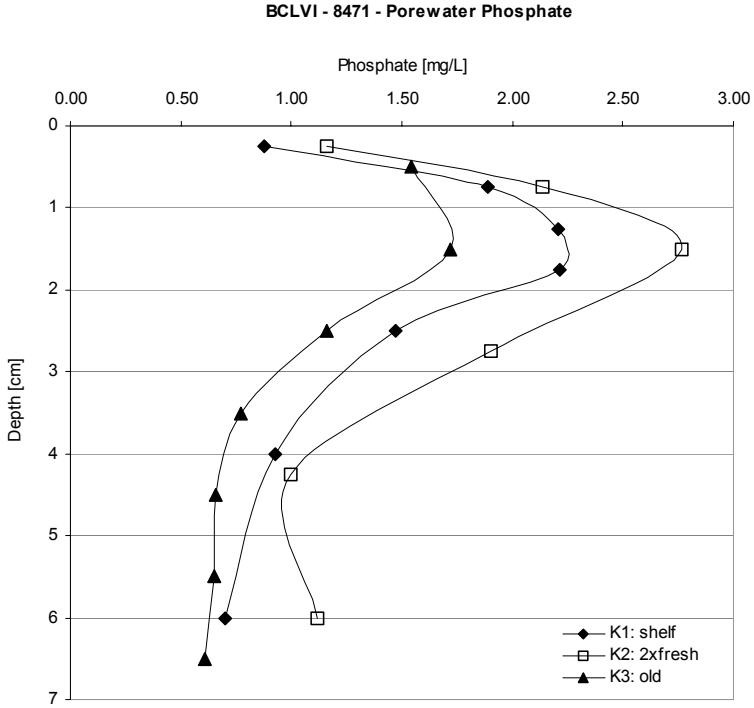


Fig. 4.6.2b Phosphate in sediment porewater of chamber 1-3 (K1-3) during BCL VI

4.6.5 *On Board* Incubations

Experimental setup

Supplementing the *in situ*-measurements, *on board*-incubations were set up to allow for longer incubation times than possible with the free falling lander. Incubations were performed on three stations (GeoB 8422, 8429, 8463), covering gradients of organic carbon concentration (2.5–5.8 % TOC) and depth (1988m, 363m, ~1000m). Two of those corresponded to lander-stations (GeoB 8422 to BCLII, GeoB 8463 to BCLIII and VI), while the third station (water depth 363m) was selected where bottom water oxygen concentrations were too low for a lander deployment (ca. 1ml l^{-1}).

Multicorer tubes with an overlying water column of max. 20cm were covered with lids keeping them air-tight but carrying valves for regular sampling of the water column. The cores were set up in *in situ* temperature seawater using big plastic tons. A magnetic stirrer was used to mix the water column in the cores.

Cores were incubated with labelled algal material of fresh and altered quality and unlabeled shelf material collected earlier during the cruise (at station GeoB8404 at 50m depth). Two time steps in the range of 6 to 15 days were selected depending on time and space available on board. As the incubation at GeoB8429 was not supplemented by a lander deployment, a short time step was added, however for logistic reasons only altered algal material could be used for the enrichment experiment. For each time step and station, a control was run with no added material.

In regular time intervals, the magnetic stirrer was stopped and the overlying water column was sampled for O_2, $DI^{13}C$ and nutrients. While $DI^{13}C$ samples were fixed with $HgCl_2$ for later analysis, O_2 and nutrients could be measured immediately using Winkler titration and an autoanalyzer. The volume removed for sampling was exactly noted and replaced by sterile filtered bottom water from a comparable depth, which was itself subsampled for the investigated parameters.

At the termination of the incubation, the cores were sliced under argon-saturated atmosphere and the sediment sampled for TOC, chlorine/reactivity and lipid analytics, FISH and bacterial productivity and sulfate reduction rates. Samples were usually taken at 0–1 cm, 1–2 cm, 2–3 cm, 3–5 cm and 5–7 cm sediment depth. Where present and accessible, macrofauna organisms were collected and stored in formaldehyde for ^{13}C-analysis. Pore water was extracted to retrieve $DI^{13}C$, nutrient and alkalinity data.

Preliminary results

Oxygen concentration in the *on board*-incubations was measured by Winkler titration. Measurements of oxygen content of the replacement water added to the cores after removal of the sample were carried out in duplicates to enable exact calculation of the volume of oxygen added to the incubated cores with this replacement water.

An example of the course of oxygen concentrations in the incubated cores is given in Figure 4.6.3. During times of closed cores, oxygen is consumed by the benthic community.

Increases in O_2 mark events when water was added to the cores to prevent them from turning anoxic.

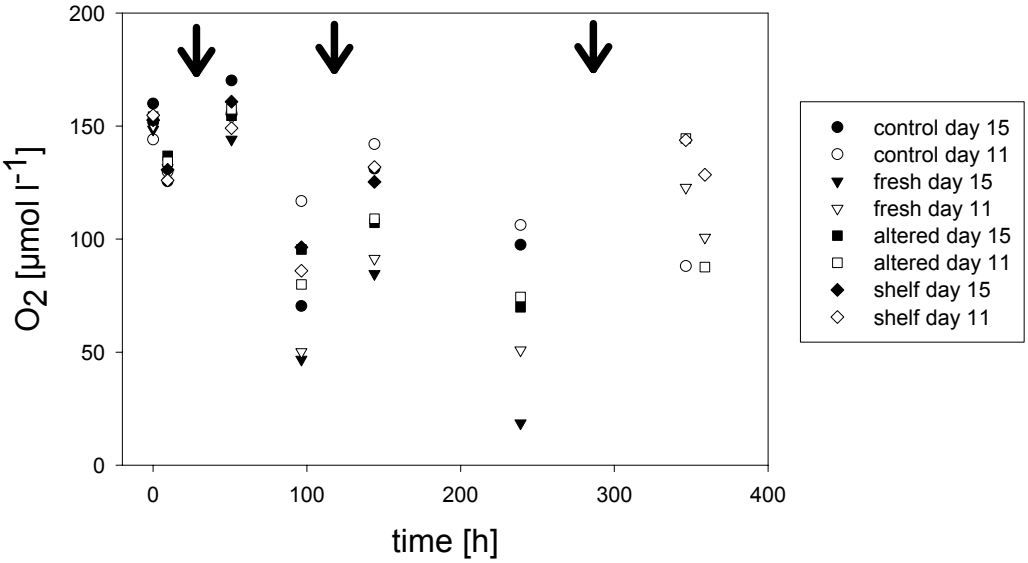


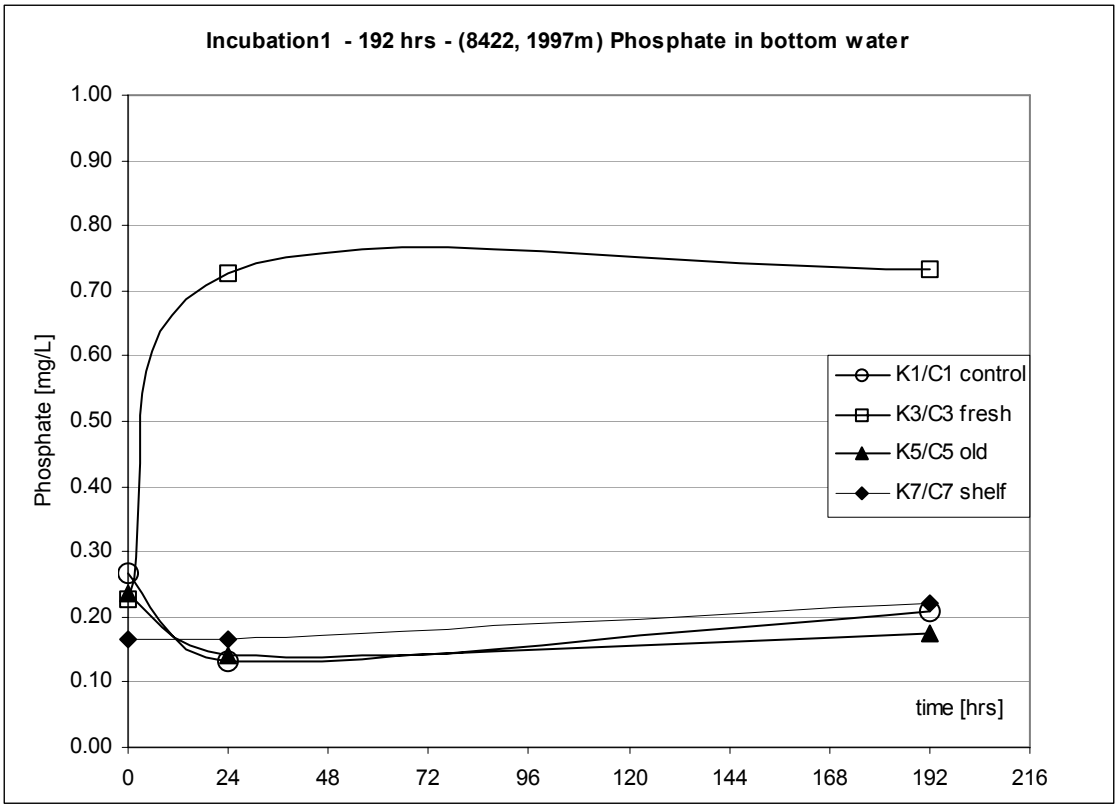
Fig. 4.6.3 Oxygen concentration in the incubated cores from GeoB 8422. Arrows mark events when bottom water of higher O_2-content was added to the cores. Open symbols mark medium incubation time of 11 days, filled symbols mark long incubation time of 15 days.

Oxygen concentrations varied between 15 and 190 µmol l^{-1}, averaging 117 µmol l^{-1} for GeoB 8422, 103 µmol l^{-1} for GeoB 8429 and 94 µmol l^{-1} for GeoB 8463. Thereby, they lay in the same range as concentrations in the *in situ*-measurements.

Sediment community oxygen consumption (SCOC) could be calculated for each sampling interval as well as for total consumption rates over the whole incubation period. They varied between 0.3 and 8.3 mmol O_2 m^{-2} d^{-1}, which is comparable to values measured *in situ* with the benthic chamber lander. While at GeoB 8422 SCOC shows a decreasing trend throughout the incubation period, no such trend could be detected for the other stations. Overall, SCOC was variable and no pronounced differences were found between treatments except for GeoB 8488, where controls and cores enriched with shelf sediment revealed remarkably lower oxygen consumption rates than those enriched with algal material.

Again, to give more detailed information about the respiratory response of the benthic community to an organic matter pulse, these oxygen data need to be complemented by the $DI^{13}C$ measurements which could not be carried out on board.

Phosphate concentrations in bottom water of incubation 1 (< 1 mg l^{-1}; Fig. 4.6.4) are in the same range as chamber water values in associated lander incubations. Similarly, phosphate concentrations initiated by fresh algae material induce much higher values than in other treatments. Immediately after starting the experiment, they rise to ~5–6 times the initial concentrations, followed by a slight. Values in incubations with altered and shelf material and the control first decline but increase after 312–336 hrs. Altered algae, shelf and control are in the range of 0.1–0.3 mg l^{-1}.



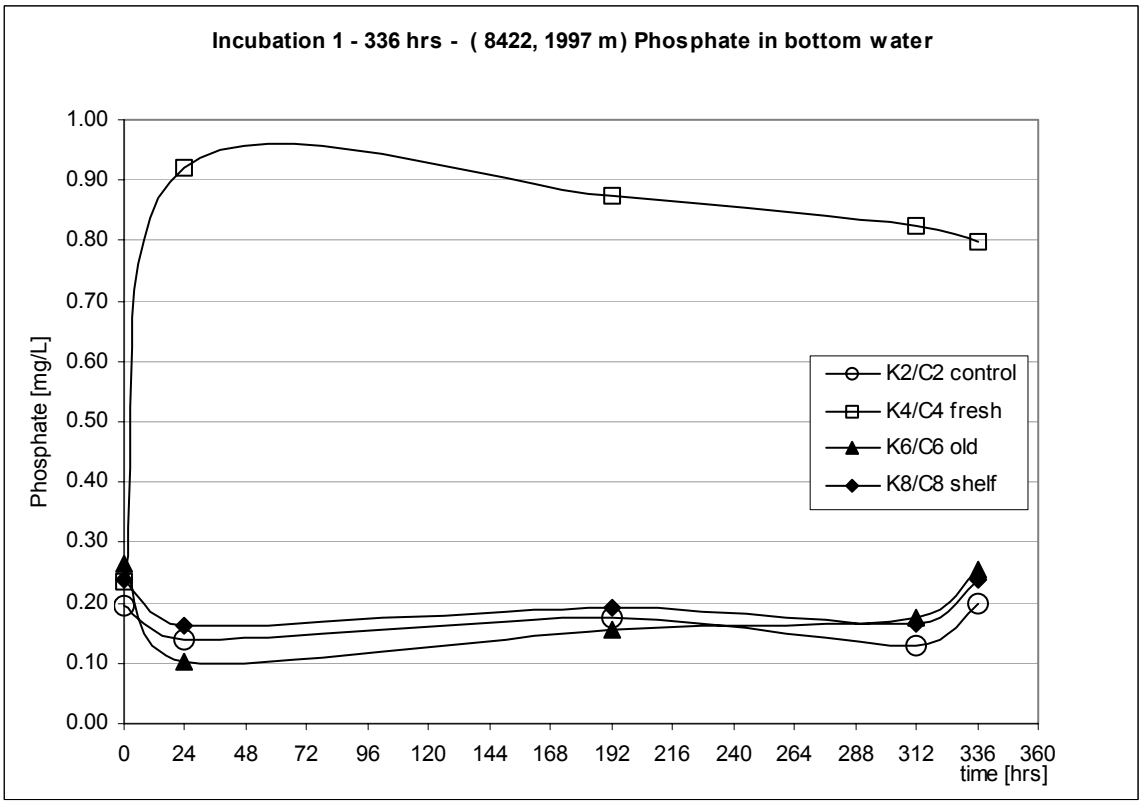


Fig. 4.6.4 Phosphate in bottom water of incubation 1 during 192 and 336 hours incubation time (GeoB 8422, 1997m)

Phosphate release due to degradation of fresh algal material is expressed in maximum values at 1.5–2 cm sediment depth after 193 hrs but at 4 cm after 336 hrs. Altered algae and shelf material induce deeper phosphate maxima at ~3.5–4 cm after 336 days. The control

tends to show highest phosphate concentrations at 4 cm depth after 193 hrs and a downward trend of the maximum after 336 hours. Pore water phosphate concentrations in cores injected with fresh or altered algal material are in a comparable or even lower range than shelf or control cores in incubation 1.

Current data are difficult to interprete so far and need to be handled with caution until the incubated substrates have experienced thorough geochemical characterization.

4.7 Characterisation of the Particle Transport

(M. Inthorn)

To obtain information about the particle transport dynamics in the upwelling area offshore Namibia the water column was extensively sampled and a set of sensors was applied using a rosette water sampler and the new bottom water sampler (BWS, Fig. 4.2.4; for the whole set of CTD and BWS stations see Tab. 4.2.4). Thereby we will be able to localize areas of enhanced particle content – the nepheloid layers. Special interest was hereby laid on the deep water column to gain information about the relevance of lateral particle transport in the benthic nepheloid layer, and the dissolution as well as microbial degradation processes taking place in that realm. We want to estimate the relative importance of these processes compared to those taking place in the upper water column and in the sediments. With the bottom water sampler we achieved a large set of samples and data from the lowermost water column which will be compared with the information and samples obtained by the rosette water sampler and by the sediment geochemistry group.

A ^{234}Th-analysis will be carried out on water, particle and sediment samples from three locations on our profiles. The determination of the activity of this stable isotope in this set of samples will help us to get a rough estimate on the time-scale of particle transport in this system.

4.7.1 Methods

Particle Filtration

Immediately after retrieval the water was sampled for nutrient and oxygen analysis in the shipboard laboratories. The rest of the water was filled into 5 l PE-canisters and then filtered through 2.5 cm pre-combusted and pre-weighed glass-fibre filters (SCHLEICHER & SCHUELL, GF52) with a pore size spectrum of 4 to 6 µm. We used a vacuum pump to suck the water through the filters, with a vacuum below 0.5 bar to avoid destruction of the particles. In some samples, high particle loads made it necessary to use more than one filter due to clogging. The amount of filtered water was determined volumetrically in advance. The filters were then rinsed with a few milliliters of distilled water to remove the sea salt and stored deep frozen. In our home laboratory the quantity of the suspended particulate matter will be determined and a set of inorganic and organic geochemical analysis as well as determination of microbial parameters will be carried out.

Sediment Surface Samples

At every BWS-station the surface sediment of a Multicorer core was sampled as well. We want to compare the composition of the sediment surface layer/fluff layer with the material we sampled with the BWS. By that we might get the information whether the suspended material in the lowermost water column is rather autochthonous or if it is transported there by bottom currents.

The sampling was done by first sucking off the superjacent water from the core until only about 1 cm of bottom water was left. By gentle rotating of the core tube we resuspended the uppermost sediment. The suspension was then sucked off with a pipette and centrifuged in a corning vial. The sediment material was frozen for later analysis in the home laboratory.

Thorium Isotope Analysis

The stable isotope ^{234}Th is produced from the decay of ^{238}U in seawater. Compared to its parent, ^{234}Th is very particle reactive and by that a good proxy for the particle dynamics in the water column. In the deep ocean and almost particle-free water however there is only approx. 3 % of its activity on particles and the removal is so slow compared to its half-life (24.1 days) that total (dissolved + particulate) ^{234}Th is in secular equilibrium with ^{238}U. But in coastal and productive surface waters or in the particle rich bottom nepheloid layer along continental margins scavenging causes a strong depletion of ^{234}Th. Via the depletion of this isotope in the benthic nepheloid layer the exchange rate between the surface sediment and the bottom water can be determined.

At three stations (cf. Tab. 4.2.4) the particulate and dissolved phase of ^{234}Th in the water column shall be determined according to the method of Rutgers van der Loeff (1999). At every station approx. 20 liters of surface water, obtained from the ships seawater supply, as well as 20 liters water from 10, 40 and 100 m above the seafloor, obtained with the rosette sampler, were filtered by air pressure onto 143 mm Nuclepore filters with a pore size of 0.4 µm directly after sample retrieval. The exact amount of water was determined volumetrically. The filters were dried for two days and folded in a reproducible manner to a small square package of approx. 2 cm side length. In the filtrate, the dissolved Th was precipitated quantitatively with MnO_2, by adding 250 µl of a $KMnO_4$ and 100µl of a MnCl-solution to an alkalized sample. We waited at least 8 hours for the MnO_2-particles to form before these were subsequently filtered as well. The filters were folded and dried in the same manner as the particulate phase.

Additionally the BWS was used to retrieve samples from the bottom water. Because of the comparatively small amount of water sampled with the Niskin-bottles of the BWS (5 liters), in this samples only the total content of ^{234}Th was determined by adding the MnO_2 directly to the unfiltered sample. By the subsequent filtration the particulate and dissolved Th was retrieved on one filter. Additionally, the in situ-pump at the BWS was used to receive a larger particle-sample from the bottom water (approx. 170 liters were filtered). All these filters were dried and folded as described above.

To determine the exchange rate of the particles between the water column and the uppermost sediment, these sediments were sampled as well at two of the three stations. The

sediment-cores, which were retrieved with the multicorer were sampled as detailed as possible, which means one sample every 2 mm in the uppermost centimeter and then every 5 mm down to 5 cm sediment depth. The sediment samples were resuspended in a few milliliters of distilled water and a subsample (approx. 1 milliliter) of that suspension was then filtered through pre-weighed Nuclepore filters and handled like the particle filters as described above.

All the Th-samples were transported home by air-freight. The ^{234}Th-activity of the samples is measured with a beta counter at the AWI Bremerhaven. Calibration is performed with spiked filters and checked with samples from intermediate depth assumed to be in secular equilibrium with ^{238}U.

4.7.2 Shipboard Results

Transmissometer Measurements

The beam transmission profiles measured with the SEATECH transmissometer that was connected to the CTD give an overview over the extent of nepheloid layers in the water column. As an example of these measurements, profiles from three stations along a transect across the continental margin of Namibia at 25.5 °S are shown in Figure 4.7.1. In all three profiles nepheloid layers extend in the upper 50 to 100 m of the water column with a decrease of the beam transmission down to 86 % and below. The decrease is strongest for station 8491-2, on station 8458-2 we didn't get a proper signal from the uppermost water column. This surface nepheloid layer (SNL) results mostly from the biological activity in the photic zone. In all three profiles there is also an intermediate nepheloid layer (INL) visible at a depth of 250 to 400 m. Its extent and intensity is diminishing from station 8458-2, which is closest to the coast, to station 8426-5, which is furthermost offshore. At this station there is even a second INL visible at a water depth of 700 to 900 m which lies directly above the bottom nepheloid layer (BNL) at that position. Further analysis of the particulate material on samples from these water layers has to be carried out to determine their origin. They might be the product of large algae blooms sinking down from the surface layers. Or it might be material from the BNL further onslope which has detached from the bottom and transported further offshore across the continental slope. At all three stations the BNL is well developed with transmission values which are as low or even lower than in the SNL. In these profiles the BNL is not clearly pronounced as distinct layers. They are characterized by a gradual increase of particle content (resp. decrease of beam transmission) at the lowermost 100 to 150 meters above the seafloor and an extraordinary increase at the lowermost 20 meters. BNLs originate from particles which are resuspended from the seafloor together with the smaller amount of material transported vertically down from the surface layer. In the BNL particles can be transported laterally over large distances by cyclic sedimentation and resuspension. This is an important factor concerning the degradation of the organic material. Our future work aims to clarify the relation of the different material-sources and the consequences of this special kind of particle transport.

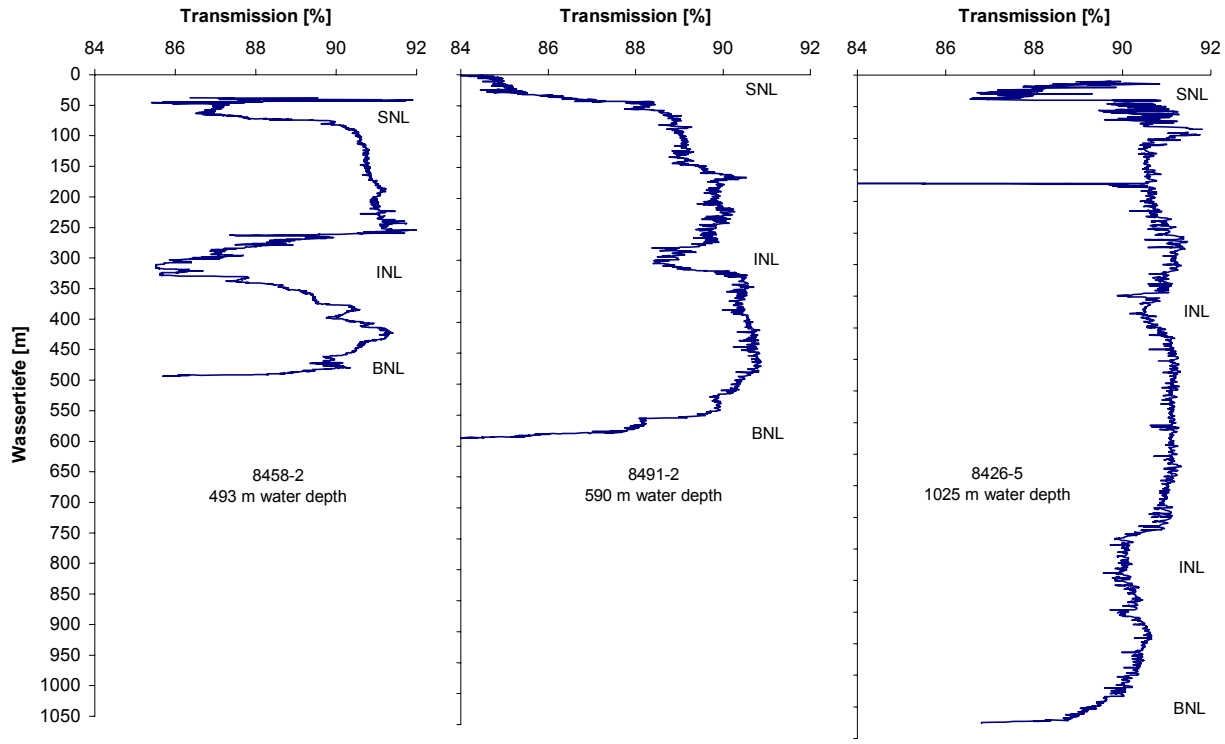


Fig. 4.7.1 Beam transmission profiles measured with a SEATECH transmissometer at 3 stations along the transect at 25.5 °S (cf. Tab. 4.2.4). A decrease in transmission indicates a higher particle content. Hereby the position and extend of nepheloid layers can be located (SNL: Surface Nepheloid Layer, INL: Intermediate Nepheloid Layer, BNL: Bottom Nepheloid Layer).

Particle Filtration

On M57/2 altogether about 300 liters of seawater from the BWS were filtered onto 174 GFF-filters. From the rosette water sampler we filtered 900 liters of water onto 305 GFF-filters (see Tab. 4.2.4). These filters were frozen for subsampling and analysis in our home laboratory. During the filtration work the expected particle distribution in the water column could be noticed. With surface water samples, the filters clogged very rapidly with a yellow-greenish to brownish slimy film of particles and aggregates. Samples from water depths of more than 100 m didn't contain as many particles so that the whole sample volume of about 4 liters could be filtered through one filter. Mostly, this changed again in the lowermost water samples where the bottom nepheloid layer attributed a higher particle-content. Furthermore, the existence of intermediate nepheloid layers was reflected by higher particle amounts.

The samples from the BWS showed generally relatively high amounts of particles with a rising content from the uppermost to the lowermost Niskin-bottle. This gradient shows that a perfectly mixed bottom water layer did not exist in our working area.

4.8 Hydrographic Studies

(T. Heene, V. Mohrholz)

The preliminary results reported here are based on the data of moored instruments until 12th February 2003, the CTD measurements and chemical measurements during the cruise. This observations were processed on board already and the accuracy of pressure, temperature and salinity were sufficient for the following conclusions.

4.8.1 Time Series at 23°S 14°03'E

To improve the knowledge about the temporal variability of hydrographic parameters at the central Namibian shelf an oceanographic mooring was deployed prior and during the cruise at the hydrographic transect in 20nm distance to the coast (Station GeoB 8401, Fig. 3.1). The collected temperature and salinity time series until the 12th February are shown in Figure 4.8.1.

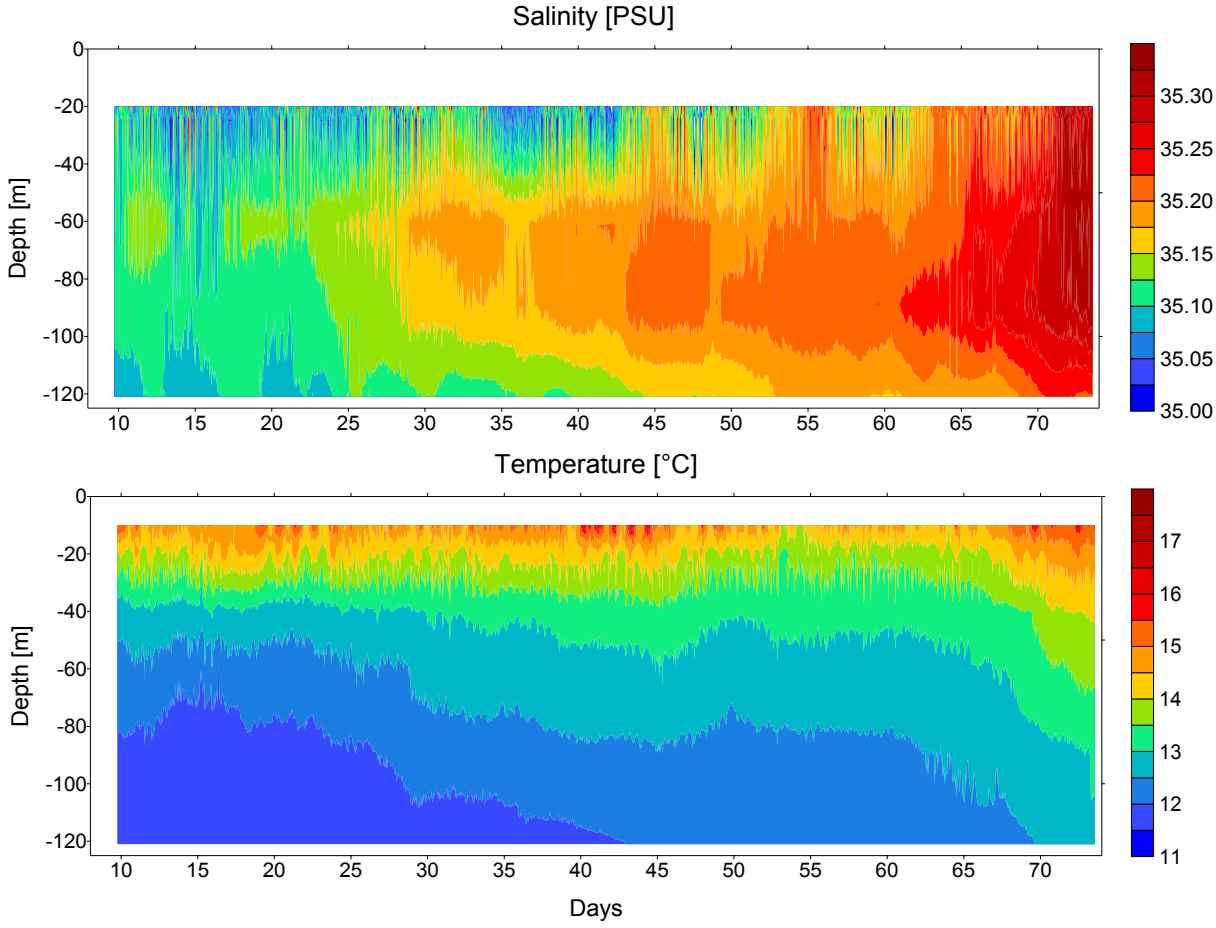


Fig. 4.8.1 Time series of temperature and salinity at the shelf off Walvis Bay (23°0.00'S; 14°3.00'E) in the periode from 10th December 2002 to 12th February 2003.

The increasing salinity during December and January with a maximum at nearly 70m depth suggest a southward transport of South Atlantic Central Water (SACW) with a pole ward undercurrent. The TS signature of this water body supports this result. Strong fluctuations of salinity in the surface layer at time scales of tidal and inertial motions may be caused by high

horizontal gradients in the surface mixed layer, due to mesoscale upwelling filaments and eddies.

According to the seasonal warming the observations show a slightly increasing surface temperature. In the beginning of February the thickness of the surface layer raised from 20 to 30m to about 50m due coastal down welling driven by northerly winds. During the entire measuring periode no strong upwelling events were observed at the mooring position. This was also detected from satellite Sea Surface Temperature (SST) data which depict an unusual high warming at the inner shelf off Walvis Bay.

The mooring was also equipped with oxygen sensors and an acoustic current meter. The processing of these measurements requires a higher effort and will be presented in an additional data report.

4.8.2 Hydrographic Transect at 23°S

Main objective of the investigations at the hydrographic transect were

- the relation between temporal fluctuations, detected by the moored instruments, and the spatial variations in hydrographic parameters across the shelf
- the impact of upwelling circulation on the dissolved matter budget in the northern Benguela
- the coupling of of the large scale circulation at the continental margin with the shelf dynamics

The hydrographic transect at 23°S was worked four times with 7 to 10 days delay between the particular legs. The transect covers the continental margin and the entire shelf from 12°E to the coast. Figure 4.8.2 shows the distribution of temperature, salinity and oxygen during the first leg.

The surface layer was characterised by warm water of higher salinity originating from the northern Benguela. The SST increases offshore and at the coast a very weak upwelling structure was fund. Below the surface mixed layer oxygen depleted central water covers the entire shelf and the continental margin to 12.2°E. The decomposition of organic matter caused anoxic conditions in the bottom layer at the shelf. Whatever, hydrogen sulphide was not detected there.

The core of the Antarctic Intermediate Water (AAIW) was identified by the salinity minimum at 800 meter depth. The secondary salinity maximum near 2200m is associated with the North Atlantic Deep Water (NADW).

The different forcing conditions at the particular legs resulted in changing patterns of hydrographic parameters in the upper 400 meters (not shown here). Whatever, it remains a subject of the detailed analysis to discuss the temporal variations.

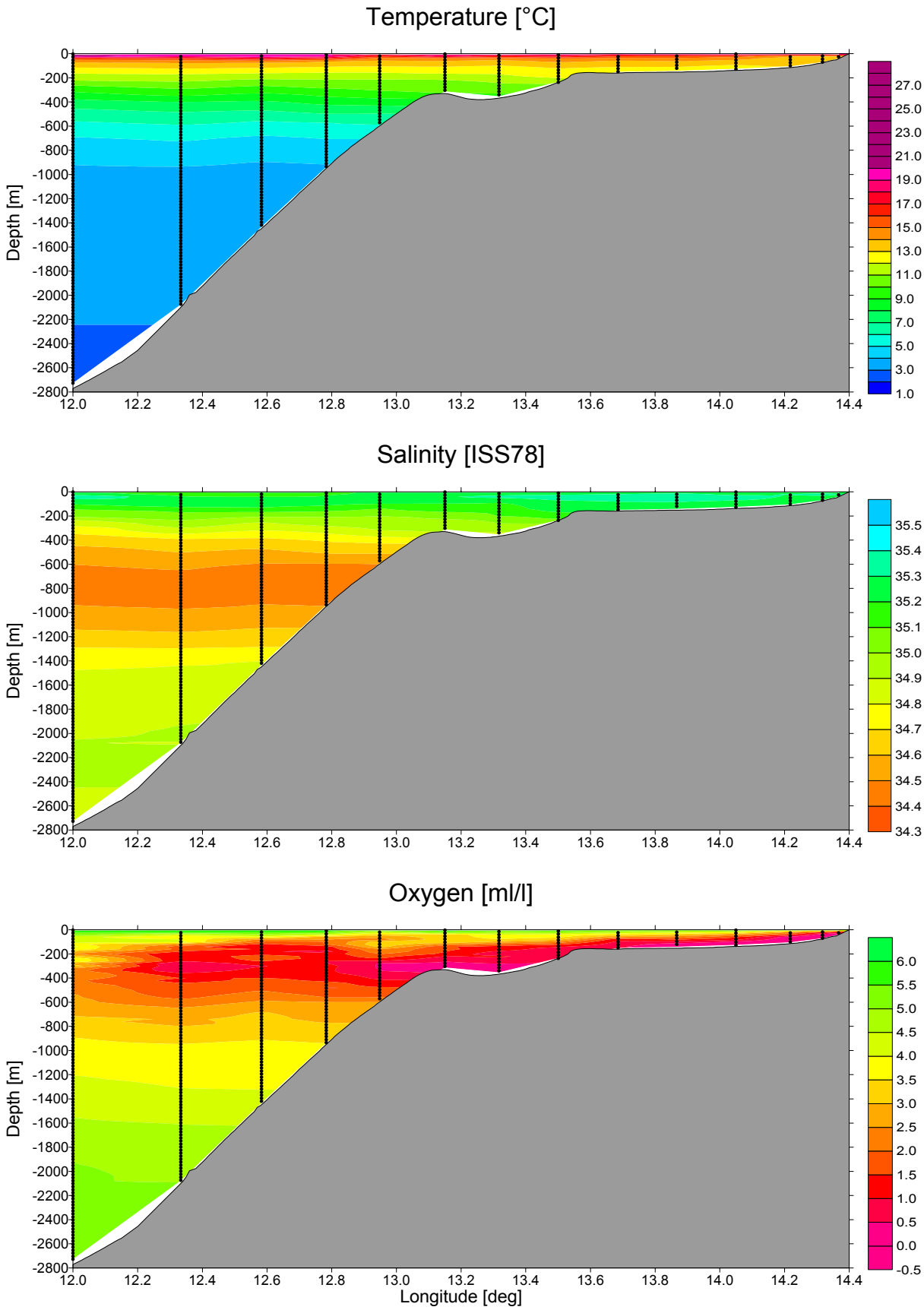


Fig. 4.8.2a Vertical distribution of temperature, salinity and oxygen at the hydrographic transect at 23°S during the first leg (13./14. Feb. 2003). The entire water column 0…2800m depth.

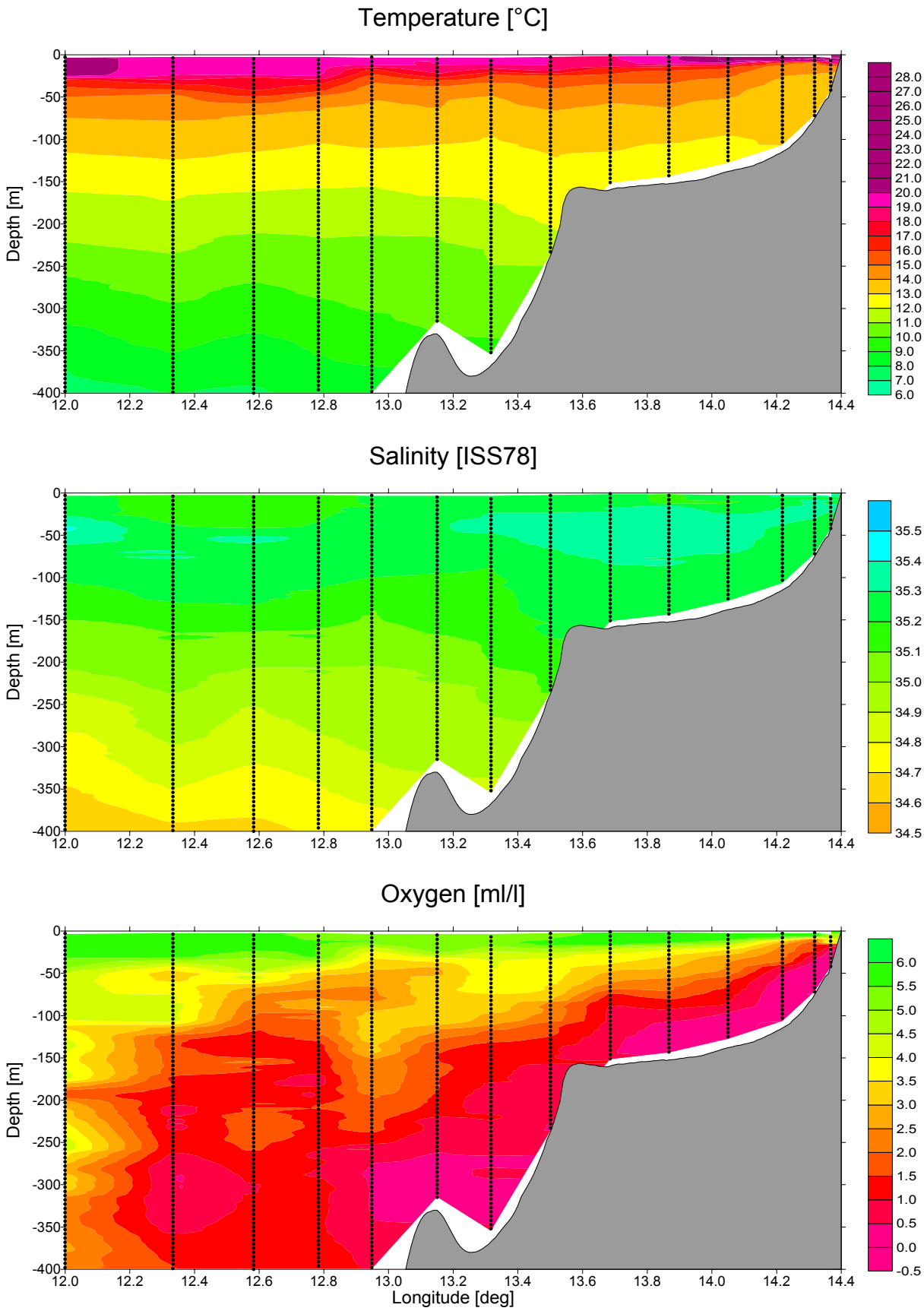


Fig. 4.8.2b Vertical distribution of temperature, salinity and oxygen at the hydrographic transect at 23°S during the first leg (13./14. Feb. 2003). The upper 400m in higher resolution.

4.8.3 Distribution of Central Water Masses

The thermocline water off Namibia consists of two different central water masses and their mixing stages. Saline, nutrient rich but oxygen depleted SACW originating from the tropical ecosystem enters the Benguela system from the north. Whereas less saline, nutrient reduced and oxygen rich Eastern South Atlantic Central Water (ESACW) is transported with the Benguela Current (BC) northward.

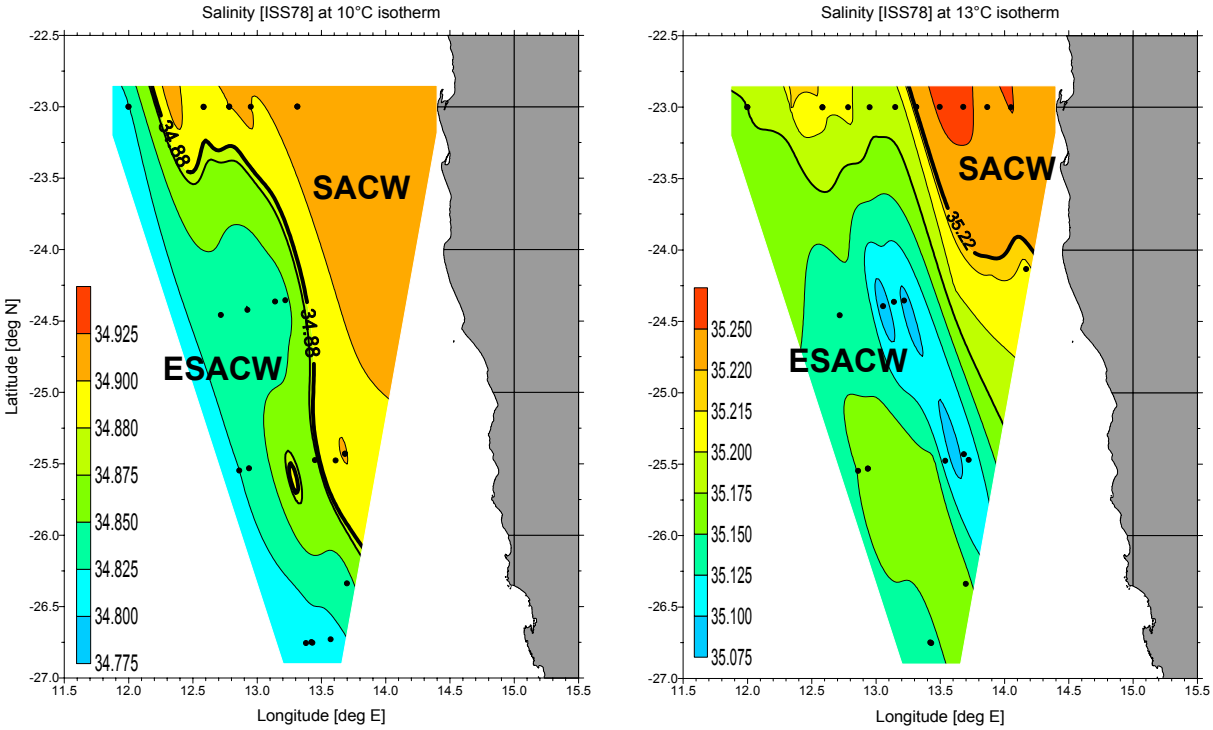


Fig. 4.8.3 Horizontal distribution of salinity at the 13°C isotherm (left) and at the 10°C isotherm (right) off the namibian coast. The front between the two central water types is depicted by the bold isoline.

The distribution of both central water types is shown in Figure 4.8.3. In the upper central water layer (13°C isotherm, ca 150m depth) the SACW reach to 24° S and covers only the shelf. The major portion of the upwelled water at the coast originating from this depth. This caused a higher on shore transport of central water. In the deeper layers increase the southward extension of SACW at the shelf (see salinity distribution at the 10°C isotherm, ca 250m depth). This may be caused by a higher intensity of the pole-ward undercurrent and a decreasing onshore transport of ESACW. Due to its different oxygen and nutrient content the distribution of central water play an important role for ventilation of the subsurface laver and the productivity of the Benguela upwelling system.

4.9 Dinoflagellate Cyst Investigations

(U. Holzwarth)

Dinoflagellates are generally unicellular, biflagellated algae that live in the upper water column of seas, oceans and lakes where sufficient light is available for photosynthesis (i.e.

the autotrophs) or enough nutrients are available in the form of other phythoplankton or organic debris (i.e. the heterotrophs). Several dinoflagellate species produce geologically preservable organic-walled or calcareous cysts as a part of their sexual reproductive cycle. These produced cysts are an important member of the marine phytoplankton. Their life cycle is divided in two parts, a motile thecate stage and a non-motile cyst stage. Dinoflagellate cysts have successfully been used as proxy-indicators for paleoenvironmental reconstructions. Hereby calcareous dinocysts were found to reach highest abundance during times of well stratified and oligotrophic surface waters whereas organic dinocysts are found in higher numbers in regions of high nutrient supply. By investigating surface samples and correlating the species compostion with the main parameters of the upper water column it is possible to reconstruct the environmental conditions of the past.

During this cruise samples were taken from the multicorer and the ships membrane-pump in order to increase the knowledge about the species distribution in surface sediments and the upper water column. At the university of Bremen cultures will be established for experiments under controlled laboratory conditions. Samples were also taken with the plankton hand net. Later they will be analysed qualitatively on dinoflagellates by M. Elbrächter, Deutsches Zentrum für marine Biodiversitätsfor-schung, Forschungsinstitut Senckenberg.

The aim is to get much material especially from the typus species of the dinoflagellates. They will be characterized in detail by modern taxonomic methods. Moreover this study contributes to the registration of the biodiversity of the dinoflagellates in the Benguela current and completes the investigations which began on Meteor 48/5 in October 2000.

First investigations of the hand net samples reveal that in the regions of upwelling the plankton community is dominated by chain-building diatoms. Remarkable is that samples taken in the late evening or night contain much less phytoplankton and are rich in zooplankton like copepods. The reason for this is most likely the diurnal migration of the planktic organisms.

5 Weather and Meteorological Conditions During the Cruise

(G. Kahl)

When the METEOR left Walvis Bay on February 11th, 2003, the belt of storm centers in the Atlantic sector of the Antarctic was at its summerly shrunken state. This meant that the General Circulation adhered closely to the coast of the sixth continent. At the beginning of M57/2 this was also true for the South Atlantic Subtropical High centered near the island of Tristan da Cunha. From such a southerly position it exerted but little influence on the area of investigation. As a result a coastal low just south of Walvis Bay had established itself for some time already when our research vessel put out to sea. It was there nearly all the time though intensity and exact position varied.

The features of the weather map mentioned so far were the essential ones for the entire voyage. They made up the weather we observed between them. Only one additional feature is left to be mentioned: During the third weak of the cruise the intense tropical cyclone “Japhet” crossed Madagascar and made her landfall south of Beira, Mozambik, and instead

of filling it moved to Zaire before it finally succumbed to the forces of friction and consequently filled. During that last part of her life span when being already extratropical she managed to influence our area of investigation, giving rise to near-gale mean winds accompanied by gale force gusts by intensifying the coastal low mentioned above already.

While there were only light southerly winds during the first days of the voyage there was no long wait for the autumnal widening of the Antarctic storm belt: It occurred already in mid-February, the subtropical high being pushed about 10 degrees of latitude to the north. For the bulk of the cruise it could be found at around 25° to 30° southern latitude.

Interdiurnal variation deserves mentioning, too, because even without a variation in the synoptic situation the southerly winds could go up from 3 Bft in late morning hours to 6 Bft near midnight, for example, following the varying intensity of the static low over the continent. The variation itself varied but little during the time of the cruise. It slackened only during the last weak of it.

Visibility has been good nearly all of the time. A southerly wind was always there, and though there were times of the winds being weak wind forces of 5 Bft or 6 Bft were often recorded.

6 Acknowledgements

The overall successful course of this expedition needs to be attributed to the friendly cooperation and very efficient technical assistance of Captain Nils Jakobi, his officers and crew. No matter in which area, we always were attentively cared for. It was always obvious that all people on board worked on a common task. For this we would like to thank everybody involved, last but not least also the Leitstelle METEOR Hamburg.

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