MD218 CROTALE

Cruise Report

La Réunion – Crozet Islands – La Réunion

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Content

Avant-propos

During MD218 CROTALE we retrieved the longest core ever (69.70 m), beating the previous record by more than 5 meters. This would have not been possible with the strong involvement of many persons.

My first acknowledgments go to Minoru Ikehara (U. Kochi, Japan) who kindly shared SBP data that helped identifying several target sites to core. Similarly, many thanks to French and international collaborators who helped improving the cruise proposal.

My second acknowledgements go to the FOF (Flotte Océanographique Française) who selected the proposal and provided some travel funds. Similarly, many thanks to IFREMER who planned the cruise and established efficient pre- and post-cruise logistics.

My third acknowledgments go to the IPEV who conducted the renovation of the R.V. Marion Dusfresne coring system within the framework of the French Equipex CLIMCOR. It would be too long to cite all persons involved in the renovation, but I deeply thank Hélène Leau, Yvan Réaud, Denis-Didier Rousseau and Michel Calzas. The MD2 is such a fantastic ship. It would be a disaster if French scientists could not use it anymore in the future.

My fourth acknowledgments go to GENAVIR coring team for its professionalism, availability, flexibility and kindness. It is amazing what these guys (sorry Fanny) can do with so little manpower. Their support to paleoceanography is immesureable.

My fifth acknowledgments go to LDA crew (bridge, machine and coring teams) for its professionalism, flexibility and kindness. It was fun to request so many small loops for site surveys in the dead of night. I reckon I was concerned by the presence of a new ship-owner I did not know, but LDA crew greatly amazed me “easily” handling the long cores. Thanks to the captain who allowed some touristic activities around Ile aux Cochons.

My sixth acknowledgments go to the scientific party. Experienced as well as newcomers were so efficient that all analyses were achieved three days before arrival. My special thanks go to Elisabeth, Isabelle and Stéphane who calibrated the MSCL with Erwan’s help, and to Jacques and Viviane who spent hours (nights??) producing the description synthetic logs.

My final acknowledgments go to the weather that was very merciful for the end of summer.

Overall, it has been a great experience and a fantastic cruise. Many thanks to all of you.

And now science begins!!

On board staff

Figure 1. Photo of MD218 CROTALE staff.

Table 1. List of on-board scientists and crew members.

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RAZAKAMAHEFA	Laiharitiana	Garçon		
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Objectives of the mission

As the major hub of oceanic circulation and nutrient redistribution (Marshall and Speer, 2012), the Southern Ocean (SO) played an important role in modulating global climate variability throughout the Cenozoic (Figure 2). The SO is a key component of the feedback loops that modulates atmospheric CO_2 concentration variability over glacial–interglacial cycles (Hain et al., 2010; Brovkin et al., 2012; Ferrari et al., 2014) through the modulation of the build-up of remineralized carbon in the ocean interior (Sigman et al., 2010; Jaccard et al., 2013; Jaccard et al., 2016). The feedback loops affecting the air-sea flux of CO_2 include the extent of sea-ice (Keeling and Stephens, 2001; Ferrari et al., 2014), the position and strength of the westerly wind regime (Denton et al., 2010; Lamy et al., 2014), the dynamics of the Antarctic Circumpolar Current (ACC) (Mazaud et al., 2010; McCave et al., 2014; Lamy et al., 2015) and associated physical structure of the water-column (Francois et al., 1997; Siani et al., 2013), the efficiency/strength of the biological pump (Marinov et al., 2006; Anderson et al., 2009; Sigman et al., 2010; Jaccard et al., 2013) and their interactions. Indeed, changes in the westerly wind field modulate ACC intensity and location, which subsequently affects vertical and horizontal oceanic heat transport and, therefore, sea-ice extent and seasonality along with primary productivity (Purich et al., 2016). In turn, changes in sea-ice extent impact on the Southern Hemisphere latitudinal thermal gradient which feedbacks on the Westerly winds (Varma et al., 2012). Therefore, a robust understanding of these physical and biogeochemical interactions would improve our ability to predict how SO and Antarctica will respond to global warming (Polvani and Smith, 2013; Boyd et al., 2015; Ritz et al., 2015).

The primary aim of MD218 CROTALE expedition is to retrieve a suite of long sediment cores along bathymetric and zonal transects in the under-sampled southwestern Indian sector of the Southern Ocean (SO). This region is particularly important as it is modulating the redistribution of heat and salt by the Agulhas Current to the global ocean (Caley et al., 2014) and the redistribution of heat and salt to the SO by the Agulhas Return Current (Graham and De Boer, 2013). Additionally, the injection of iron via dust-born iron from South Africa (Lamy et al., 2014) and iron-leached from the Crozet Archipelago Plateau (Pollard et al., 2009) stimulates regional phytoplankton productivity with strong impact on geochemical cycles (C, N, Si).

Non-exhaustively, the main scientific objectives of MD218 CROTALE expedition are:

- To characterize the temporal and spatial variability of the ACC, including surface transport and deep water flow as well as the Atlantic-Indian inter-basinal property exchange, complementing the objectives outlined for IODP Leg 361 site U1475 and for IndienSud project based on several cores off Kerguelen Islands.
- To characterize the causes (dust iron vs remobilized iron; upwelling intensity) and consequences of changes in export production patterns and their implications for the biogeochemical cycles of carbon and nutrients over the Pleistocene.

The investigations will focus on different timescales. First, the new records will allow to characterize mean interglacial and glacial climate states over the past 2 million years, hence covering periods of drastic reorganization of the climate system such as the mid-Bruhnes Transition (MBT, ~0.43 Ma) and the mid-Pleistocene transition (MPT, 1,25-0.7 Ma). Second,

the new records will allow to document, and further constrain, the perturbations and forcing mechanisms involved in physical circulation and biogeochemical inventory changes at the millennial timescale during very different mean climate states (glacial and interglacial periods) and transitory climate (glacial inceptions, deglaciations).

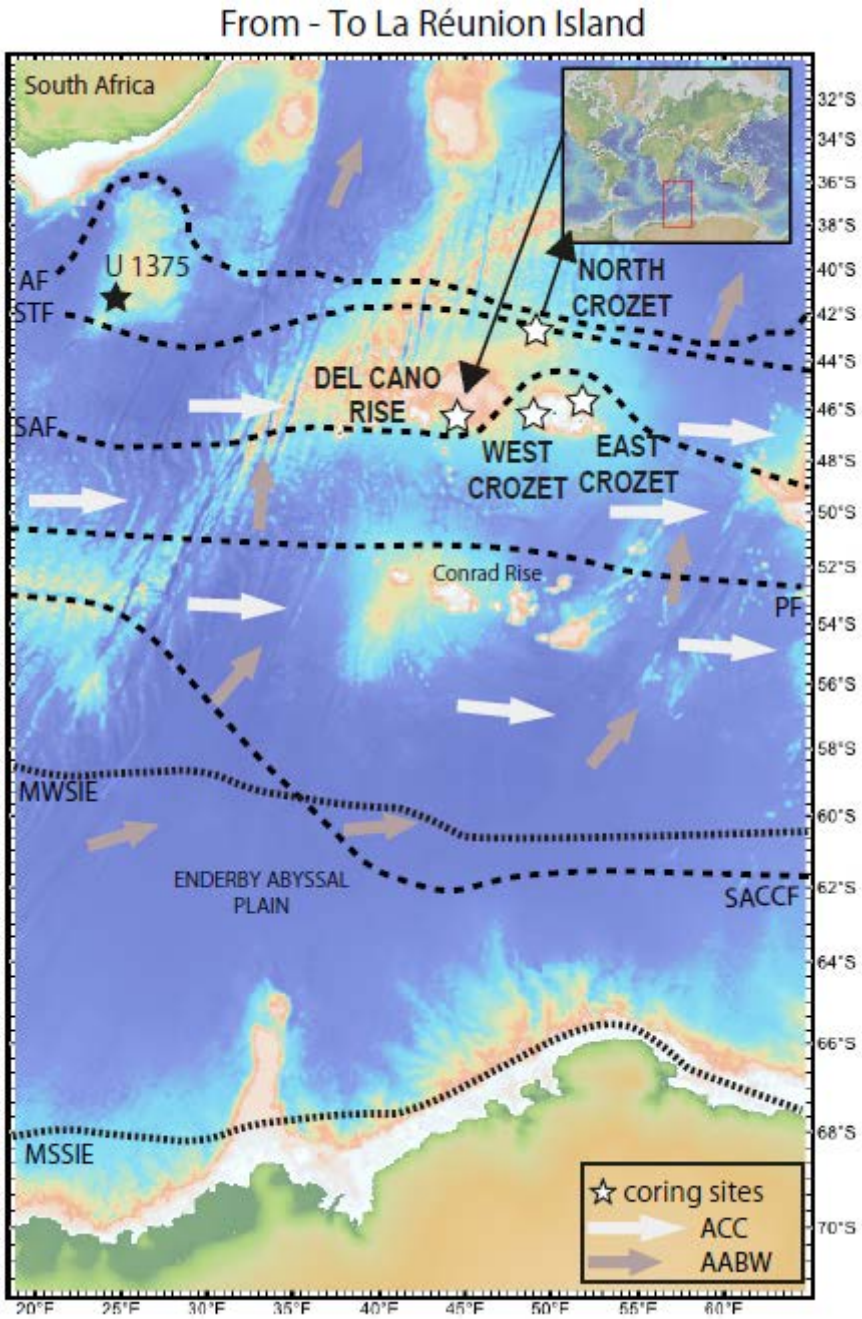

Figure 2. Location of the coring sites in Del Caño Rise, West Crozet, East Crozet and North Crozet regions along with mean topography and bathymetry. ACC: Antarctic Circumpolar Current, AABW: Antarctic Bottom Water; STF: Sub-tropical Front, SAF: Subantarctic Front, PF: Polar Front, SACCF: Southern Antarctic Circumpolar Current Front (Orsi et al., 1995; Belkin et al., 1996), MWSIE: mean winter sea ice edge, MSSIE: mean summer sea ice edge (Schweitzer, 1995).

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Operations

On board acquisition

Multi-beam echo sounder

The EM 122 is designed to perform seabed mapping to full ocean depth with at ultra-high resolution, coverage and accuracy. The nominal sonar frequency is 12 kHz with an angular coverage sector of up to 150 degrees (130 degrees during this cruise) and 864 soundings per ping. The swath width is typically 6 times the water depth to almost 4000 m depth. The sounding spacing is normally equidistant with equiangle available (equidistant during this cruise).

Water column echo sounder

The beam inside water column sounder is part of the EM122. The beams used to map the seabed are read to detect density changes in the water column. Density changes can be due to fish swarms or, of interest here, traces of deep sea gas expulsion.

Sub-bottom profiler

The SBP 120 is an optional extension to the EM 122. The primary application of the SBP 120 is to do imaging of sediment layers and buried objects. The nominal sonar frequency is 3.5 kHz. Due to its narrow beamwidth, the SBP 120 offers a deep penetration in the sediment and a high angular resolution. During CROTALE reflectors, sediment layers having different density and composition than the surrounding ones, have been detected as deep as 100 m.

EM 120 and SB 122 equipments have been turned on at ~35°S – 49° 30’E and turned off at 29°S – 53°30E.

Coring devices used on board

CASQ

The CASQ (Calypso square section) is a 9 to 12 meters long gravity corer showing a large section (25 cm per 25 cm). Its wide opening and its length allow sampling of a large volume of undisturbed sediment (Figure 3). It especially allows the preservation of top most sediments covering of the last millennia. Sampling is generally performed using pre-cut D-tubes that are pushed down in the sediment. Several series can be carved as presented in Figure 4.

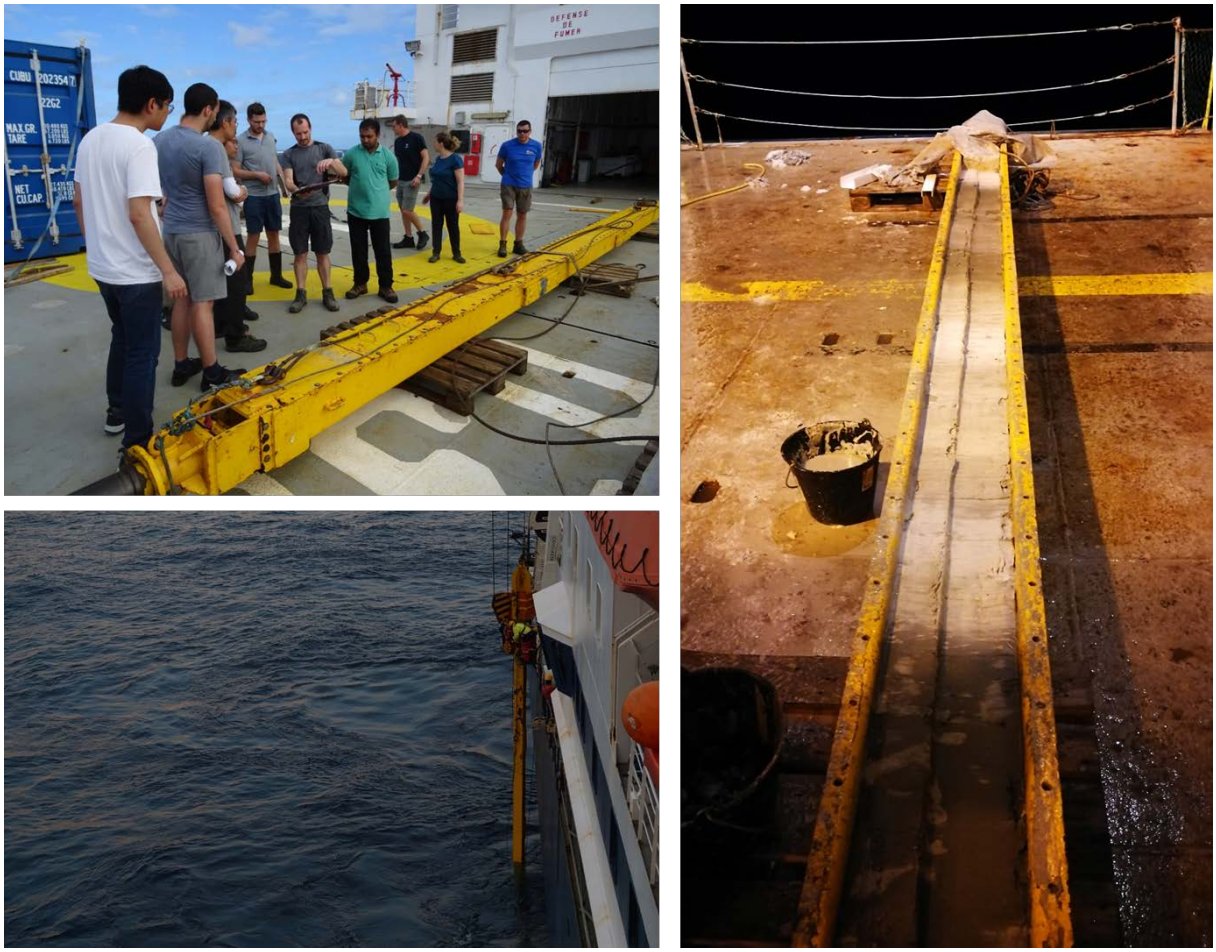


Figure 3. Photo of the CASQ at sea before coring and on board before and after coring

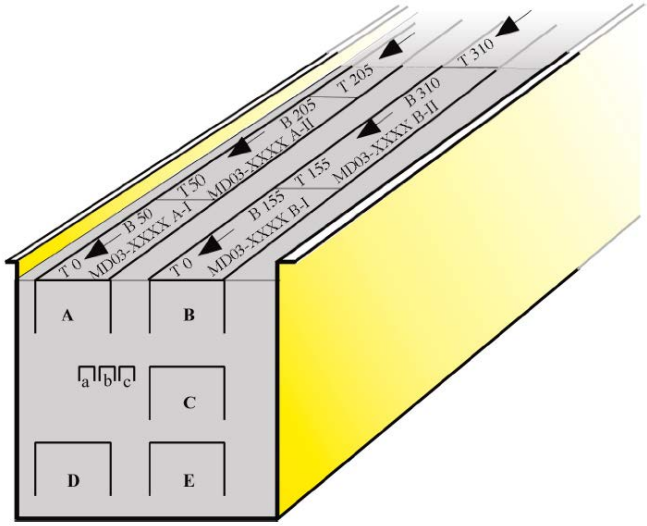


Figure 4. Schematic representation of the sampling protocol in the CASQ corer.

CALYPSO

The CALYPSO corer is a giant piston corer that can retrieve sediment sequences up to 75 meters long, down to 7500 meters depth (Figure 5). Based on a Kullenberg piston coring system, it has been developed in size and rigged to the MD vessel with necessary handling equipments amongst which a 45 tons SWL Kley France annular traction coring winch and dedicated A-frames and booms. It is associated to the CINEMA software in order to prevent stretching of the upper part of long cores. By modeling and computing the kinematics of the coring operations with data loggers, the software allows to optimize all coring parameters before the operation and to quantify the quality of the cores after the operation (Figure 6).

Figure 5. Photo of the CALYPSO corer at sea before coring and on board after coring.

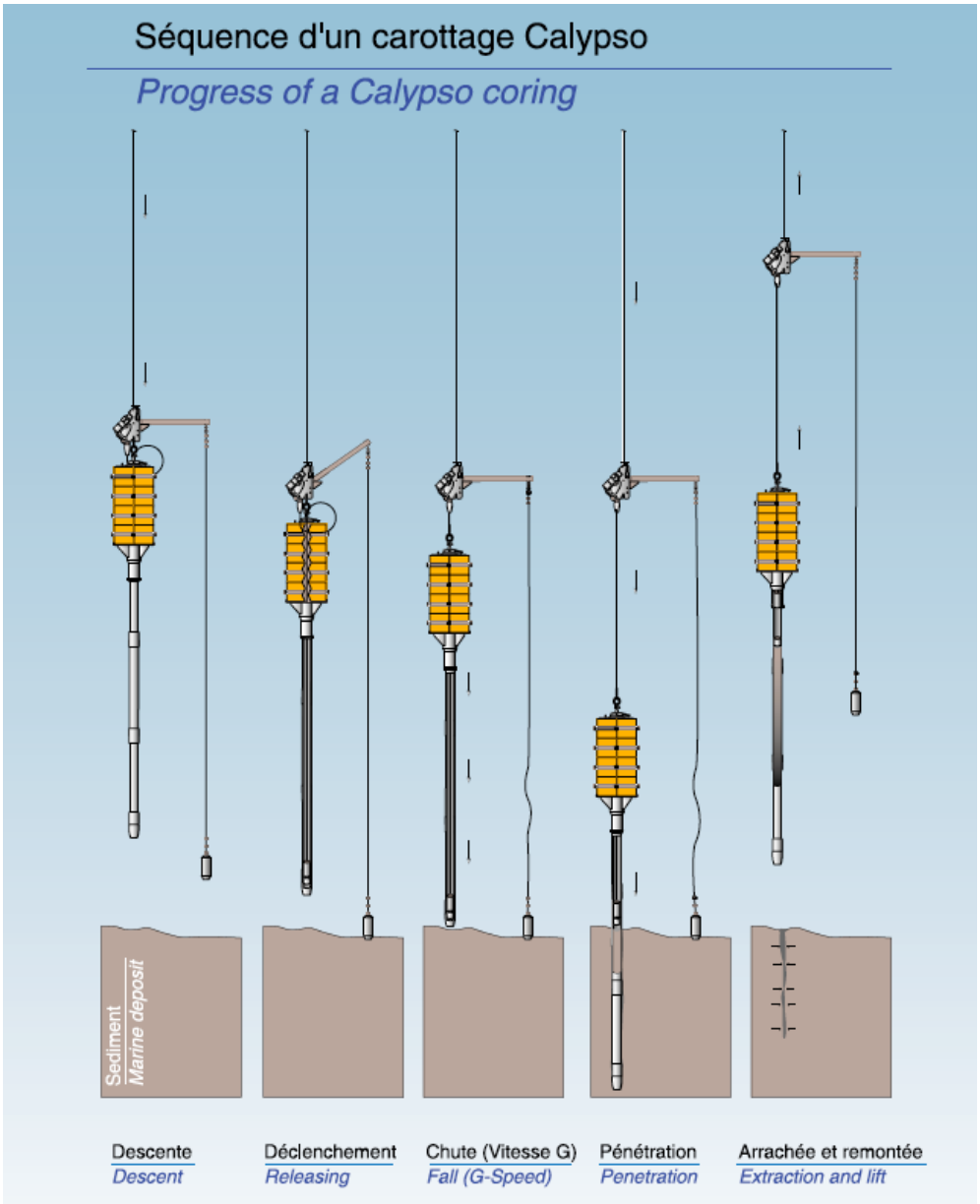


Figure 6. Schematic of a Calypso coring.

Coring workflow

The core, after been pulled out from the corer, is measured, labelled and cut in 1.5 m long sections. Figure 7 presents the different steps in core handling on the deck prior to core splitting/opening, while Figure 8 presents the labelling method adopted by the *Images* community (The International Marine Past Global Change Study).

Figure 7. Photo of core handling on deck.

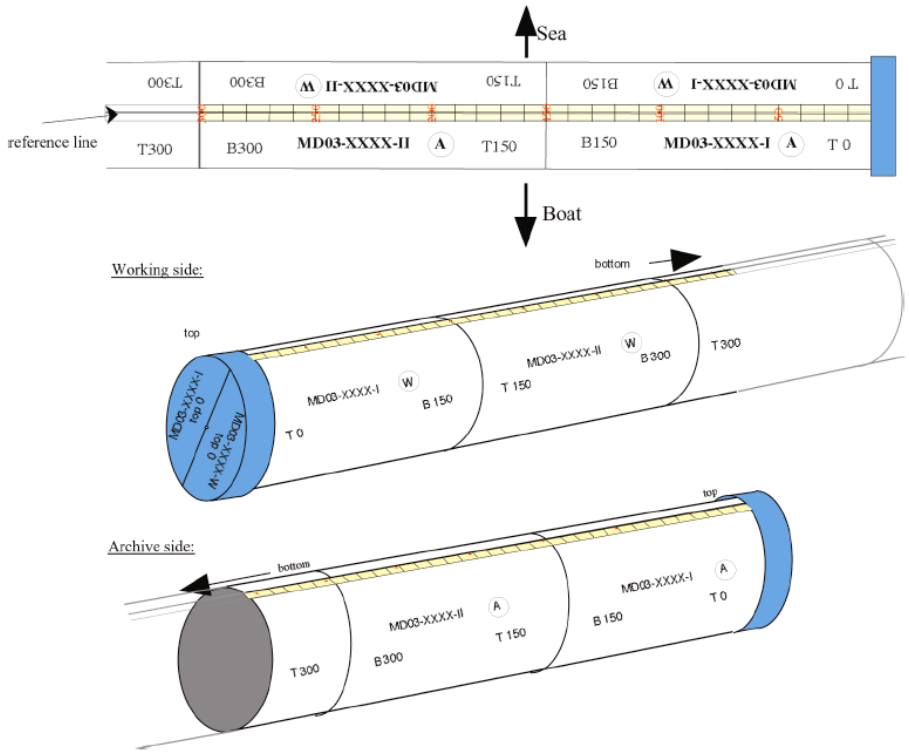


Figure 8. Schematic representation of the core labelling adopted by Images program.

The sections were subsequently opened in two halves using IFREMER new automated saw tool (Figure 9). The Archive half was sent to the sedimentological description and photo (Figure 10) while the Work half was sent to the MSCL (multi-sensor core logger; Figure 11). The GEOTEK MSCL on board R.V. Marion Dufresne is composed of a natural gamma detector, a magnetic susceptibility detector and a color spectrophometry detector. All cores have been analyzed at 1 cm resolution for gamma density, P Wave amplitude, P Wave velocity,

impedance, fractional porosity, magnetic susceptibility, L*, a*, b* and color reflectance from 360 to 740 nm every 10 nm allowing the calculation of red (595-700 nm), green (515-595 nm) and blue mean reflectance (400-515 nm). The MSCL can also be equipped with an Olympus Innov-X handheld XRF spectrometer, which has been used only on core MD19-3575CQ for comparison with XRF cores-scanners.

Figure 9. Photo of IFREMER core opening tool and core splitting.

Figure 10. Photo of the description/photo laboratory.

Figure 11. Photo of the MSCL laboratory.

After completion of on-board measurements both Archive and Work halves were packed in hard boxes (D-tubes) and stored in a cold room at 4°C. Again, labelling of the D-tubes followed *Images* rules (Figure 12).

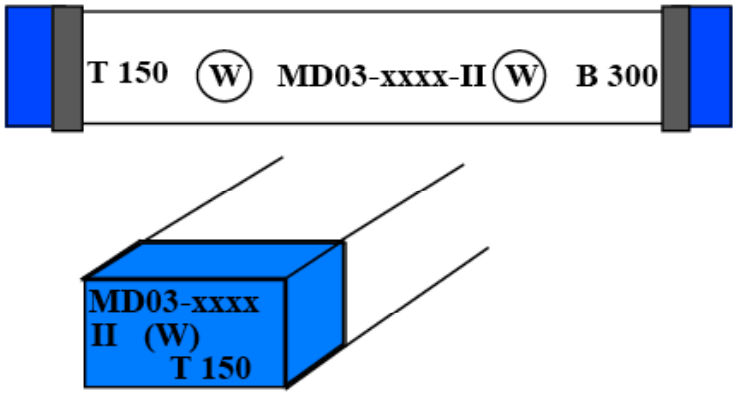


Figure 12. Schematic of D-tube labelling before storage.

Coring activities

Del Caño Rise region

Del Caño Rise (DCR) is located in the western Indian sector of the SO. Because of bathymetric highs above 2000m DCR represents an important topographical constrain on the Antarctic Circumpolar Current Front (ACC) flow and on the location hydrological fronts. The Subantarctic Front (SAF) is anchored to the south of DCR while the Subtropical Front is located north of DCR (Figure 1). However, the SAF is free to bend northward in between DCR and Crozet Plateau, thus passing north of Crozet Archipelago.

Del Caño Rise region has been partly surveyed by Japanese colleagues in 2010, from which was identified a potential coring site in the southwestern part of DCR. An extended survey performed during MD218 CROTALE (Figure 13) allowed the identification of several additional targets on southern Del Caño Rise by ~2400 m water depth (Figure 14). These targets present a sedimentary draping thicker than 100 m. A CASQ (MD19-3575CQ) was first sent at 46°02.83'S – 44°22.21'E – 2410 m of water depth. The bioturbated aspect of the retrieved sediment did not encourage to send a long Calypso at the same site. It was decided to move back to the original target at 46°01.36'S – 44°19.68'E to send the long Calypso (MD19-3576).

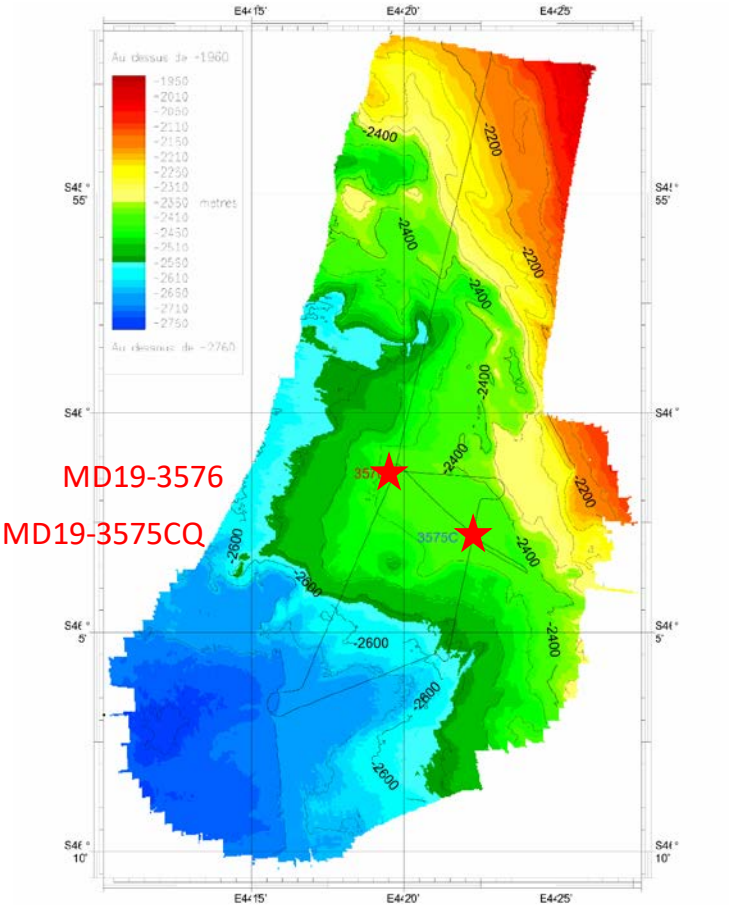


Figure 13. Local bathymetry and position of cores MD19-3575CQ and MD19-3576 (modified after Xavier Morin).

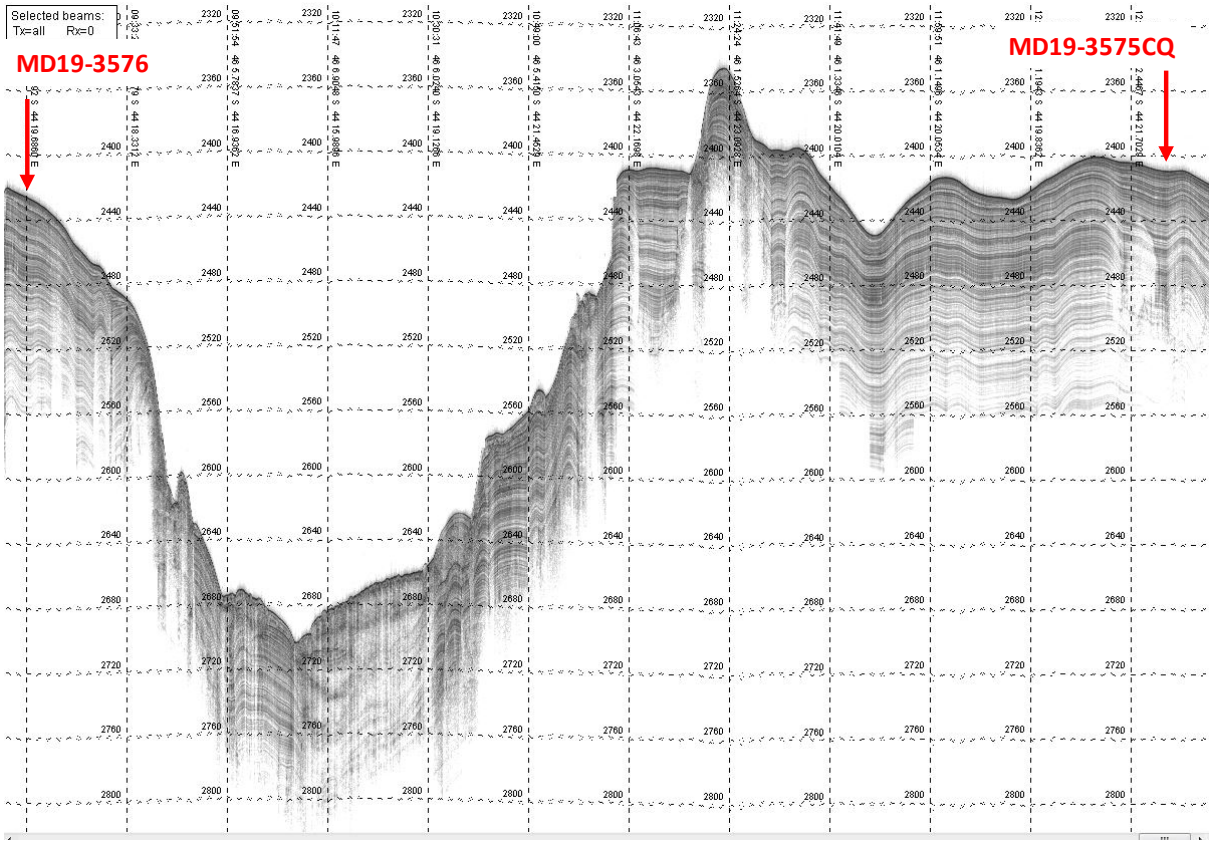


Figure 14. CHIRP 3.5 kHz profile around Del Caño Rise site. Locations of the CASQ (MD19-3575CQ) and Calypso (MD19-3576) cores are indicated by the red arrows.

Core MD19-3575CQ

A 9 meters long CASQ corer was sent. The CASQ was sampled for 4 series. In the first layer, both a large (named a) and a small (named b) series were carved. The small series was offset by 50 cm compared to the large series to create an overlap at the section ends/beginnings. In the second layer, again a large (named c) and a small series (named d) were carved and again the series were offset in between themselves and between the upper layer series (Table 2). The rest of the interface sediment was sampled and preserved in small plastic bags.

The total length of the upper layer series was 8.09 m while the total length of the lower layer series was 8.14 m. This discrepancy was caused by the pressure exerted on the sediment when pushing down the opened D-tubes, which created a small expansion of the very bottom (Table 2).

The core is composed of foraminifera-bearing silt alternating with diatomaceous silt. The core is strongly bioturbated with the presence of numerous centimeter-scale burrows (Figure 15 and Figure 16).

The MSCL data indicate that the core may cover the period from the Holocene to MIS7.5 (Figure 17).

Table 2. MD19-3575CQ core general information.

NOM DE LA CAMPAGNE	Date : **28 February 2019**	Météo : (force) / Direction
MD218 CROTALE	N° de station : **DCR**	Vent : Mer : Variation tension (maxi) :

CAROTTE (N°) :	LONGUEUR m :	POSITION :
MD19-3575CQ *(MD année -numéroCQ)*	**8.09 m**	**Latitude : 46°02.83'S** **Longitude 44°22.21'E**

CASQ		
Tubes (longueur)	**9,00**	**m**
Sonde	**2408**	**m**
ligne filée (touché)	**2 410**	**m**

HEURES (GMT)		
En station :		**GMT**
Début manœuvre :	**14h05**	**GMT**
touché:	**14H47**	**GMT**
Fin de manœuvre :	**16H25**	**GMT**
Départ station :		**GMT**

INSTRUMENTATION OPERATIONS ANNEXES
CTD (hydro) :
CTD (bouteilles) :
Filet à plancton :
Autres : /

0	*150*	*299*	*449*	*598*	*748*	*807*	
a 1	**a 2**	**a 3**	**a 4**	**a 5**	**a 6**		

0	*50*	*194*	*342*	*491*	*640*	*740*	*809*	
b 1	**b 2**	**b 3**	**b 4**	**b 5**	**b 6**	**b 7**		

0	*50*	*200*	*350*	*500*	*650*	*750*	*814*	
c 1	**c 2**	**c 3**	**c 4**	**c 5**	**c 6**	**c 7**		

0	*150*	*301*	*451*	*606*	*757*	*814*	
d 1	**d 2**	**d 3**	**d 4**	**d 5**	**d 6**		

Commentaires

Core a : 2 cm at bottom falling off the sediment sequence before sampling (lost)

Core c and d : Small expansion at bottom when pushing the D-tubes into the sediment

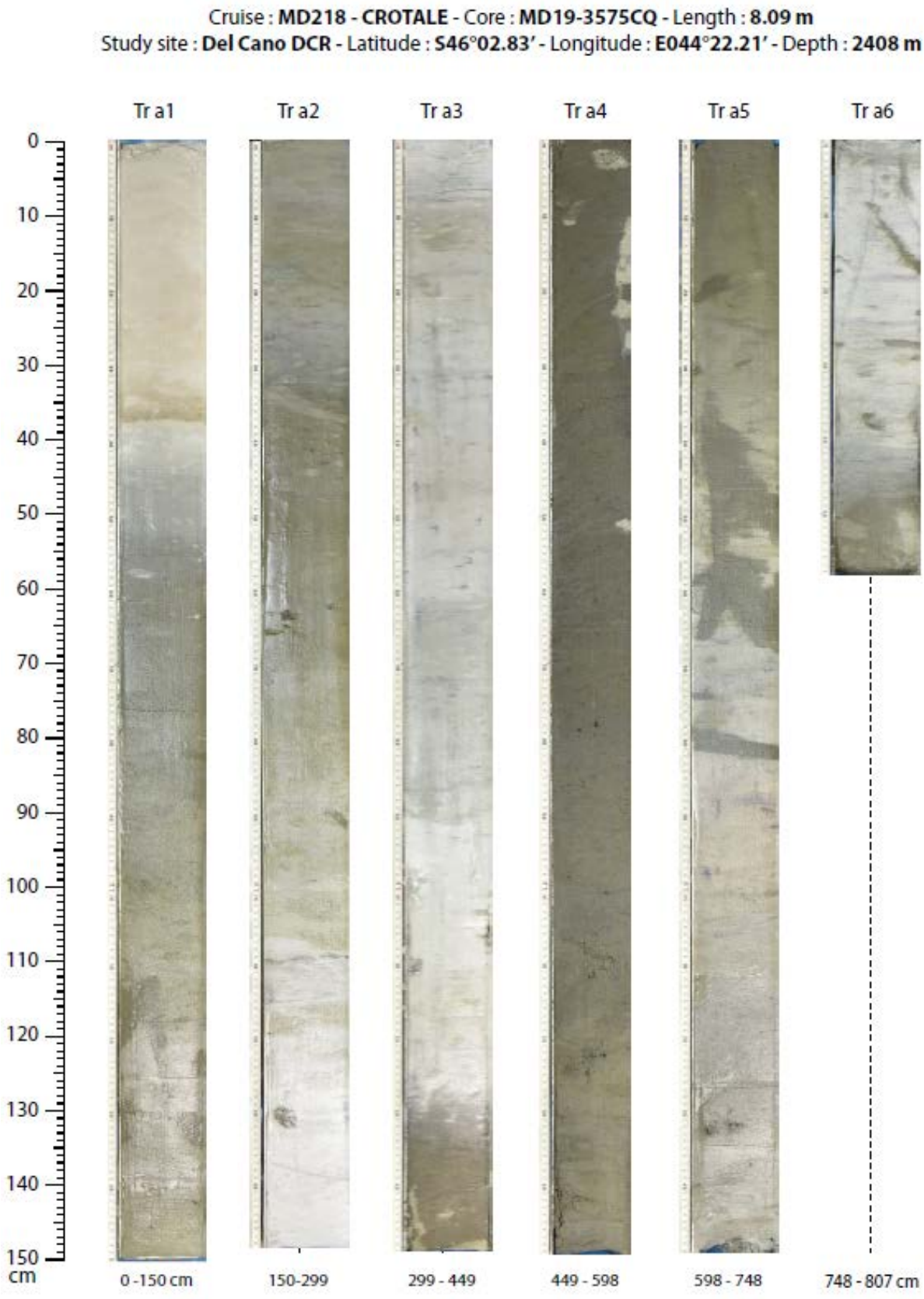
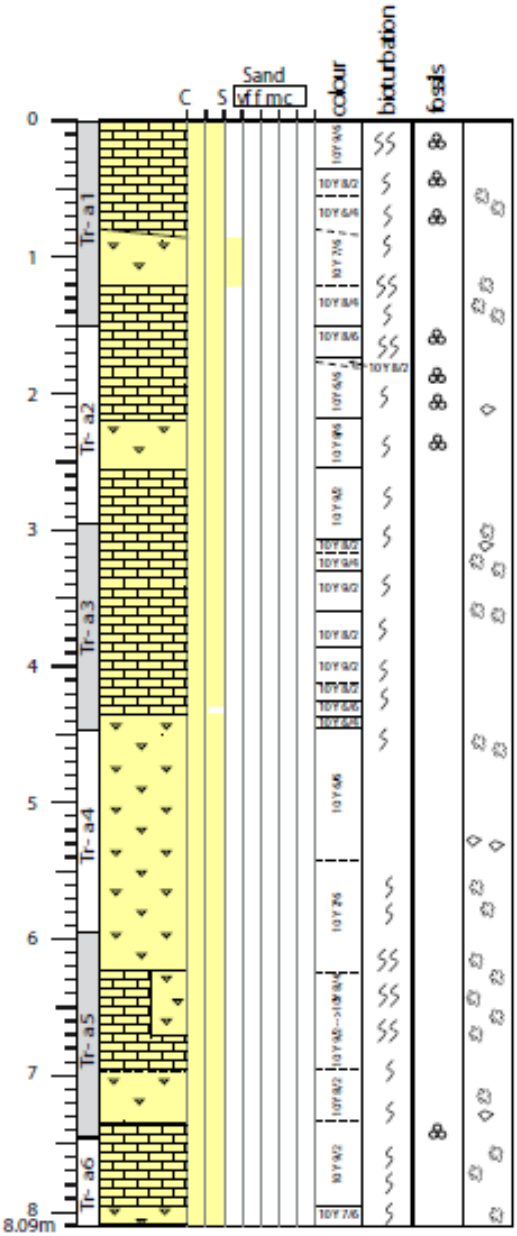


Figure 15. Composite photo of core MD19-3575CQ.

Cruise : MD218 - CROTALE

Core : MD19-3575CQ - **Length** : 8.09m - **Coring site** : Del Cano DCR
Latitude : S 46°02.83 - **Longitude :** E 44°22.21' - **Water depth** : 2408 m



Detailed description:

Massive foraminifera-bearing calcareous bioturbated silt alternating with diatomaceous silt to very fine sand.

Changes from one lithology to one another are often severely bioturbated.

Several colour changes from 10Y 9/2 (calcareous silt) to 10Y 7/6 (diatomaceous silt), with minor colour changes throughout the core (10Y 8/6, 10Y 6/6, 10Y 8/2, 10Y 6/6, 10Y 6/4, 10Y 8/4).

Severe bioturbation throughout the core, mainly large burrows filled with diatomaceous silt in the calcareous silt.

Some lithoclasts at: 212.5 cm, 311cm, 526 cm (0.4cm diameter) and 528 cm (0.2 cm diameter), 730 cm (0.2 to 0.5 cm diameter).

Legend:

clay
silt
sand
diatomaceous
calcareous
ash
lithoclast
foraminifera
burrow
shell
diatom floc
coring disturbance
bioturbation
corals
colored laminae
void

Figure 16. Synthetic log description of core MD19-3575CQ.

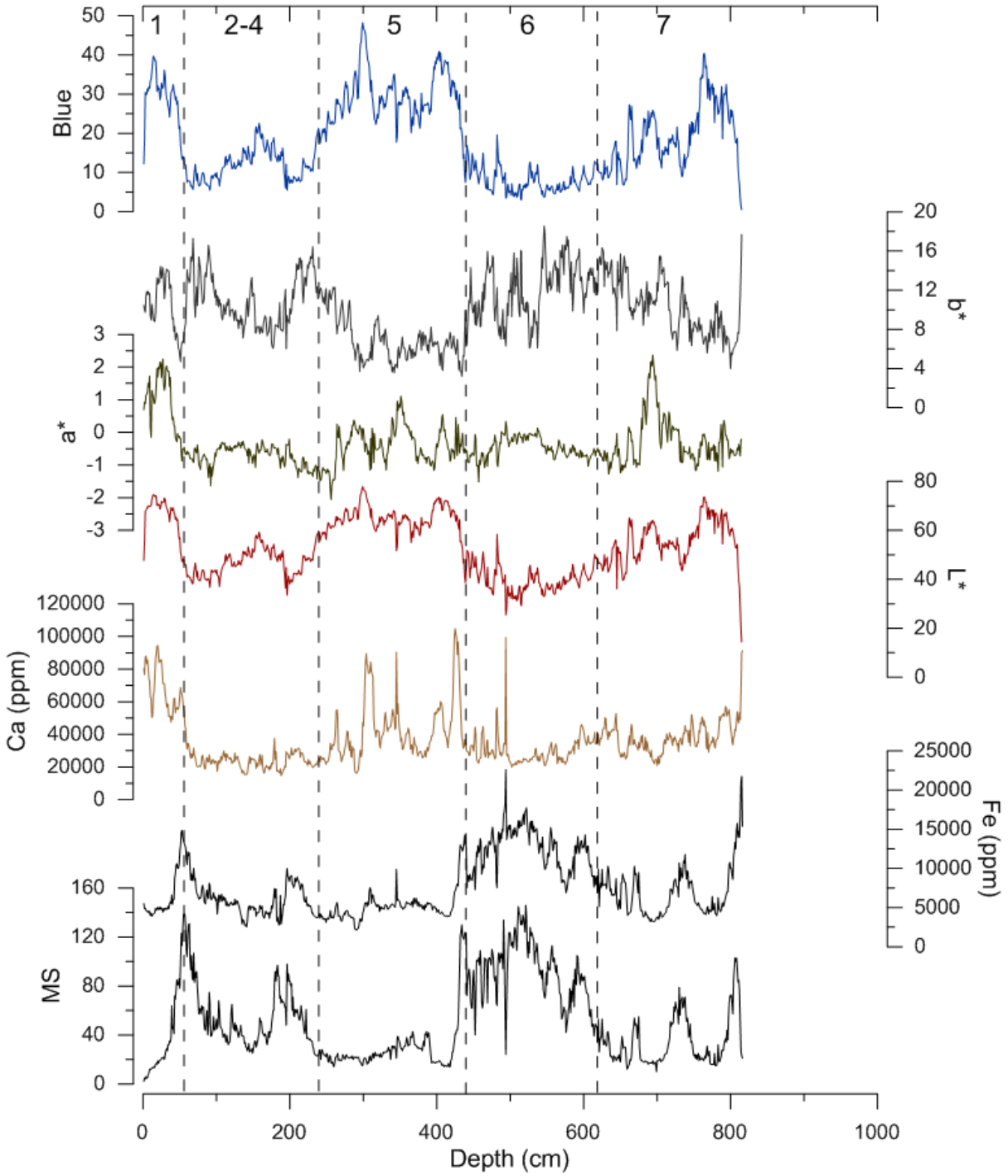


Figure 17. MD19-3575CQ data. From bottom to top: Mass specific susceptibility (in 10^{-8} (m^3.kg)), Fe concentration (in ppm), Ca concentration (in ppm), L, a*, b* and blue reflectance (mean 400-515 nm). Preliminary stratigraphy is highlighted by vertical dashed lines and MIS.*

Core MD19-3576

A 59,08 meters long Calypso corer was sent. Its length prevented to extrude the core liner in one piece. The liner was cut in three pieces that were subsampled in 1.5 meters long sections whenever possible (Table 3). Shorter sections were however produced at the pieces' tops to accommodate back to 1.5 m long sections downcore. MD19-3376 composition is similar to MD19-3575CQ. The upper sections were a bit soupy as well as some deeper parts, probably

associated to more porous sediments. Numerous traces of bioturbation were still observed down to 2700 cm (Figure 18 and Figure 19). Nonetheless, the MSCL data suggest that the core covers the period from the Holocene to ~1.5 Ma (Figure 20 and Figure 21).

Table 3. MD19-3576 core general information.

NOM DE LA CAMPAGNE	Date : 28 February 2019 – 1 March 2019	Météo : (force) / Direction Vent : Mer : Variation tension (maxi) :
MD218 CROTALE	N° de station : **DCR**	

CAROTTE (N°) :	LONGUEUR m :	POSITION :
MD19-3576 *(MD année -numéro)*	**57, 56 m**	**Latitude :** 46°01.36'S **Longitude :** 44°19.68'E

CAROTTIER (type) (1) : CALYPSO	REGLAGES :	CONTREPOIDS :
Poids total (air) : 6,0 t	**Tubes** (longueur) : 59,08 m	**Type (2) :** CYLINDER 100 KG
Poids total (eau) : surf t bottom t	**Câbles :** Chute libre : 1,70 m Boucle : 6,42 m LC poids : m (3m50 lest)	Longueur PVC : m Pénétration : m Longueur de carotte : m + Ogive (+ 0,15 m)

PARAMETRES MESURES :	HEURES (GMT)	INSTRUMENTATION OPERATIONS ANNEXES
Sonde corrigée : 2 419 m	En station : GMT	CTD (hydro) :
Ligne filée : 2 368 m	Début manœuvre : 22h59 GMT	CTD (bouteilles) :
Arrachement/total *(tonne)* : 13,50 t	**Déclenchement :** 0h55 GMT	Filet à plancton :
Pénétration/apparente *(m)* : m	Fin de manœuvre : 3h59 GMT	Autres : /
Pénétration/tensiomètre *(m)* : m	**Durée de manœuvre :**	
Description / incidents :	Départ station : GMT	

0	*150*	*300*	*392*	*450*	*600*	*750*	*900*
TR 1	**TR 2**	**TR 3**	**TR 4**	**TR 5**	**TR 6**	**TR 7**	

900	*1050*	*1200*	*1350*	*1500*	*1650*	*1800*	*1950*
TR 8	**TR 9**	**TR 10**	**TR 11**	**TR 12**	**TR 13**	**TR 14**	

1950	*2100*	*2250*	*2400*	*2550*	*2700*	*2850*	*3000*
TR 15	**TR 16**	**TR 17**	**TR 18**	**TR 19**	**TR 20**	**TR 21**	

3000	*3080*	*3150*	*3300*	*3450*	*3600*	*3750*	*3900*
TR 22	**TR 23**	**TR 24**	**TR 25**	**TR 26**	**TR 27**	**TR 28**	

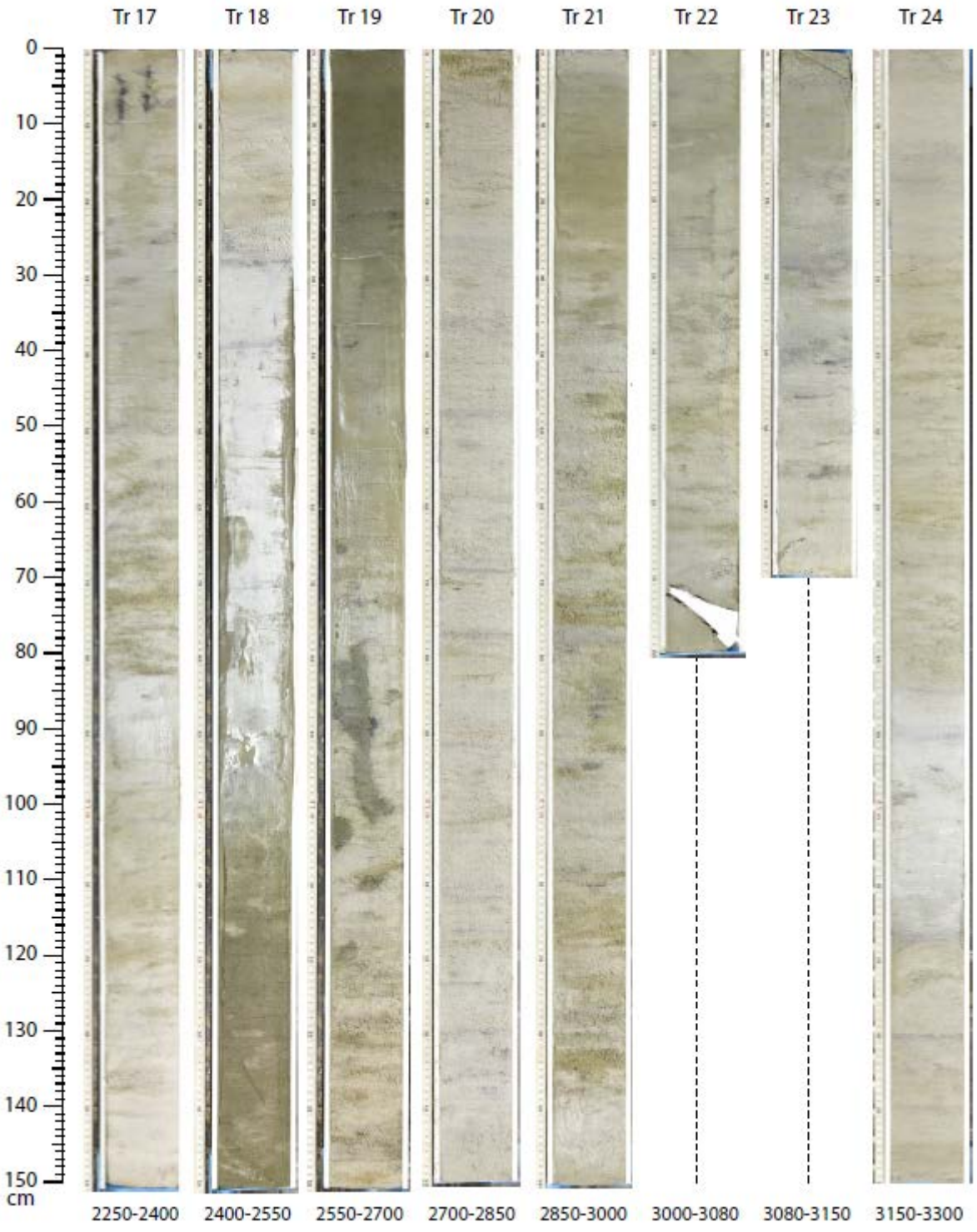
3900	*4050*	*4200*	*4350*	*4500*	*4650*	*4800*	*4950*
TR 29	**TR 30**	**TR 31**	**TR 32**	**TR 33**	**TR 34**	**TR 35**	

4950	*5100*	*5250*	*5400*	*5550*	*5700*	*5756*
TR 36	**TR 37**	**TR 38**	**TR 39**	**TR 40**	**TR 41**	

Commentaires

Cruise : **MD218 - CROTALE** - Core : **MD19-3576** - Length : **57.56 m**
Study site : **Del Cano DCR** - Latitude : **S46°01.36'** - Longitude : **E044°19.68** - Depth : **2419 m**


Tr 9
Tr 10
Tr 11
Tr 12
Tr 13
Tr 14
Tr 15
Tr 16
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
cm
1050-1200
1200-1350
1350-1500
1500-1650
1650-1800
1800-1950
1950-2100
2100-2250


Tr 17
Tr 18
Tr 19
Tr 20
Tr 21
Tr 22
Tr 23
Tr 24
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
cm
2250-2400
2400-2550
2550-2700
2700-2850
2850-3000
3000-3080
3080-3150
3150-3300


Tr 25
Tr 26
Tr 27
Tr 28
Tr 29
Tr 30
Tr 31
Tr 32
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
cm
3300-3450
3450-3600
3600-3750
3750-3900
3900-4050
4050-4200
4200-4350
4350-4500

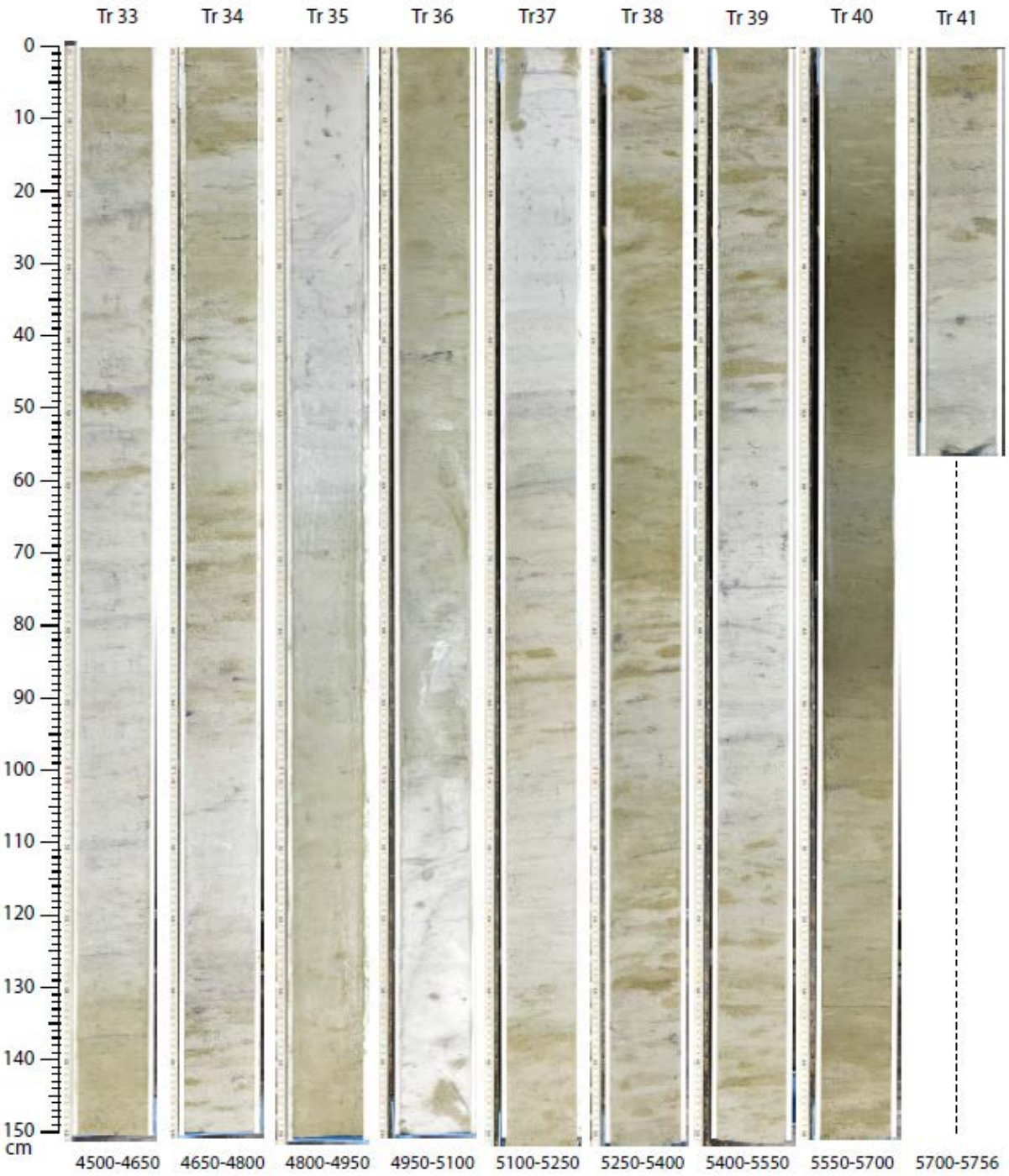
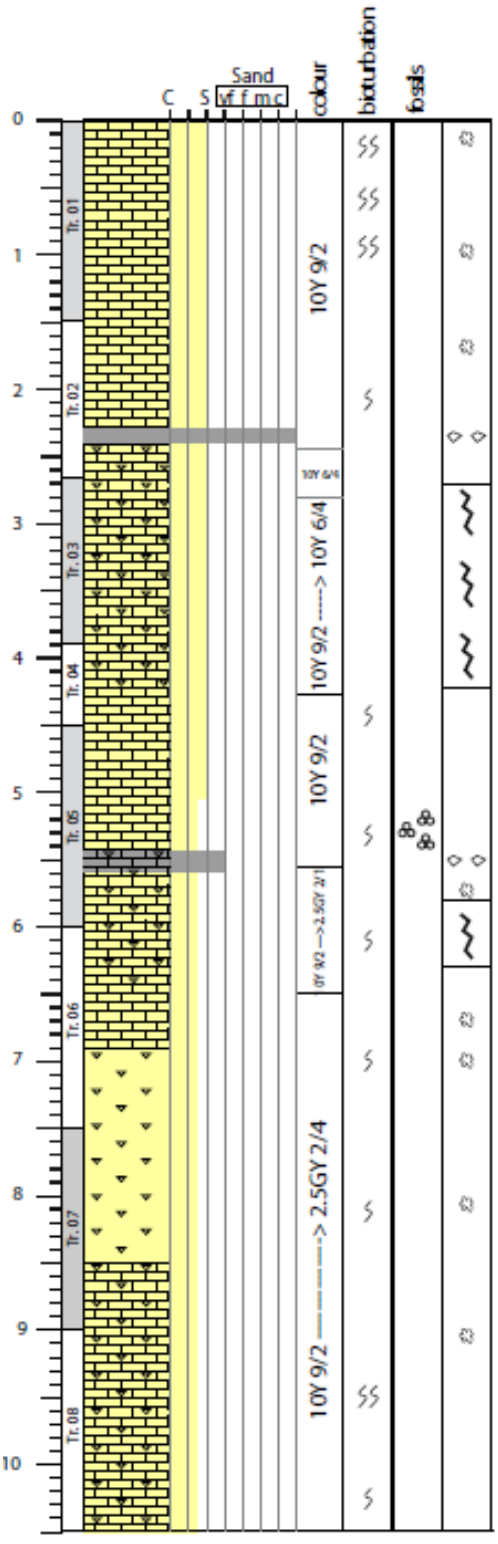


Figure 18. Composite photo of core MD19-3576.

Cruise : MD218 - CROTALE

Core : MD19-3576 - **Length** : 57,56 m - **Coring site** : Del Cano DCR
Latitude : S 46°01.36' - **Longitude :** E 44°19.68' - **Water depth** : 2419 n



Detailed description 1/6 : Sections 1 to 8

Foraminifera-bearing calcareous silt alternating with diatomaceous silt, becoming clayey toward the bottom.

Colour ranges from 10Y 9/2 (calcareous silt) to 2.5GY 2/4 (diatomaceous silt).

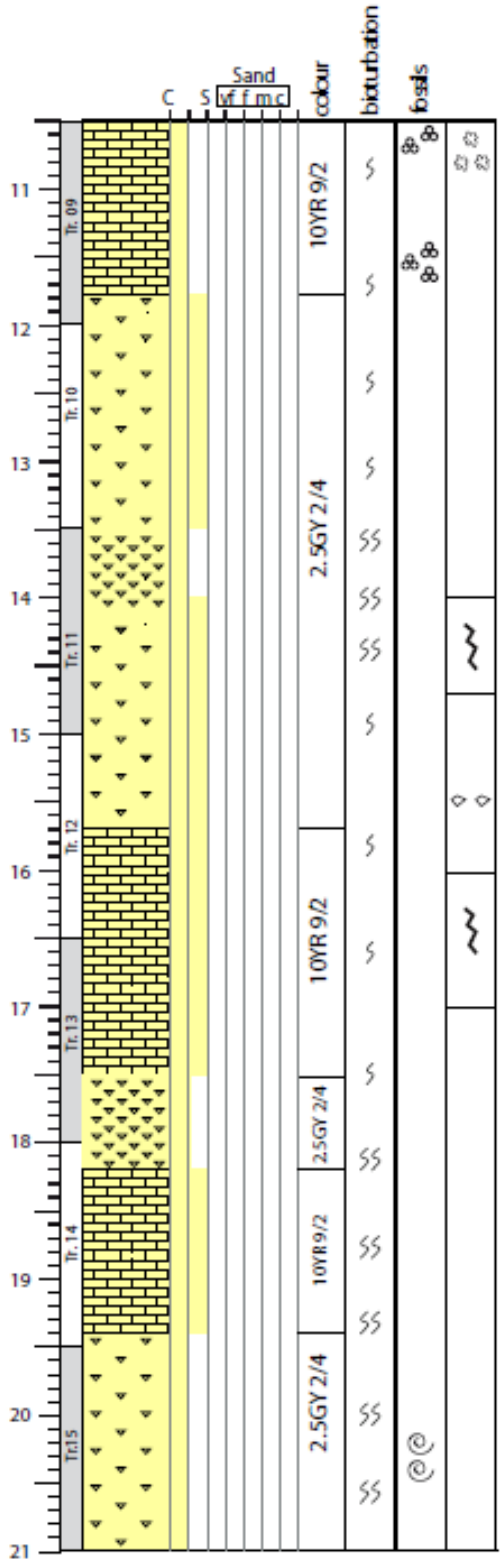
Abundant coarse lithic grains (ca. 5 mm diameter), probably dropstones, within two intervals : 230-240 cm and 547-560 cm.

Chaotic intervals from 270 to 422 cm and from 580 to 630 cm interpreted as coring disturbance (or mass flow deposit?).

Frequent burrows dispersed throughout.

Legend:

- clay
- silt
- sand
- diatomaceous
- calcareous
- ash
- lithoclast
- foraminifera
- burrow
- shell
- diatom floc
- coring disturbance
- bioturbation
- corals
- colored laminae
- void



Detailed description 2/6 : Sections 9 to 15

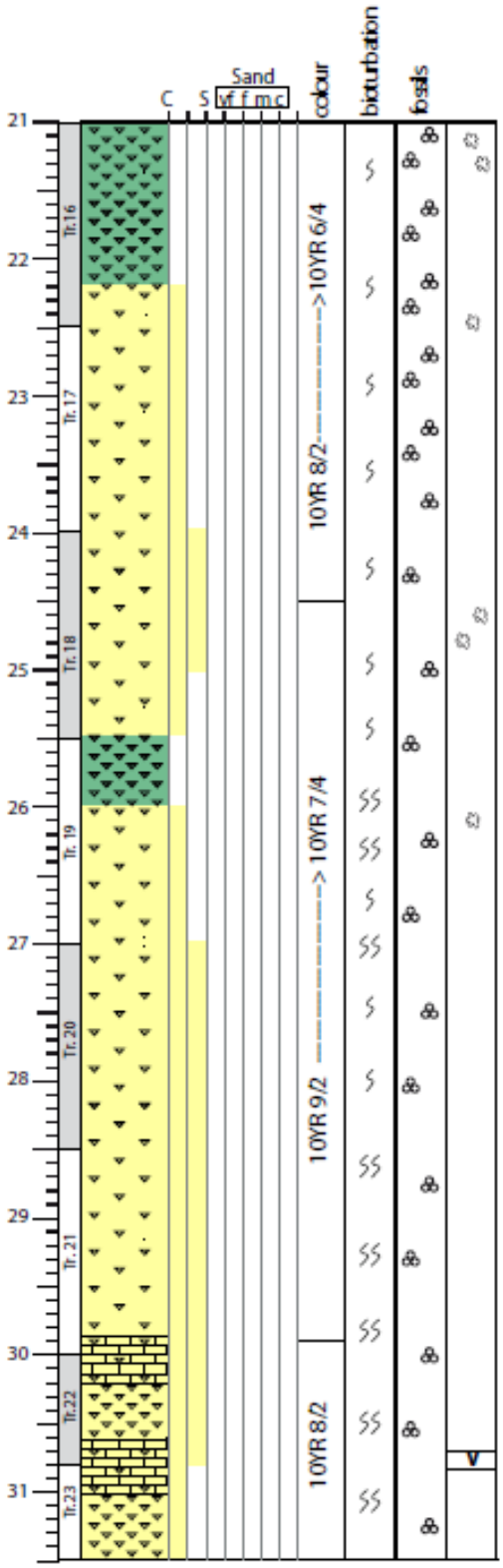
Foraminifera-bearing calcareous clayey silt to silty clay alternating with diatomaceous silt to silty clay.

Colour ranges from 2.5GY 2/4 (diatomaceous silt and silty clay) to 10YR 9/2 (calcareous silt to silty clay).

Two chaotic intervals from 1400 to 1470 cm and from 1600 to 1700 cm interpreted as coring disturbance.

Legend:

- clay
- silt
- sand
- diatomaceous
- calcareous
- ash
- lithoclast
- foraminifera
- burrow
- shell
- diatom floc
- coring disturbance
- bioturbation
- corals
- colored laminae
- void

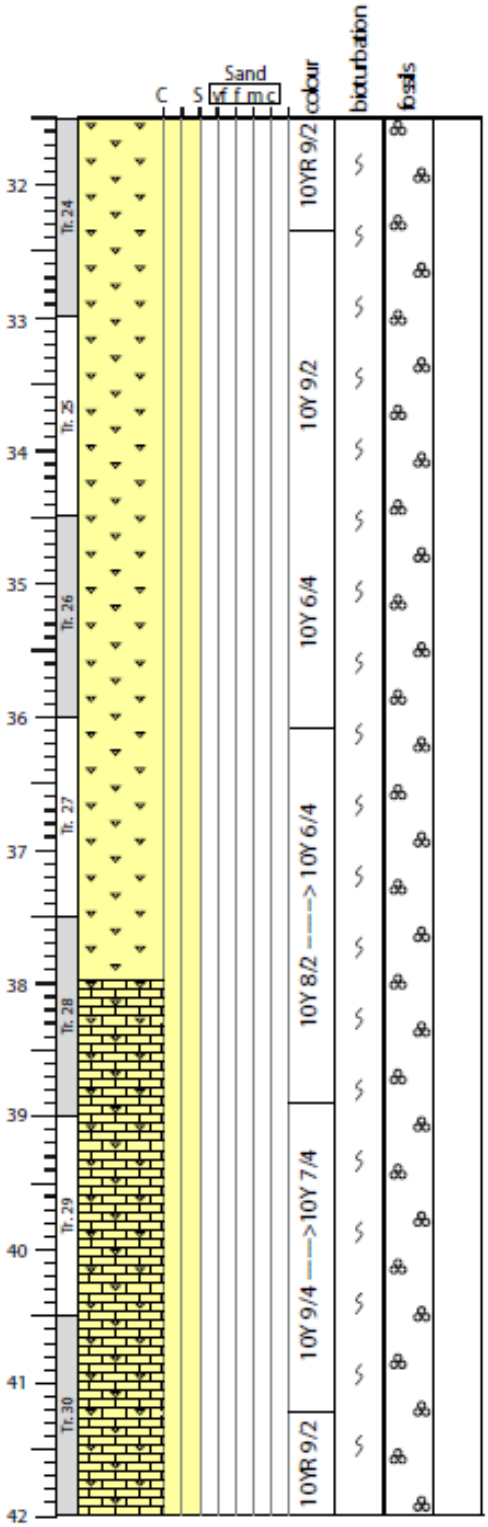


Detailed description 3/6 : Sections 16 to 23

Foraminifera-bearing diatomaceous clay to silt grading to diatomaceous ooze.

Legend:

- clay
- silt
- sand
- diatomaceous
- calcareous
- ash
- lithoclast
- foraminifera
- burrow
- shell
- diatom floc
- coring disturbance
- bioturbation
- corals
- colored laminae
- v void



Detailed description 4/6 : Sections 24 to 30

Lithology ranges from diatomaceous silt (ooze) to foraminifera-bearing silt .

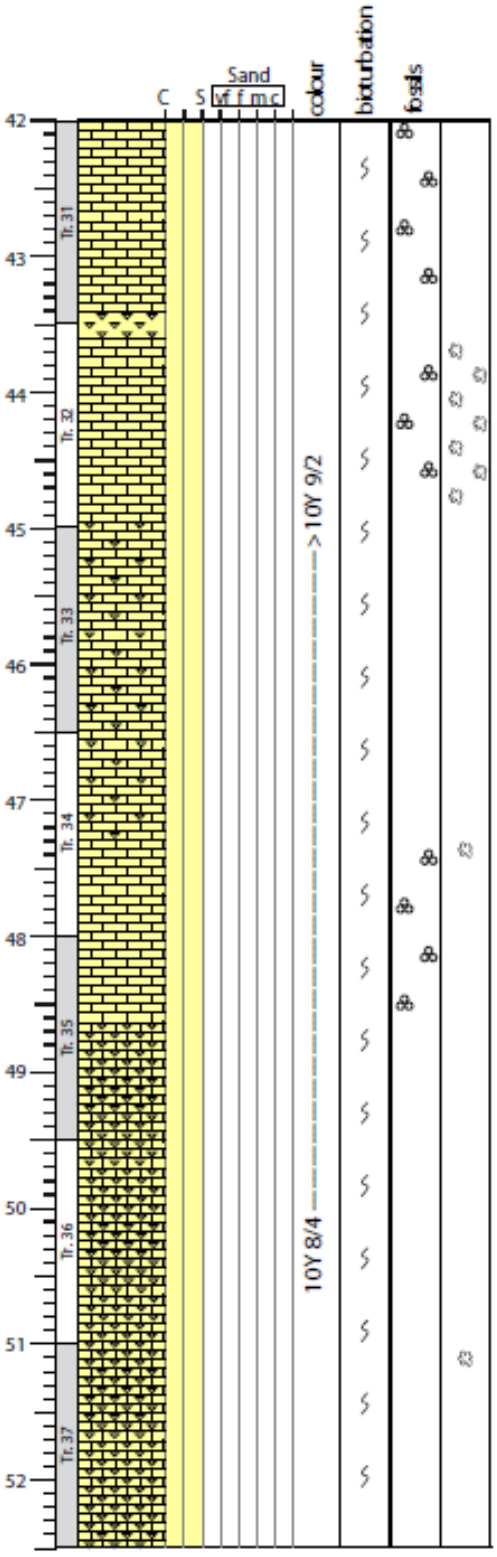
Colours range from 10Y 9/2 to 10Y 6/4 according to diatoms abundances.

Mostly bioturbated with faint horizontal structures throughout.

No apparent coring disturbances.

Legend:

- clay
- silt
- sand
- diatomaceous
- calcareous
- ash
- lithoclast
- foraminifera
- burrow
- shell
- diatom floc
- coring disturbance
- bioturbation
- corals
- colored laminae
- void



Detailed description 5/6 : Sections 31 to 37

Foraminifera-rich calcareous silt with increasing abundance of diatoms toward the bottom.

Colour range from 10Y 9/2 to 10Y 8/4 according to diatom abundance.

Faint horizontal layers throughout, some of them rich in diatoms.

No coring disturbance.

Legend:

- clay
- silt
- sand
- diatomaceous
- calcareous
- ash
- lithoclast
- foraminifera
- burrow
- shell
- diatom floc
- coring disturbance
- bioturbation
- corals
- colored laminae
- void

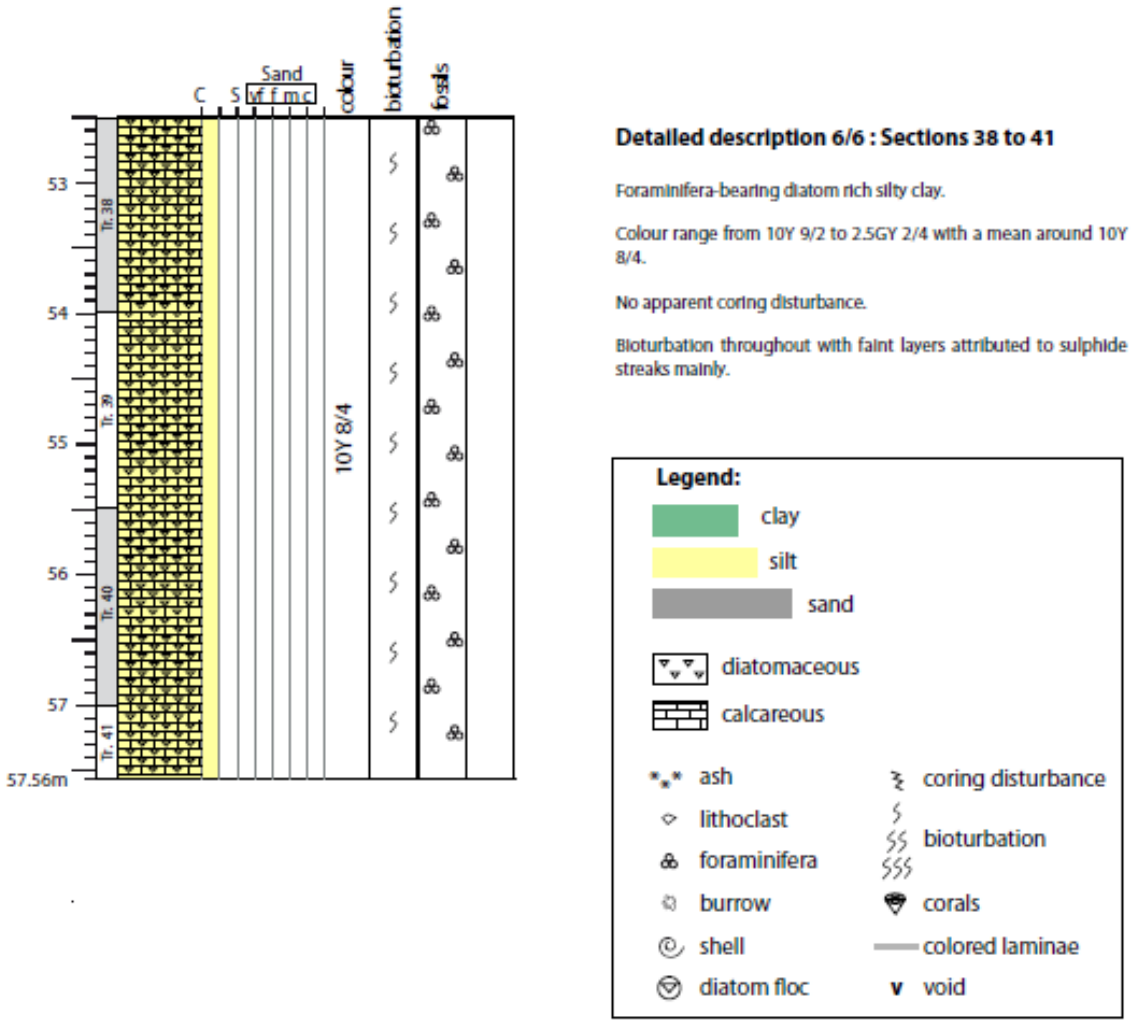


Figure 19. Synthetic log description of core MD19-3576.

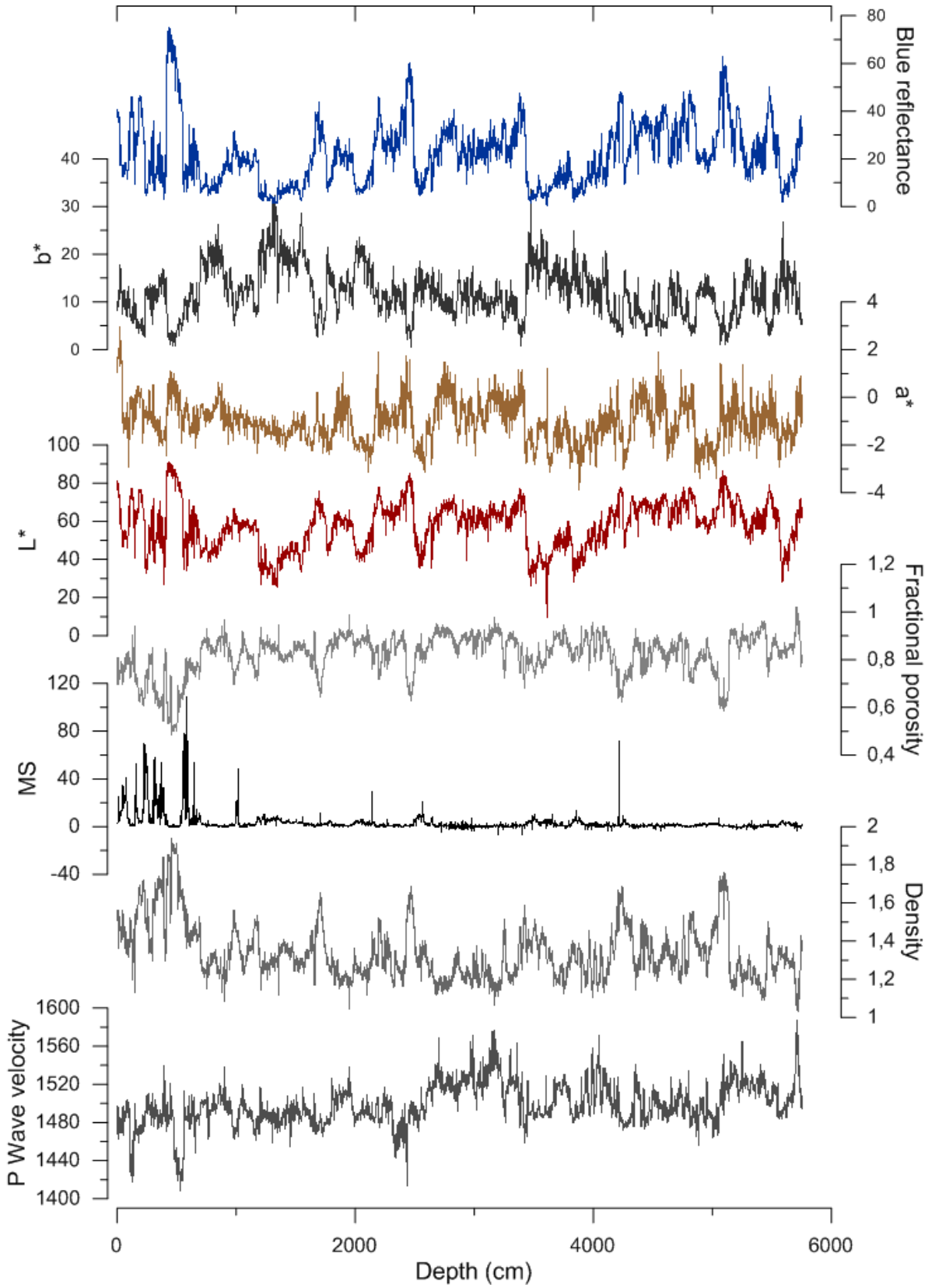


Figure 20. MD19-3576 data. From bottom to top: P Wave velocity (in $m.s^{-1}$), Density (in $g.cm^{-1}$), Mass specific susceptibility (in 10^{-8} ($m^3.kg$)), Fractional porosity, L, a*, b* and blue reflectance (mean 400-515 nm).*

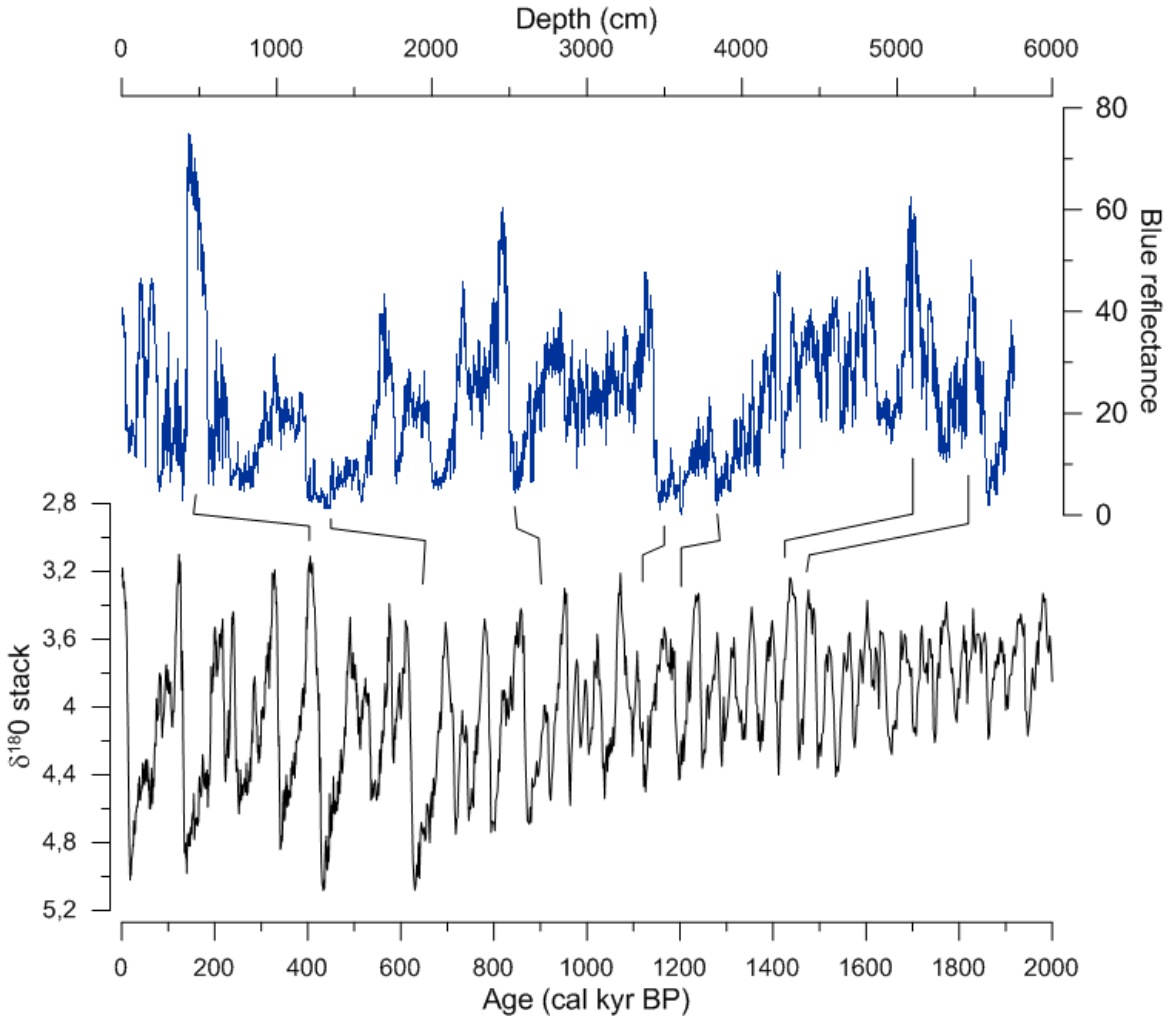


Figure 21. Preliminary chronology of core MD19-3576 based on the comparison of its color reflectance record to the reference $\delta^{18}O$ stack record of Lisiecki and Raymo 2004.

West Crozet Region

The Crozet Archipelago is located 5° east of Del Caño Rise. However, conversely to DCR, Crozet Archipelago is located south of the SAF because this one bends northward between DCR and Crozet. Crozet Archipelago is composed of several volcanic islands delineating a very shallow plateau that strongly constrain the ocean circulation in this area. The ACC flow sweeps the plateau and remobilizes volcanic material, thus providing a large iron source to the surface waters east of Crozet Archipelago as shown by the intense phytoplanktonic blooms observed in this region (Pollard et al., 2009). The plateau is mainly barren of hemipelagic sediments, as shown by the 3.5 khz profiles between the transit between west Crozet and the Crozet sites, and sediments mainly accumulate over the slope and rises. Been located south of the SAF, the Crozet region should be less influenced by the Agulhas Return Current than the DCR region.
The target site originally proposed was chosen based on old 3.5 kHz and bathymetry profiles measured on board the MD. The survey performed during MD218 CROTALE greatly improved the bathymetry of the area and showed that the small depressions seen in the original 3.5 kHz profile were abandoned channels linking the plateau to the plain (Figure 22). The target site

was lying in between two depressions/channels. Another target site, also on a ridge in between two channels was identified and chosen over the original site (Figure 23).

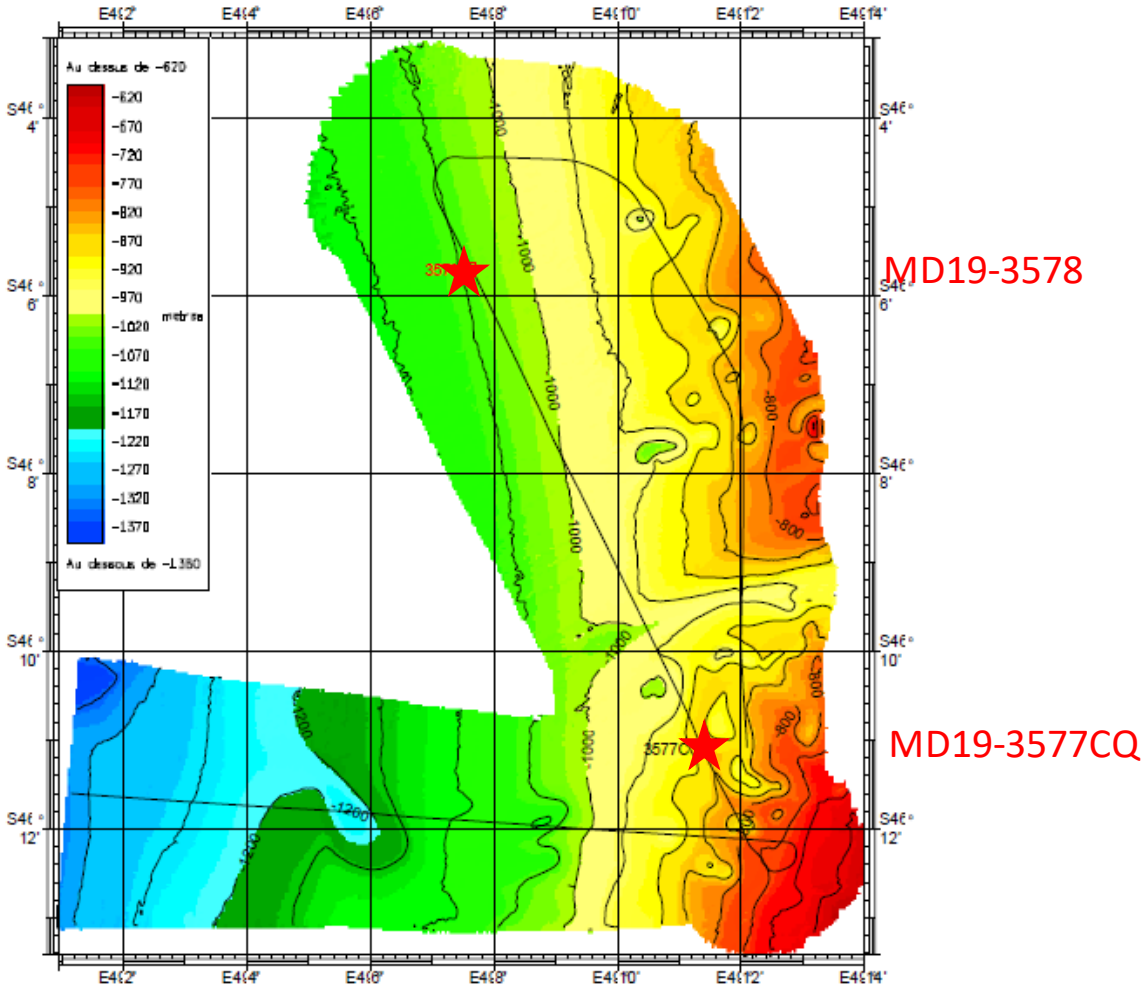


Figure 22. Local bathymetry and position of cores MD19-3577CQ and MD19-3578 (modified after Xavier Morin).

A CASQ (MD19-3577CQ) was first sent at 46°11.09'E – 49°11.37'E – 850 m of water depth. The ~6 meters of sediment were uniformly dark, composed of compact silt and fine volcanic particles and seemed barren of microfossils. It was decided to send a ~43 meters-long Calypso (MD19-3578) at a deeper target, located farther from the canyons, at 46°05.71'S – 49°07.59'E – 1025 m of water depth. The sediment was also quite dark, but less than in the CASQ core, and mainly composed of diatom ooze mixed with terrigenous material of volcanic origin.

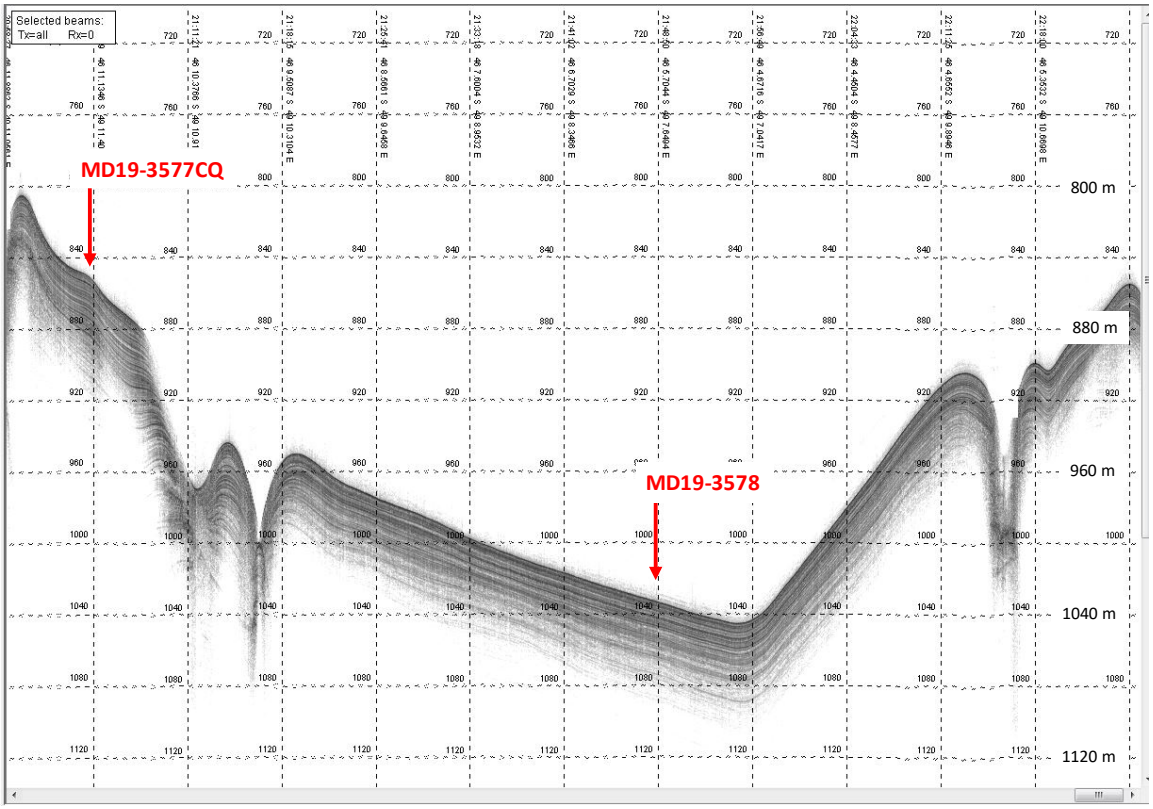


Figure 23. CHIRP 3.5 kHz profile around West Crozet site. Locations of the CASQ (MD19-3577CQ) and Calypso (MD19-3578) cores are indicated by the red arrows.

Core MD19-3577CQ

A 9 meters-long CASQ was sent. The CASQ was sampled for 3 series. In the first layer, a large (named a) series was carved. In the second layer a large (named b) and a small (named c) were sampled. The series c was offset from the two other ones to allow for overlap (Table 4).

The core is composed of well sorted dark grey silt (top 1m) and very fine sand (rest of the core) of volcanic origin throughout. Sediment structure is mainly massive without any macroscopic bioturbation (Figure 24). Small void probably represent ash layers that have been flushed out. Few foraminifera were observed in the top meter and corals in the bottom 3 meters (Figure 25). The MSCL, and especially the MS, data suggest that the core covers the period from the Holocene to MIS 3 (Figure 26).

Table 4. MD19-3577CQ core general information.

NOM DE LA CAMPAGNE	Date : 1 March 2019 2 March 2019	Météo : (force) / Direction Vent : Mer : Variation tension (maxi) :
MD218 CROTALE	N° de station : **W CROZET**	

CAROTTE (N°) :	LONGUEUR m :	POSITION :
MD19-3577CQ *(MD année -numéroCQ)*	**5,44**	**Latitude : 46°11.09'S** **Longitude 49°11.37'E**

CASQ			HEURES (GMT)			INSTRUMENTATION OPERATIONS ANNEXES
Tubes (longueur)	**9,00**	**m**	En station :	**23h25**	**GMT**	CTD (hydro) :
		m	Début manœuvre :	**23h53**	**GMT**	CTD (bouteilles) :
Sonde	**850**	**m**	touché:	**0h15**	**GMT**	Filet à plancton :
ligne filée (touché)	**857**	**m**	Fin de manœuvre :	**1h57**	**GMT**	Autres : /
			Départ station :		**GMT**	

0	*150*	*300*	*450*	*544*			
a 1	**a 2**	**a 3**	**a 4**				

0	*150*	*300*	*450*	*545*			
b 1	**b 2**	**b 3**	**b 4**				

0	*94*	*246*	*395*	*544*			
c 1	**c 2**	**c 3**	**c 4**				

Commentaires

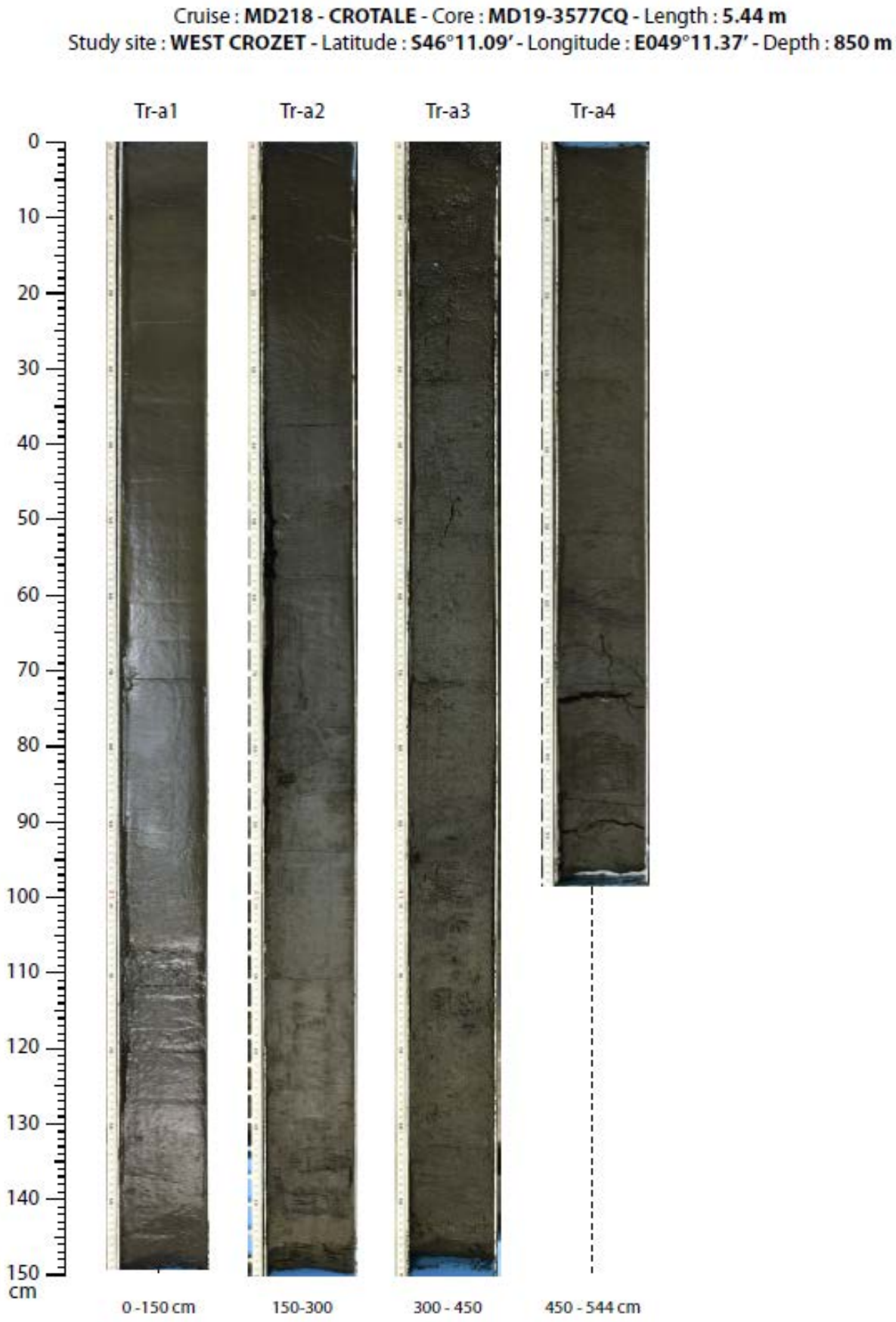


Figure 24. Composite photo of core MD19-3577CQ.

Cruise : CROTALE

Core : MD19-3577CQ - **Length** : 5.44 m - **Coring site** : Western Crozet
Latitude : S 46°11.09′ - **Longitude :** E 49°11.37′ - **Water depth** : 850 m

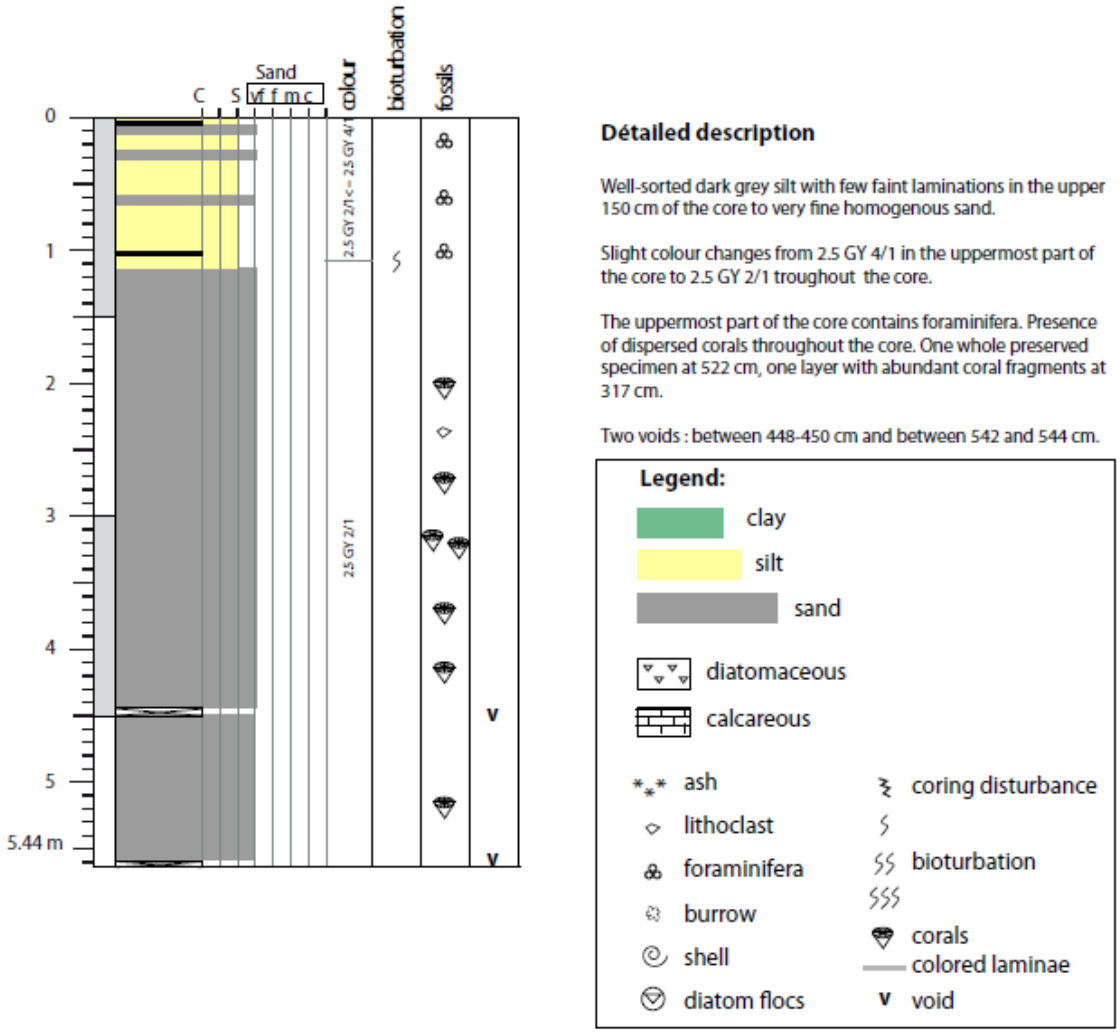


Figure 25. Synthetic log description of core MD19-3577CQ.

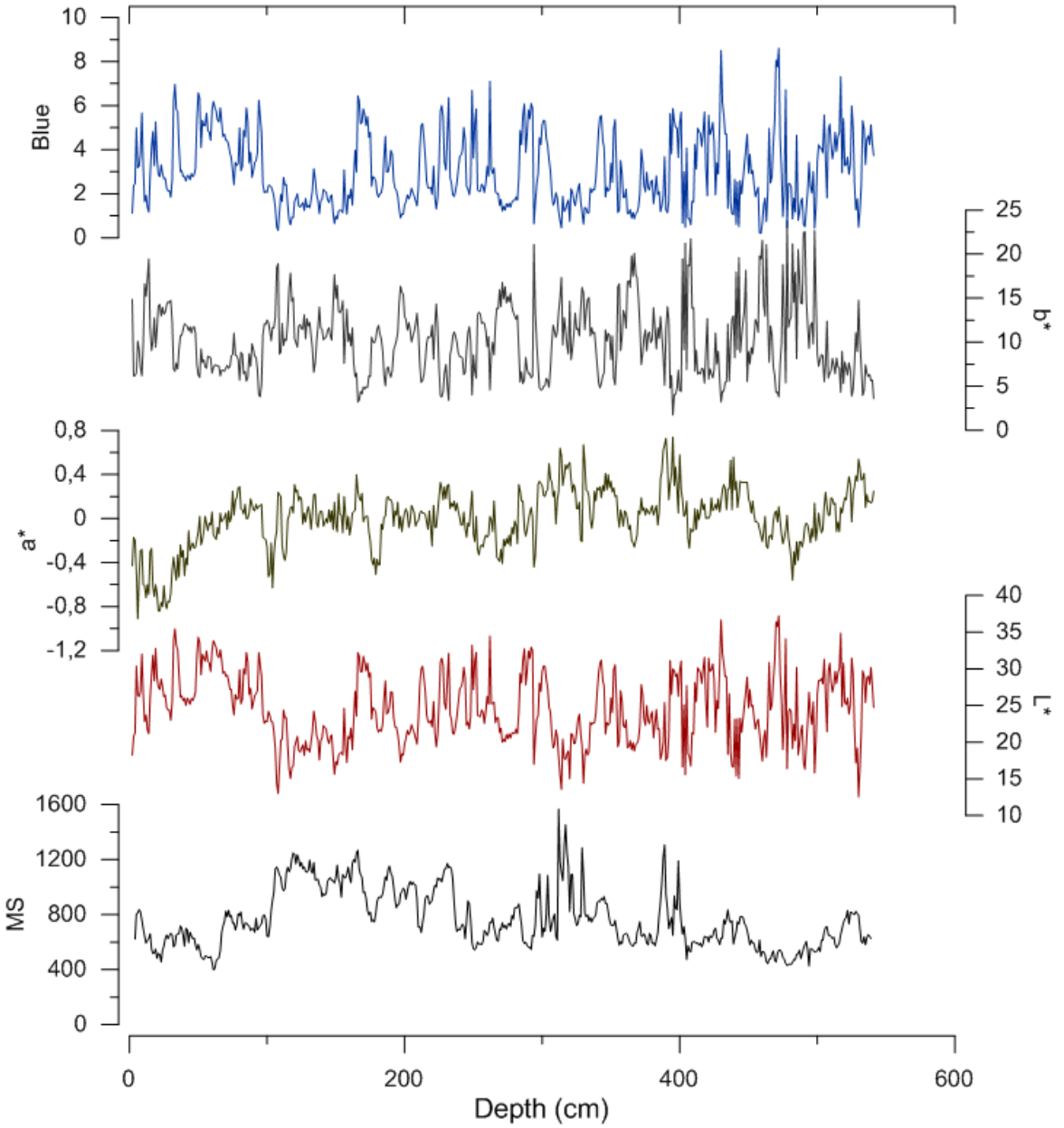


Figure 26. MD19-3577CQ data. From bottom to top: Mass specific susceptibility (in 10^{-8} (m^3.kg)), L, a*, b* and blue reflectance (mean 400-515 nm).*

Core MD19-3578

A 43,67 meters-long Calypso was sent. This time the liner was extruded in one piece and cut into 1.5 meters long sections except for the last two sections (100 cm and 90 cm, respectively) to avoid handling a bottom section of 40 cm long (Table 5). The sediment is mainly composed of foraminifera-bearing diatomaceous silt with presence of shells and corals throughout (Figure 27 and Figure 28). Important bioturbation is evident throughout the core. A ~1m long void is present at ~16.5 m, probably due to the presence of a centimeter-thick ash layer that has been flushed out and subsequent sediment stretching. A "true depth" must be calculated. The MSCL data suggest that the MIS 11 is present à ~25 meters down in the core (Figure 29). If so the magnetic susceptibility record suggest that glacials (high values) are much more expanded than the interglacials (low values).

Table 5. MD19-3578 core general information.

NOM DE LA CAMPAGNE	Date : 2 March 2019	Météo : (force) / Direction
MD218 CROTALE	N° de station : **W CROZET**	Vent : Mer : Variation tension (maxi) :

CAROTTE (N°) :	LONGUEUR m :	POSITION :
MD19-3578 *(MD année -numéro)*	**42,40 m**	**Latitude :** 46°05.709'S **Longitude :** 49°07.594'E

CAROTTIER (type) (1) : CALYPSO	REGLAGES :	CONTREPOIDS :
Poids total (air) : 6,5 t	**Tubes** (longueur) : 43,67 m	**Type (2) :** CYLINDER 100 KG
Poids total (eau) : surf t bottom t	**Câbles :** Chute libre : 1,50 m	Longueur PVC : m
	Boucle : 4,14 m	Pénétration : m
	LC poids : m (3m50 lest)	Longueur de carotte : m + Ogive (+ 0,15 m)

PARAMETRES MESURES :	HEURES (GMT)	INSTRUMENTATION OPERATIONS ANNEXES
Sonde corrigée : 1 025 m	En station : 4h00 GMT	CTD (hydro) :
Ligne filée : 997 m	Début manœuvre : 5h15 GMT	CTD (bouteilles) :
Arrachement/total *(tonne)* : 16,50 t	**Déclenchement :** 5h55 GMT	Filet à plancton :
Pénétration/apparente *(m)* : m	Fin de manœuvre : 7h15 GMT	Autres : /
Pénétration/tensiomètre *(m)* : m	**Durée de manœuvre :**	
Description / incidents :	Départ station : GMT	

0	*150*	*300*	*450*	*600*	*750*	*900*	*1050*
TR 1	**TR 2**	**TR 3**	**TR 4**	**TR 5**	**TR 6**	**TR 7**	

1050	*1200*	*1350*	*1500*	*1650*	*1800*	*1950*	*2100*
TR 8	**TR 9**	**TR 10**	**TR 11**	**TR 12**	**TR 13**	**TR 14**	

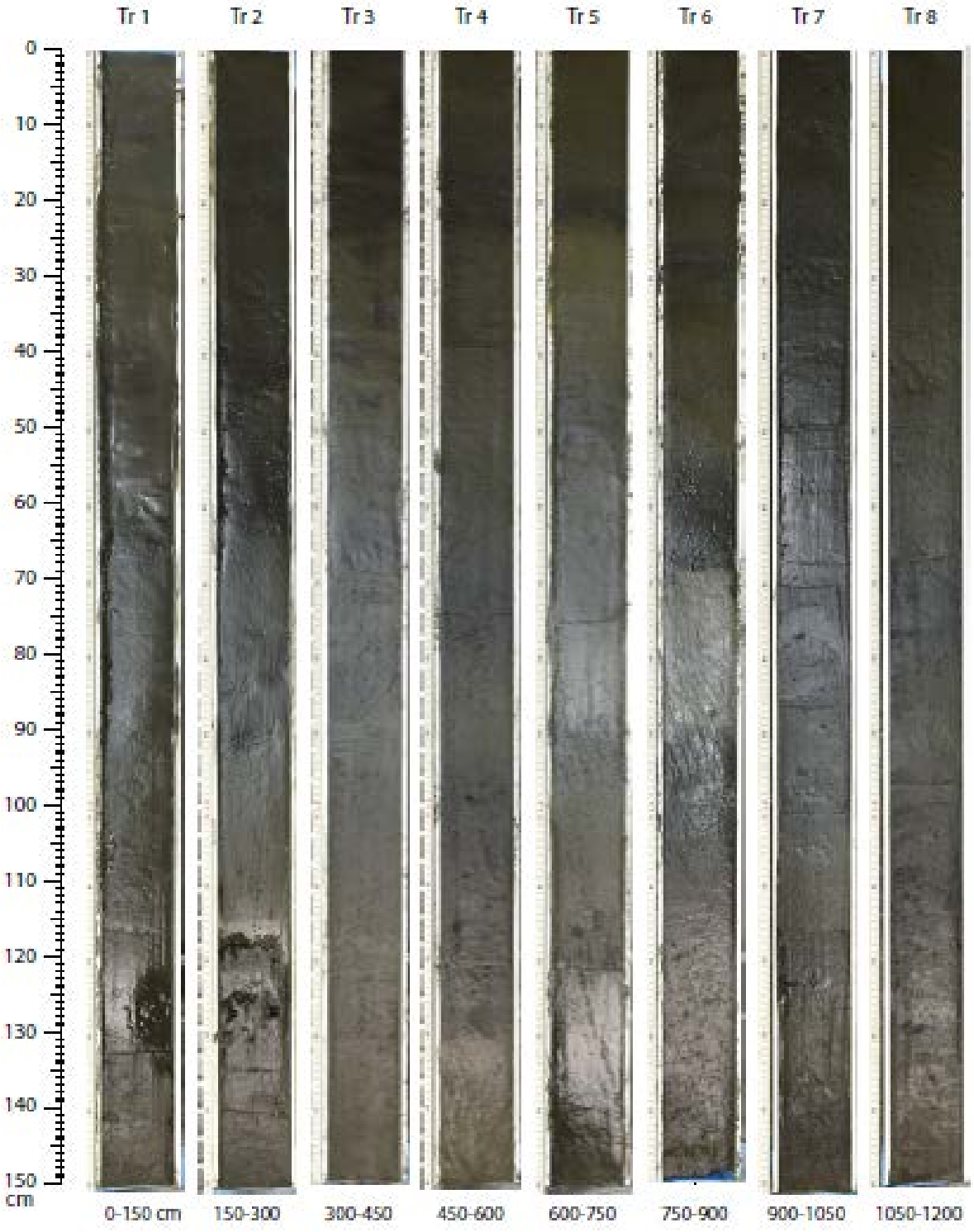
2100	*2250*	*2400*	*2550*	*2700*	*2850*	*3000*	*3150*
TR 15	**TR 16**	**TR 17**	**TR 18**	**TR 19**	**TR 20**	**TR 21**	

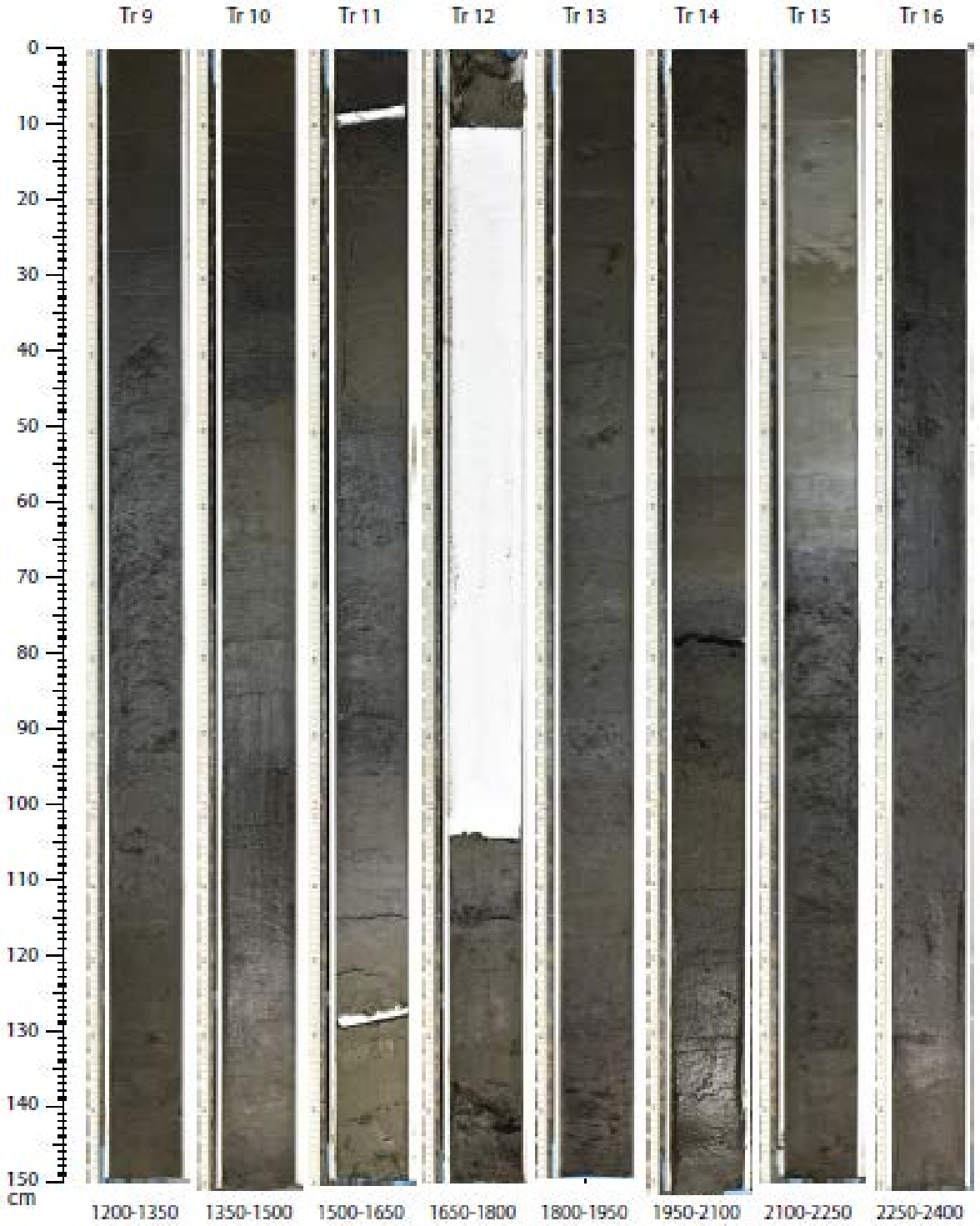
3150	*3300*	*3450*	*3600*	*3750*	*3900*	*4050*	*4150*
TR 22	**TR 23**	**TR 24**	**TR 25**	**TR 26**	**TR 27**	**TR 28**	

4150	*4240*					
TR 29						

Commentaires
Two last sections cut in 100 cm and 90 cm, respectively, to avoid handling a bottom section of 40 cm

Cruise : **MD218 - CROTALE** - Core : **MD19-3578** - Length : **42.40m**
Study site : **West Crozet** - Latitude : **S46°05.709'** - Longitude : **E049°07.584'** - Depth : **1025m**




Tr 9
Tr 10
Tr 11
Tr 12
Tr 13
Tr 14
Tr 15
Tr 16
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10
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70
80
90
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110
120
130
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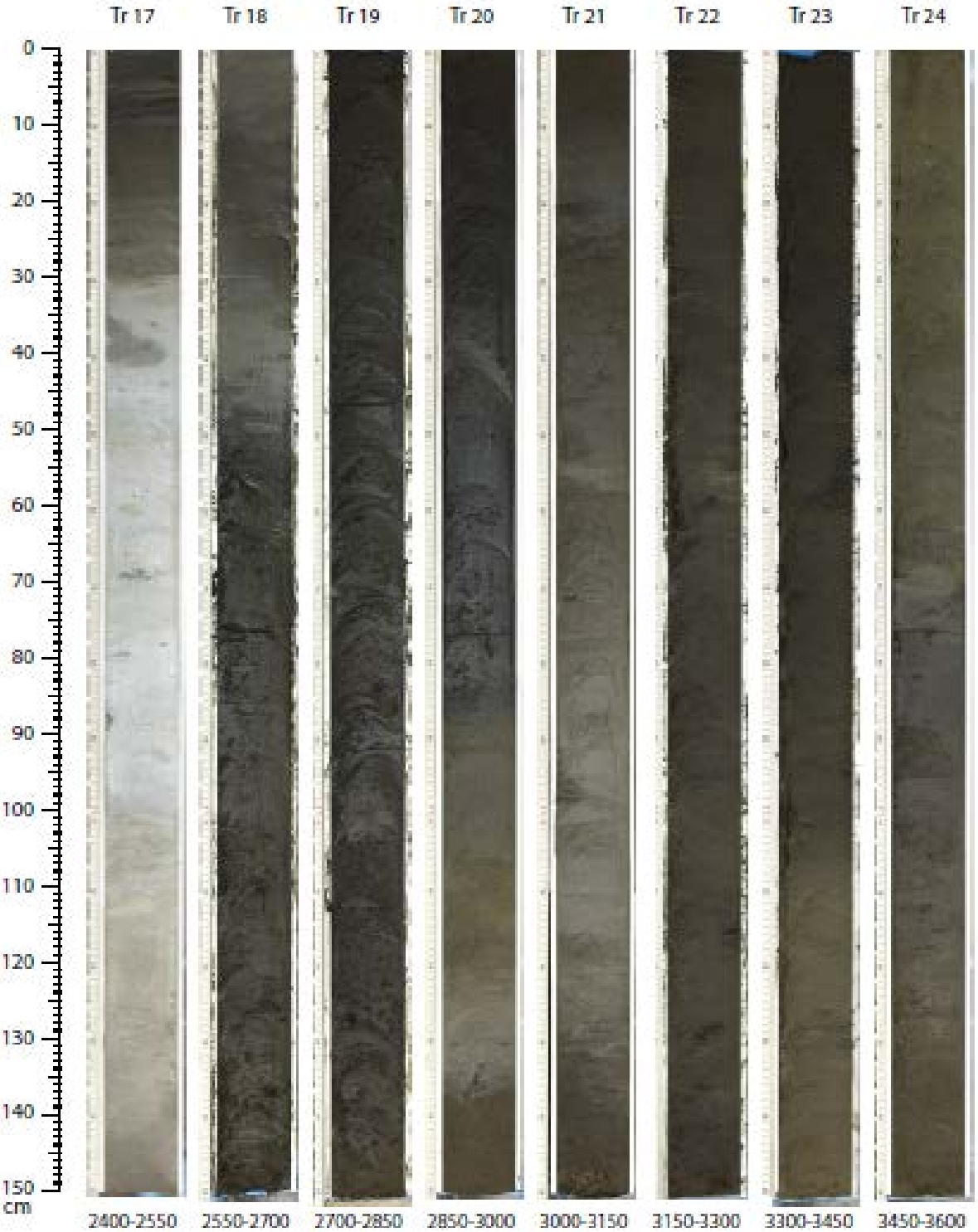
cm
1200-1350
1350-1500
1500-1650
1650-1800
1800-1950
1950-2100
2100-2250
2250-2400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Tr 18
Tr 19
Tr 20
Tr 21
Tr 22
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Tr 24
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3000-3150
3150-3300
3300-3450
3450-3600

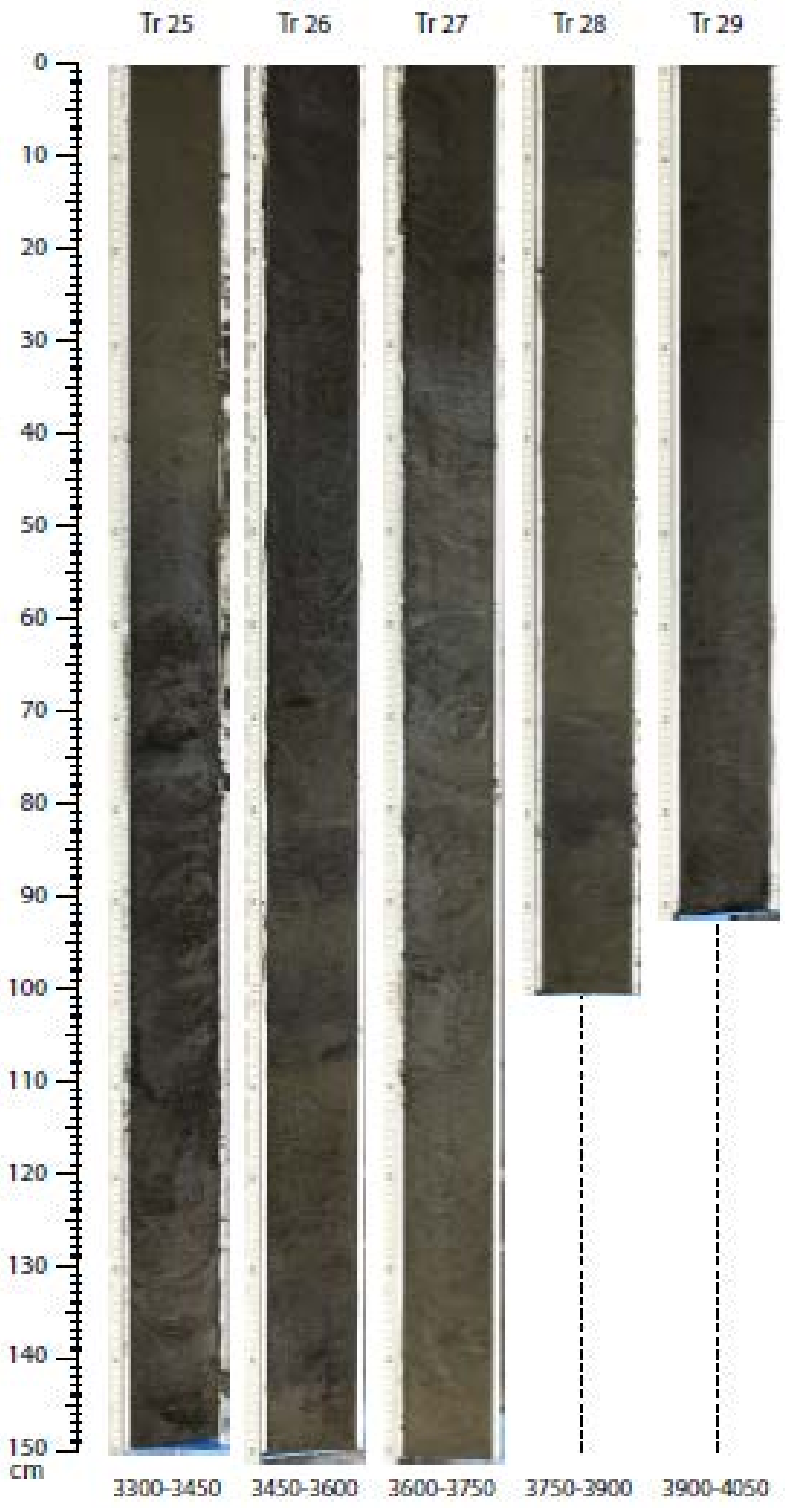
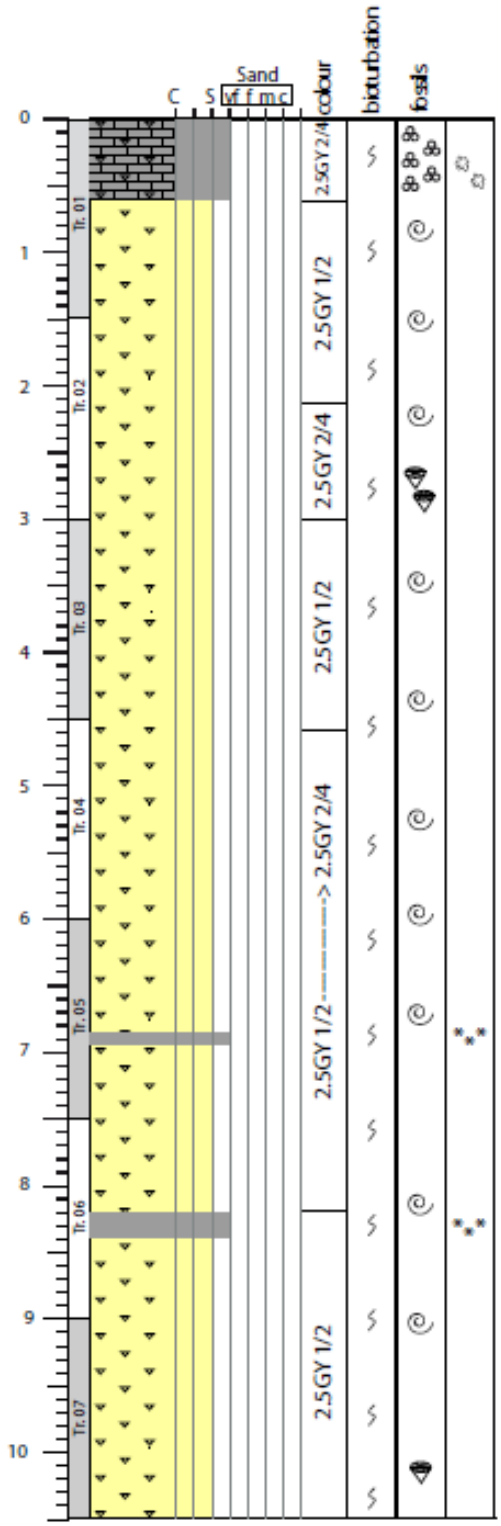


Figure 27. Composite photo of core MD19-3578.

Cruise : MD218 - CROTALE

Core : MD19-3578- **Length** : 42.40 m - **Coring site** : West Crozet
Latitude : S 46°05.709' - **Longitude :** E 49°40.594' - **Water depth** : 1025 m



Detailed description 1/4 : Sections 1 to 7

The general lithology is foram-bearing diatomaceous silt with colour ranging essentially from 2.5GY 2/4 to 2.5GY 1/2.

Two sand (very fine) layers at 686-692 cm and 820-840 cm are interpreted as ash layers.

Abundant coarse lithic grains within a silt matrix define the interval 269-284 cm.

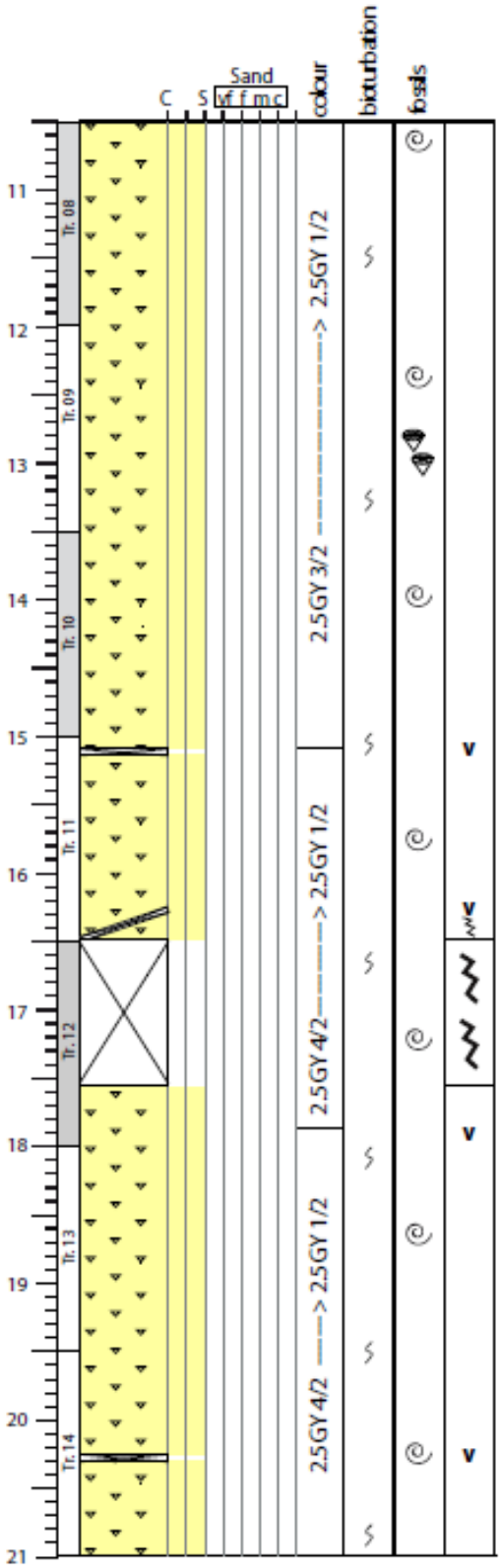
Shell/coral fragments frequent thorughout.

Frequent sulphide streaks thorughout.

No coring disturbance.

Legend:

- clay
- silt
- sand
- diatomaceous
- calcareous
- ash
- lithoclast
- foraminifera
- burrow
- shell
- diatom floc
- coring disturbance
- bioturbation
- corals
- colored laminae
- void



Detailed description 2/4 : Sections 8 to 14

Massive silt, mostly of lithic nature, with variable contribution of diatoms.

Foraminifera rare or absent.

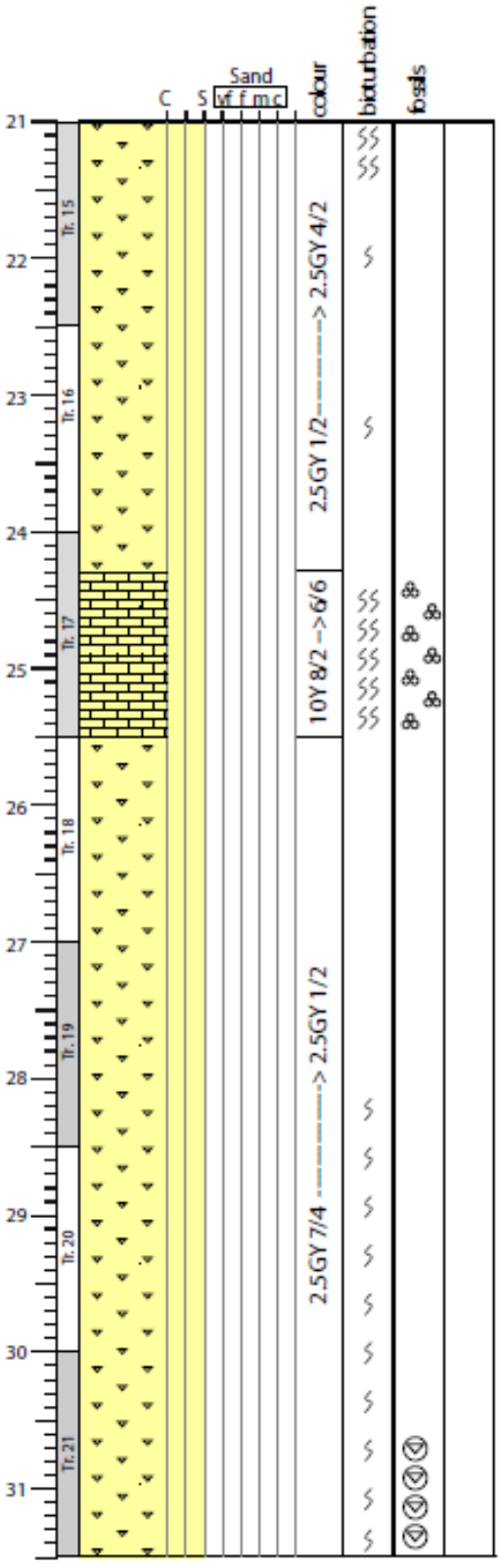
Sediment colour within the 2.5GY range grading between 1/2 and 4/2.

Coring disturbance : 1508-1510 cm, 1626-1629 cm, 1650-1754 cm, 1787-1792 cm, 2027-2029 cm.

Void : 1508-1510 cm, 1626-1629 cm, 1650-1754 cm, 2027-2029 cm.

Legend:

- clay
- silt
- sand
- diatomaceous
- calcareous
- ash
- lithoclast
- foraminifera
- burrow
- shell
- diatom floc
- coring disturbance
- bioturbation
- corals
- colored laminae
- v void



Detailed description 3/4 : Sections 15 to 21

Bioturbated diatomaceous silt with increasing diatom contribution with depth.

One foraminifera-rich calcareous silt with sharp upper and lower boundaries from 2429 to 2550 cm.

Legend:

- clay
- silt
- sand
- diatomaceous
- calcareous
- ash
- lithoclast
- foraminifera
- burrow
- shell
- diatom floc
- coring disturbance
- bioturbation
- corals
- colored laminae
- void

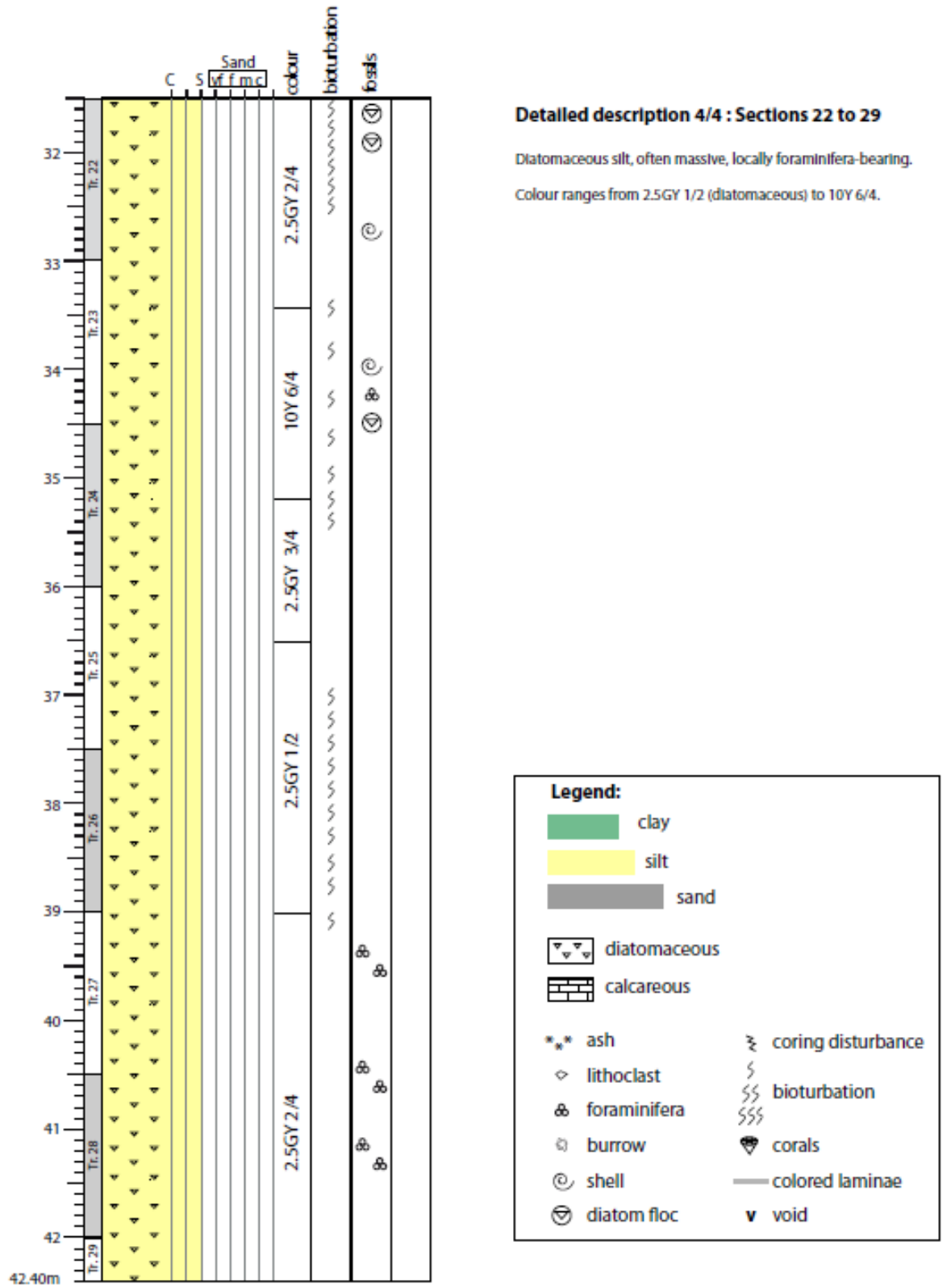


Figure 28. Synthetic log description of core MD19-3578.

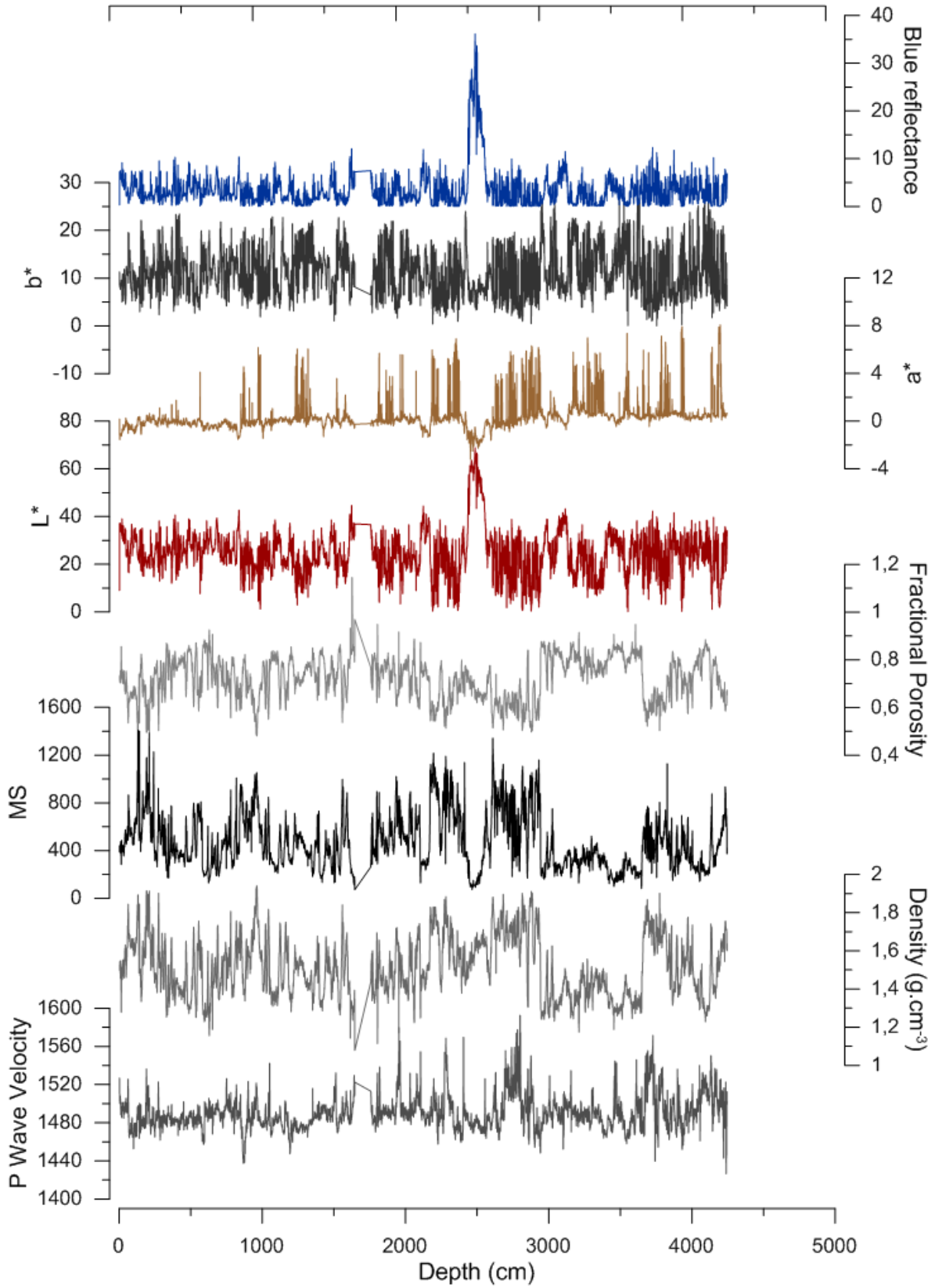


Figure 29. MD19-3578 data. From bottom to top: P Wave velocity (in $m.s^{-1}$), Density (in $g.cm^{-1}$), Mass specific susceptibility (in 10^{-8} (m^3.kg)), Fractional porosity, L, a*, b* and blue reflectance (mean 400-515 nm). The peak in L* and blue reflectance is probably the MIS 11.*

East Crozet Region

A quick survey indicated that the proposed site, selected on old 3.5 kHz and bathymetry profiles measured on board the MD, was a good target for coring with a sediment draping of ~60 m (Figure 31). The site is located northeast of the internal plateau and is located on the slope of a small bank oriented WSW-ENE by ~2450 m of water depth (Figure 30). The 9 meters-long CASQ was completely filled and retrieved a sediment sequence of dark silty clay mixed with volcanic particles and microfossils (diatoms and foraminifera). It was decided to send a ~44 meters-long Calypso at the same location.

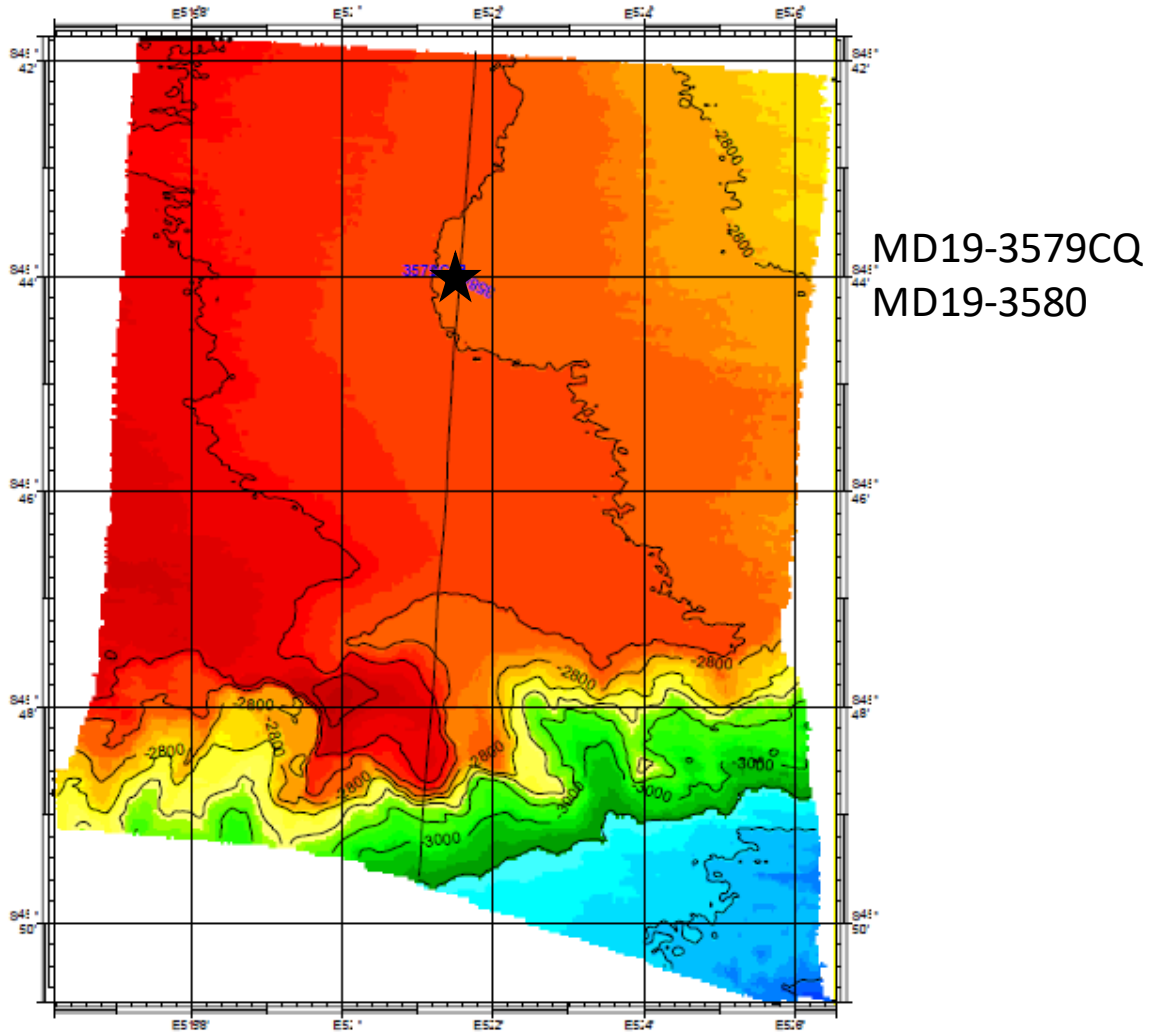


Figure 30. Local bathymetry and position of cores MD19-3579CQ and MD19-3580 (modified after Xavier Morin).

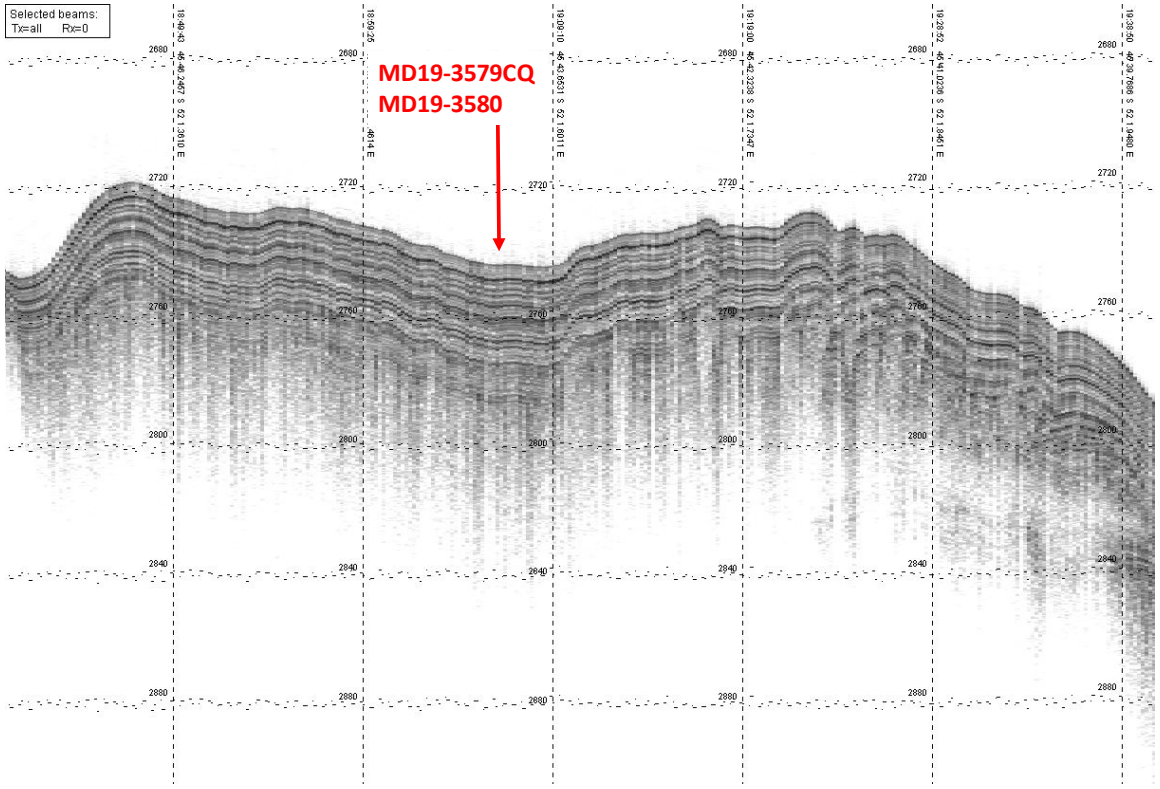


Figure 31. CHIRP 3.5 kHz profile around East Crozet site. Locations of the CASQ (MD19-3579CQ) and Calypso (MD19-3580) cores are indicated by the red arrows.

Core MD19-3579CQ

A 9 meters-long CASQ was sent. The CASQ was sampled for 4 series. In the first layer, both a large (named a) and a small (named b) series were carved (Table 6). In the second layer, again a large (named c) and a small (named d) series were sampled. The second layer series were offset from the upper layer ones to allow for an overlap on the sections beginnings/ends. Some sediments felt on the deck when opening the core catcher. This sediment was stored in plastic bags and called “ogive”. Some sediment from the core catcher was also stored in plastic bags and called “core catcher”. To note also that the upper layers flow over few centimeters on both side of the Styrofoam cap. A part was pushed back in place, another part was sampled in plastic bags called “top”.

The sediment is uniformly composed of diatom-rich silty clay, with the presence of foraminifera throughout. The sediment is bioturbated throughout (Figure 32 and Figure 33).

From the data point of view, the very high values in magnetic susceptibility represent centimeter-thick ash layers, probably due to volcanic activity in the nearby Crozet Islands (Figure 34). MSCL data suggest that the core may cover down to MIS 3.

Table 6. MD19-3579CQ core general information.

NOM DE LA CAMPAGNE	Date : 2 March 2019 3 March 2019	Météo : (force) / Direction Vent : Mer : Variation tension (maxi) :
MD218 CROTALE	N° de station : **E CROZET**	

CAROTTE (N°) :	LONGUEUR m :	POSITION :
MD19-3579CQ *(MD année -numéroCQ)*	**8,3**	**Latitude : 45°43.941'S** **Longitude 52°01.554'E**

CASQ		
Tubes (longueur)	**9,00**	**m**
		m
Sonde	**2447**	**m**
ligne filée (touché)	**2766**	**m**

HEURES (GMT)		
En station :		**GMT**
Début manœuvre :	**21h20**	**GMT**
touché:	**22h30**	**GMT**
Fin de manœuvre :	**5h05**	**GMT**
Départ station :		**GMT**

INSTRUMENTATION OPERATIONS ANNEXES
CTD (hydro) :
CTD (bouteilles) :
Filet à plancton :
Autres : /

0	*150*	*301*	*451*	*601*	*750*	*830*	
a 1	**a 2**	**a 3**	**a 4**	**a 5**	**a 6**		

0	*150*	*299*	*448*	*598*	*748*	*829*	
b 1	**b 2**	**b 3**	**b 4**	**b 5**	**b 6**		

0	*50*	*200*	*351*	*500*	*650*	*799*	*829*	
c 1	**c 2**	**c 3**	**c 4**	**c 5**	**c 6**	**c 7**		

0	*50*	*199*	*349*	*499*	*648*	*798*	*830*	
d 1	**d 2**	**d 3**	**d 4**	**d 5**	**d 6**	**d 7**		

Commentaires

Offset of 1 cm at the bottom results from an inegal interface due to sediment falling off when opening the core catcher. Some sediment was preserved in plastic bags.
Top laterally overflowed. Partly pushed back. Partly sampled in plastic bags.

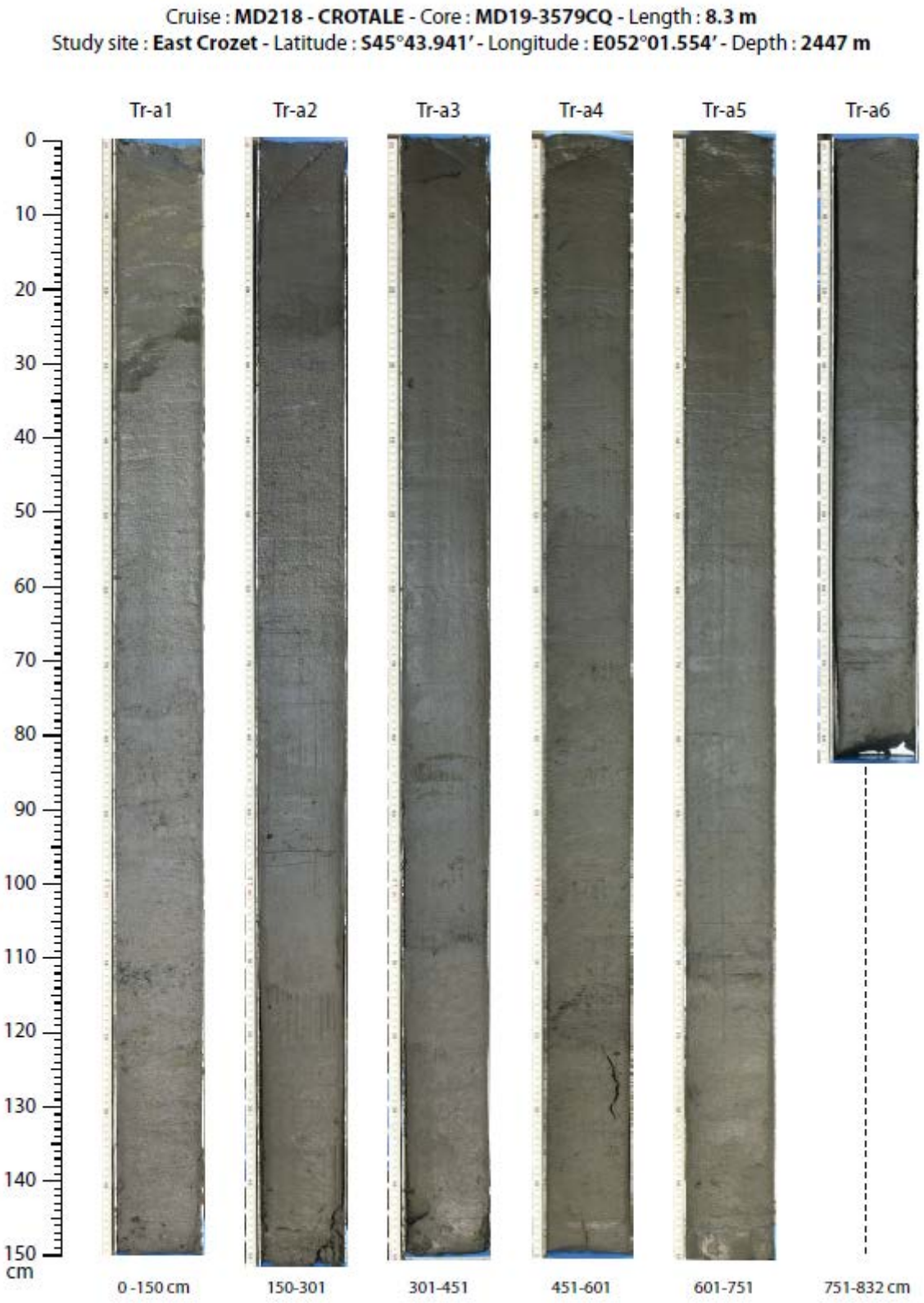


Figure 32. Composite photo of core MD19-3579CQ.

Cruise : MD218 - CROTALE

Core : MD19-3579CQ - **Length** : 8.3 m - **Coring site** : East Crozet
Latitude : S 45°43.941' - **Longitude :** E 52°01.554' - **Water depth** : 2447 m

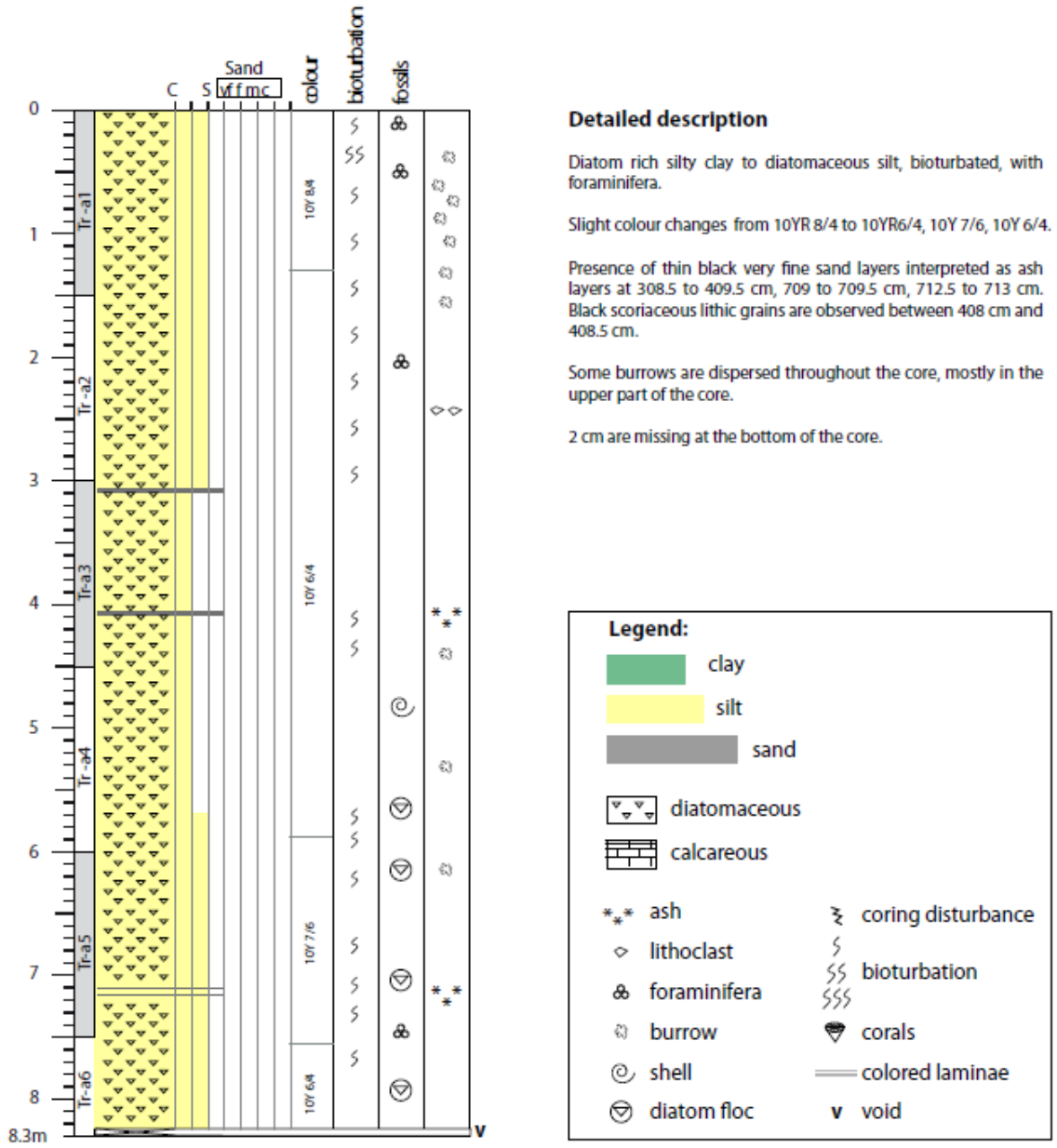


Figure 33. Synthetic log description of core MD19-3579CQ.

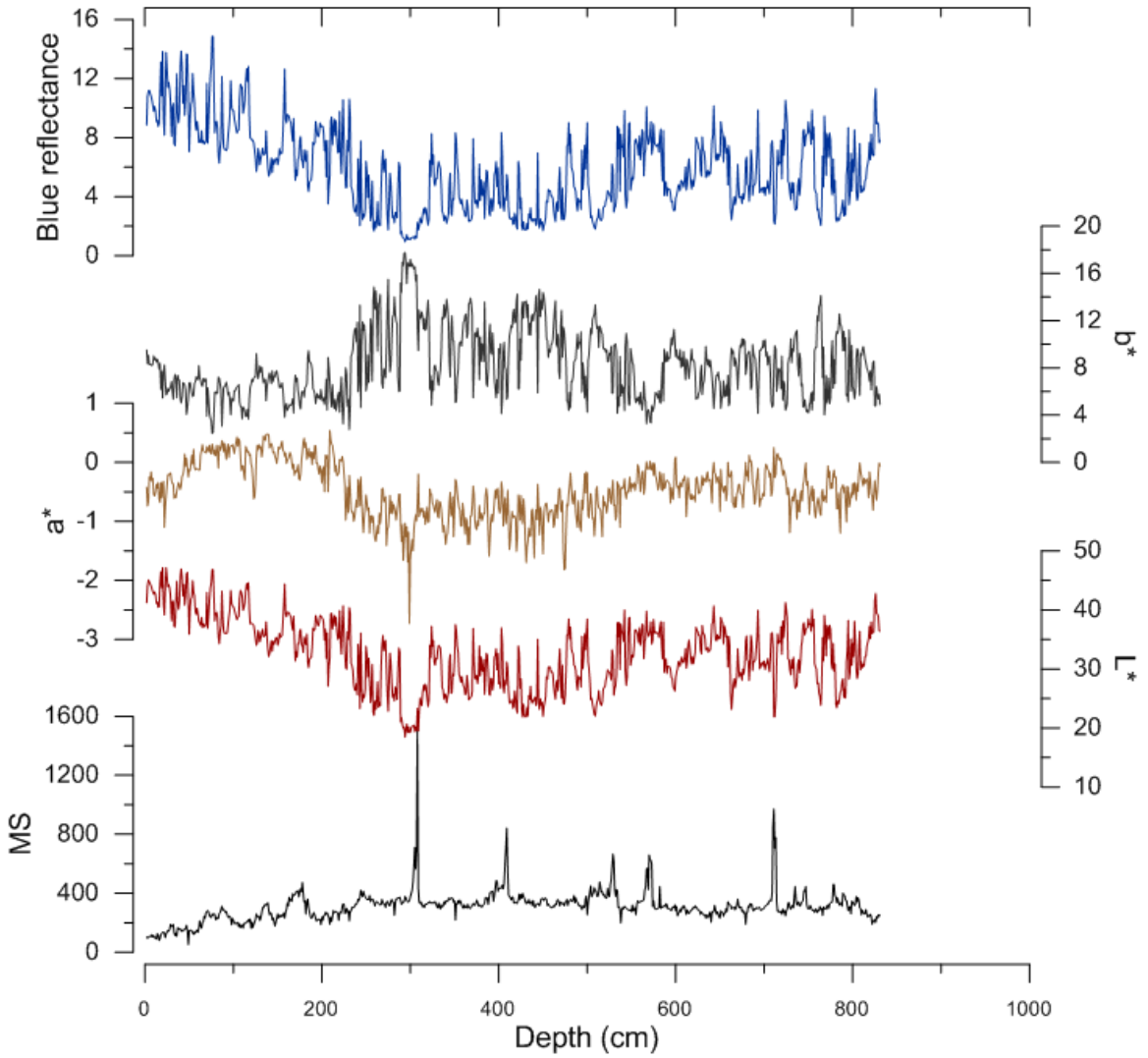


Figure 34. MD19-3579CQ data. From bottom to top: Mass specific susceptibility (in 10^{-8} (m^3.kg)), L, a*, b* and blue reflectance (mean 400-515 nm).*

Core MD19-3580

A ~44 meters-long Calypso was sent. The liner was extruded in two pieces and cut into 1.5 meters long sections except for the sections 2-4 (1.18, 0.92 and 0.90 m long, respectively) to avoid transferring non-conventional depths downcore (Table 7). Few decimeter thick voids are present due to flushed out ash layers. The presence of intact, decimeter thick ash layers may indicate that the sediment has probably not been stretched over the voids.

The main lithology is dark greenish grey diatomaceous silt to silty-clay with foraminifera only observed in the upper 5 m (Figure 35 and Figure 36). The sporadic high values in magnetic susceptibility indicate the presence of centimeter thick ash layers from nearby Crozet archipelago. The MSCL data suggest that the core reaches mid-late MIS 6 (Figure 37).

Table 7. MD19-3580 core general information.

NOM DE LA CAMPAGNE	Date : 4 March 2019	Météo : (force) / Direction
MD218 CROTALE	N° de station : **E CROZET**	Vent : Mer : Variation tension (maxi) :

CAROTTE (N°) :	LONGUEUR m :	POSITION :
MD19-3580 *(MD année -numéro)*	**43,17**	**Latitude :** **45°43.99'S** **Longitude :** **52°01.52'E**

CAROTTIER (type) (1) : Calypso	REGLAGES :	CONTREPOIDS :
Poids total (air) : **6,2** t	**Tubes** (longueur) : **43,67** m	**Type (2) :** CYLINDER 100 KG
Poids total (eau) : **surf** t **bottom** t	**Câbles :** Chute libre : **1,95** m Boucle : **6,48** m LC poids : m (3m50 lest)	Longueur PVC : m Pénétration : m Longueur de carotte : m + Ogive (+ 0,15 m)

PARAMETRES MESURES :	HEURES (GMT)	INSTRUMENTATION OPERATIONS ANNEXES
Sonde corrigée : **2 748** m	En station : **GMT**	CTD (hydro) :
Ligne filée : m	Début manœuvre : **07h35** **GMT**	CTD (bouteilles) :
Arrachement/total *(tonne)* : **10,00** t	**Déclenchement :** **08h30** **GMT**	Filet à plancton :
Pénétration/apparente *(m)* : m	Fin de manœuvre : **11h00** **GMT**	Autres : /
Pénétration/tensiomètre *(m)* : m	**Durée de manœuvre :** Départ station : **GMT**	
Description / incidents :		

0	*150*	*268*	*360*	*450*	*600*	*750*	*900*
TR 1	**TR 2**	**TR 3**	**TR 4**	**TR 5**	**TR 6**	**TR 7**	

900	*1050*	*1200*	*1350*	*1500*	*1650*	*1800*	*1950*
TR 8	**TR 9**	**TR 10**	**TR 11**	**TR 12**	**TR 13**	**TR 14**	

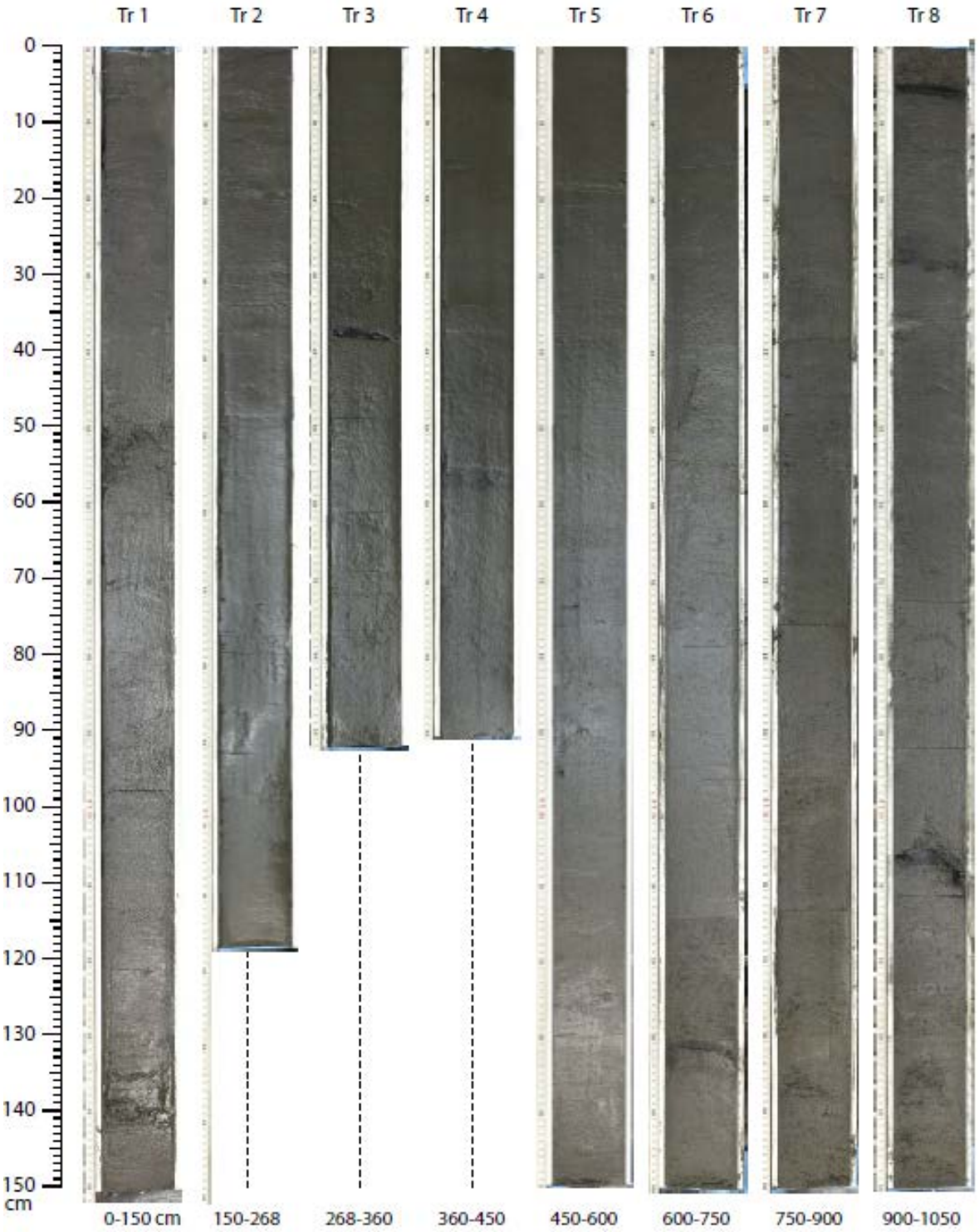
1950	*2100*	*2250*	*2400*	*2550*	*2700*	*2850*	*3000*
TR 15	**TR 16**	**TR 17**	**TR 18**	**TR 19**	**TR 20**	**TR 21**	

3000	*3150*	*3300*	*3450*	*3600*	*3750*	*3900*	*4050*
TR 22	**TR 23**	**TR 24**	**TR 25**	**TR 26**	**TR 27**	**TR 28**	

4050	*4200*	*4317*				
TR 29	**TR 30**					

Commentaires
Few places where ash layers cracked during coring => hole in sediment (cf description)

Cruise : **MD218 - CROTALE** - Core : **MD19-3580** - Length : **43.17 m**
Study site : **East Crozet** - Latitude : **S45°43.99'** - Longitude : **E52°01.52'** - Depth : **2748 m**




Tr 9
Tr 10
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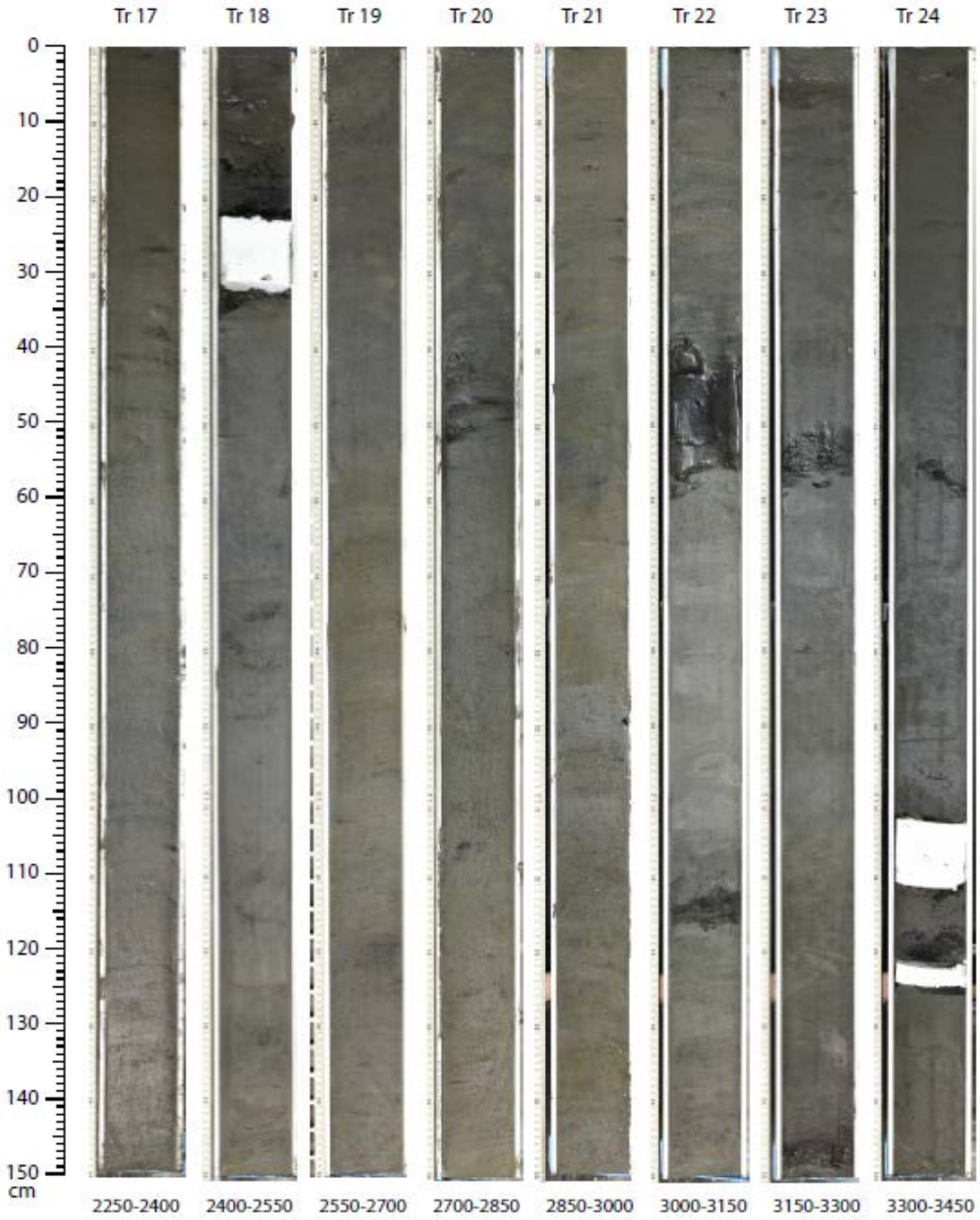
1950-2100
2100-2250


Tr 17
Tr 18
Tr 19
Tr 20
Tr 21
Tr 22
Tr 23
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2850-3000
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3150-3300
3300-3450

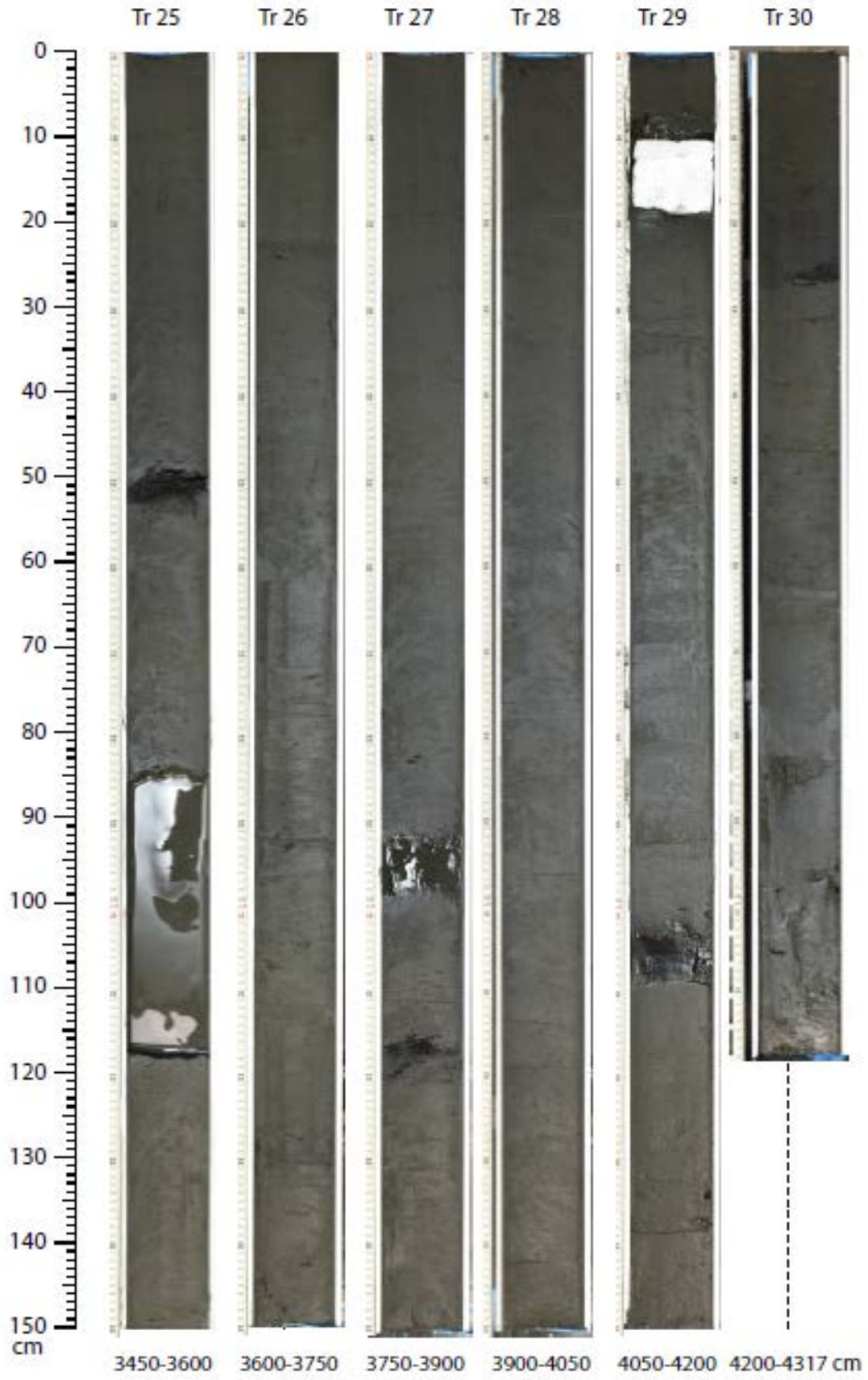
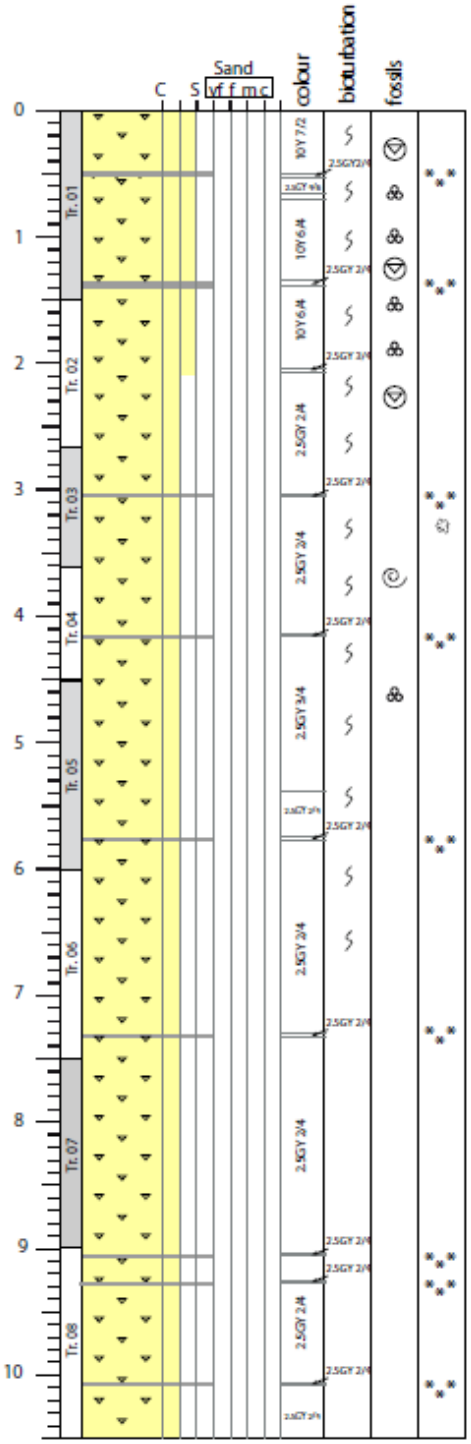


Figure 35. Composite photo of core MD19-3580.

Cruise : MD218 - CROTALE

Core : MD19-3580 - **Length** : 43.17 m - **Coring site** : East Crozet
Latitude : S 45°43.99' - **Longitude :** E 52°01.52' - **Water depth** : 2748 m



Detailed description 1/4 : Sections 01 to 08

The main lithology is dark greenish gray diatomaceous silt to silty-clay.
Foraminifera are observed in the uppermost two meters of the core.

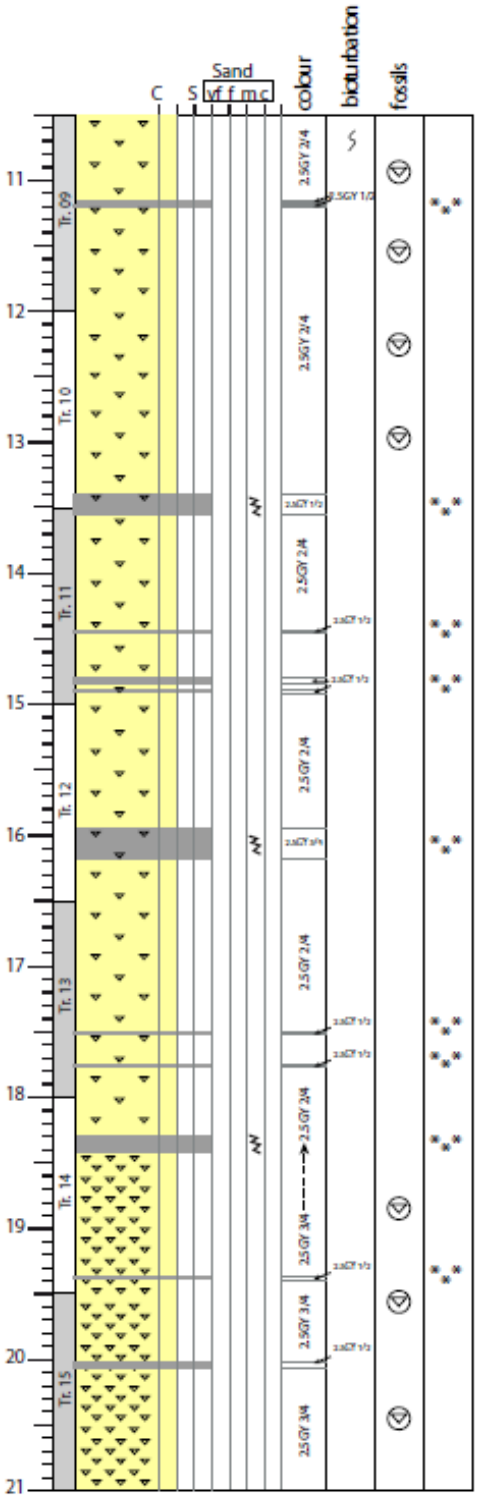
Bioturbation occurs throughout the core.

The main colour is 10Y 6/4.

Discrete black fine sand ash layers : 50-51.5 cm, 66.5-71.5 cm, 136.5-140 cm, 304.5-306 cm, 416.8-418.2 cm

Legend:

- clay
- silt
- sand
- diatomaceous
- calcareous
- ash
- lithoclast
- foraminifera
- burrow
- shell
- diatom floc
- coring disturbance
- bioturbation
- corals
- colored laminae
- v void



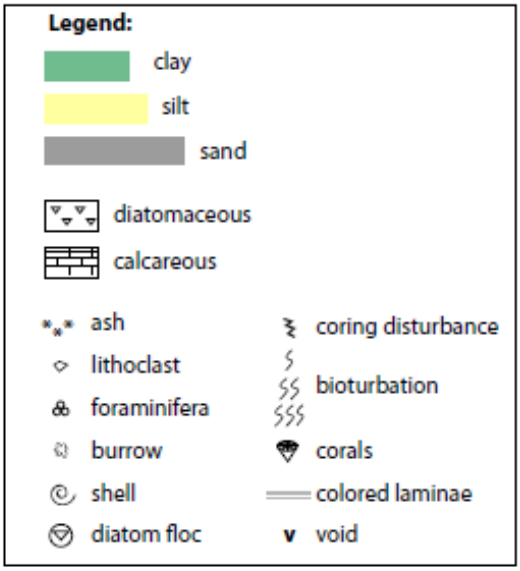
Detailed description 2/4 : Sections 09 to 15.

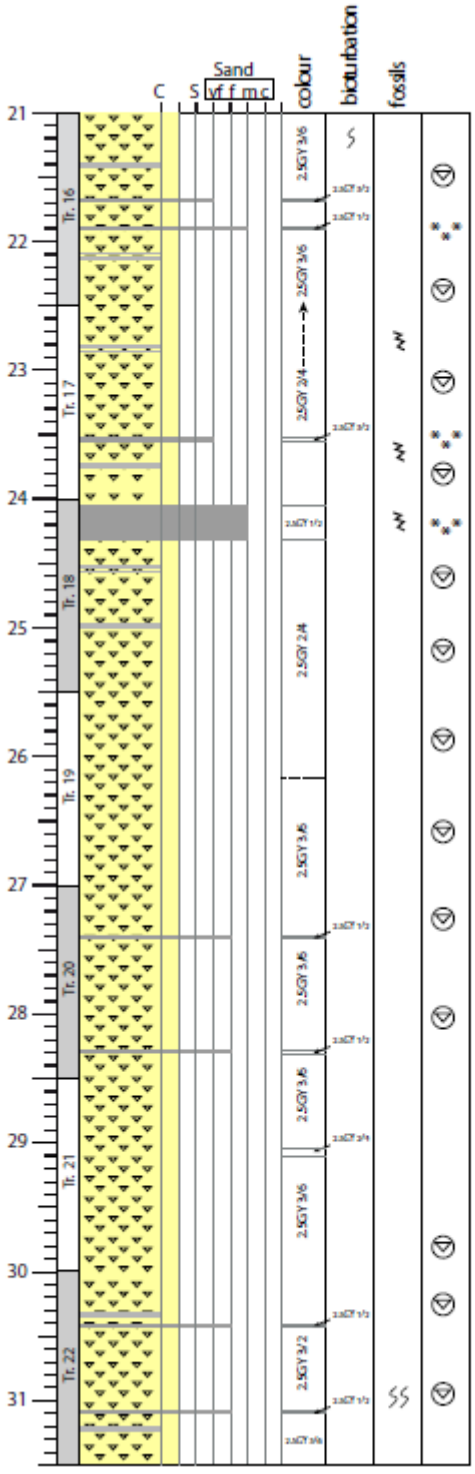
The main lithology is dark greenish gray diatomaceous silty-clay. No foraminifera, no structures.

The main colour is 2.5GY 2/4.

Discrete black fine sand ash layers : 1114-1115 cm, 1120-1122 cm, 1445-1446 cm, 1480-1484 cm, 1490-1491 cm, 1752-1753 cm, 1775-1782 cm, 1937 cm, 2003-2007 cm.

Some ash layers have been flushed out and replaced by water during coring : 1340-1355 cm, 1597-1617 cm, 1830-1842 cm





Detailed description 3/4 : Sections 16 to 22.

The main lithology is dark greenish gray diatomaceous ooze. The main grain size is silty clay. Presence of frequent diatom flocs throughout the core. Faint colored (orange, green, purple, blue) laminations throughout the core .

No foraminifera.

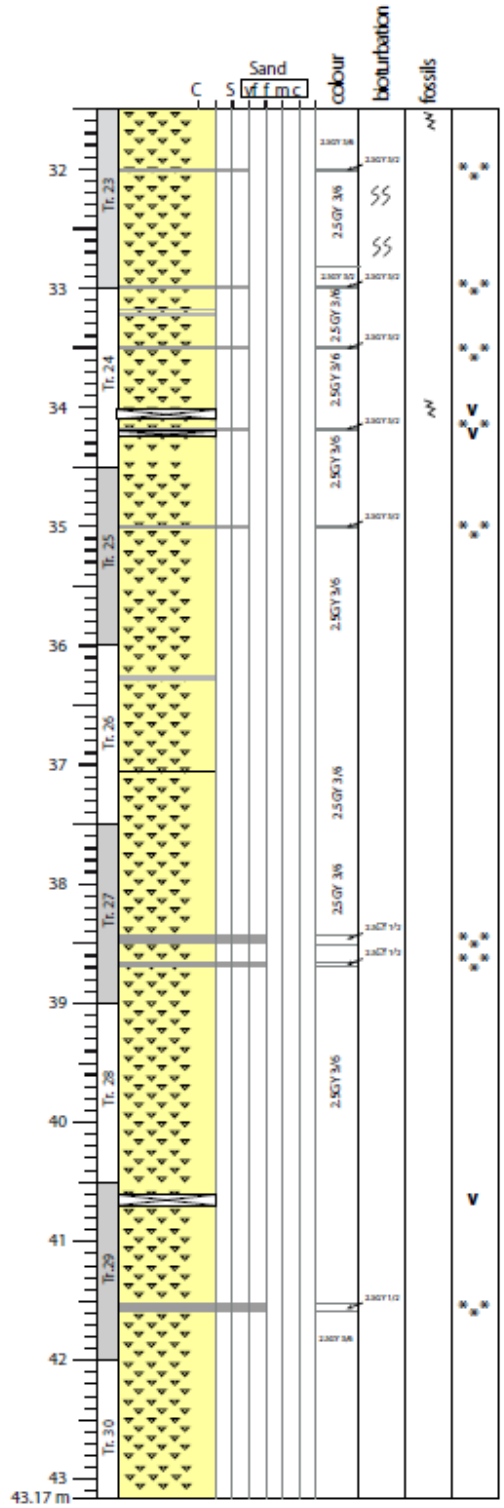
The main colors are 2.5GY 2/4 to 2.5GY 3/6.

Discrete black very fine to medium sand ash layers : 2316-2319 cm, 2340-2347 cm, 2356 cm, 2747-2752 cm, 2873 cm, 2903-2910 cm, 3043-2053 cm, 3112-3116 cm.

One massive ash layer have been flushed out and replaced by water during coring : 2406-2433 cm.

Legend:

- clay
- silt
- sand
- diatomaceous
- calcareous
- ash
- lithoclast
- foraminifera
- burrow
- shell
- diatom floc
- coring disturbance
- bioturbation
- corals
- colored laminae
- void



Detailed description 4/4 : Sections 23 to 30.

The main lithology is dark greenish gray diatomaceous ooze. The main grain size is silty clay. Bioturbation observed at colour changes.

No foraminifera.

The main colour is 2.5GY 3/6.

Discrete black very fine to medium sand ash layers : 3200-3204 cm, 3295-3299 cm, 3350-3352 cm, 3417-3422 cm, 3500-3504 cm, 3842-3850 cm, 3866-3870 cm, 4153-4159 cm.

Some ash layer have been flushed out and replaced by water during coring : 3402-3411 cm, 3422-3425 cm, 4060-4070 cm.

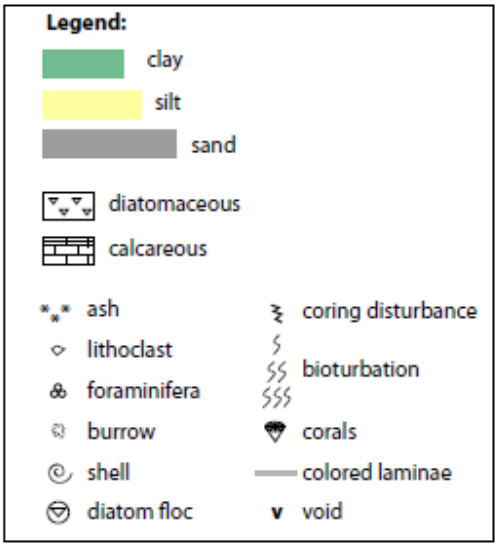


Figure 38. Synthetic log description of core MD19-3580.

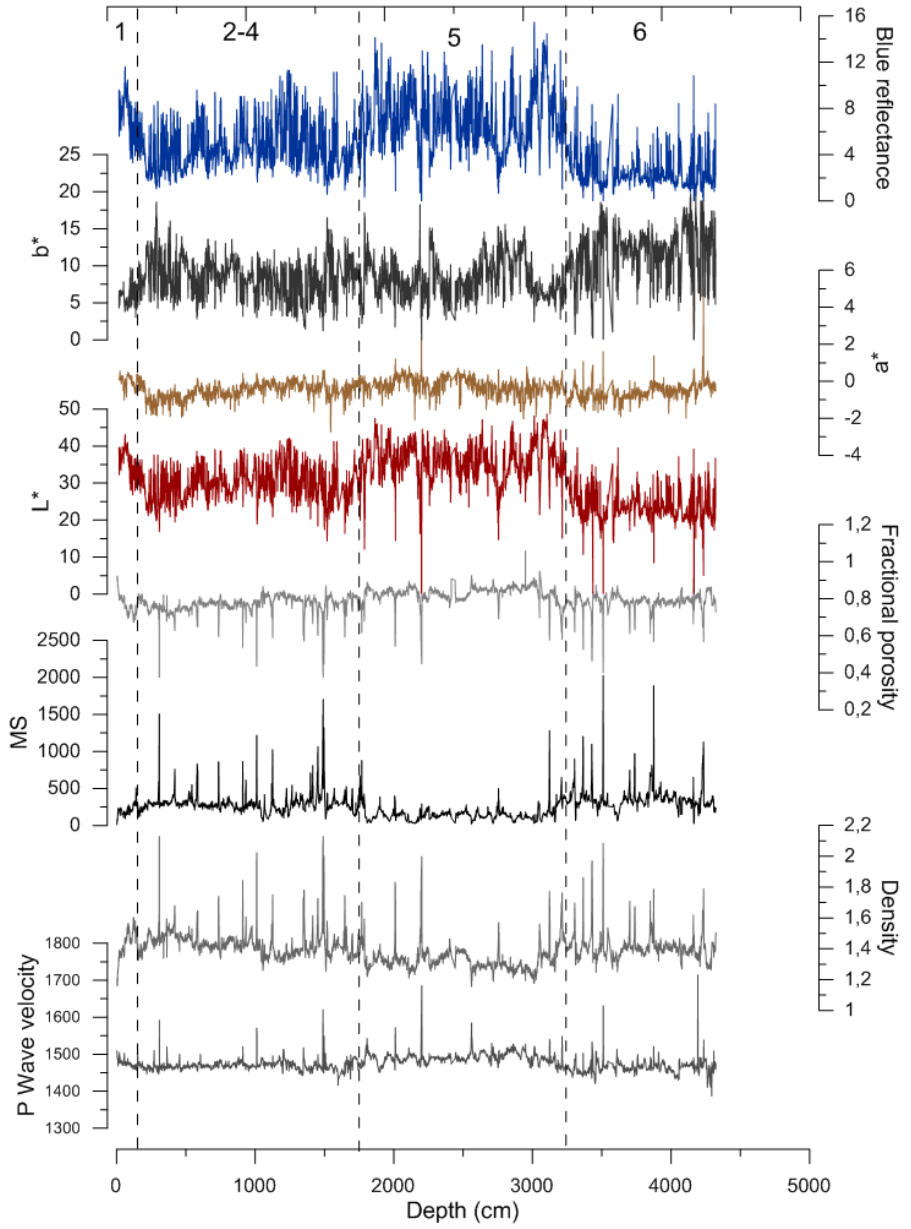


Figure 37. MD19-3580 data. From bottom to top: P Wave velocity (in $m.s^{-1}$), Density (in $g.cm^{-1}$), Mass specific susceptibility (in 10^{-8} (m^3.kg)), Fractional porosity, L, a*, b* and blue reflectance (mean 400-515 nm). Preliminary stratigraphy is highlighted by vertical dashed lines and MIS.*

North Crozet Region

This site was not listed in the expedition proposal. Enough time was spared on the other sites to plan another coring operation on the way back to La Réunion Island. Previous surveys demonstrated the presence of a sediment draping thicker than 120 m on the northern slope of a W-E elongated rise located just south of the Mid Indian Ocean Ridge (Figure 38). A short Calypso retrieved in 2004 demonstrated the presence of soft diatom oozes due to the inflection of the SAF and ACC towards the north in between Del Caño Rise and Crozet Plateau fueling surface waters with iron. High micro-nutrient concentrations stimulate phytoplankton productivity (Pollard et al., 2009), essentially diatoms, allowing for high sediment accumulation (Figure 39).

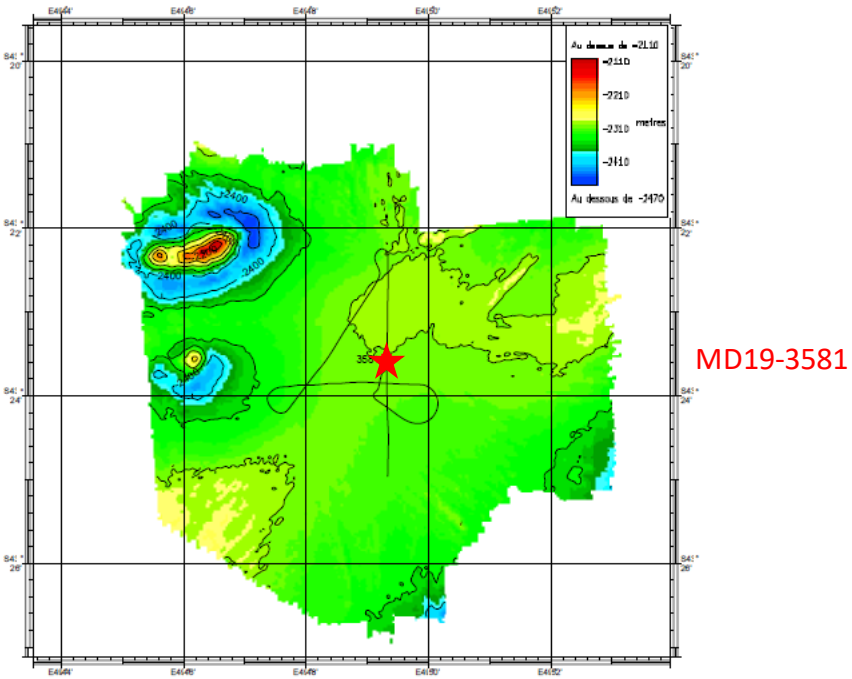


Figure 38. Local bathymetry and position of core MD19-3581 (modified after Xavier Morin).

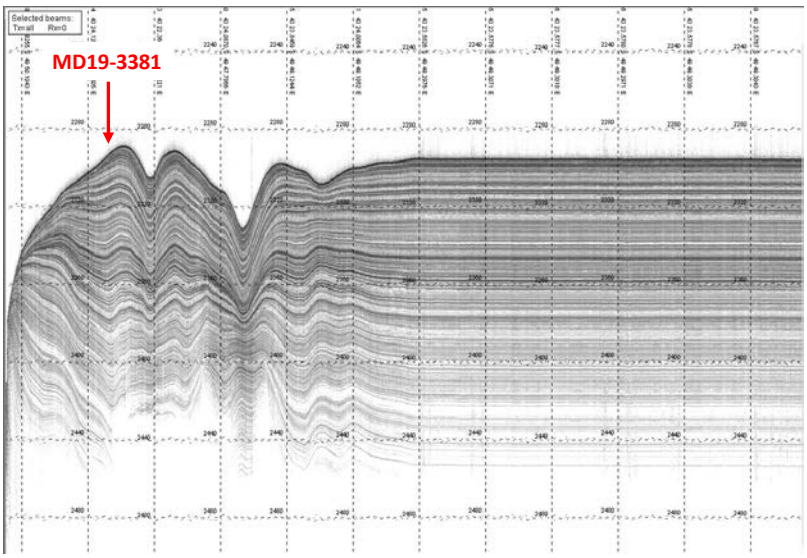


Figure 39. CHIRP 3.5 kHz profile around North Crozet site. Locations of the Calypso (MD19-3581) cores are indicated by the red arrows.

Core MD19-3581

A ~70 meters-long Calypso was sent. The liner was extruded in five pieces and cut into 1.5 meters long sections whenever possible (Table 7). Few decimeter thick voids are present due to flushed out ash layers. The presence of intact, decimeter thick ash layers may indicate that the sediment has probably not been stretched over the voids.

The main lithology is diatom ooze. Foraminifera were observed in several sections probably accumulated during warm periods (Figure 40 and Figure 41). Macro-bioturbation is observed throughout the core.

MSCL data suggest that the core reach ~1.5 million years (and maybe beyond) and that the Holocene-to-last glacial period is very compacted or absent (Figure 42 and Figure 43).

Table 8. MD19-3581 core general information.

NOM DE LA CAMPAGNE	Date : 4 March 2019 5 March 2019	Météo : (force) / Direction Vent : Mer : Variation tension (maxi) :
MD218 CROTALE	N° de station : **N CROZET**	

CAROTTE (N°) :	LONGUEUR m :	POSITION :
MD19-3581 *(MD année -numéro)*	**69,69**	**Latitude :** **43°23.57'S** **Longitude :** **49°49.31'E**

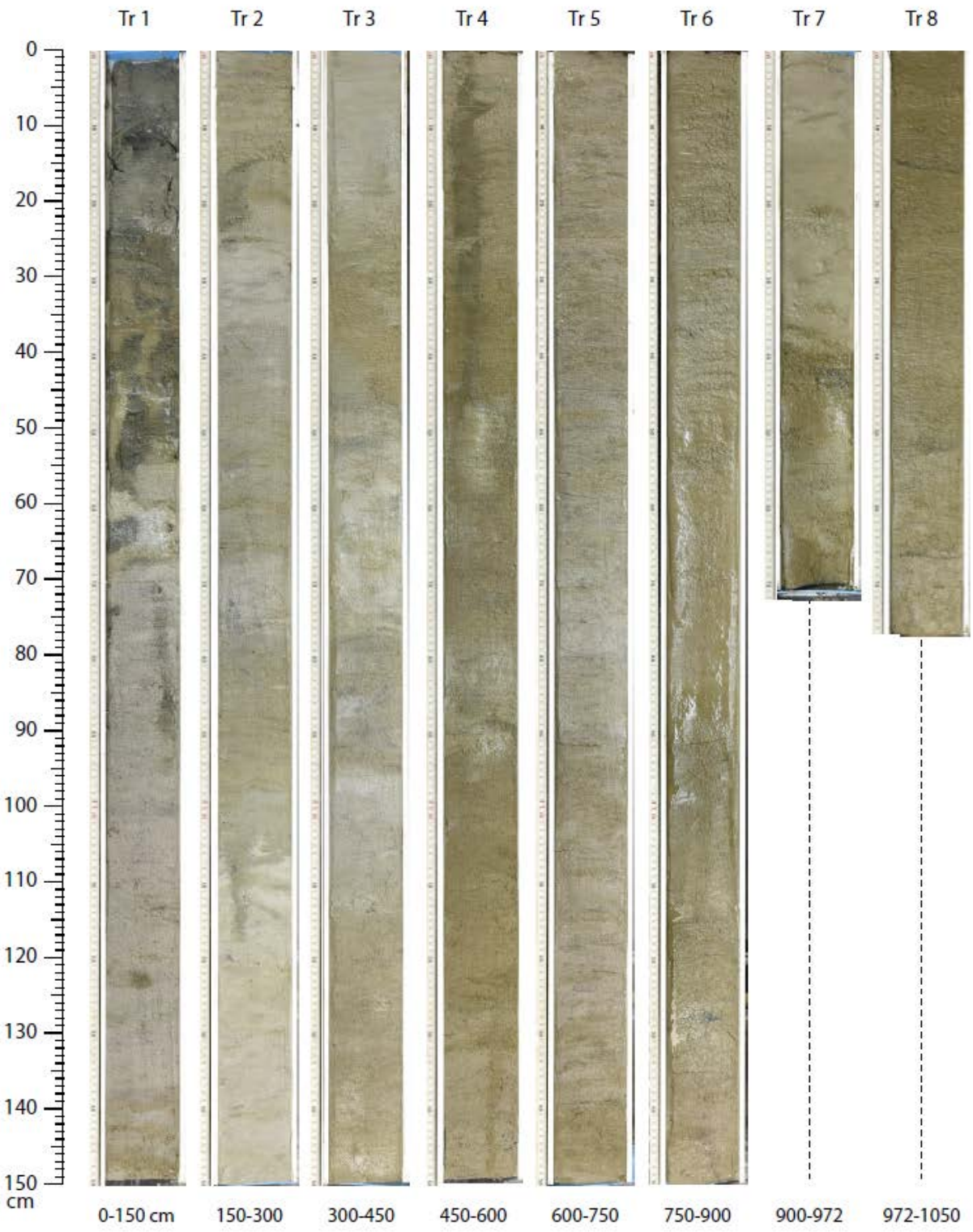
CAROTTIER (type) (1) : Calypso	REGLAGES :	CONTREPOIDS :
Poids total (air) : 7,9 t	**Tubes** (longueur) : 70,13 m	**Type (2) :** CYLINDER 100 KG
Poids total (eau) : surf 7,5 t bottom t	**Câbles :** Chute libre : 1,65 m	Longueur PVC : m
	Boucle : 6,38 m	Pénétration : m
	LC poids : m (3m50 lest)	Longueur de carotte : m + Ogive (+ 0,15 m)

PARAMETRES MESURES :	HEURES (GMT)	INSTRUMENTATION OPERATIONS ANNEXES
Sonde corrigée : 2 295 m	En station : 22h00 GMT	CTD (hydro) :
Ligne filée : 2 225 m	Début manœuvre : 01h42 GMT	CTD (bouteilles) :
Arrachement/total *(tonne)* : 15,30 t	**Déclenchement :** 02h38 GMT	Filet à plancton :
Pénétration/apparente *(m)* : m	Fin de manœuvre : 06h40 GMT	Autres : /
Pénétration/tensiomètre *(m)* : m	**Durée de manœuvre :**	
Description / incidents :	Départ station : GMT	

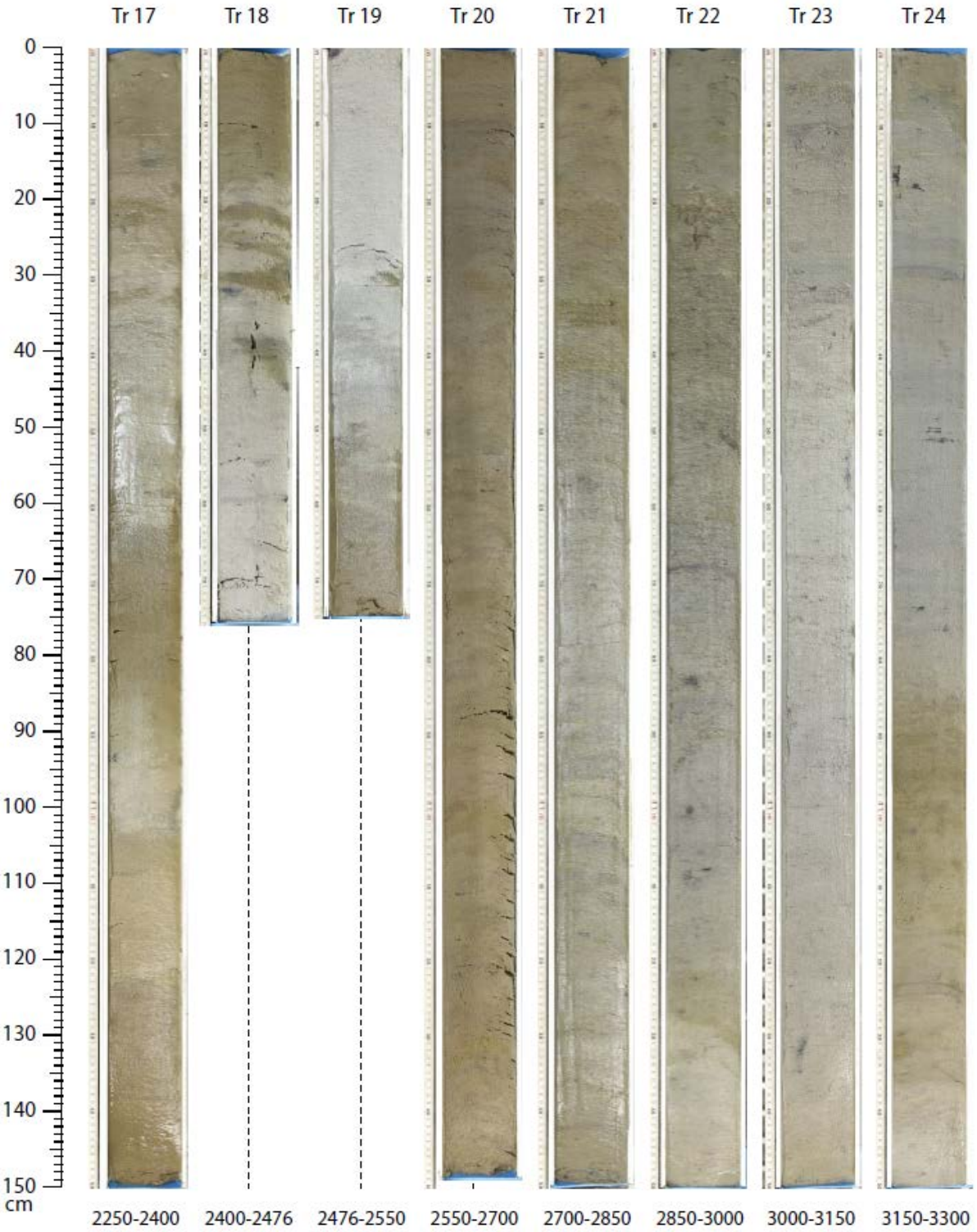
0	150	300	450	600	750	900	972
TR 1	TR 2	TR 3	TR 4	TR 5	TR 6	TR 7	
972	1050	1200	1350	1500	1650	1800	1950
TR 8	TR 9	TR 10	TR 11	TR 12	TR 13	TR 14	
1950	2100	2250	2400	2476	2550	2700	2850
TR 15	TR 16	TR 17	TR 18	TR 19	TR 20	TR 21	
2850	3000	3150	3300	3450	3600	3750	3900
TR 22	TR 23	TR 24	TR 25	TR 26	TR 27	TR 28	
3900	3971	4050	4200	4350	4500	4650	4800
TR 29	TR 30	TR 31	TR 32	TR 33	TR 34	TR 35	
4800	4950	5100	5250	5400	5454	5550	5700
TR 36	TR 37	TR 38	TR 39	TR 40	TR 41	TR 42	
5700	5850	6000	6150	6300	6450	6600	6750
TR 43	TR 44	TR 45	TR 46	TR 47	TR 48	TR 49	
6750	6900	6969					
TR 50	TR 51						

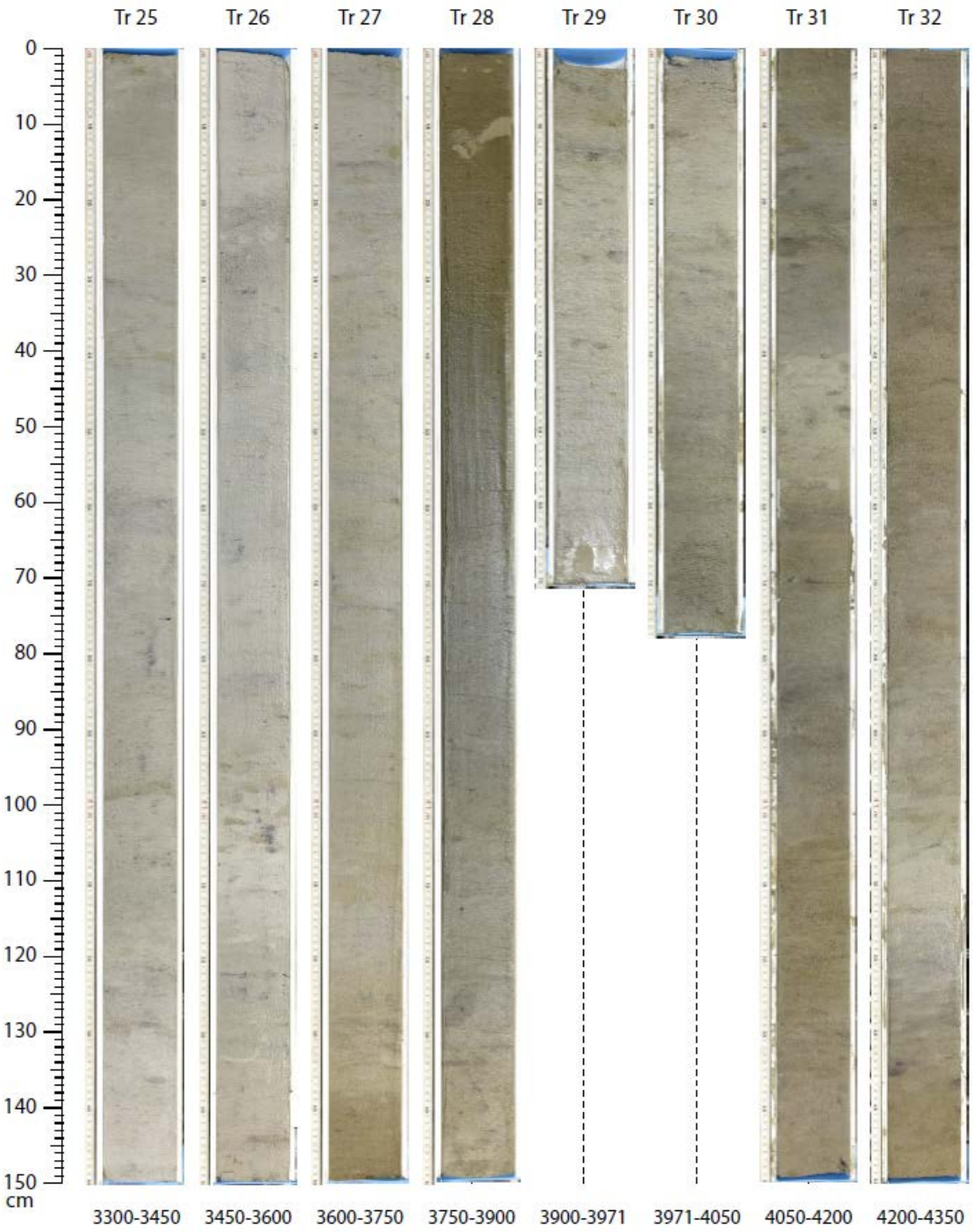
Commentaires
Slight difference between on deck core length (69,73cm) and MSCL core length (69,69cm)

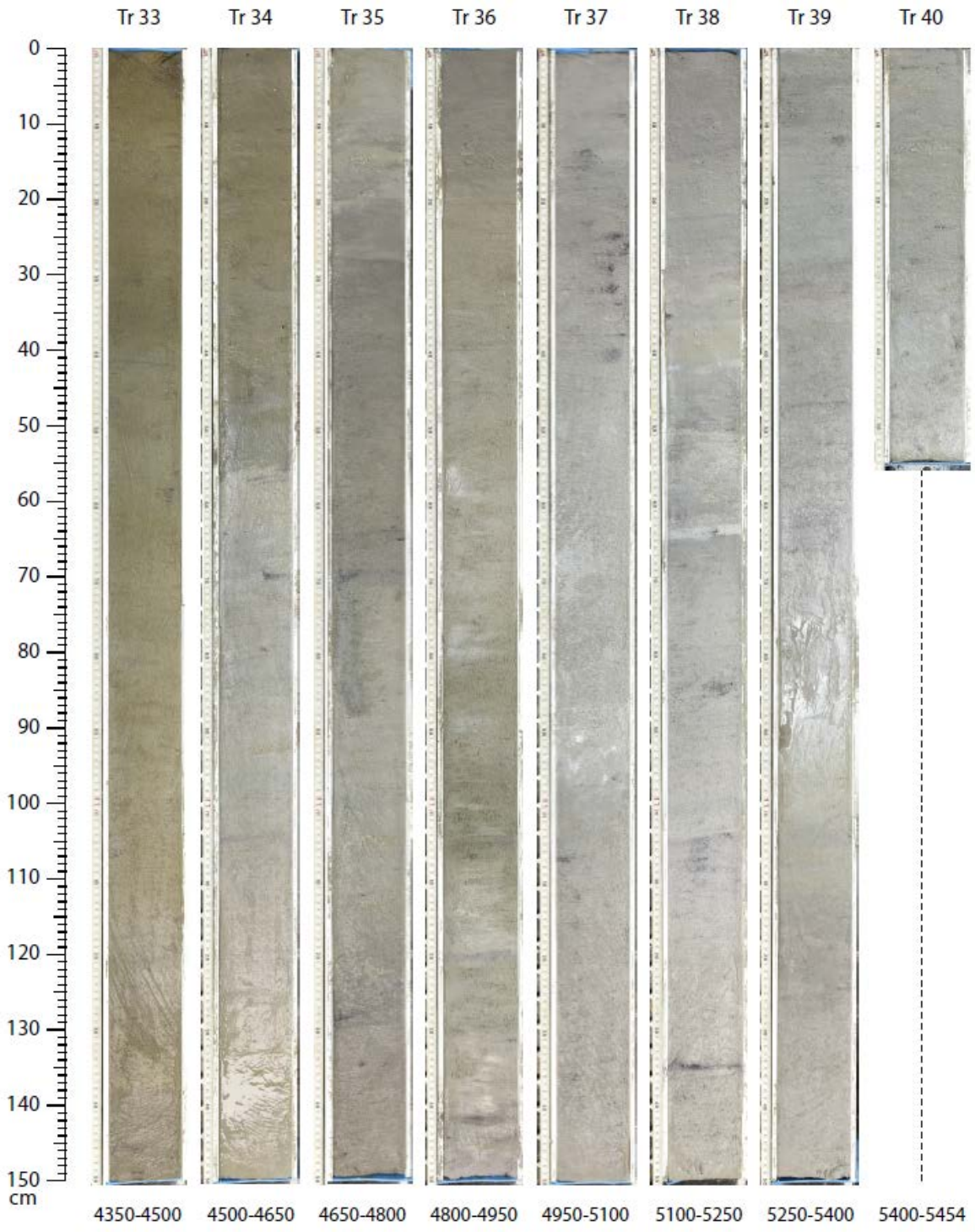
Cruise : **MD218 - CROTALE** - Core : **MD19-3581** - Length : **69.69 m**
Study site : **North Crozet** : - Latitude : **S43°23.57'** - Longitude : **E49°49.31'** - Depth : **2295 m**

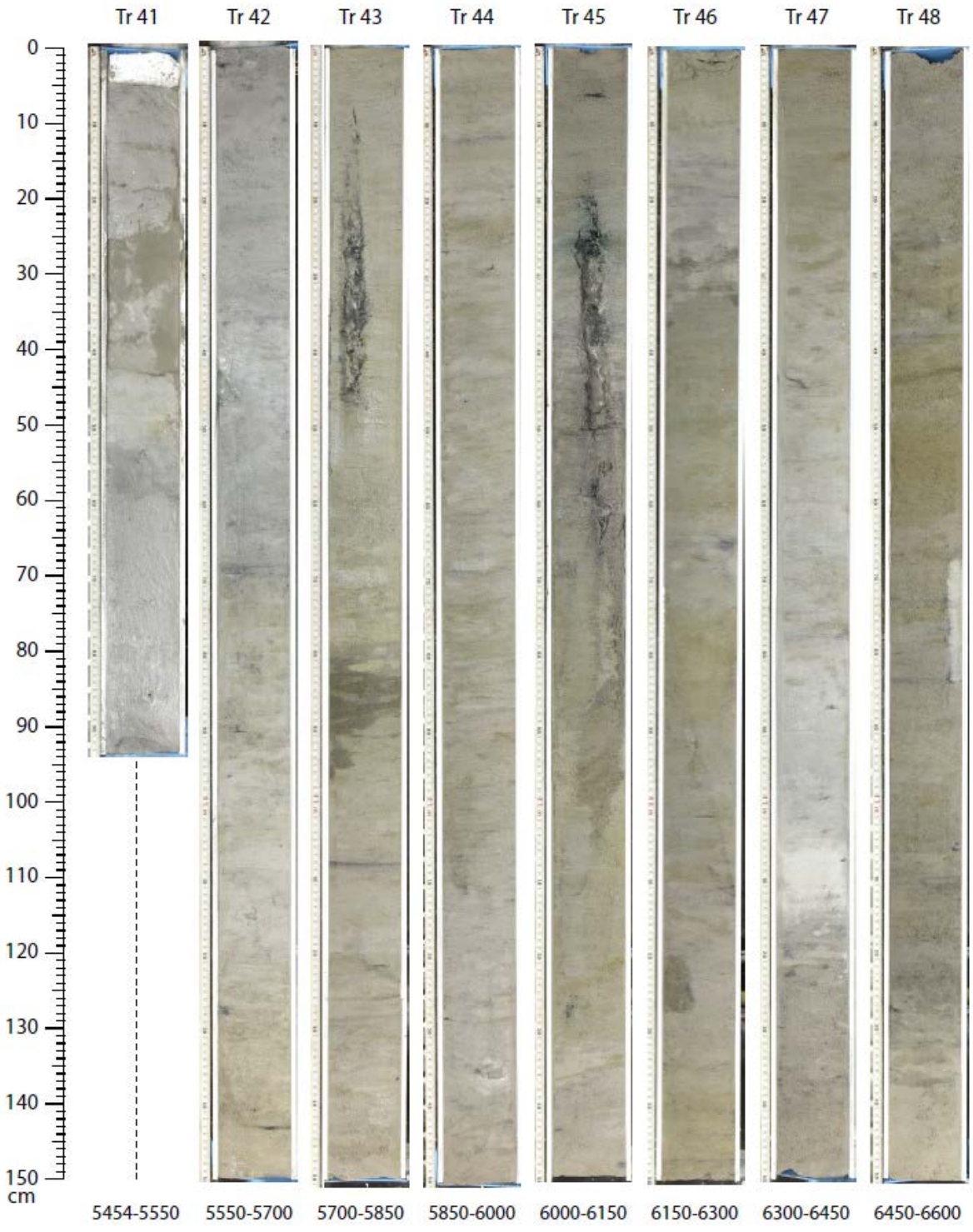



Tr 9
Tr 10
Tr 11
Tr 12
Tr 13
Tr 14
Tr 15
Tr 16
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
cm
1050-1200
1200-1350
1350-1500
1500-1650
1650-1800
1800-1950
1950-2100
2100-2250


Tr 17
Tr 18
Tr 19
Tr 20
Tr 21
Tr 22
Tr 23
Tr 24
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
cm
2250-2400
2400-2476
2476-2550
2550-2700
2700-2850
2850-3000
3000-3150
3150-3300


Tr 25
Tr 26
Tr 27
Tr 28
Tr 29
Tr 30
Tr 31
Tr 32
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
cm
3300-3450
3450-3600
3600-3750
3750-3900
3900-3971
3971-4050
4050-4200
4200-4350


Tr 33
Tr 34
Tr 35
Tr 36
Tr 37
Tr 38
Tr 39
Tr 40
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
cm
4350-4500
4500-4650
4650-4800
4800-4950
4950-5100
5100-5250
5250-5400
5400-5454


Tr 41
Tr 42
Tr 43
Tr 44
Tr 45
Tr 46
Tr 47
Tr 48
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
cm
5454-5550
5550-5700
5700-5850
5850-6000
6000-6150
6150-6300
6300-6450
6450-6600

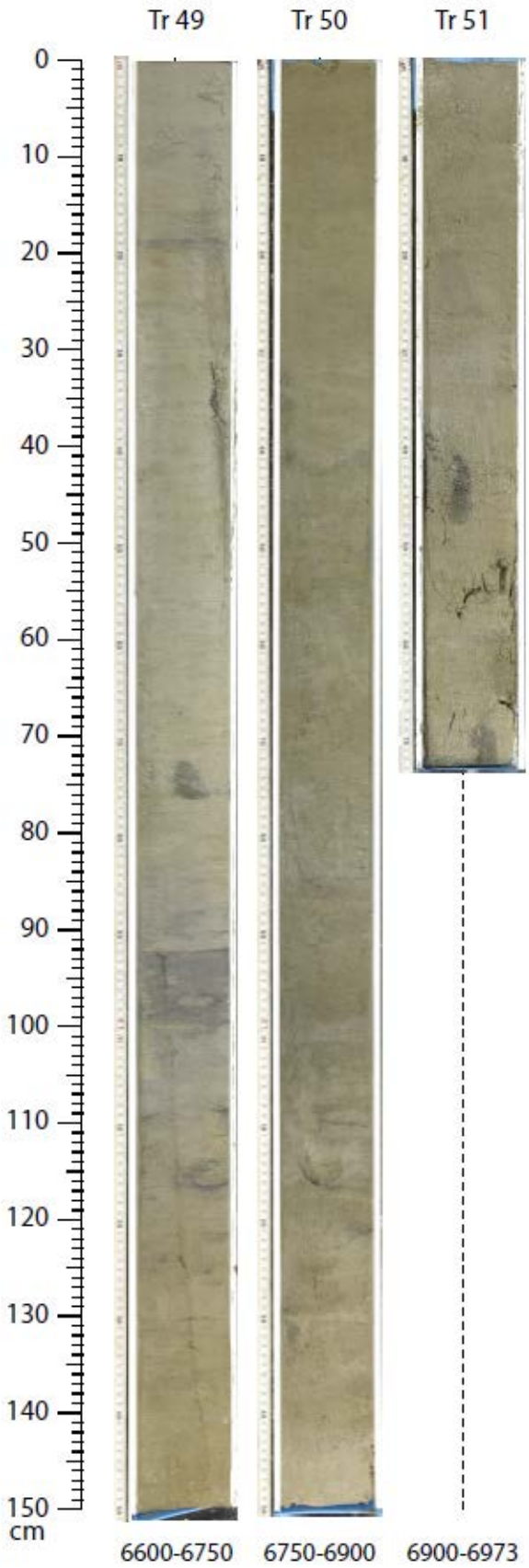
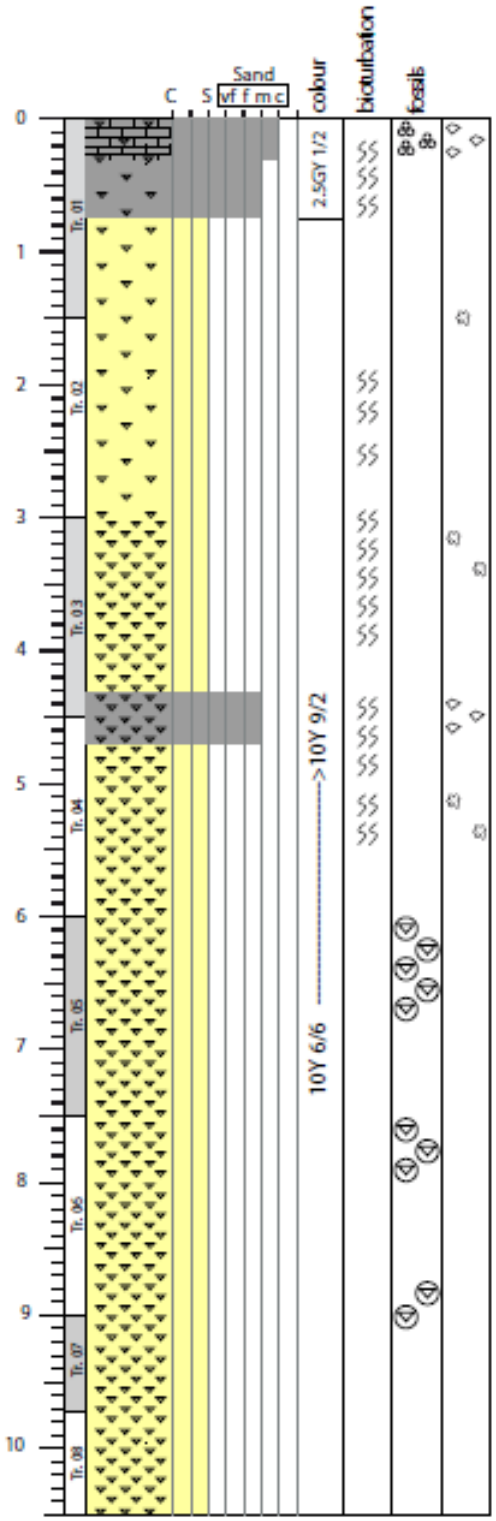


Figure 40. Composite photo of core MD19-3581.

Core : MD19-3581- **Length** : 69.69 m - **Coring site** : North Crozet
Latitude : S 43°23.57′ - **Longitude :** E 49°49.31′ - **Water depth** : 2295 m



Detailed description 1/7 : Sections 1 to 8

Diatom ooze with colour ranging from 10Y 9/2 in the upper part to 10Y 6/6 in the lower part.

Two coarse grain intervals, the uppermost one including very coarse grains to gravels (dropstones) and foraminifera (otherwise rare to absent).

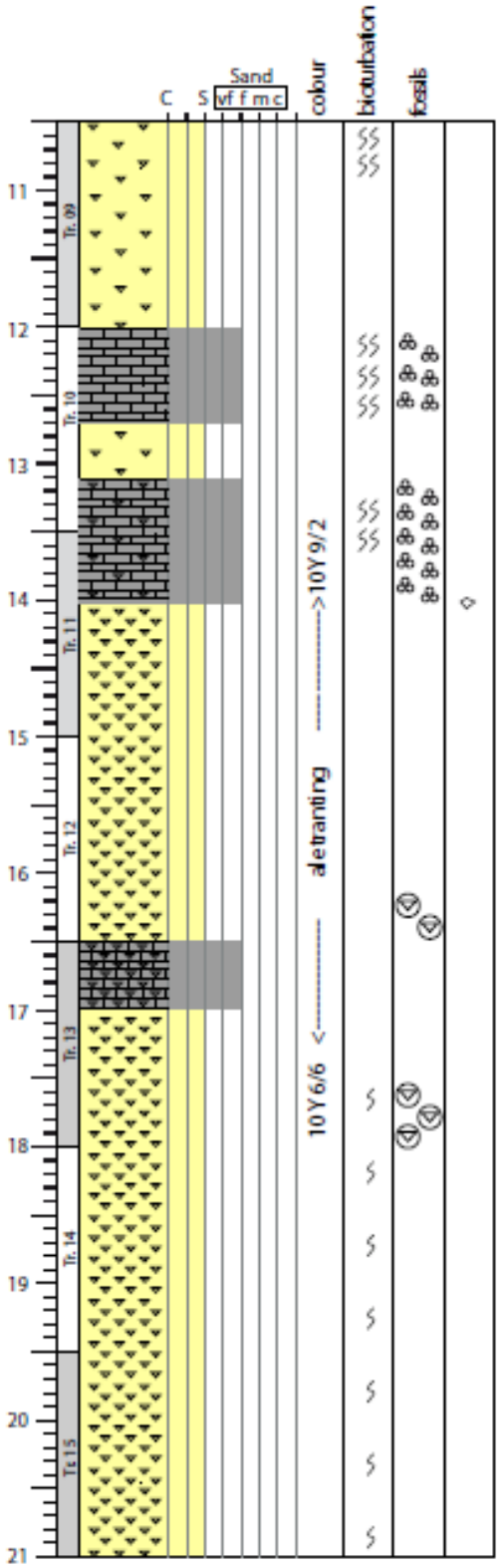
Diatom flocs common within the lower part of the interval.

Frequent colour changes induced by sulphide streaks and greenish cm-thick layers.

Rare burrows filld with sand-size material.

Legend:

- clay
- silt
- sand
- diatomaceous
- calcareous
- ash
- lithoclast
- foraminifera
- burrow
- shell
- diatom floc
- coring disturbance
- bioturbation
- corals
- colored laminae
- void



Detailed description 2/7 : Sections 9 to 15

Diatomaceous-rich to diatom ooze (silt) of colour from 10Y 9/4 (foraminifera-rich) to 10Y 6/6.

Moderately bioturbated throughout.

Three intervals of foraminifera-rich fine sand.

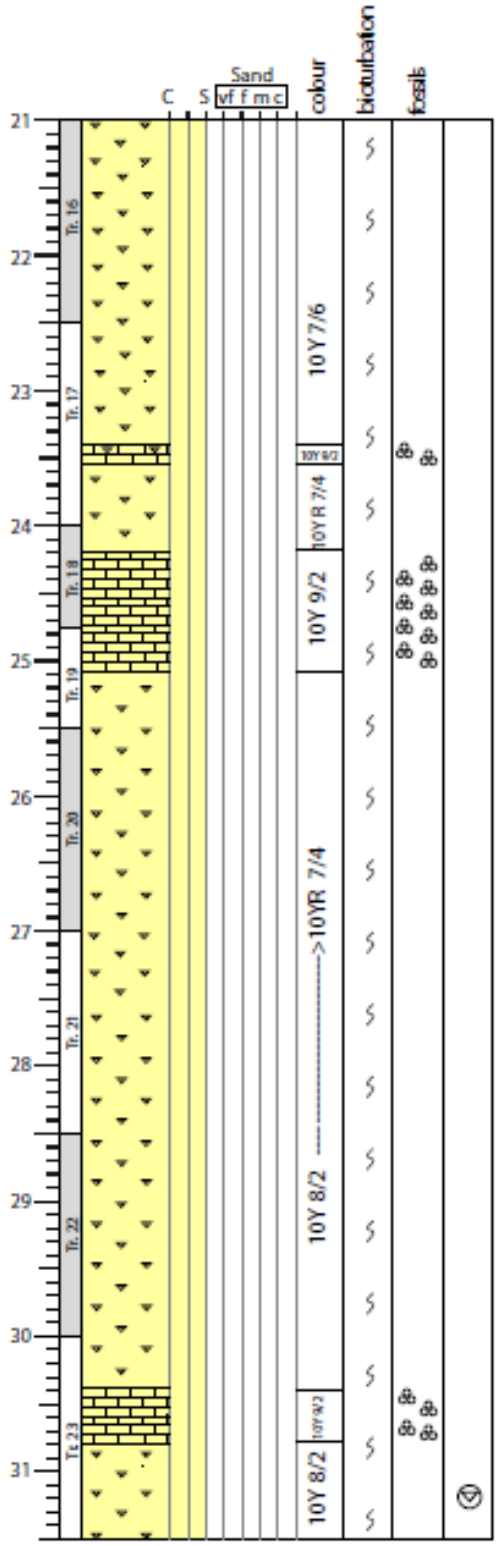
Diatom flocs more abundant in the lower part of the interval.

Black (sulphide streaks) and green colour bands throughout.

Rare to common foraminifera throughout.

Legend:

- clay
- silt
- sand
- diatomaceous
- calcareous
- ash
- lithoclast
- foraminifera
- burrow
- shell
- diatom floc
- coring disturbance
- bioturbation
- corals
- colored laminae
- v void



Detailed description 3/7 : Sections 16 to 23

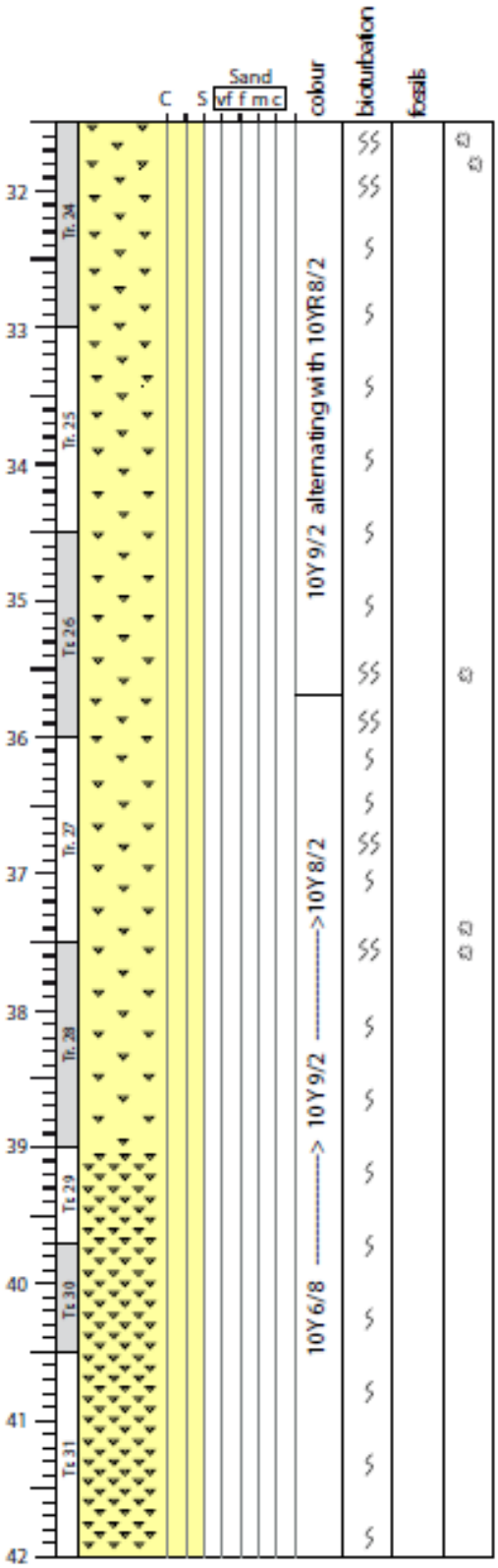
Foraminifera-bearing bioturbated diatomaceous silt, alternating with foram-bearing diatom ooze.

Three intervals of foraminifera-rich calcareous silt with gradual bottom and top boundaries at : 2342-2353 cm, 2418-2509 cm and 3042-3078 cm.

Frequent diatomaceous silt filling burrows within calcareous silt intervals.

Legend:

- clay
- silt
- sand
- diatomaceous
- calcareous
- ash
- lithoclast
- foraminifera
- burrow
- shell
- diatom floc
- coring disturbance
- bioturbation
- corals
- colored laminae
- void



Detailed description 4/7 : Sections 24 to 31

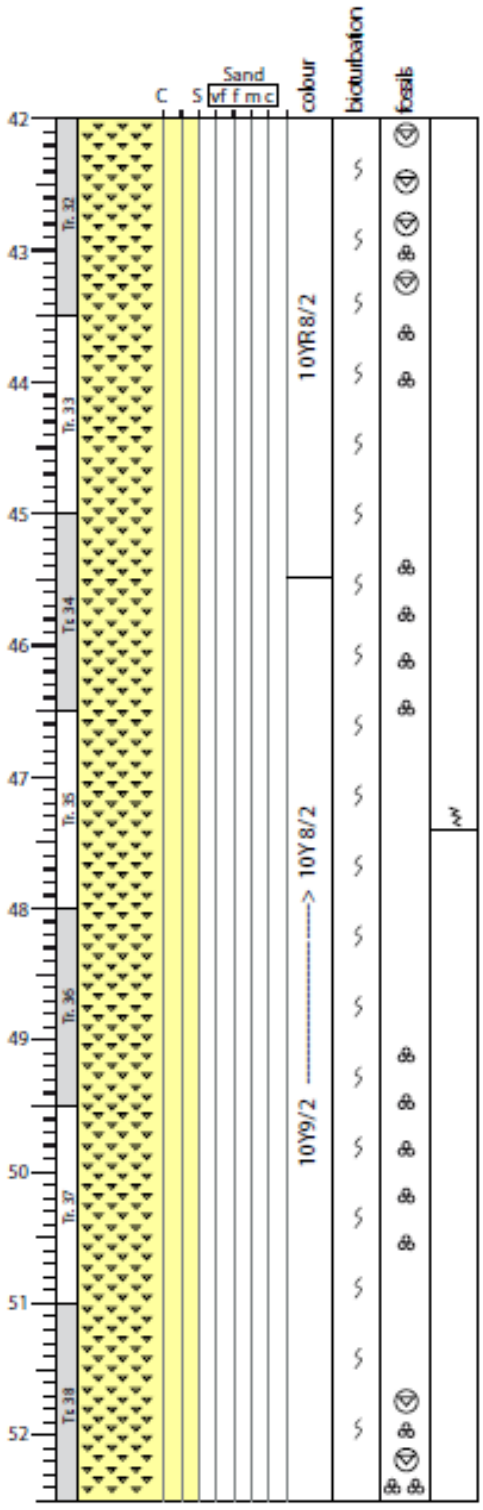
Diatomaceous silt at the top of the interval to diatom ooze at the bottom

Foraminifera-bearing and bioturbated throughout

Small (silt-size) volcanic (?) black particles present throughout the interval.

Legend:

- clay
- silt
- sand
- diatomaceous
- calcareous
- ash
- lithoclast
- foraminifera
- burrow
- shell
- diatom floc
- coring disturbance
- bioturbation
- corals
- colored laminae
- void



Detailed description 5/7 : Sections 32 to 38

Diatom ooze (silt), bioturbated throughout with scattered occurrence of foraminifera.

Diatom flocs mostly concentrated in uppermost and lowermost part of this interval.

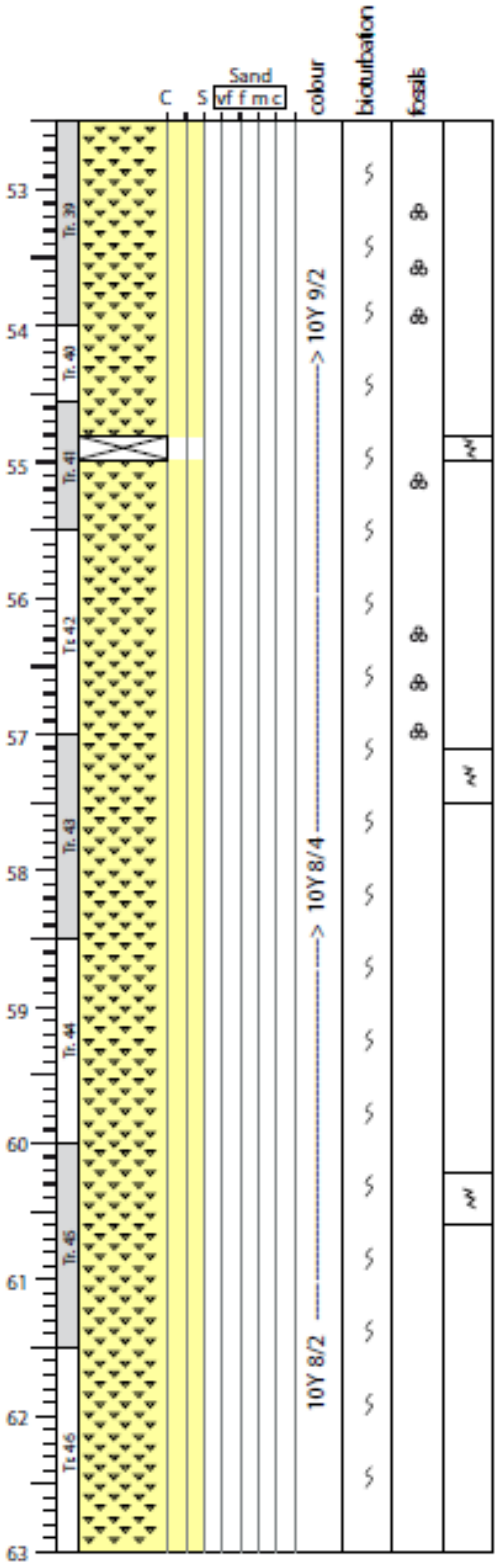
One sharp colour change at 4555 cm.

Colour ranges from 10Y 9/2 to 10Y 6/12.

One coring disturbance between 4720 and 4740 cm.

Legend:

- clay
- silt
- sand
- diatomaceous
- calcareous
- ash
- lithoclast
- foraminifera
- burrow
- shell
- diatom floc
- coring disturbance
- bioturbation
- corals
- colored laminae
- v void



Detailed description 6/7 : Sections 39 to 46

Homogeneous diatom ooze (silt).

Gradual colour changes from 10Y 9/2 at the top, to 10Y 8/4 to 10Y 8/2 at the bottom of the interval.

Foraminifera only present in the upper part of the interval.

Three coring disturbances at : 5480-5500 cm, 5710-5750 cm, 6020-6070 cm. The upper one is related to a void in section 41.

Frequent black (sulphide streaks) and green cm-thick bands throughout the interval.

Legend:

- clay
- silt
- sand
- diatomaceous
- calcareous
- ash
- lithoclast
- foraminifera
- burrow
- shell
- diatom floc
- coring disturbance
- bioturbation
- corals
- colored laminae
- v void

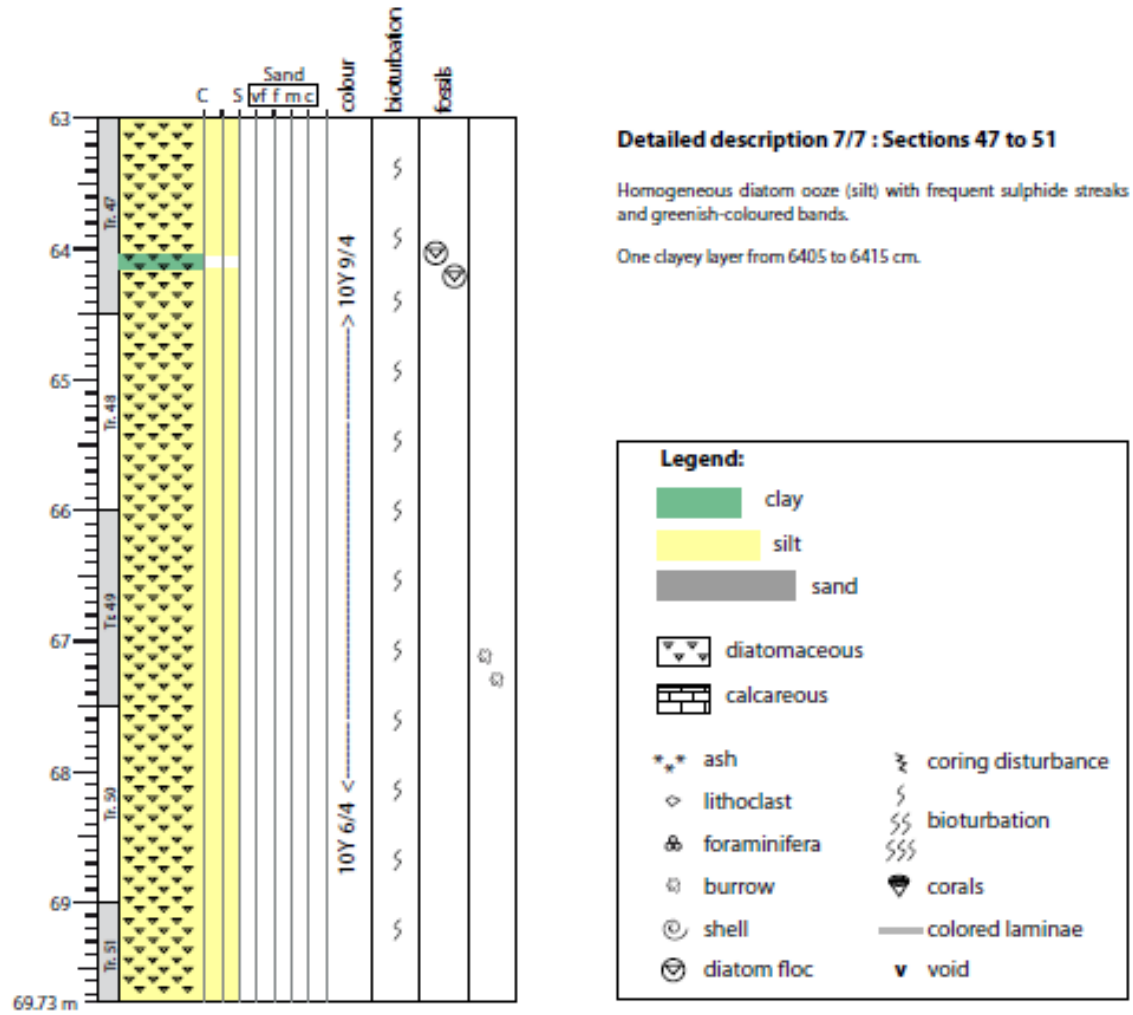


Figure 41. Synthetic log description of core MD19-3581.

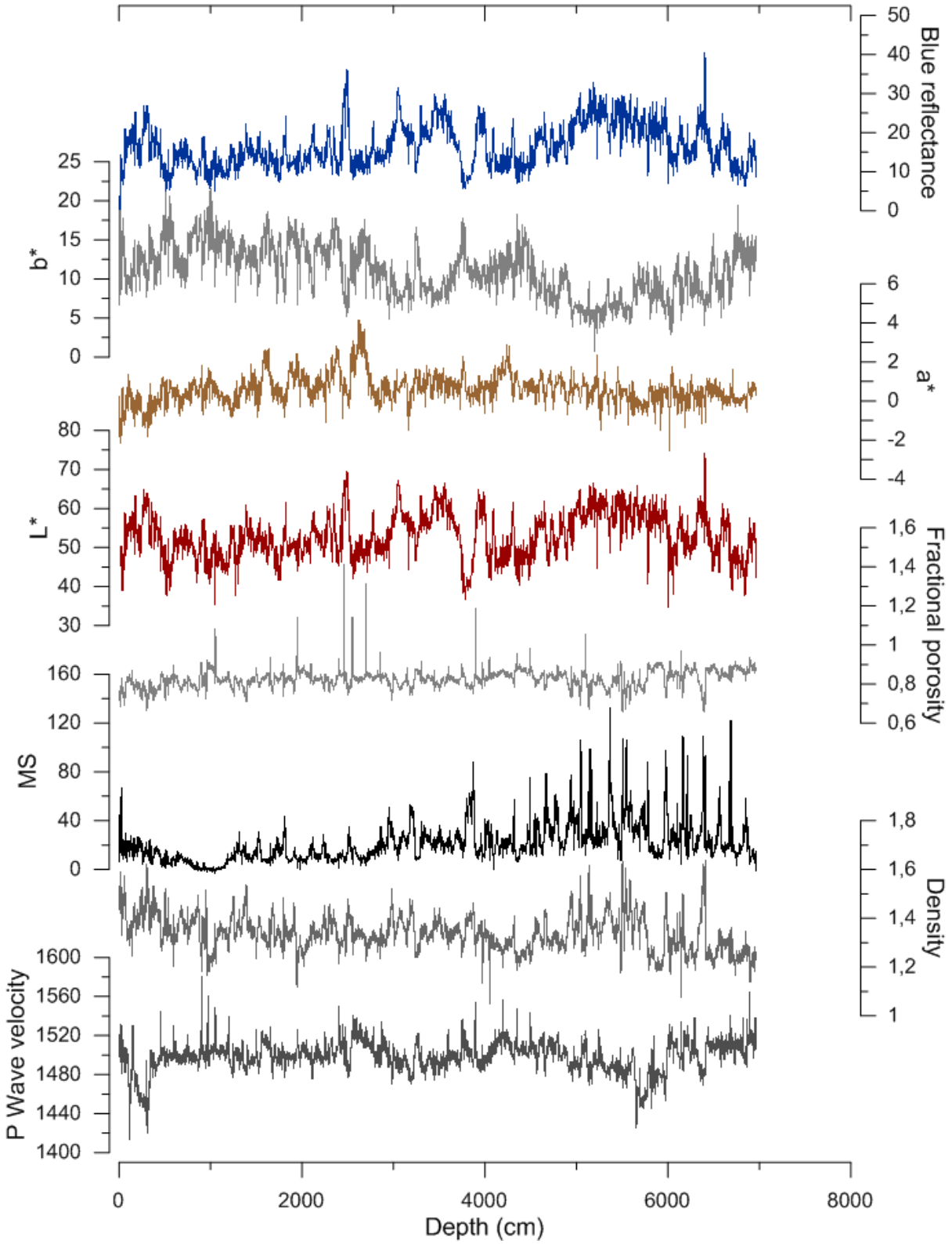


Figure 42. MD19-3581 data. From bottom to top: P Wave velocity (in $m.s^{-1}$), Density (in $g.cm^{-1}$), Mass specific susceptibility (in 10^{-8} (m^3.kg)), Fractional porosity, L, a*, b* and blue reflectance (mean 400-515 nm).*

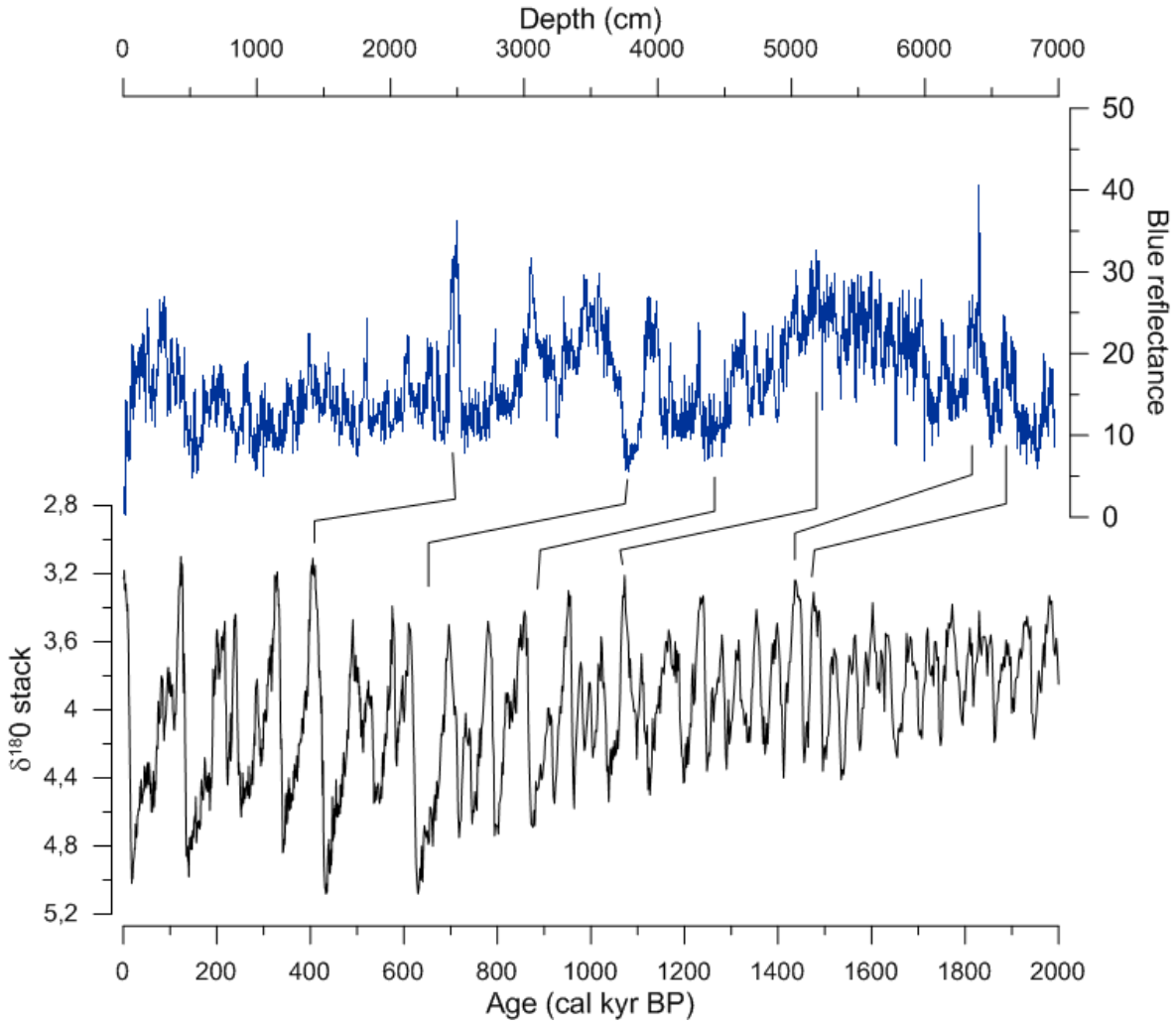


Figure 43. Preliminary chronology of core MD19-3581 based on the comparison of its color reflectance record to the reference $\delta^{18}O$ stack record of Lisiecki and Raymo 2004.