Cardiff University

School of Earth, Ocean and Planetary Sciences

Cruise Report

RRS Charles Darwin Cruise 154

Agulhas 'Leakage' and Abrupt Climate Change

13 / 12 / 2003 - 10 / 01 / 2004
Durban to Cape Town, South Africa

Co-Principal Scientists:

Dr I.R. Hall
Prof. R. Zahn

Frontispiece: adapted from NOAA 17 satellite image of the tropical cyclone Cela (raw unprojected format, standard channel data, enhanced calibration)

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2.	Mr K.G. Jethwa	Chief Engineer
3.	Mr M.H. Graves	Chief Officer
4.	Mr M.P. Hood	Second Officer
5.	Mr J.C. Holmes	Third Officer
6.	Mr J.R.C. Clarke	Second Engineer
7.	Mr G. Collard	Third Engineer
8.	Mr P. Dooley	Third Engineer
9.	Mr D.W.J. Jakobaufderstroht	Electrical Technical Officer
10.	Mr G.A. Pook	Bosun

3. CD154: Cruise Statistics

Sailed Durban	1300	13/12/03
Arrived Cape Town	0730	10/01/04
Total Cruise Time	642 hrs	
Station time	364 hrs	
Down time	40 hrs*	
Steaming and Surveying time	238 hrs	

*due to weather 28.7 hrs; CTD faults 1.1 hrs, winch faults 2.1 hrs, 6 hrs due to bridge not following survey track. It should also be noted that the cruise was delayed/shortened by 192 hours (8 days) due to technical difficulties associated with the Ships winch system during the cruise mobilisation.

4. Abstract

Cruise CD154 was dedicated to retrieving sample material in support of the NERC-funded research project 'Agulhas 'leakage' and abrupt climate change: the past 50,000 years' (grant NER/A/S/2000/01161, PIs R. Zahn and I.R. Hall).

The Agulhas Current system is a key component of the ocean's thermohaline 'conveyor belt' circulation as it is involved in the warm return flow to the Atlantic. Provisional palaeoceanographic evidence suggests that the Agulhas Current and associated ocean fronts have varied on glacial to interglacial time scales with lower temperatures in the current region during glacial periods and a shift in the frontal systems to the north, possibly restricting water leakage through the Agulhas ring corridor. The resulting change in salt and heat budgets of the Atlantic may have had far reaching consequences for ocean and climate stability. For example, decadal to millennial climate variability in NW Europe is associated with the ocean's thermohaline 'conveyor belt' circulation and anomalous convection and production of deep water in the northern hemisphere sub-polar seas. Recent investigations have shown that within the not too distant past periods of rapid ocean and climate upheaval persisted. Such rapid changes, the so-called Dansgaard/Oeschger oscillations, are documented in polar ice core records and in palaeoceanographic records from major ocean basins. There is a broad consensus that marine heat transport to high latitudes must have played a central role in causing these climatic oscillations. Observational and modelling data indicate a possible linkage between the amount of northward heat transport across the Atlantic and the leakage of heat and, importantly, salt through the Agulhas Corridor into the South Atlantic.

Primary scientific objectives of the project thus are:

- to reconstruct Agulhas Current water transport during periods of rapid climate change;
- to assess ocean front instability and Agulhas 'leakage' into the South Atlantic;
- to test for advective salinity feedback between the Agulhas leakage and North Atlantic thermohaline overturn;
- to assess the vigour and hydrography of Atlantic deep water flow to the Indian Ocean.

During the cruise 20 piston cores, 21 Kasten cores and 13 short pilot Kasten cores were obtained from locations along the main flow path of the Agulhas Current from the Tugela cone off Durban in the North to the Mallory Seamount in the South. Coring locations were chosen on the basis of shipboard 3.5 kHz site surveys as well as multichannel seismic lines and core log information from previous cruises to the area. Four CTD hydrocast stations were positioned along the current pathway to obtained samples for water column Pa/Th, Sr, Nd and stable isotope analyses. Additional Stand-Alone-Pumps were deployed to collect the suspended sediment load for Nd isotope provenance studies. The ship's non-toxic seawater pump was used to collect surface water samples for stable oxygen isotope analysis so as to calibrate foraminiferal isotope ratios to ambient surface temperature and seawater isotope composition.

5. Oceanography, Present and Past - the Current State of Knowledge

Warm water surface flow. The Agulhas Current constitutes an ocean jet boundary current that is driven by regional wind forcing and fed by waters flowing through the Mozambique Channel and from the Indian Ocean subtropical gyre (Figure

1). It carries some 70 Sv (10^6 m^3 s^{-1}) of warm and saline water polewards along the SE African margin (Bryden and Beal, 2001) and undergoes strong temporal variations in response to seasonal variability of wind forcing (Biastoch *et al.*, 1999). In the region immediately south of the Cape of Good Hope, between 16ºE and 20º E, the current undergoes an anticyclonic retroflection and much of the flow is redirected back into the southern Indian Ocean as the Agulhas Return Current (Figure 1).

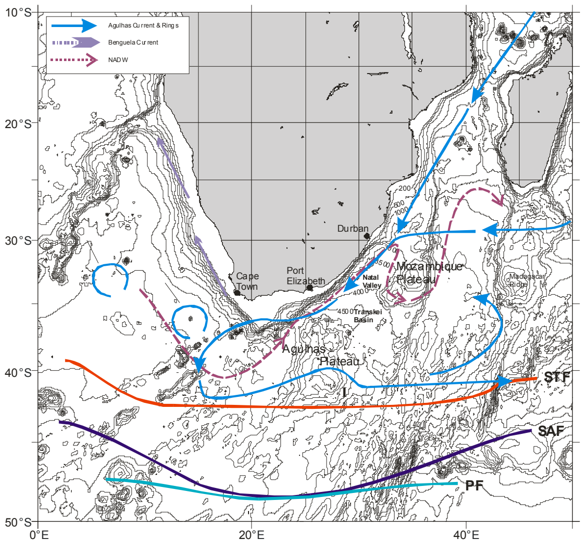

Figure 1. Map showing cruise area with approximate flow paths of the major water masses, mainly after Dingle *et. al.* (1997). Note that for clarity the path of Antarctic Bottom Water (AABW) is not shown. NADW, North Atlantic Deep Water, STF, Subtropical front; SAF, Subantarctic front; PF, Polar front.

Some Indian Ocean Water (IOW) enters the South Atlantic by eddy shedding at the western end of the Agulhas Retroflection and by the generation of intermittent streams of IOW. In the retroflection area, large anticyclonic warm water eddies ('Agulhas Rings') spin off from the main current and penetrates westwards into the South Atlantic. Shedding of Agulhas Rings has received considerable attention in recent years, as Agulhas Rings are possibly the major component of the interbasin exchange of heat and salt between the Indian and South Atlantic Oceans (Gordon and Haxby, 1990; Wells *et al.*, 2000). Indian Ocean Water within the Agulhas Current typically has a temperature in the range of 16-19 ºC and a salinity of around 35.6 (Gordon *et al.*, 1992). The total flux of Agulhas water into the South Atlantic is estimated to be between 5 and 15 Sv (Gordon and Haxby, 1990; Schmitz, 1996) and causes a salinity anomaly of +0.2 in the South Atlantic thermocline.

Cold water deep flow. North Atlantic Deep Water (NADW) leaves the Atlantic in the South and contributes directly to the deep-water flow entering the Indian Ocean through the SW Indian Ocean Gateway (Bailey and Rodgers, 1997). Deep ocean circulation in the Cape Basin is dominated by the clockwise poleward flow of Antarctic Bottom Water (AABW) and NADW from the South Atlantic. This circulation regime is reflected in the presence of a major sea floor erosion zone, mantled by abundant ferromanganese nodules, at the foot of the continental rise (Tucholke and Embley, 1984). South of the tip of the Agulhas Bank, the NADW and AABW flow paths swing east into the Agulhas Passage and transit into the Transkei Basin to the north (Figure 1). Antarctic Bottom Water is then steered to the east by the northeast-shallowing contours of the Natal Valley. In response to the AABW current, an east-west contourite drift, the Agulhas Drift, has been deposited (Dingle and Camden-Smith, 1979). From thereon NADW flow is not constrained by topography and directly enters the Natal Valley where its interaction with the seafloor has led to the deposition of margin-parallel contourites along the foot of the continental slope. Guided by the enclosure of the Valley's northern end and the Mozambique Ridge to the east, NADW recirculates back into the Transkei Basin, on route plastering sediment along the plateau slope to form the west Transkei Drift.

Past palaeoceanographic work. The limited palaeoceanographic research that has been carried out to date into the past variations of the Agulhas Current has only been conducted at a moderate stratigraphic resolution (multi-millennial). From the analyses of coccolithophore and planktonic foraminiferal assemblages, in some cases in combination with planktonic foraminiferal $\delta^{18}O$, an inconclusive picture has been drawn that ranges from little or no changes in Agulhas Current flow to systematic glacial-interglacial fluctuations in surface temperature and lateral displacements of the current retroflection area (Dingle and Camden-Smith, 1979; Winter and Martin, 1990; Flores *et al*., 1999). Much of the current evidence from near-shore sites located within the immediate current flow is from short (1-2 m) sediment cores with low stratigraphic resolution. Such cores do not allow a detailed reconstruction of the flow regime and hydrographic patterns. Yet these cores do highlight the potential quality of the sedimentary sequences obtainable from this region (good foraminifera and silt abundance). Therefore, some of the core sites chosen for the cruise are reoccupations of earlier sites that have a demonstrated record of intact stratigraphy.

6. Cruise Objectives and Work Programme

The primary aim of cruise CD154 was to collect a suite of sediment cores along the flow path of the Agulhas Current that would enable the history of the current during the last glacial period to the present to be reconstructed. Of particular interest are episodes of rapid climate change that punctuated glacial climes and are known to also exist during the current Holocene warm period.

The coring programme was supported by extensive site surveys mainly employing the ship's 3.5 kHz sediment echo profiler to identify coring sites with stratigraphic continuity, high sediment accumulation rates and strong contribution of marine sedimentation. Intense surveying was planned as the pattern of sediment accumulation within the immediate Agulhas Current pathway is known to be complex because of the frequent slumping and sliding of the sediment pack. Vigorous bottom currents associated with the mid-depth AAIW flow and, on occasion, the deep NADW flow also cause sediment accumulation to be low in places or even Tertiary sediments to outcrop at the seafloor due to complete erosion/non-deposition of Pleistocene sediments. A further complicating factor is the high speed of the surface current flow (up to 200 cm s^{-1}) which makes coring operations within the immediate current path difficult as the stable positioning of the ship on site over several hours is not easily achieved or at all possible.

The quality of the sediment cores retrieved and estimates of the stratigraphic range they covered was assessed onboard through the routine micropalaeontological inspection of core top and core catcher sediment samples. Sediment colour spectrophotometry and magnetic susceptibility logging of the cores provided additional control on the quality of material recovered.

A water column hydrocast programme was to be carried out during the cruise to collect water samples that will enable the calibration of palaeoceanographic proxies to be measured in the sediment cores. These tracers today are closely linked with the advection history of water masses either through biological cycling and water mass 'ageing' or through the uptake and dispersion of the suspended sediment load along the flow path of individual water bodies. A more detailed description of some of the proxies to be employed is given in the initial results chapters below and a listing of the total range of proxies is provided in the hydrocast chapter.

During the 25 day-long shipboard scientific work programme 26 stations were occupied and a total of 54 cores, adding up to a total of 235 m of sediment, were retrieved (13 short pilot Kasten cores, 21 longer Kasten cores, 20 piston cores) (see sections 18 and 19). The three CTD hydrocast stations occupied yielded continuous water column profiles from the surface down to a maximum depth of 4150 m for a variety of parameters and a total of 71 water samples.

7. Cruise Narrative

The tortuous mobilisation period finally concluded late on the morning of the 13th December and the Charles Darwin sailed at 13:15, heading NE towards the first waypoint to commence a 3.5 kHz survey towards site 1 (site 2 of the CD154 trials cruise). The first working are was the Tugela Cone which broadly lies beneath the inception of the Agulhas current. We intended to survey and core along three transects which tracked the high carbonate contents measured in surface sediments and overrun previous gravity core sites which low resolution work by Goodlad (1986) suggested as promising. While the weather was beautifully sunny, strong southerly winds at 20-30 knots and large 3-4 m swell slowed progress. No scientific watches were kept over night. December 14th started overcast but with a rising barometer and diminishing swell. We arrived at the first way point at 10:40 and commenced our survey along the first transect broadly perpendicular to the slope, arriving at site 1 at 12:00. This first site had been occupied during the UKORS trials leg when we had successfully recovered a 971 cm piston core. As the use of the NIOZ box corer necessitated a re-rigging of the deck configuration we revised our coring strategy and used a 2-m pilot Kasten core to check the sediment suitability for longer Kasten and Piston coring operations. Our first pilot Kasten recovered ~170 cm of silty clay. A rapidly produced sediment lightness record suggested the base of the core was around glacial Termination II, ~135 kyr. We decided to deploy a six metre Kasten core (30 m per minute entry speed). A poor tension record during penetration and recovery was our first hint that all was not well. The corer arrived at the sea surface with a damaged core barrel joint. The top plate was lost and the lower barrel was held on by only two bolts in the 'U' sleeve. Luckily the damaged corer was recovered onboard. We sent down a single 4 m barrel and this time recovered 356 cm of sediment. Not wanting to deploy our 8 m Kasten corer we abandoned site and continued with our survey up slope where the parallel sub-seafloor reflectors were soon replaced by a single strong surface return. Strong winds and large swell associated with the tropical cyclone Cela (see frontispiece) hampered our operations around the Tugela cone and this series of stations took us until early morning on the 21st December.

Re-rigging the deck configuration to enable CTD and SAP operations commenced at 08:00 and was complete by 11:00. Christmas decorations were also put up and the main laboratory looked extremely festive mainly thanks to the considerable effort of Helen Medley who managed to even pack a small Christmas tree! We then embarked on a set of full-depth CTD casts with water bottle sampling, under-CTD small gravity corer and SAP stations. Three stations were occupied moving south following the Agulhas current from the Tugela Cone towards East London (34°S). During the first TD deployment communication with the hardware was lost at ~500 m water depth. The CTD was recovered and it was found that the termination connector had failed. We therefore deployed the SAPS prior to recommencing the CTD cast. Recovery with the under CTD small gravity corer was minimal and so the device was abandoned in upcoming CTD stations. At the second water station (station 12) the CTD records were very noisy and the deployment was abandoned at 800m water depth. This time it was found that the conductivity sensor had developed a fault which was affecting the pump system. The sensor was replaced but forced us to deploy the SAPS again prior to the CTD. The third water station was completed without a hitch. The UKORS transmissometer did not functioned on any of the deployments. Time constraints caused by the delayed sailing and slightly slower progress than planned disappointingly forced us to cancel the detailed hydrographic survey across the Agulhas Current at East London.

Re-rigging started at 04:15 on the 24th December and was completed by 07:00. Coring operations commenced at site 13 which was a reoccupation of an Amos Winter site with a 2 m pilot Kasten followed by 4 m Kasten and 12 m piston cores. The piston core was recovered just before midnight on Christmas Eve. At 06:30 on the 25th December we sent down a 2 m pilot Kasten but it was recovered empty probably a result of excessive roll on the ship caused by the empty ballast tanks. Watches stood down at 1200 on Christmas day and we had a superb Christmas lunch, which included ostrich steaks, prepared by the catering staff. A small celebration followed and watches commenced again at 0000 on the 26th December. However, overnight increasing winds (45 knot) and heavy seas shut down science operations and we could not resume work until 09:00 on the 27th December.

Up to this point we had been increasingly concerned about the lack of stability of the ship caused by the empty stability tanks. This, along with our perception of the overall poor state of the Darwin led to our decision of abandoning the work programme that was planned in the "roaring forties" on the southern Agulhas Plateau. Rather we decided to concentrate our effort around Mallory Seamount and the western most offshore Agulhas Bank.

Work continued off Port Elizabeth where the occupation of two sites and the recovery of two piston cores for which shipboard MS suggest high rates of accumulation. On 31st December a core was being hauled at five minutes to midnight so we retired to the bar for a toast to celebrate the arrival of 2004. The winch problems returned when the main winch jumped out of gear resulting in a loss of grip while a sediment core (CD154 20-15P) was on wire and being hauled. The 1.2 t coring tool free fell for several 10s m before the winch was stopped by its emergency brake following commendable action from the winch operator and a UKORS technician. The winch was repaired and the core recovered.

We then steamed on towards Mallory Seamount. Up to this point we had occupied 21 stations and deployed 13 pilot Kasten, 22 Kasten and 15 piston cores. Mallory Seamount lies under the path of AAIW and there was only a small chance that there might be some unscoured regions. The seamount shallow top confirmed our expectation with little or no surface penetration of the 3.5 kHz profiler. Coring was limited to the deeper northern eastern flank of the seamount. With time running short we abandoned the seamount survey at 0800 on the 7th January and steamed at full speed towards the westernmost offshore tip of the Agulhas Bank. We were rewarded by the recovery of several piston cores of foraminiferal ooze.

We concluded coring work at 08:00 on the 8th and steamed due south to find deeper waters (>4000 m) for a final full-depth CTD and SAP station. Science operations finished at 01:00 on the 9th January. Fine weather and calm seas allowed an end of cruise BBQ enjoyed by many.

We made good progress, passing the Cape of Good Hope, and arrived in Cape Town early in the morning of the 10th January and were alongside the fashionable Waterfront by 08:00 to wrap up the cruise. Fortunately, the ship was sailing directly to Newport after CD154 for its much needed final refit and so our material and samples could travel back with the ship for a convenient final demobilisation in the UK. Our thanks go to all the scientific staff, ships officers, crew and UKORS technical staff who, despite the disappointments, made this successful collection of material possible.

8. 3.5 kHz Profiling

The 3.5 kHz profiler was operated with few interruptions throughout the cruise. Penetration was highly variable but typically less than 10 m but occasionally up to 30 m. The echo character varied considerably depending on the margin typography. Classification of the echo types for seabed character mapping will follow that of Damuth (1980). The 3.5 kHz record on the Charles Darwin degrades considerably at speed in excess of 7-8 knots. Typical survey speeds were 6 knots. The 3.5 kHz records are held in Cardiff.

9. Coring operations

On cruise CD 154 the 15 cm square Kasten core barrels were employed. The Cardiff sections (4 m, 4 m, 2 m and 1 m) were supplemented by a suite of two barrels (4 m + 3 m) on loan from the Department of Earth Sciences at the University of Cambridge. An additional 3 sections of 1 m and a 2 m section belonging to UKORS were also available. All Kasten cores have been built after the same design of Zangger and McCave (1990). The core head was loaded with 1.5 tonne of lead.

The pre-cruise plan included the deployment of the box core before obtaining Kasten/piston cores at a given site. However, the combination of a delayed departure and the requirement to move the bucket of the coring bomb whenever the box core was required forced us to revise this plan in order to make most efficient use of the time available at sea. The compromise solution consisted of the aforementioned deployment of a short, 2-m Kasten core (pilot Kasten) prior to the use of a longer combination of sections or of a piston core. This proved to be quite a faithful decision as several of the early sites around the Natal Valley and the Mozambique Plateau contained coarse sand-sized carbonaceous layers which severely limited the penetration of the Kasten core into the sediment. However, this did not prevent us from losing the Cardiff 2 m section that had been attached at the bottom of a 4 m barrel. We believe this occurred because of either or both the heavy swell and the presence of a sand layer which prevented penetration beyond the joint of the barrels causing it to snap.

Despite the loss of the 6 m combined Kasten core length we still had other permutations available to us (4 m + 3 m and 4 m + 4 m). We tried both the 7 m and 8 m option at a couple of localities during the second half of the cruise when we felt more confident about the type of sediments to expect. Unfortunately, neither of these attempts was successful and in the case of the 8 m Kasten, the bottom section inexplicable came up bent at an angle of ~30^{o} about 1.5 m above the core catcher!

To ensure a suitable recovery of sediments and make up for the poor perfomance of the Kasten coring kit in the sandy sediments encountered, a combination of piston core barrels ranging from 3 to 15 m in length was regularly employed. Recovery with this coring system was consistently good.

All piston cores were not sub-sampled on board but simply cut in 1.5 m sections and stored in the cold room at 4^{o}C. On the other hand, the Kasten cores were sub-sampled in the conventional way used on cruise CD88 for the NEAPACC project (McCave, 1994). The standard Kasten core sub-sampling routine was:

1) Following the removal of the lid on the Kasten core section, the uppermost centimetre was extruded upwards and disposed of using T-bars pushing on the double-bottom plate. Then, the length of the core surface was covered with cellophane to allow the measurement of the light reflectance at 2 cm spacing.
2) The core was described after carefully scraping its surface to highlight sedimentary structures.
3) A continuous succession of specially moulded styrene trays (330 x 15 x 25 mm) was pressed along the length of the core barrel. These were individually labelled before the core was extruded. The slabs were removed sideways and bagged in polythene after the mud was separated from the remainder of the core using a cheese wire. This first set of sub-samples constitutes the working material.
4) A second set of "X-ray" trays was collected in an identical manner.
5) Small (5-10 cm^3) water content samples were collected at 4 cm intervals using cut-off syringes from the sediments lying between the two sets of sub-cores of points 3 and 4 and stored in air-tight containers.
6) The core was extruded enough to clear the depth of the holes left by the water content sampling and that layer of mud was disposed of. A final set of "Archive" trays was collected.

Core penetration and pullout. Figures 2-4 show typical penetration and pullout tensions recorded on the main coring warp during CD154. The absolute tension in tonnes has been adjusted according to the calibration estimate calculated by Colin Day (UKORS) during the CD154 trials cruise.

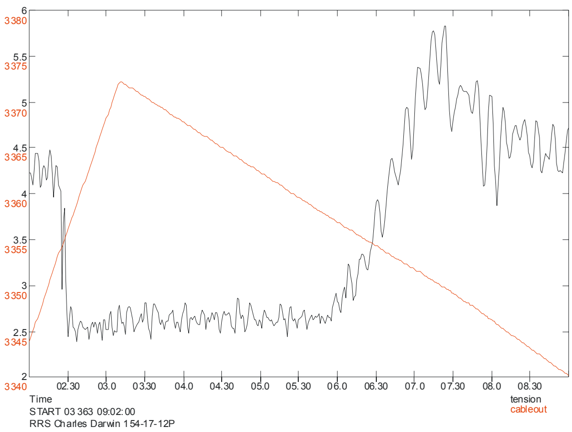

Figure 2. Coring warp tension during triggering and recovery of the 15 m barrel length piston core CD154-17-12P. The trace shows a clean penetration and pull-out which recovered 1384 cm of sediment. The core was taken during light seas (<10 knot winds and <1 m wave height)

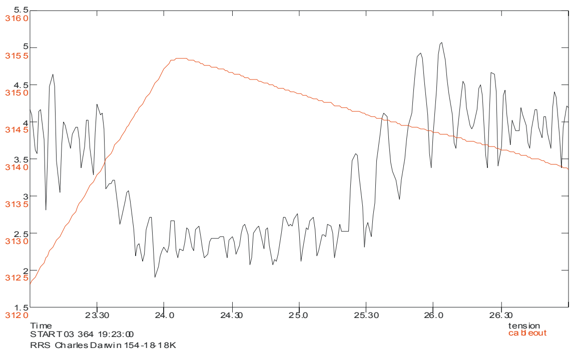

Figure 3. Coring warp tension during triggering and recovery of the 4 m barrel length Kasten core CD154-18-18K. The trace shows a clean penetration but a swell affected pull-out. The core recovered 383 cm of sediment. The core was taken during moderate seas (20-30 knot winds and 2-3 m wave height)

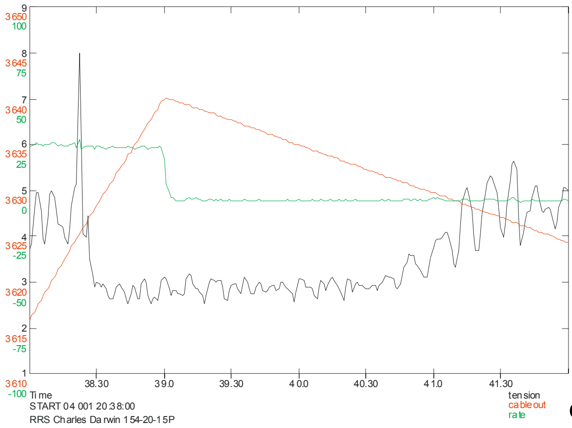

Figure 4. Coring warp tension during triggering and recovery of the 12 m barrel length piston core CD154-20-15P. The trace shows an unusually large tension spike during penetration a swell affected pull-out. The core recovered 875 cm of sediment, but the barrel was bent. Laminae visible through the core liner suggest that the core penetrated vertically. We believe, as with other cores taken during CD154, that the core barrel was bent during its recovery from the sediment. The core was taken during moderate seas (20-30 knot winds and 2-3 m wave height) but with a 2-3 knot current. The ship drift after deployment coupled with the heave produced by the swell would have produced a none vertical lift from the sediment which may have caused enough lateral stress on the core barrel to bend it.

10. Micropalaeontology (I.M)

All site details of studied cores are to be found in the main body of the cruise report. Nearly all of the following foraminiferal identifications were undertaken while aboard ship, without any literature, often in difficult conditions. While the great majority of identifications are correct, some uncertainty exists, especially with the benthic species, and many of these have only been informally identified. This report should be regarded as provisional.

Foraminifera results from Tugela leg of cruise CD154

Since leaving Durban on 13th December 2003, some thirty samples have been collected, processed and studied from the Tugela leg of the cruise, principally from core catcher samples from both the Kasten corer and the piston main and trigger cores. These samples can be attributed to three preliminary age units, termed “Early” Pleistocene, “Late” Pleistocene and Holocene. No older sediments were encountered in any of the recovered core sections.

The following samples have been studied:-

1A) CD154t-03-4Pte –Core Catcher – “Early” Pleistocene.
1B) CD154t-03-4Pte –Just above CC – “Early” Pleistocene.
2) CD154t-01-01P – Core Catcher – “Early” Pleistocene.
3) CD154t-02-02P – Core Catcher – “Late” Pleistocene.
4) CD154t-02-02P – Core Cutter – “Late” Pleistocene.
5) CD154-01-1PK – Core Catcher – Holocene.
6) CD154-01-2K – Core Catcher – “Late” Pleistocene.
7) CD154-02-2PK – Core Catcher – “Late” Pleistocene.
8) CD154-02-3K – Core Catcher – “Late” Pleistocene.
9) CD154-02-1P – Core Catcher – “Late” Pleistocene.
10) CD154-03-5K - Core Catcher – “Late” Pleistocene.
11) CD-154-03-5K – Base of Core. – “Late” Pleistocene.
12) CD154-04-4PK – Core Catcher – Holocene.
13) CD154-04-6K – Core Catcher – Holocene.
14) CD154-05-5PK – Core Catcher – Holocene.
15) CD154-06-6PK – Core Catcher – “Late” Pleistocene.
16) CD154-06-6PK – Just above 0.455m – Holocene.

17) CD154-06-6PK – Just below 0.455m – "Late" Pleistocene.
18) CD154-06-4P – Core Catcher – "Early" Pleistocene.
19) CD154-07-7PK – Core Catcher – Holocene.
20) CD154-07-7PK – Top of Core – Holocene.
21) CD154-09-9PK – Core Catcher – "Late" Pleistocene.
22) CD154-09-9K – Core Catcher – "Late" Pleistocene.
23) CD154-09-5P – Core Catcher – "Late" Pleistocene.
24) CD154-10-10K – Core Catcher – "Late" Pleistocene.
25) CD154-10-6P – Core Catcher – "Late" Pleistocene.
26) CD154-10-6P – Trigger Core Catcher – "Late" Pleistocene.
27) CD154-11-7P – Core Catcher – "Late" Pleistocene.
28) CD154–11-7P – Trigger Core Catcher – "Late" Pleistocene.
29) CD154–12–3C – Core Catcher on CTD – Holocene.

"Early" Pleistocene. Three cores intersected sections attributable to an "Early" Pleistocene age (sample numbers 1A and 1B, 2 and 18). These sediments tend to be stiff greenish-grey or brownish-grey slightly silty clays. "Early" Pleistocene is taken to be that part of the Pleistocene pre-dating the Matuyama-Brunhes boundary at about 730,000 years. This magnetic reversal boundary has been correlated in deep ocean cores with the "*Stilostomella* extinction", now recognised world-wide in the oceans as the last major deep-ocean extinction of benthic foraminifera (Lutze, 1979; Weinholz & Lutze, 1989; Hayward, 2002).

Benthic foraminifera. A wide variety of benthic foraminifera became extinct during the "*Stilostomella* extinction", including species of *Stilostomella*, *Nodogenerina*, *Pleurostomella* and related genera, and several genera of polymorphinids. Especially present in samples 1A and 1B, 2 and 18 are species of *Stilostomella*, *Nodogenerina* and *Pleurostomella*.

A typical benthic assemblage is given below (sample 1B):-

Smooth *Dentalina* spp.
Rectuvigerina cf. *nicoli*
Nodosaria cf. *longiscata*
Large ribbed *Dentalina* sp.
"*Pseudonodosaria*" *hirsuta*
Ribbed *Amphicoryna* sp.
Elongate *Polymorphina* sp.
Globobulimina sp.
Stilostomella sp.
Finely ribbed *Dentalina* sp.
Bulimina orangensis
Dentalina sp. with ribbed septal necks
Melonis pompilioides
Elongate ribbed *Lagena* sp.
Thin *Martinottiella* sp.
Cibicidoides sp.
Nodogenerina spp.
Ribbed *Lagena* sp. with corkscrew neck
Smooth *Vaginulina* sp.
Fissurina cf. *marginata*
Oridorsalis umbonatus

Flat *Nonion* sp.

Elongate *Nodosaria* sp. with spiralling ribs

This particular assemblage is marked by large-sized ornamented nodosarids, which are absent in all studied samples of the “Late” Pleistocene from the Tugela Cone.

Planktic foraminifera. The four "Early" Pleistocene samples have fairly different planktic assemblages, for samples 1B and 2 are distinguished by abundant *Globoquadrina altispira*, while 18 is distinguished by small numbers of beautifully preserved *Globigerinoides fistulosus*. However, sample 1A has no particularly distinctive aspect to its planktic assemblage. *Globorotalia inflata*, usually so dominant in the samples of “Late” Pleistocene age, is extremely rare in all these “Early” Pleistocene samples. All four samples are also distinguished by the presence of *Globorotalia truncatulinoides*, and so, nominally, can be no older than earliest Pleistocene in age. However, in the Bolli *et al*. volume “Plankton Stratigraphy” of 1985, both *Globoquadrina altispira* and *Globigerinoides fistulosus* are regarded as having become extinct before the evolutionary appearance of *Globorotalia truncatulinoides*. According to “Plankton Stratigraphy”, the latest possible age for the two former species is mid-Pliocene.

Because all four cores were only sampled from the core catcher or just above, at or near maximum depth of each core, it is as yet not clear whether these cores intersected a “complete” succession of “Early” Pleistocene, “Late” Pleistocene and Holocene units, or whether, for example, the “Late” Pleistocene interval is absent.

A typical planktic assemblage (sample 1B) is listed below:-

Orbulina universa

Globoquadrina altispira (abundant)

?*Globorotalia menardii* (?juveniles only)

Globigerina bulloides

Globoquadrina dutertrei

Globigerinoides triloba

Globorotalia hirsuta

Globorotalia truncatulinoides

?*Chiloguembelina* sp.

Globigerinoides ruber (all white)

Globorotalia inflata (extremely rare)

This particular planktic assemblage appears to possess comparatively sparse numbers of few warm-water species. The other studied “Early” Pleistocene samples contain rather more warm-water species, with *Pulleniatina obliquiloculata*, *Globigerinoides sacculifer*, and *Globigerinoides conglobatus* also present.

“Late” Pleistocene. Seventeen samples (numbers 3, 4, 6, 7, 9, 10, 15, 17, and 21 to 28) recovered foraminifera assemblages interpreted as being of “Late” Pleistocene age. These samples are in the main greenish-grey, variably silty clays. Occasional localised sands occur in the succession.

Planktic foraminifera. Planktic foraminifera assemblages are marked by the well-developed predominance of temperate water species: abundant *Globorotalia inflata*, generally with subordinate numbers of *Globorotalia hirsuta* and *Orbulina universa*. The last-named species may also be locally abundant. However, there are also smaller, but consistent numbers of warm water species, notably *Globigerinoides* *ruber* (white only), *Globigerinoides triloba*, *Globigerinoides conglobatus*, *Globigerinoides sacculifer* (usually with the final sac-like chamber poorly formed), *Globoquadrina dutertrei*, *Pulleniatina obliquiloculata*, *Hastigerina pelagica*, and very rare *Sphaeroidinella dehiscens*. There are also smaller numbers of cool water species such as *Globorotalia truncatulinoides* (present in every sample), *Neogloboquadrina pachyderma* (right-coiling only), and very rare specimens of *Globigerina bulloides* and *Globigerina quinqueloba*. One distinctive planktonic species, seen throughout the samples collected during the course of the CD154 cruise, is a tiny red *Globigerina* sp. It is the only persistent coloured planktonic present, and was also seen in samples from the western continental margin of South Africa collected during Meteor cruise M57-1 in January-February 2003.

Benthic foraminifera. Benthic foraminifera assemblages of the "Late" Pleistocene interval are generally poor, and consist mainly of scattered examples of: -

Pyrgo serrata
Uvigerina hirsuta
Sphaeroidina bulloides
Thin *Martinottiella* sp.
Fontbotia wuellerstorfi (generally only rare juveniles)
?*Eggerella bradyi*
Fat *Cibicidoides* sp.
Agglutinated *Sigmoilina* sp.
Globobulimina sp.
Loxostomum cf. *eleyi*
Melonis pompilioides
Thin *Nonion* sp.
Laticarinina paupercula
Oridorsalis umbonatus
Fissurina spp.
Lagena spp.
Brizalina spp.

Some of these also occur in the "Late" Pleistocene sections of the Meteor M57-1 cores recovered from off the western margin of southern Africa. In general, the Tugela Cone "Late" Pleistocene benthic assemblages are much sparser and very much less diverse than those of either the "Early" and "Late" Pleistocene intervals of the Meteor cores, or than those from the "Early" Pleistocene of the Tugela Cone. Quite a few washed residues appear to contain almost no benthic species.

Transported foraminifera from the shelf

These "Late" Pleistocene samples are usually marked by variable abundances of very fine angular quartz grains in the fines of the clay samples, generally no coarser than 150 microns diameter. There are also localised occurrences of glauconite pellets, and rarely, occurrences of innermost shelf and littoral foraminifera in both sandy and clayey intervals. Shallow marine foraminifera are especially common and very well-preserved in a half metre thick gritty and shelly sand in sample 9. Amongst many other species, typical littoral to innermost shelf foraminifera of this particular sand unit include:-

Sphaerogypsina globulus
Pararotalia nipponica
Amphistegina madagascariensis

Elphidium crispum
Homotrema rubrum
Challengerella persica
Triloculina tricarinata
?*Sorites* or *Archaias* sp.
Planorbulina mediterranensis
Rotalia "serrata"

In addition, these sands contain fragments of probable Middle to Late Eocene larger foraminifera *Nummulites* sp., infilled with glauconite. This shallow marine foraminifera assemblage is essentially the same as that seen in the onshore marine calcarenites and aeolianites of the Uloa Formation, which forms a veneer (up to about 30 m thick) across the present-day northern KwaZulu coastal plain. An offshore equivalent of the Uloa Formation, with the same foraminiferal assemblage, occurs as a thin veneer (less than 1 m thick in offshore oil exploration borehole tops) just below the present day sea-floor, down to a water depth of at least 96 m (McMillan, 1997). This formation is regarded as having accumulated during the Eemian to Weichselian sea-level fall, as a littoral abandonment facies (McMillan, 1993, 1997). The latest Pleistocene age of the Uloa Formation preserved onshore is emphasised by the presence of the age-diagnostic benthic foraminifera *Helenina anderseni*, *Elphidium crispum* sensu lato and *Challengerella persica*, all three of which are constrained to the latest Pleistocene and/or the Holocene.

The "Late" Pleistocene – Holocene boundary

In cutting open Kasten core CD154-06-6PK a sharp boundary was recognised at 0.455 m, marked by a thin ferruginised (presumably mostly ferric iron oxides) crust about 1 or 2 mm thick. This boundary occurs at the base of the pinkish brown silty clays regarded as Holocene, as described below, and above the silty greenish-grey clays regarded as "Late" Pleistocene, as described above. The thin ferruginised crust, when washed clean of the surrounding sediment, was found to contain small numbers of planktic foraminifera tests, notably of *Orbulina universa*. However, the lack of foraminiferal abundance in this crust made it impossible to establish whether these tests were typical of the "Late" Pleistocene assemblage or of the Holocene assemblage. It is probable that the same boundary occurs in quite a number of other cores: for example it certainly is present either at 0.525 m or at 0.69 m in core CD154-09-9K. In this particular core there appears to be an extra section, of undated yellowish-greenish-brown clay, between the depths 0.525 m and 0.69 m, which lies within the time-span of the unconformity. The same unconformity must occur in adjacent cores CD154-09-9PK, and CD154-09-5P, as well as widely elsewhere.

In order to attempt to resolve whether the colour-change boundary is a true unconformity, rather than an ox-redox boundary caused by sea-floor chemical oxidation processes, two samples were taken in core CD154-06-6PK, one from just above and one from just below the ferruginised boundary at 0.455 m. That from the presumed "Late" Pleistocene just below contains:

Orbulina universa (common)
Globorotalia inflata (abundant)
Globorotalia menardii (present)
Globorotalia hirsuta (moderate)
Globigerinoides triloba (common)
Globigerinoides sacculifer (rare)
Globoquadrina dutertrei (moderate)

Hastigerina pelagica (present)
Globigerinoides conglobatus (present)
Pulleniatina obliquiloculata (present)
Globigerinoides ruber (present – white only)
Globorotalia truncatulinoides (present)
Globorotalia scitula
Neogloboquadrina pachyderma (right - present)
Benthic foraminifera are extremely rare.
Abundant angular quartz grains in fines (<125 microns).

In contrast, the presumed Holocene sample from just above the boundary contains:

Globoquadrina dutertrei (few)
Globorotalia inflata (many)
Globorotalia menardii (moderate)
Globigerinoides conglobatus (many)
Globorotalia truncatulinoides (rare)
Globigerinoides sacculifer (rare)
Globigerinoides triloba (common)
Globigerinoides ruber (few – white)
Orbulina universa (moderate)
Neogloboquadrina pachyderma (right – rare)
Hastigerina pelagica (few)
Pulleniatina obliquiloculata (rare)
Tiny red *Globigerina* sp.
Globorotalia scitula
Globigerinella aequilateralis (rare)
Orbulina bilobata (very rare)
Benthic foraminifera are rare.
Moderate angular quartz grains in fines (<125 microns).

Notably missing in the upper (Holocene) sample is *Globorotalia hirsuta*, and neither *Globorotalia inflata* nor *Orbulina universa* are as abundant just above the ferruginised horizon as they are just below it. It should also be noted that there is no trace of the large agglutinated benthic foraminifera assemblage seen in a number of Tugela Holocene core sections (see description in Holocene section below). Further sampling will be undertaken to establish exactly how far down the Holocene section the benthic agglutinated foraminifera assemblage actually ranges.

Vincent (1970, 1972, 1976) Shackleton & Vincent (1978not in ref. list) and Hutson (1980) all analysed planktic foraminiferal changes across the Pleistocene-Holocene boundary in the vicinity of the Agulhas Current, but I've not had time to follow up these references, in order to compare results of my study with theirs.

Holocene. Holocene sediments were sampled in eight samples (numbers 5, 12, 13, 14, 16, 19, 20 and 29). There is a general tendency for Holocene sediments to be distinctive pinkish brown or pale brown in colour, and are generally foraminiferal silty or fine sandy muds. One or two localised sandy intervals were recognised within this interval. There are two main aspects to the foraminiferal assemblages, concerning firstly the planktics and secondly the benthics.

Planktic foraminifera. Holocene planktic foraminifera assemblages are characterised by much the same species as those seen in the "Late" Pleistocene, except that the proportions of the different species are distinctly changed. In particular, the warmer-water planktonics are much more common: these include *Globorotalia menardii*, *Pulleniatina obliquiloculata*, *Sphaeroidinella dehiscens*, *Globigerinoides triloba*, *Globigerinoides sacculifer* (almost always with well-formed final chamber), *Globigerinoides ruber* (usually white tests only), *Globigerinoides conglobatus* and *Hastigerina pelagica*. In addition, there are occasional examples of exotic warm-water species such as *Beella digitata*. However, the temperate planktic indicators, such as *Orbulina universa*, *Globorotalia inflata* and *Globorotalia hirsuta*, remain present, but in substantially smaller numbers than seen in the "Late" Pleistocene samples. Furthermore, there remain small numbers of colder water species as *Globorotalia truncatulinoides*, but *Neogloboquadrina pachyderma* (right coiled), *Globigerina quinqueloba* and *Globigerina bulloides* have mostly not been found.

Benthic foraminifera. Also distinctive of almost all of the Holocene samples studied is an agglutinated benthic assemblage, not seen at all in "Late" or "Early" Pleistocene assemblages. These agglutinated foraminifera are usually distinguished by bright orange, yellow or orange-brown tests, presumably caused by the precipitation of iron within the test cement. Some of these tests are unusually large-sized, with even broken fragments of *Bathysiphon* and *Astrorhiza* being up to 1 cm long. They are commonest in the more clastic-rich Holocene sediments, especially in the watery muddy "slurry" at the top of the Holocene section, immediately below the present sea floor. They seem to be less common, or even absent, lower in the Holocene section where the succession is more compacted, or close to the Holocene-"Late" Pleistocene boundary unconformity. Typical species of this agglutinated assemblage include:-

Cyclammina sp.
Trochammina sp.
Saccammina sp.
Pelosina sp.,
Bathysiphon sp.
Astrorhiza sp.
Hormosina spp.
Reophax pilulifer
Verneuilina sp.

There are also a variety of indeterminate irregular tests composed in part of sponge spicules, and an irregular ovate agglutinated species with a single long sponge spicule extending through the centre. In addition, there are attached specimens of *Tolypammina* sp., which are often found rambling over tests of *Globorotalia menardii*, *Globorotalia inflata*, or mollusc shell fragments. This agglutinated assemblage can probably be considered a "typical" east coast benthic assemblage. It is comparable to some of the *Cyclammina*-*Haplophragmoides*-*Reophax* assemblages described from off the narrow Saldanha coast (southern west coast) of South Africa by Birch (1975). Probably because of an apparent virtually complete lack of clastic debris moving into deep water off the wider parts of the Atlantic shelf of southern Africa (cores from Meteor Cruise 57-1), this type of agglutinated assemblage appears to be restricted to margins with a narrow continental shelf, where transport of bed-load into deep water is not hindered.

Age indications. None of the above foraminifera species provide a diagnostic Holocene age for this interval. The reasons why it is regarded as being of Holocene age are as follows. Firstly, this is the topmost sedimentary interval encountered in most of the cores; its topmost part is unconsolidated, watery and runny; and consequently, the top must reflect the environmental conditions prevailing at the present-day sea floor. Secondly, its foraminiferal assemblage is typically predominated by warm-water species (for example *Globigerinoides* species), which suggests this interval accumulated during an interglacial episode. Thirdly, the distinctive agglutinated benthic assemblage typical of this interval clearly occurs extensively off the entire east coast of South Africa, and yet is completely absent everywhere in the underlying greenish grey clays interpreted as being of "Late" Pleistocene age. This faunal difference suggests that very different sea-floor conditions prevailed during these two episodes of sedimentation.

Foraminifera from the Bluff Sandstone Formation, Durban harbour entrance. While cooped up in a Durban beachfront hotel prior to commencing cruise CD154, various walks along the beachfront inevitably led to the south arm of Durban Harbour. This concrete construction has been protected on its seaward side by blocks of concrete piled in disorder along almost the entire length of the south arm. Among the concrete blocks on the beach (southern) side of the south arm, at about the high water mark, lay numbers of small pieces of variably shelly and/or gritty calcarenite ("beach rock"), attributable to the Bluff Sandstone Formation. Most of these are wedged in to the substrate, but are probably all *ex situ*. This rock unit underlies the "Berea Sands", a unit that comprises the entire Durban coastal dune succession. The Bluff Sandstone Formation has frequently been encountered in outcrop and in drilling both deep and shallow boreholes on The Bluff, and elsewhere in outcrop around the city of Durban (Berea, Burman Bush, and Isipingo Beach).

It remains unclear whether the entire Bluff Sandstone Formation succession accumulated in a littoral environment, or whether it is partly aeolian and partly littoral. Such a feature, based on bedding patterns and lithology, can only be established in outcrops, and cannot easily be resolved in borehole sections. This problem also exists for the Uloa Formation of the northern KwaZulu coastal plain, which is considered synchronous with the Bluff Sandstone Formation (McMillan, 1993, 1997).

Several authors have previously reported small numbers of benthic foraminifera from the Bluff Sandstone. Short lists of species are given by Chapman (in Krije, 1932), Smitter (unpublished data, about 1956/1957, Smitter foraminifera slide collection, University of the Witwatersrand), Frankel (1964, 1966), King (1964, and unpublished slide data at University of Natal, Durban, probably by King, McCarthy or other researchers), and McCarthy (1967). However, up to now, apart from one illustration of an *Ammonia* species (McMillan, 1987), none of these foraminifera have been illustrated in publication. This is principally because of the generally poor state of preservation of foraminifera tests in the Bluff sandstone, most of which have been abraded by wave action, and subsequently calcified during post-depositional carbonate cementing processes. Consequently, there is a fairly good understanding of what constitutes a typical Bluff Sandstone foraminifera assemblage, but the finer points of the species present can only be displayed through illustration. The poor state of preservation precludes their illustration by either scanning electron microscope or by normal light microscope.

Comments on the stratigraphic position of the Bluff Sandstone Formation have been made by a wide variety of authors, and most are confident of a Pleistocene age (see SACS, 1985). However, using the foraminifera species, especially the presence of *Elphidium crispum* (Linné) s.l., regarded by McMillan (1993) as typical of the Eemian - Weichselian portion of the Pleistocene only, a much more restricted, and hopefully more accurate age was achieved. This age can be compared against that of the much more complete Saldanha Pleistocene raised beach succession, and its well-illustrated foraminifera detailed by Dale & McMillan (1999). At Saldanha, and all along the west coast of South Africa, Elphidium crispum is found restricted to the 4 to 6 m (Eemian-Weichselian) raised beach and the associated forced regressive systems tract lying across the inner shelf down to a water depth of about 140m.

The typical foraminifera species of the Bluff Sandstone Formation are:

1) *Pararotalia nipponica* (Asano, 1936).

2) *Lobatula lobatula* (Walker & Jacob, 1798).

3) *Ammonia* species, such as that illustrated by McMillan (1987), and probably also *Ammonia japonica* (Hada, 1931).

4) A variety of mostly unornamented miliolid species, principally of the genera *Quinqueloculina* and *Triloculina*, most of which are particularly poorly preserved.

5) *Elphidium crispum* (Linné, 1758) *sensu lato*.

6) *Cibicides refulgens* Montfort, 1808.

7) *Amphistegina madagascariensis* D'Orbigny, 1839.

8) *Glabratella "australensis* (Heron-Allen & Earland, 1932)": This is not the species illustrated by Brady (1884) as supposedly coming in part from the Port Elizabeth littoral (Nuttall, 1928; Barker, 1960), but which occurs only in Australia – compare with illustrations in Moura (1965) and McMillan (1987, 1990), and see McMillan (1993).

No planktic foraminifera tests have been recovered from the Bluff Sandstone. The benthic foraminiferal assemblage is typical of a warm-water littoral, high energy environment of deposition. However, the different component foraminifera species probably derive from distinctly different settings within the littoral, such as from periodically exposed or continuously covered rocky surfaces, rock pools exposed at low tide, and so on. The full list of *in situ* foraminifera of the Bluff Sandstone Formation, following study of the present sample will be given later.

The sample which is the focus of the present study is singular in that the foraminiferal assemblage also includes reworked foraminifera from the Late Cretaceous (Early Santonian) rocks that probably directly and unconformably underlie the Bluff Sandstone Formation, especially in the harbour area of Durban city. The reworked tests are preserved in a different manner than the in situ tests, and are generally a glassy golden brown in colour. The reworked species in the present sample will be given later.

BIG QUESTION: How does one correlate accurately between inshore and onshore Pleistocene raised beaches and other sea-level-driven sedimentary deposits, and the presumably much more complete deep ocean Quaternary sedimentary record?

Foraminifera results from East London leg of cruise CD154

Foraminifera results from the East London leg of the cruise mirror results previously obtained from the Tugela leg. A total of 35 samples were washed, sieved and studied from this leg. In addition, 25 samples were collected at a 2 cm interval down the core CD154-18-18K, in order to examine the stratigraphic ranges of particular foraminifera species across the apparent Pleistocene-Holocene boundary (the colour change from greenish-grey clays to pinkish-brown clays, seen in most cores and described in the section devoted to the Tugela leg). The 25 closely-spaced samples will be processed and studied at a later date, so that no results are available from the cruise period.

The following 35 samples have already been studied:-

30) CD154-10-10K – Core Catcher – “Late” Pleistocene.
31) CD154-10-6P – Core Catcher – “Late” Pleistocene.
32) CD154-10-6P – Trigger Core Catcher – “Late” Pleistocene.
33) CD154-11-7P – Core Catcher – “Late” Pleistocene.
34) CD154-11-7P – Trigger Core Catcher – “Late” Pleistocene.
35) CD154-12-3C – Short Core on CTD – Holocene.
36) CD154-13-10PK – Core Catcher – Holocene.
37) CD154-13-10PK - Sandy layer near top of core – “Late” Pleistocene.
38) CD154-13-10PK – Greenish-grey clay just below sand – “Late” Pleistocene.
39) CD154-13-10PK – Top of core – Holocene.
40) CD154-13-12K – Core Catcher – “Late” Pleistocene.
41) CD154-13-8P – Core Catcher – “Late” Pleistocene.
42) CD154-13-8P – Trigger Core Catcher – “Late” Pleistocene.
43) CD154-15-12PK – Core Catcher – “Late” Pleistocene.
44) CD154-15-13K – Core Catcher – “Late” Pleistocene.
45) CD154-15-13K – Sample at 0.40m – “Late” Pleistocene.
46) CD154-15-9P – Core Catcher – “Late” Pleistocene.
47) CD154-15-9P - Trigger Core Catcher – Holocene.
48) CD154-15-14K – Core Catcher – “Late” Pleistocene.
49) CD154-15-14K – Pteropod sand – Holocene.
50) CD154-16-13PK – Core Catcher – “Late” Pleistocene.
51) CD154-16-15K – Core Catcher – “Late” Pleistocene.
52) CD154-16-15K – Top of core – Holocene.
53) CD154-16-10P – Core Catcher – “Late” Pleistocene.
54) CD154-16-10P – Trigger Core Catcher – “Late” Pleistocene.
55) CD154-17-11P – Core Catcher – “Late” Pleistocene.
56) CD154-17-11P – Trigger Core Catcher – “Late” Pleistocene.
57) CD154-17-12P – Core Catcher – “Late” Pleistocene.
58) CD154-17-12P – Trigger Core Catcher – “Late” Pleistocene.
59) CD154-17-16K – Core Catcher – “Late” Pleistocene – only temperate planktics.
60) CD154-17-17K – Core Catcher – “Late” Pleistocene.
61) CD154-18-13P – Core Catcher – “Late” Pleistocene.
62) CD154-18-13P – Trigger Core Catcher – “Late” Pleistocene.
63) CD154-18-18K – Core Catcher – “Late” Pleistocene.
64) CD154-18-18K – Clean sandy unit in Pleistocene – “Late” Pleistocene.

Of these, 29 are of “Late” Pleistocene age and six are of Holocene age. The grounds for discrimination of these two age units remain the same as detailed above in the section on the Tugela leg. Little clear difference can be seen in either the planktic foraminifera assemblages or the sediment types of the warmer-temperate Holocene and the temperate or cooler-temperate “Late” Pleistocene units sampled from the East London leg, when compared with those of the Tugela leg. The only especially distinctive sample in this regard is sample 59, which contains almost exclusively temperate planktics (mostly *Globorotalia inflata*), and minimal numbers of warm-water species. This is clearly the coldest-water (though still only temperate) planktic assemblage yet found.

Benthic foraminifera assemblages remain consistent too, much as previously described for the Tugela leg. There is no sign of older sedimentary units, and the "*Stilostomella* assemblage" has not been found. However, all studied samples contain *Globorotalia truncatulinoides*, and this, coupled with the benthic assemblages, indicates that all studied samples must post-date the Brunhes - Matuyama magnetic reversal boundary. Although both the Holocene and the "Late" Pleistocene units locally contain clean shelly sands, very few transported shallow-marine benthic foraminifera tests have been found in East London leg sands. Generally, the shell fragments in these sands have proven to be almost exclusively pteropod shell debris.

Foraminifera results of Port Elizabeth leg of cruise CD154

Relatively few cores were recovered in this leg of the cruise. Samples studied are listed below:-

65) CD154-19-19K – Core Catcher – "Late" Pleistocene.
66) CD154-19-14P – Core Catcher – "Late" Pleistocene.
67) CD154-19-14P – Trigger Core Catcher – "Late" Pleistocene.
68) CD154-20-20K – Core Catcher – "Late" Pleistocene.
69) CD154-20-21K – Core Catcher – "Late" Pleistocene.
70) CD154-20-15P – Core Catcher – "Late" Pleistocene.

All of these cores are distinguished by noticeably finer lithologies than seen previously in the Tugela and East London legs of the cruise. Both clays and the occasional sandy units are finer grained. The topmost orange-brown sedimentary unit,interpreted as Holocene in age, is much thinner here, often amounting to only a few centimetres: is this real, or due to core loss? Foraminifera assemblages remain essentially the same as previously described for the Tugela and East London legs. No record of the "*Stilostomella* assemblage" was found.

One noteworthy sample studied from this leg of the cruise has been sample 70, from the core catcher of piston core CD154-20-15P. Recovery in both the core catcher and core cutter was sparse, owing to the loose, silty character of the sediment, which is a greenish-yellow clayey silt. Although a typical "Late" Pleistocene deep marine foraminifera assemblage was recovered from the silt, more interest has been centred on the presence of diverse, very well-preserved innermost shelf and littoral foraminifera and associated shell debris, whose age can be fairly rigorously constrained. These well-preserved foraminifera and shelly (mollusc and bryozoan species) components must have lived, died and been transported downslope extremely rapidly, for there is no evidence of shell abrasion, calcite dissolution or precipitation, or calcite infilling of tests and cavities. These foraminifera thus provide a "golden spike" between the Pleistocene shelf-top foraminiferal biostratigraphy, based in the main on shallow benthic species, and the Pleistocene slope foraminiferal biostratigraphy, based in the main on planktic and deep benthic species.

The following shelly components and foraminifera species in sample 70 are interpreted as deriving from waters shallower than about 30 m depth:-

Robustly built echinoid spines
Bryozoan fragments
Gastropod and bivalve shell fragments, some retaining life colours (pinks and purples)
Quinqueloculina contorta
Gavelinopsis praegeri

Elphidium advenum
Elphidium cf. *advenum*
Lobatula lobatula
Brizalina sp.
Quinqueloculina dunkerquiana
Globular *Miliolinella* sp.
Fissurina lucida
Spiny *Brizalina* sp.
Shallow-water ostracods
Spirillina sp.
Cibicidoides sp. (Reworked from Miocene deposits)
Cassidulina laevigata
Pararotalia nipponica
Brizalina pseudopunctata
Elphidium cf. *alvarezianum*
Ammonia japonica
Planodiscorbis rarescens
Brizalina sp. (Reworked from Miocene deposits)
Lagena semilineata
Oolina sp. A
Triloculina terquemiana
Cibicidoides sp (Latest Pleistocene one)
Lagena tenuis
Angulogerina angulosa
Bulimina elongata

This foraminifera assemblage is a cooler-water but synchronous equivalent to the "Uloa Formation"-style shallow marine foraminifera assemblage seen in sample 9 from the core catcher of piston core CD154-02-1P, recovered from the Tugela Cone (see section above). There are a number of species in common between the two assemblages, but the larger foraminifera (reflecting warmer waters) encountered in latest Pleistocene deposits along the northern KwaZulu coast are absent everywhere on the south coast of South Africa. This assemblage from off the Port Elizabeth coast compares closely with that described from Unit III of the Upper Algoa Group, developed on low-lying ground closest to the present-day coast along the entire Jeffrey's Bay to Port Alfred coastline. This unit has previously been interpreted as having accumulated during the fall in sea-level from the Eemian highstand to near (but excluding) the last glacial maximum in the later Weichselian (McMillan, 1990b), and consists of a veneer up to 100 m thick of underlying shallow marine calcarenites and overlying aeolianites, with both sedimentary packages containing benthic foraminifera typical of innermost shelf to littoral environments. This succession extends offshore as a progressively thinning veneer, becoming often much less than 1 metre thick, until it disappears completely at about 140 m water depth. This latest Eemian to early Weichselian veneer, essentially littoral in character, has been recognised down to about 140 m water depth off the west, south and east coasts of South Africa. It can be considered a forced regressive systems tract. Onshore, it correlates with the 4-6 m Package (raised beach) along the west coast, with Unit III of both the Bredasdorp Group and the upper Algoa Group along the southern Cape coast, with the Bluff Sandstone Formation at Durban, and with the Uloa Formation along the northern KwaZulu-Natal coast.

The shallow marine foraminifera assemblage from piston core CD154-20-15P consequently correlates to a period when sea-level was generally falling across the inner continental shelf. Foraminifera assemblages from Weichselian lowstand tract deposits, which must have accumulated at the last glacial maximum, and when sea-level was neither falling nor rising, contain entirely different species, and did not contribute to the CD154-20-15P assemblage. Weichselian lowstand tract deposits occur only deeper than a water depth of 156 m off the west coast of South Africa: their distribution off the south and east coasts remains unknown.

Foraminifera results from the Agulhas Passage leg of cruise CD154

The following three samples were studied:-

71) CD154-22-14PK – Sample at 0m – Age probably "Late" Pleistocene.

72) CD154-22-14PK – Sample at 0.28m – Age probably "Late" Pleistocene.

73) CD154-22-14PK – General sample – Age probably "Late" Pleistocene.

Of the one site from which core recovery was achieved, CD154-22-14PK, one sample, at 0.28 m, has been studied in detail. This site (and probably also at the adjacent sites where there was no core recovery) recovered the first clastic-starved sediments encountered during the cruise, being essentially foraminifera oozes, with perhaps only 2 or 3 percent terrigenous content. The more strongly temperate nature of the oceanic water at these sites can be inferred from a distinct decline in the abundance of warm-water planktonic species, especially in numbers of *Globigerinoides* species, *Pulleniatina obliquiloculata*, *Hastigerina pelagica*, and *Globorotalia menardii*. Temperate water species such as *Orbulina universa* and *Globorotalia hirsuta* are common, but the overwhelmingly predominant temperate species is *Globorotalia inflata*, which must constitute over 80 % of the planktonic foraminifera assemblage here. Of the warm-water species, only *Globoquadrina dutertrei* remains common. It seems probable that these samples are all "Late" Pleistocene in age, since they contrast markedly with those from the Holocene succession cored on the flank of the Mallory Seamount (see below).

Foraminifera results from the seamount leg of cruise CD154

The following samples were studied:-

74) CD154-23-15PK – Core Catcher – Holocene.

75) CD154-23-15PK – Top of core – Holocene.

76) CD154-23-24K – Core Catcher – Holocene.

77) CD154-23-16P – Core Catcher – "Late" Pleistocene.

78) CD154-23-16P – Trigger Core Catcher – Holocene.

79) CD154-23-16P – Top of piston core – Holocene.

Coring was carried out on the flank of Mallory Seamount, into a pile of sediment that has accumulated on the down-current, lee-side of the main seamount peak. This succession proved particularly distinctive, in that the upper part consists of soft watery green or brown-green mud with abundant foraminifera, radiolaria and sponge spicules, but larger-sized planktic foraminifera tests are almost completely absent. This sediment thus appears to have been winnowed out from elsewhere, leaving the larger foraminifera tests behind. This mud succession accumulated in unusually quiet waters, and obviously was very protective of its fossil content, for its contained microfossil assemblage is one of the most delicate and beautifully preserved encountered throughout cruise CD154. Lower down in the succession (sample 77), sediments are not quite so soft, more green-grey in colour, and lack the siliceous elements (radiolaria, sponge spicules), but the same emphasis on small sized foraminifera remains.

Planktic foraminifera assemblages in these six samples show a marked decline in the numbers of the warmer water species, which have all become rare in the assemblage. *Globoquadrina dutertrei*, the surviving warm-water indicator still occurring in moderate numbers, is no longer quite so well-formed. Specimens of this species have become smaller, and display fewer chambers (five or six) in the final whorl than seen in previous samples on this cruise. However, the major change evident in the planktic assemblages of these samples is a substantial increase in numbers of *Globigerina bulloides*, a species that has occurred in negligible numbers in all previous samples. With these changes in the planktic assemblages, the distinction between warmer water Holocene assemblages, and cooler-water "Late" Pleistocene assemblages, seen in all previous samples, is here becoming less easy to discriminate.

Cooler-water benthic species also make their appearance here: *Hyalinea balthica*, *Bolivinita cincta*, *Oolina* cf. *squamososulcata*, large *Globocassidulina* sp., *Cibicidoides pseudoungerianus* and *Uvigerina bassensis*, all of which are widespread on the Atlantic margin of southern Africa.

Results from the western most offshore Agulhas Bank leg of cruise CD154

Two sites were visited on the farthest westernmost portion of the offshore Agulhas Bank, located close to where the Agulhas Current undergoes retroflexion back into the Indian Ocean, and to where warm water masses travel north-westwards into the Atlantic Ocean. The following samples were studied from this final portion of the cruise:-

80) CD154-24-25K - Top of core – Holocene.
81) CD154-24-25K – Core Catcher – "Late" Pleistocene.
82) CD154-24-17P – Core Catcher – "Late" Pleistocene.
83) CD154-24-17P - Trigger Core Catcher – "Late" Pleistocene.
84) CD154-25-18P – Core Catcher – "Late" Pleistocene.
85) CD154-25-18P – Sample at 3.36m – "Late" Pleistocene.
86) CD154-25-18P – Sample at 1.92m – "Late" Pleistocene.
87) CD154-25-18P – Top of core – "Late" Pleistocene.
88) CD154-25-18P – Trigger Core Catcher – Holocene.
89) CD154-25-19P – Core Catcher – "Late" Pleistocene.
90) CD154-25-19P – Trigger Core Catcher – Holocene.
91) CD154-25-20P – Core Catcher – "Late" Pleistocene.
92) CD154-25-20P – Trigger Core Catcher – Holocene.

Sediments encountered in these cores were stiff yellowish-green pale-grey clay in the "Late" Pleistocene and brown soft mud in the Holocene (Kasten core). In contrast, the piston cores recovered soft foraminifera-rich pale greenish-grey clay to greyish-white foraminiferal sand in the "Late" Pleistocene. All samples are extremely rich in foraminifera tests, and the fines are almost exclusively tiny foraminifera tests. Towards the base of the "Late" Pleistocene section there are common black grains (?ilmenite or manganese?) with common glauconite pellets (but no reworked foraminifera tests), but these elements disappear up-core. Small numbers of tiny angular quartz grains occur in the "Late" Pleistocene residues, but these are absent in the Holocene samples. Most of these samples can be considered as unconsolidated foraminiferal sands, as, except for the lower parts of the section, there is minimal clay or mud.

Trends seen in the seamount leg of the cruise were repeated here. Planktic foraminifera assemblages of the westernmost Agulhas Bank again contain small numbers of comparatively few warm-water species, with *Globigerinoides conglobatus, Hastigerina pelagica, Pulleniatina obliquiloculata, Globorotalia menardii* everywhere very rare. *Globigerina bulloides* is often common, and right-coiled *Neogloboquadrina pachyderma* is locally significant. *Globorotalia inflata* remains the dominant species.

These samples all contained comparatively diverse benthic foraminifera assemblages, most of which were to be found only in the <250 microns fractions. Typical benthics in the "Late" Pleistocene include:-

Brizalina cf. rocklandsensis
Bladed and spiky Fissurina sp.
Globobulimina sp.
Cassidulina laevigata
Ribbed Bulimina sp.
Brizalina spathulata
Laticarinina paupercula
Bulimina orangensis
Globocassidulina sp.
Keeled Fissurina sp.
Bulimina marginata
Brizalina cf. striata
Melonis pompilioides
Flat Nonion sp.
?Tolypammina sp.
Nodogenerina sp.
Fontbotia wuellerstorfi (juvenile)

In contrast, a Holocene sample (sample 92) contains only rare benthics:_

?Osangularia sp.
Cassidulina laevigata
Bathysiphon sp.

11. Colour Spectrophotometry and Magnetic Susceptibility

Shipboard core "logging" consisted of down-core sediment colour spectrophotometry ("colour scanning") and magnetic susceptibility measurements. Both methods provided primary means for core-to-core correlation. Colour scanning was done using a handheld Minolta Series CM-503c spectrophotometer with a measurement area of 3 mm in diameter and 45° illumination / 0° viewing angle geometry. The instrument was calibrated prior to each new measurement series using the Minolta white calibration standard. The spectrophotometer measures the spectral reflectance of sediment colour that, once calibrated to sediment geochemistry, provides an indirect indication of sediment geochemical variation such as e.g., the down-core variation of carbonate concentration. Output of the colour measurements are numerical absolute colour values for L*a*b* and reflectance wave lengths from 400-700 nm at 10 nm increments. For graphical presentation of the colour profiles the L* "lightness" value is used below. The measurement area diameter used here is smaller than that of 1 cm typically used in sediment core colour scanning, providing for a finer resolution of the scans but, at the same time, potentially introducing "noise" to the records through the contribution of individual colour specks (e.g. from bioturbation). Therefore, care was taken during the measurements to avoid burrows and only areas of the cut core surface were scanned that were representative of the colour trend in a particular section. Colour measurements were routinely performed on Kasten cores at 2 cm intervals through the cores. Piston cores were not split onbord which will be colour scanned post-cruise.

Magnetic susceptibility measurements were carried out both on the Kasten cores and piston cores. The measurements were done with a Bartington MS2 magnetic susceptibility meter using either an MS2F probe or a 125 mm MS2C loop sensors. Measurements were made in the constant temperature laboratory (6°C) and, as with the colour scans, they were carried out at 2 cm intervals.

The following graphs provide a first assessment of the correlations between the different cores. The correlation was done using the AnalySerie Version 1.0a7 programme (Paillard et al., 1996) that enables easy graphical correlation of two records by implementing a series of tie points that link the structure of the 'distorted' record to that of the reference record. Rather than establishing correlative age scales for the records we chose to correlate the records to a common depth scale. For this a core was chosen as reference that fulfilled two requirements: systematic down-core variations at a reasonably well developed and easy-to-detect amplitude (i.e. high signal to noise ratio) and long core recovery. This was not possible at the last working station, CD154-25, where only piston cores were retrieved that consisted of water-rich sandy (foraminiferal sands) sediments that yielded only very low magnetic susceptibility values. The correlations shown below are to be considered prospective at best. In many cases the correlation was obvious as the profiles displayed distinctive variations that were easily correlatable. In other cases down-core profiles provided less distinctive features making the correlation ambiguous. It should be noted here again that this correlation is not intended to provide an estimate of stratigraphy in terms of temporal resolution or stratigraphic reach, but should be viewed merely as an indication of the degree of similarity of down-core variability along the different cores. Obviously, the correlation is expected to vary from one working area to the next such that for each working area a new reference record for comparison was chosen. This variation from area to area reflects distinctive sedimentation regimes at the different working areas, such as varying degrees of terrestrial (riverine) vs marine contribution to the sediment record. These differential contributions become particularly obvious from the varying degree of correlation between sediment colour changes and changes of magnetic susceptibility.

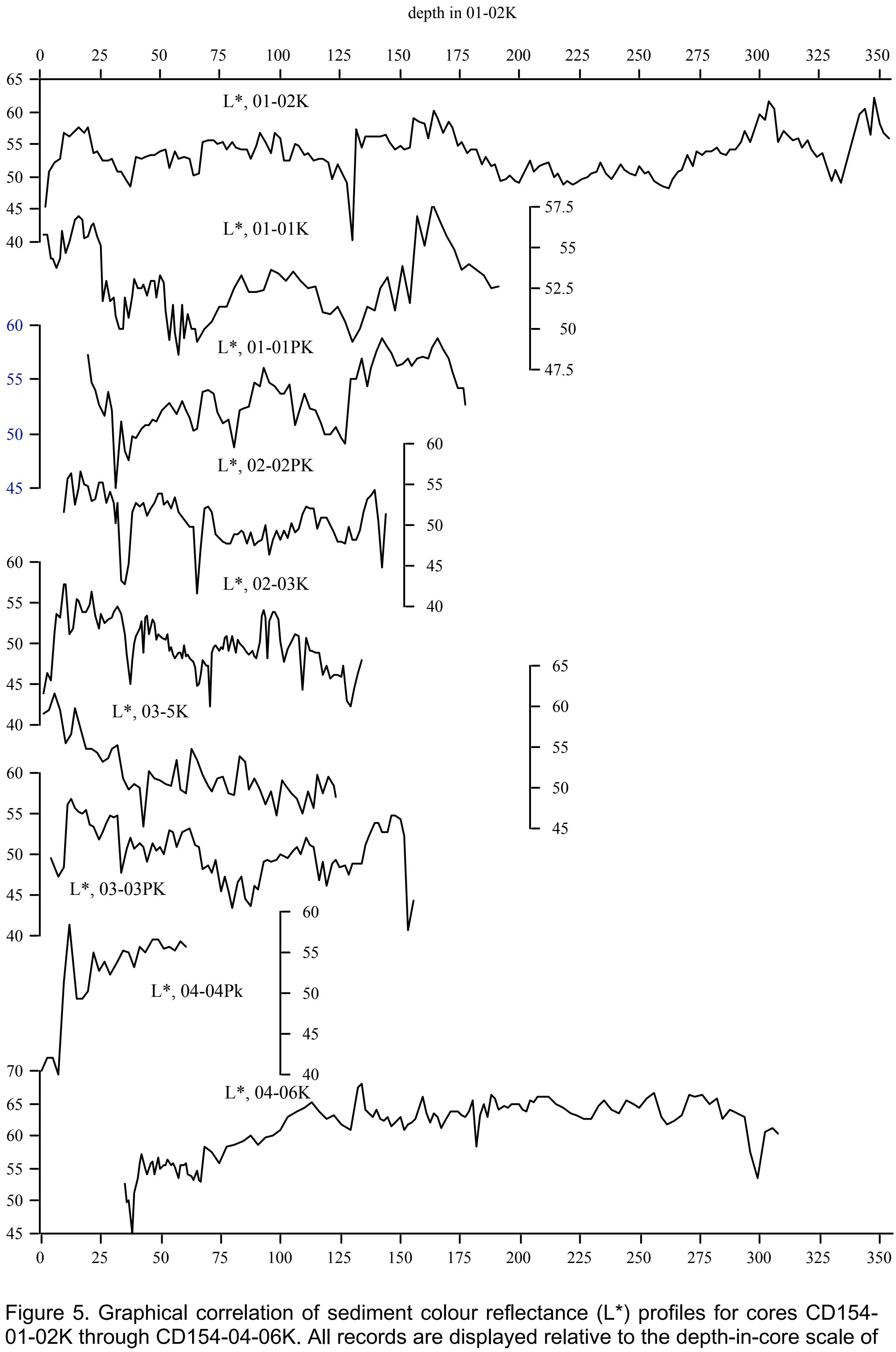

Figure 5. Graphical correlation of sediment colour reflectance (L*) profiles for cores CD154-01-02K through CD154-04-06K. All records are displayed relative to the depth-in-core scale of core CD154-01-02K. See Appendix for colour records on their individual depth scales.

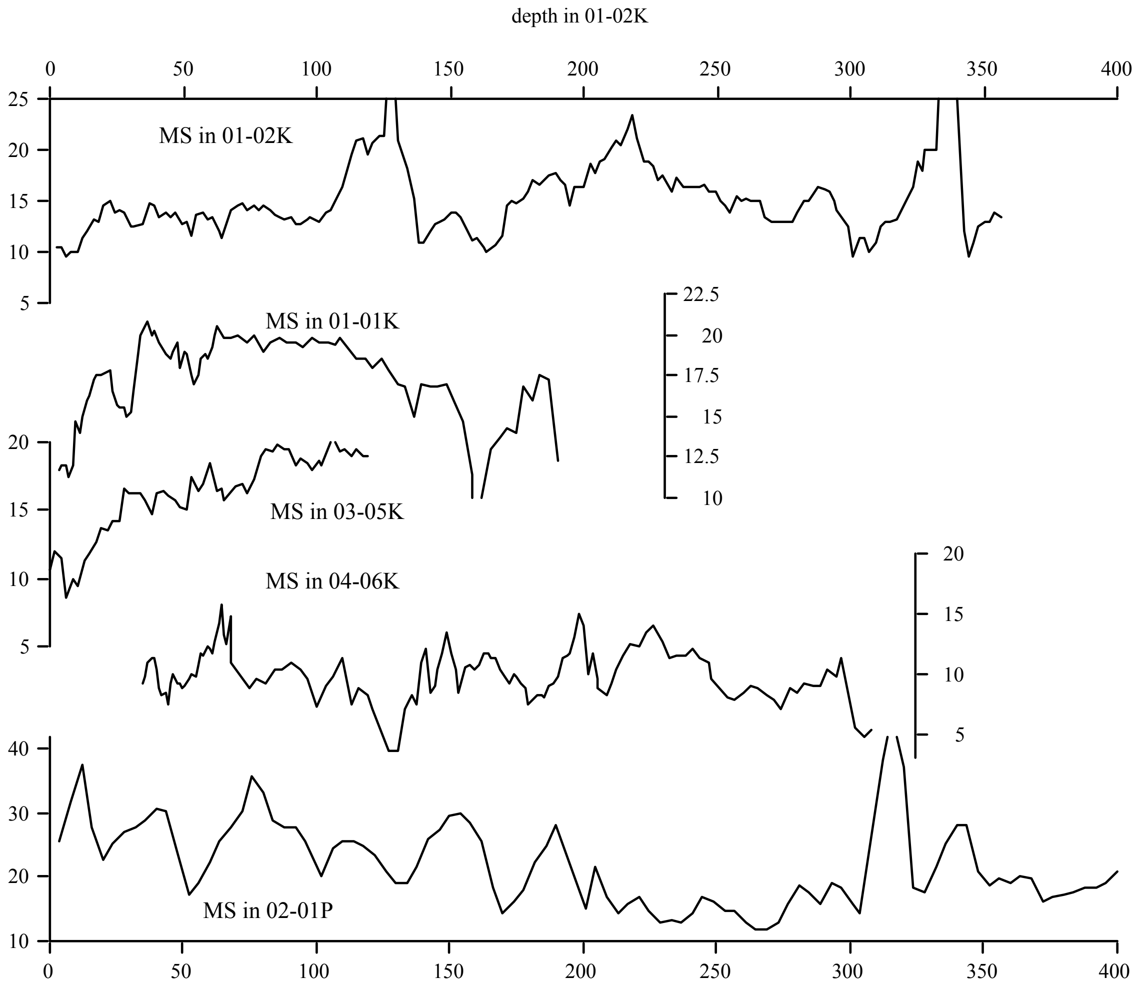

Figure 6. Graphical correlation of magnetic susceptibility profiles for cores CD154-01-02K through CD154-04-06K. All records are displayed relative to the depth-in-core scale of core CD154-01-02K using the correlation derived from the sediment colour reflectance profiles. See Appendix for magnetic susceptibility records on their individual depth scales. N.B.: Magnetic susceptibility records were not measured on the pilot Kasten (PK) cores shown in Figure 6.

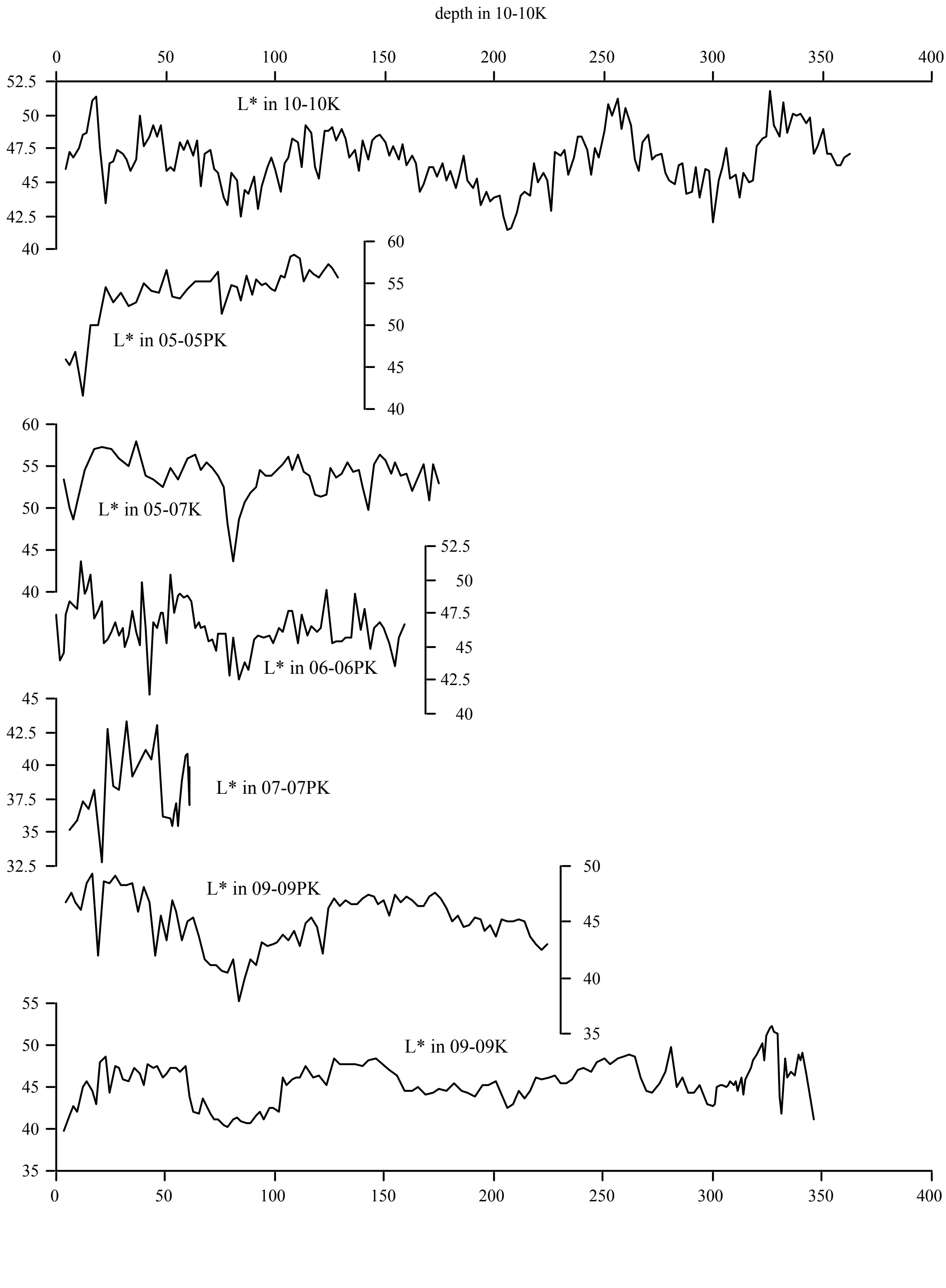

Figure 7. Graphical correlation of sediment colour reflectance (L*) profiles along cores CD154-05-05K through CD154-10-10K. All records are displayed relative to the depth-in-core scale of core CD154-10-10K. See Appendix for colour reflectance records on their individual depth scales.

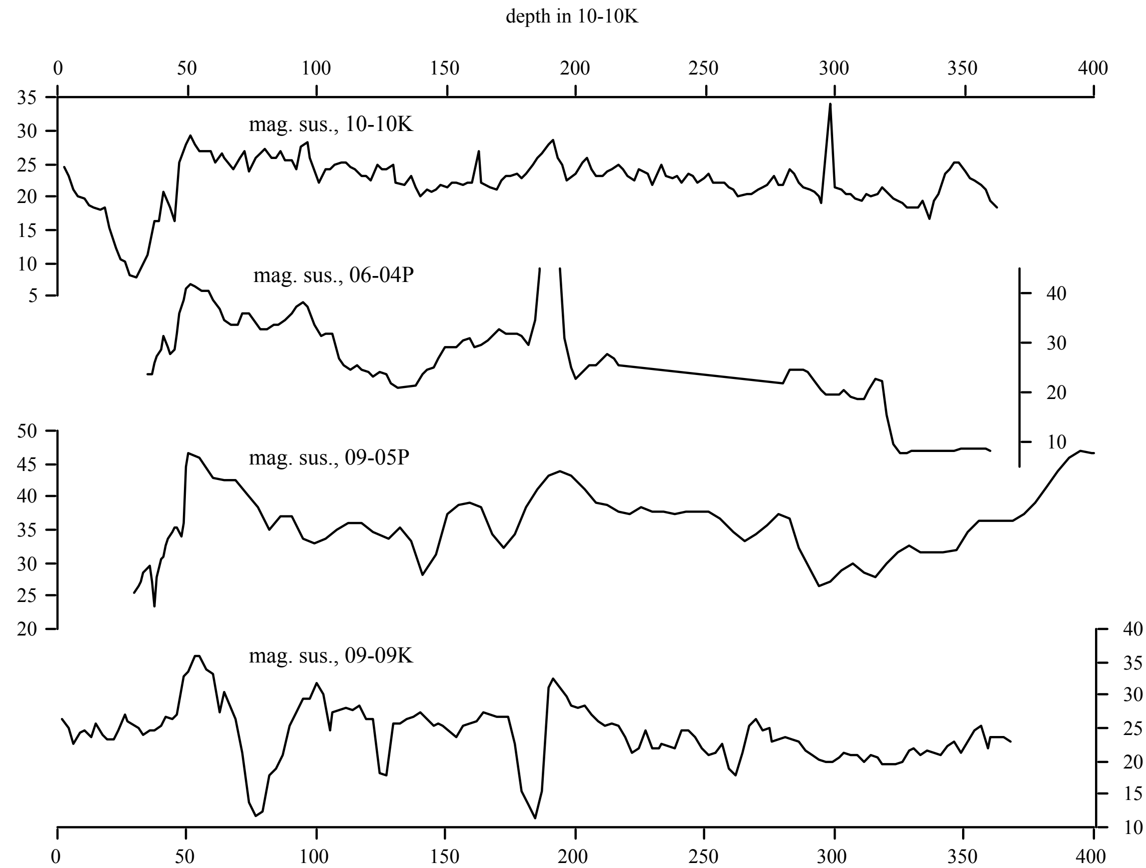

Figure 8. Graphical correlation of magnetic susceptibility profiles for cores CD154-06-04P through CD154-10-10K. All records are displayed relative to the depth-in-core scale of core CD154-10-10K in part using the correlation derived from the sediment colour reflectance profiles. See Appendix for magnetic susceptibility records on their individual depth scales. NB Magnetic susceptibility records were not measured on the pilot Kasten (PK) cores shown in Figure 8.

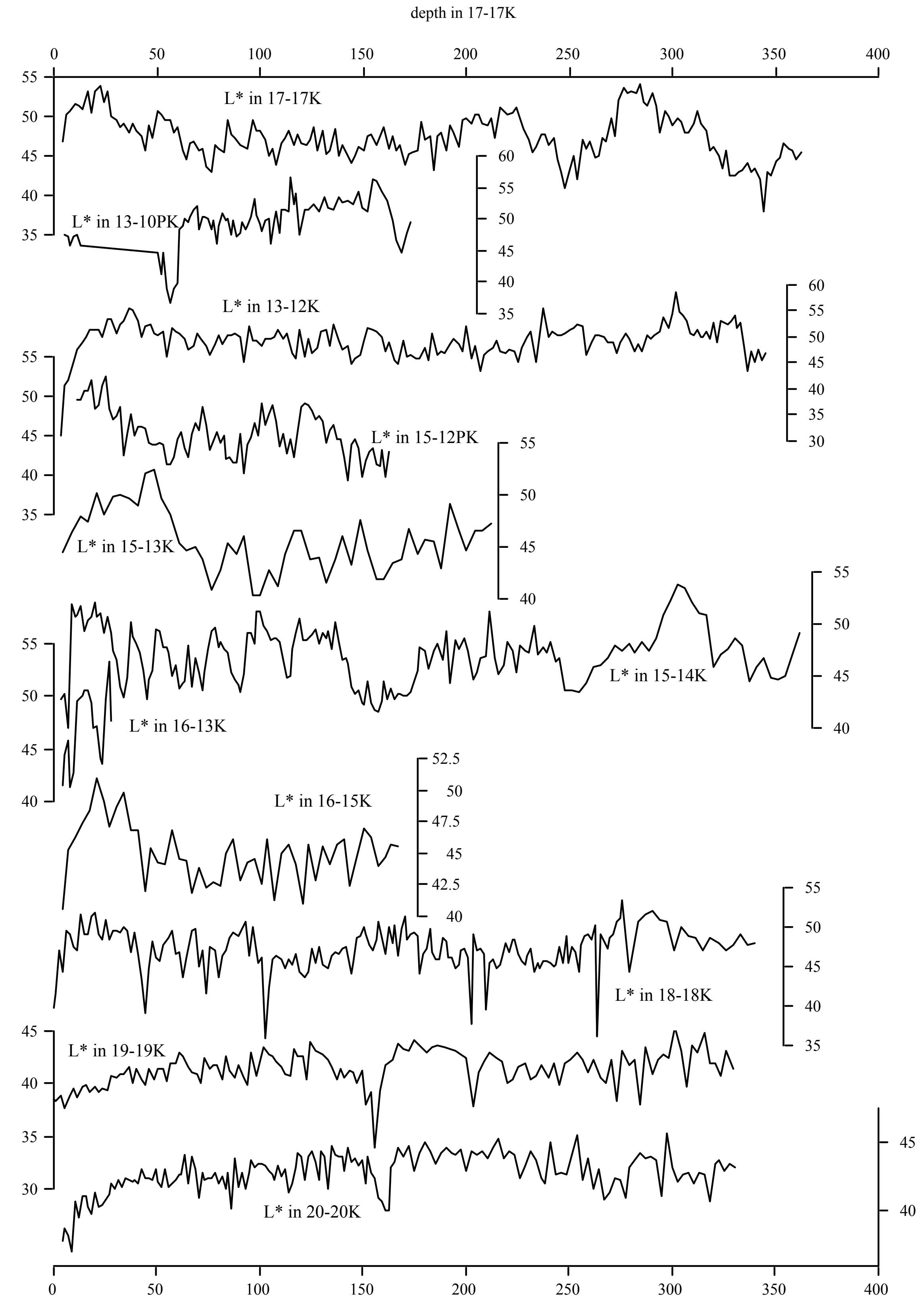

Figure 9. Graphical correlation of sediment colour reflectance (L*) profiles along cores CD154-13-10PK through CD154-20-20K. All records are displayed relative to the depth-in-core scale of core CD154-17-17K. See Appendix for colour reflectance records on their individual depth scales.

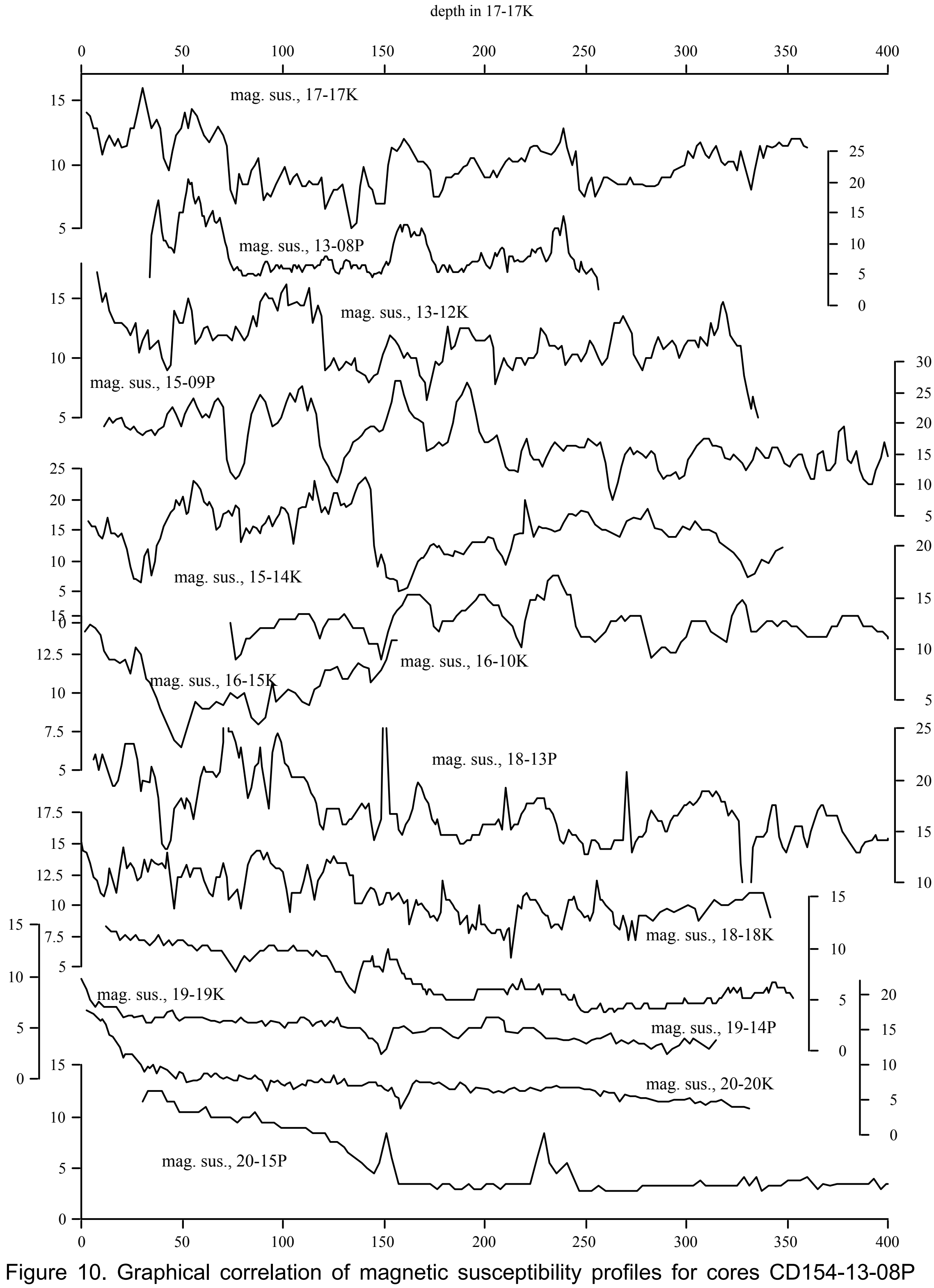

Figure 10. Graphical correlation of magnetic susceptibility profiles for cores CD154-13-08P through CD154-20-20K. All records are displayed relative to the depth-in-core scale of core CD154-17-17K using the correlation derived from the sediment colour reflectance profiles. See Appendix for magnetic susceptibility records on their individual depth scales. NB Magnetic susceptibility records were not measured on the pilot Kasten (PK) cores shown in Figure 10.

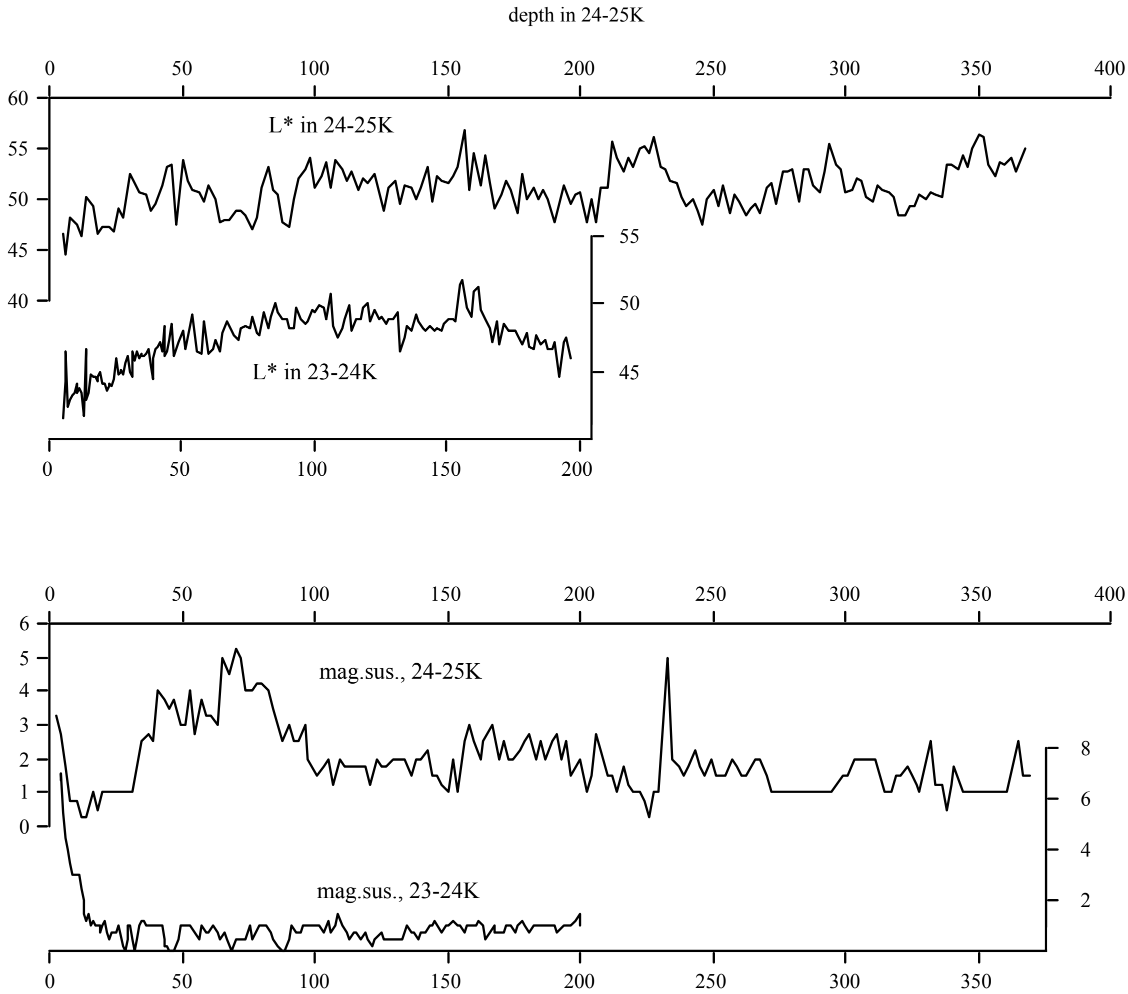

Figure 11. Graphical correlation of sediment colour reflectance (top, L*) and magnetic susceptibility profiles (bottom) for cores CD154-23-24K and CD154-24-25K. The records are displayed relative to the depth-in-core scale of core CD154-24-25K. Note very low magnetic susceptibility values. See Appendix for colour and magnetic susceptibility records on their individual depth scales.

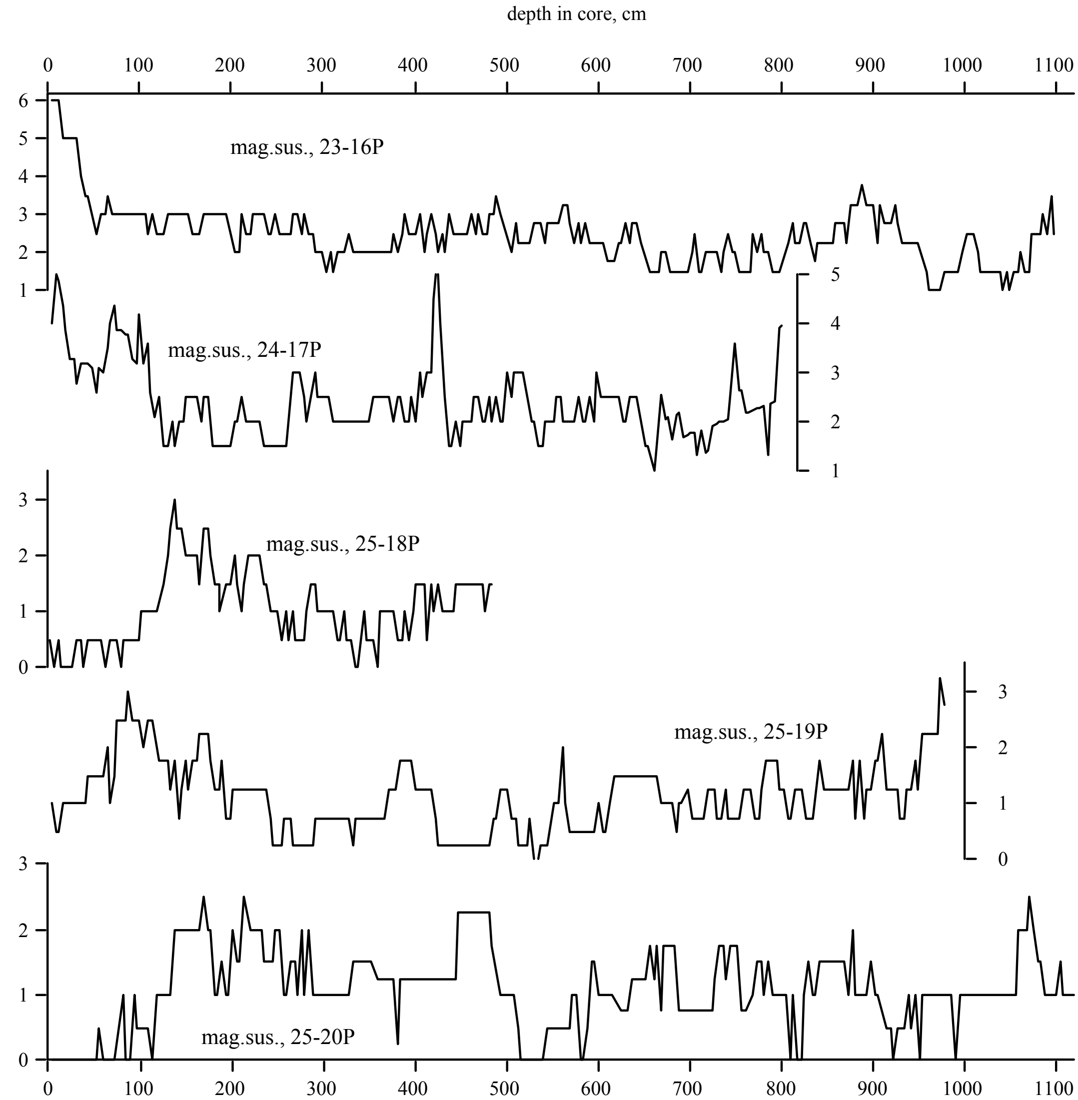

Figure 12. Magnetic susceptibility profiles of cores CD154-23-16P through CD154-25-20P. The records are displayed on their own depth scales. Note very low magnetic susceptibility values in the water-rich largely sandy (foraminiferal sands) cores. N.B.: Piston cores were not split onboard so sediment colour reflectance records were not measured on these cores.

12. CTD Operations

Data on salinity, temperature, transmission were collected from both the Neil Brown Mk IIB CTD system and (non-toxic) underway pumped system. In addition the CTD was equipped with sensors for the measurements of oxygen, transmission, light scattering and up-welling and down-welling irradiance. In total 5 CTD casts were made. The 24 bottle rosette worked well. However, we noted considerable noise in the temperature and salinity profile from the first cast and during the second cast the TS sensor failed completely. The sensor was replaced and worked well for the remaining casts. The optical transmission data (Chelsea instruments Alpha tracker Mk II) was also unusable, suffering from a severe drift in the baseline voltage during deployment. This pressure/temperature problem was sufficient to provide totally unrealistic clear water minimum attenuation coefficients. After cast 2 an additional 0.25 m path-length SeaTech transmissometer was added to the CTD rosette. These data along with those from the light scattering sensor were used to select appropriate water sampling depths . The maximum depth to which the CTD could be deployed was determined from the 10kHz pinger trace. All data are held in Cardiff.

13. Stand Alone Pumps

Large volume filtration of seawater at specific depths in the water column was achieved using stand alone pumps (SAPS), in support of the radiogenic isotope studies described below in section 14. The water was passed through a 293 mm diameter 0.4 µm Nucleopore membrane, supported on a 293 mm diameter, 1 µm GFC filter. A total of 5 SAPS deployments were made and no serious problems were encountered. Station positions, water depths and volumes filtered are given in the operation sheets.

14. Stable isotopes

A series of water samples was taken from the Niskin Rosette and the ship's non-toxic pump for shore based analyses of stable oxygen and carbon isotopes. The oxygen isotopic composition of ambient seawater in conjunction with water temperature determines the isotope signal of foraminiferal calcite ($\delta^{18}O_c$) that is commonly used to infer palaeo-hydrography. The carbon isotope signal of water column total dissolved CO_2 ($\delta^{13}C_{TCO2}$) is linked with the marine carbon cycle through isotope fractionation in the course of photosynthetic carbon fixation, marine biologic productivity and organic matter remineralisation in the deeper water column. Distribution patterns of $\delta^{13}C_{TCO2}$ in the world ocean directly mirrors the advection flow paths of major deep water masses and thus this isotope signal is a preferred proxy to trace water masses in palaeoceanographic studies. The signals are incorporated into foraminiferal $\delta^{13}C$ ($\delta^{13}C_c$) so that down-core $\delta^{13}C_c$ variations document water mass $\delta^{13}C_{TCO2}$ variability in conjunction with mode changes of thermohaline circulation and global climate.

The primary intention to carry out stable isotope analyses on water samples from the Agulhas Current region was to enable calibration of foraminiferal $\delta^{18}O_c$ and $\delta^{13}C_c$ to water isotope ratios. Such calibration is essential in determining if and to what extent foraminiferal isotope signals reflect ambient water mass properties. Materials to be used in this exercise, aside from the water samples, are plankton samples from surface water collections using the ship's non-toxic pump, and sediment surface samples. Paired water column-foraminiferal isotope measurements will also allow to decipher calcification depths and seasons which are essential in the reconstruction of thermocline palaeo-structur variations from multi-species planktonic foraminiferal isotope analyses. A total of 60 water samples were taken from the CTD Niskin casts and non-toxic surface water pumping. The water column samples were positioned using the down-cast T and S profiles. Samples were distributed along the hydrographic profiles such that the main water masses (thermocline, AAIW, CDW/NADW, AABW) were targeted with sufficient spatial resolution to provide a robust data base for the water column vs foraminiferal isotope calibration. Water column T-S profiles and depth position of the water samples taken are shown in Figs. 13-16. All samples were transferred into brown 250 ml screw-cap glass bottles. Water samples for carbon isotope analyses were poisoned using 10 cc of a saturated mercuric chloride solution that was injected into the sample immediately after transfer into the sample bottle so as to suppress metabolic activity that would interfere with the water $\delta^{13}C_{TCO2}$ signal. Care was taken that samples were transferred from the Niskin bottles bubble-free so as to eliminate entry of atmospheric gas into the sample. Caps were screwed tightly on the bottles and sealed with Parafilm wax. The cap and wax seal was then secured with elastic Scotch tape to ensure water can not evaporate through the cap and no air enters the sample during storage.

Hydrocast station CD154-11-2C

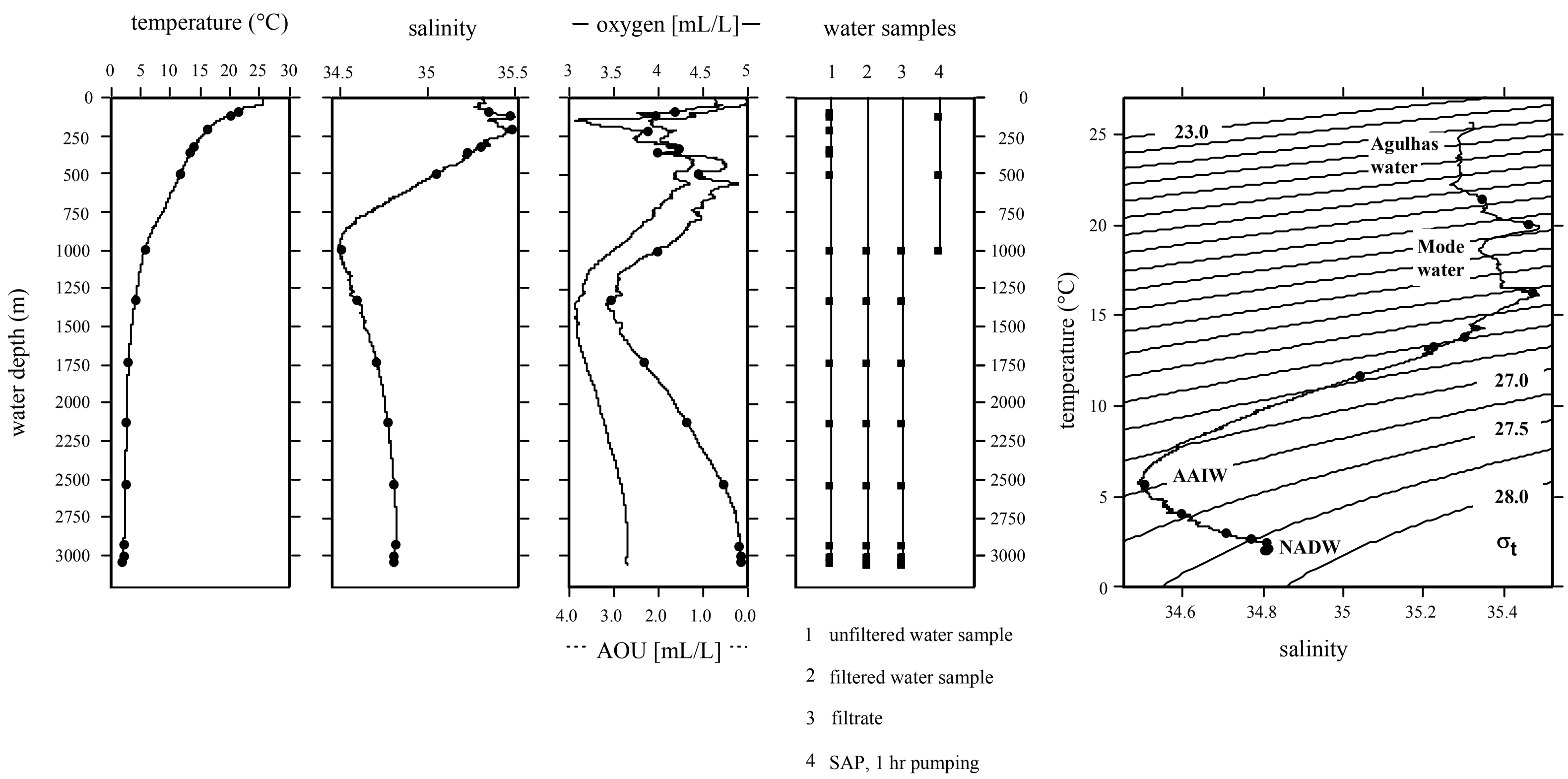

Figure 13. Hydrographic profiles at CTD Station CD154-11-2C. Symbols indicate depth positions of water samples. Unfiltered samples were taken for both radiogenic and light stable isotope analyses.

Hydrocast station CD154-12-3C

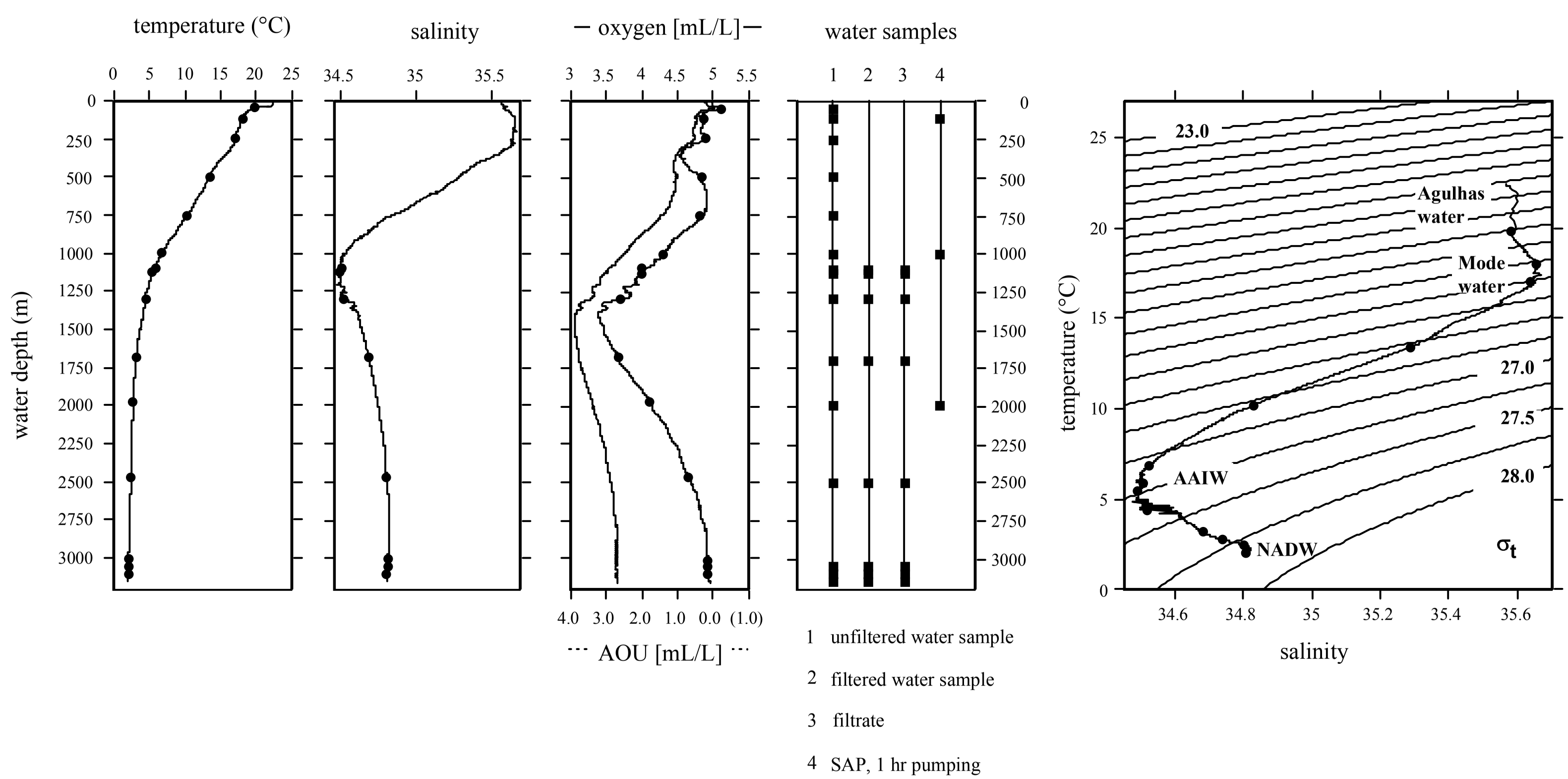

Figure 14. Hydrographic profiles at CTD Station CD154-12-3C. Symbols indicate depth positions of water samples. Unfiltered samples were taken for both radiogenic and light stable isotope analyses.

Hydrocast station CD154-13-4C

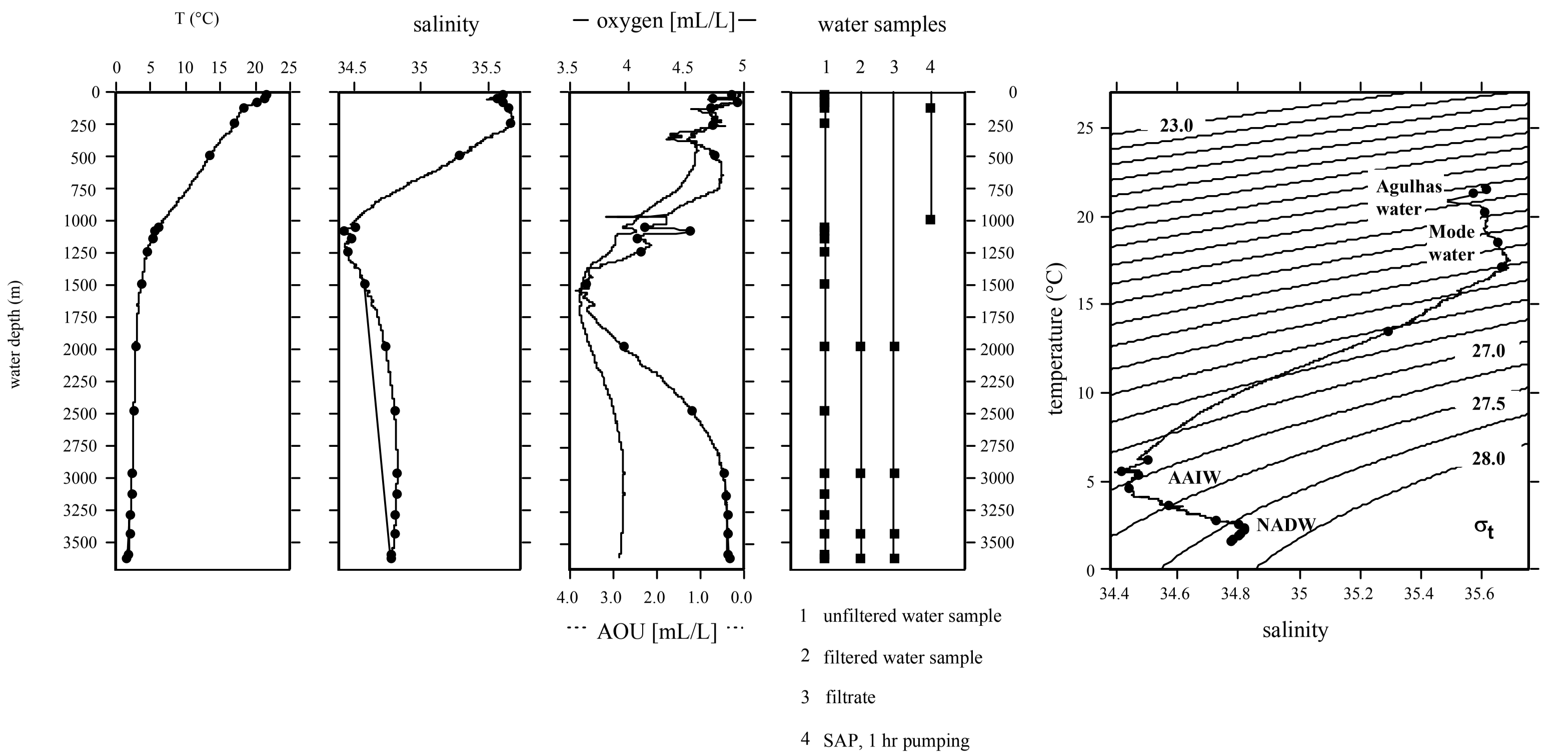

Figure 15. Hydrographic profiles at CTD Station CD154-13-4C. Symbols indicate depth positions of water samples. Unfiltered samples were taken for both radiogenic and light stable isotope analyses.

Hydrocast station CD154-26-5C

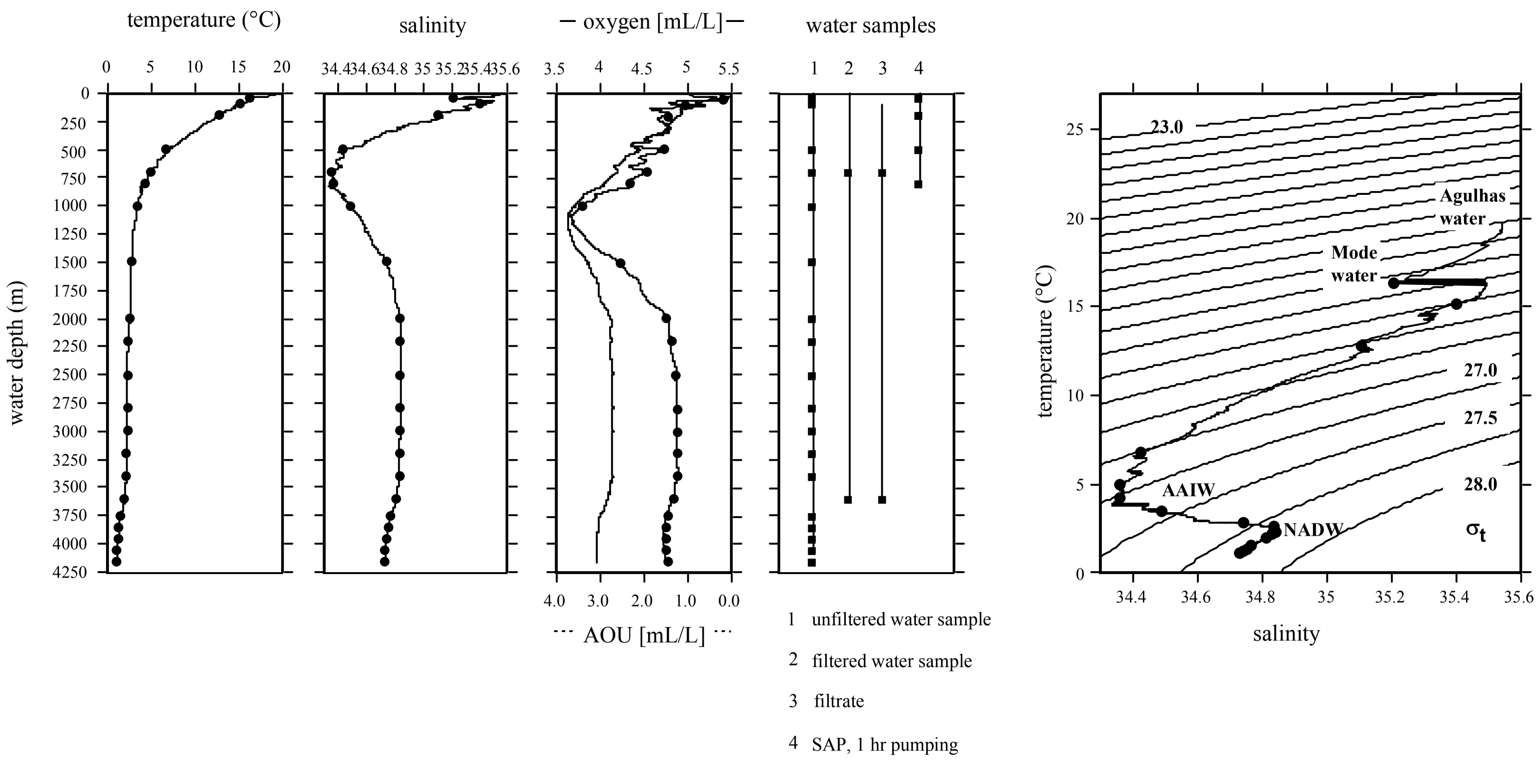

Figure 16. Hydrographic profiles at CTD Station CD154-26-5C. Symbols indicate depth positions of water samples. Unfiltered samples were taken for both radiogenic and light stable isotope analyses.

14. Radiogenic Isotope Studies (SG, SRH and AT)

Introduction

The overarching goal of sampling the water and suspended sediments was to ground-truth the application of unstable short-lived ($^{231}Pa/^{230}Th$) and as well as stable (Nd, Sr) radiogenic isotope tracers of the sources of terrigenous sediments to the oceans and the flow pathways of ocean water masses. The sampling strategy was to obtain water column samples to characterize the main water mass trends for $^{231}Pa/^{230}Th$ and Nd isotope ratios. Suspended sediments, collected from large volumes of water with SAPS will be analyzed for $^{231}Pa/^{230}Th$ as well as Nd and Sr isotope ratios. The surface sediment samples will be measured for bulk $^{231}Pa/^{230}Th$, Nd and Sr isotopes in the authigenic Fe-Mn fraction, which should represent the water, and Nd and Sr isotopes in the terrigenous detrital fraction. Where cores are available from the same sites as water column work, down-core analyses will yield insights in to how these systems responded in different climatic regimes. It is particularly desirable that these cores will also be studied for other palaeoclimate-palaeocirculation variations using a wide suite of proxies such as faunal and floral analyses, stable isotopes on multiple species, Mg/Ca and alkenone temperature estimates, sortable silt, etc.

We have three sub-projects within this sampling program, all have potential as palaeoceanographic tools, but require further studies of modern processes: 1) $^{231}Pa/^{230}Th$ as a bottom flow tracer (Thomas), 2) provenance of terrigenous particles as current tracers (Goldstein/Hemming), and 3) Nd isotopes to trace water masses (Goldstein/Hemming).

Short-lived radiogenic isotopes. Both ^{231}Pa and ^{230}Th are produced in the water column from the decay of ^{235}U and ^{234}U (^{238}U) respectively. The production ratio can be considered constant at 0.093 (activity) due to both the long residence time of U in the oceans and the constant $\delta^{234}U$ value observed over the last 1 Ma. Both Pa and Th have very short residence times in the oceans due to their strong particle reactivity. The scavenging of Th and Pa to particle is a reversible process, which leads to generally increasing concentration profiles of dissolved as well as particulate phases with depth. Th has a residence time of 20-40 years while Pa is slightly less particle-reactive and has a residence time of 80-120 years. Thus Th is effectively quantitatively scavenged to the seafloor as it is produced in the water column, which has led to $^{230}Th_{ex}$ to be used as a constant flux proxy. Pa, on the other hand, is less efficiently scavenged, so a significant fraction is advected "downstream" with the water mass. Accordingly, due to its greater residence time, Pa is more easily equilibrated along the flow path of bottom water. This means that the $^{231}Pa/^{230}Th_{ex}$ ($^{231}Pa/^{230}Th_{ex}$ is the $^{231}Pa/^{230}Th$ ratio in sediments corrected for any ingrowth of ^{231}Pa and ^{230}Th from authigenic and detrital U) of sediments should vary as a function of the rate of bottom water flow.

The $^{231}Pa/^{231}Th_{ex}$ preserved in the sediments can therefore be used as a proxy for advection as the rate at which the $^{231}Pa/^{230}Th$ ratio changes downstream is dependant on the flow rate of the water. A slow moving water mass will reach an equilibrium state where the $^{231}Pa/^{230}Th_{ex}$ of the sediments is equal to the production ratio, whereas a faster moving water mass will require a much longer distance to reach equilibrium.

The flow speed is, however, not the only factor controlling the $^{231}Pa/^{230}Th_{ex}$ ratio in the sediments. The concentration of particles in the water column is also a significant factor. The higher the particle concentration, the more effectively Pa is scavenged from the water column. In contrast, the particle concentration has little effect on the scavenging of Th due its extreme particle reactivity. Thus assumptions of palaeoproductivity, or an independent proxy such as Ba concentrations, need to be employed. The fractionation of Th and Pa owing to the different particle reactivity of each element has been observed to vary with particle type. Thorium is approximately 10 times more particle reactive than Pa on carbonate particles, whereas clays appear to fractionate poorly, while opal may cause Pa to be more strongly adsorbed. This substrate control on Th-Pa fractionation must be considered while using $^{231}Pa/^{230}Th_{ex}$ and a proxy, especially across varying lithologies. There also may be sediment refocusing effects, which need to be corrected for. This correction can be made by combined use of a constant flux proxy such as ^{230}Th with independent age model estimates for the sediment.

The aims of this cruise were to establish a "ground truth" between the water column composition and the $^{231}Pa/^{230}Th_{ex}$ preserved in the sediments. In particular, a longitudinal transect, of water column profiles and surface sediment samples, along the path of NADW, has been taken to examine the evolution of $^{231}Pa/^{230}Th$ ratio as the water mass moves downstream. Pairs of 10 litre water samples, filtered and unfiltered, have been taken along the water column profiles so that the contribution of ^{231}Pa and ^{230}Th from the particles to the sediments can be investigated. Samples were taken at smaller intervals around the deep water, particularly in the nepheloid layer, a portion of the water column which is critical for the preservation of the water column $^{231}Pa/^{230}Th$ signal into the sediments. If the reversible nature of the scavenging to particles is rapid enough to allow the water at the very bottom to equilibrate with the $^{231}Pa/^{230}Th$ ratio of the particles resuspended in the nepheloid layer, and if the particles in the nepheloid layer have been transported a significant distance from a region with a marked difference in $^{231}Pa/^{230}Th$ in the sediments, then this will have significant implications for the use of $^{231}Pa/^{231}Th_{ex}$ as a proxy for palaeoceanography. Ultimately, if $^{231}Pa/^{230}Th_{ex}$ can be shown to work as a proxy for past flow rates, then down-core sampling will enable deep water flow rates to be reconstructed, which will shed light on the behaviour of the thermohaline circulation of the oceans under past climatic conditions.

Long-lived radiogenic isotopes. Long-lived radiogenic isotopes are useful tracers for palaeoceanography and palaeoclimate studies because they vary over the surface of the Earth and within it. The long-lived decay systems that will be the focus of the investigations associated with this cruise are $^{87}Rb \rightarrow {}^{87}Sr$ (half-life ~48 Ga) and $^{147}Sm \rightarrow {}^{143}Nd$ (half-life ~105 Ga). Rb and Nd are more likely to enter magma than their partner elements Sr and Sm, and as a result the continents have higher Rb/Sr and lower Sm/Nd ratios than the Earth's mantle. Over time this has resulted in the continents having high Sr isotope ratios ($^{87}Sr/^{86}Sr$) and low Nd isotope ratios ($^{143}Nd/^{144}Nd$ or ε_{Nd}) compared to the mantle and bulk Earth, with the variability or these isotope ratios in rocks strongly tied to their age. These tracers can be important both in the solid and dissolved fractions of marine samples. Solid terrigenous detritus that gets dispersed in the oceans carries the isotopic signal reflecting its continental origin. Elements dissolved in seawater can have varying isotope ratios if their residence time is shorter than the mixing time of the oceans. Sr isotope ratios are uniform in the oceans due to the long residence time of Sr, but Nd isotope ratios vary and show great promise as a water mass tracer.

Provenance of terrigenous particles. Our inspiration for studying the provenance of terrigenous particles around South Africa comes from the downcore observations from RC11-83 from the southern Cape Basin, and V34-157 from the Agulhas Plateau. RC11-83 is from a drift deposit with a high sedimentation rate (~25 cm/kyr). The Holocene Sr isotope ratios of the terrigenous clastic sediment fraction are very high, with $^{87}Sr/^{86}Sr$ ~ 0.723. In addition, there is a striking systematic variation of the provenance with climate cycles on Milankovitch and millennial time scales (Fig. 17). One explanation for this pattern is changes in the strength of the Agulhas Current (explained below). Accordingly, in order to determine the reasons for these temporal changes, we seek to better understand the present-day particle compositions within the water column and on the seafloor surface around the southeastern tip of Africa.

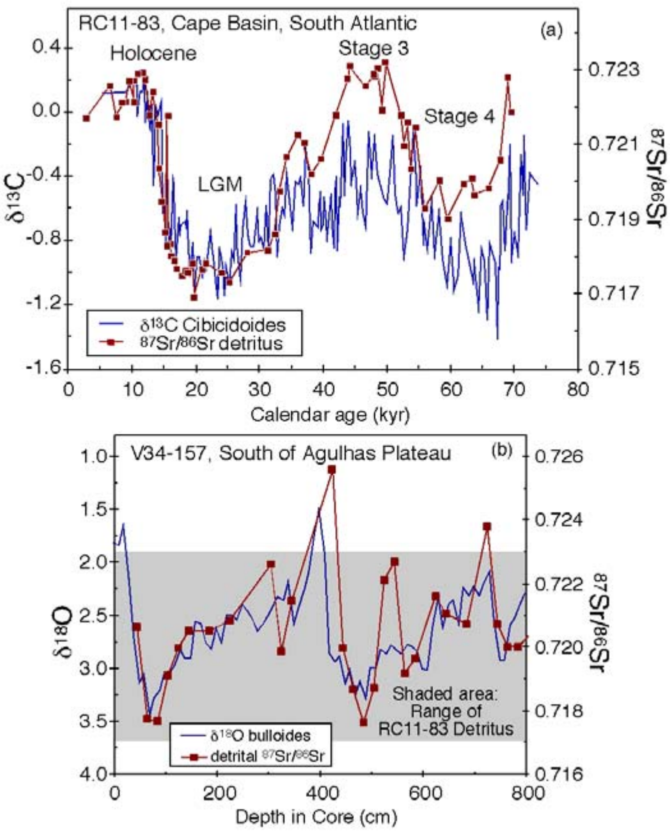

Figure 17. *Profiles of Sr isotopes in terrigenous detritus.* (a) Terrigenous detrital $^{87}Sr/^{86}Sr$ ratios and benthic foraminiferal $\delta^{13}C$ vs age in RC11-83, Cape Basin. The $^{87}Sr/^{86}Sr$ variations show sharp MIS transitions occurring with $\delta^{13}C$ transitions. Sr isotopes are LDEO data, benthic $\delta^{13}C$ are from Charles and Fairbanks (1992) and Charles et al. (1996). (b) Terrigenous detrital $^{87}Sr/^{86}Sr$ and planktonic foraminiferal $\delta^{18}O$ versus depth in V34-157, from the southern flank of the Agulhas Plateau. The detritus shows glacial-interglacial variations similar to RC11-83, reflecting climate-forced changes in sources, and with the high $^{87}Sr/^{86}Sr$ signal reflecting a southeast Africa provenance carried by the Agulhas Current. $\delta^{18}O$ data are from Verardo (1995). Errors of Sr isotope ratios are smaller than the symbols.

In our efforts to identify the provenance of the radiogenic terrigenous sediments from the southern Cape Basin we have mapped Sr isotopic compositions of the terrigenous fraction of near-surface Holocene sediments around the tip of South Africa (Fig.18). Our conclusion is that the only sensible source for the highly radiogenic values in the Cape Basin is the SE coast of Africa along the path of the Agulhas Current, where the Sr isotope ratios of surface detritus are consistently high. Sr isotope ratios are too low in continental detritus sources contiguous to the Cape Basin and also in the marine sources to the north, west, and south. Because the deep currents in the area are travelling northeastwards, away from the Cape Basin, this implicates the Agulhas Current as the carrier of high $^{87}Sr/^{86}Sr$ terrigenous detritus signal.

The immediate transport of sediment to the Cape Basin drift must be the clockwise bottom current that flows around the deep Cape Basin at about the depth of these cores. Accordingly, there are three (or four) potential "end member" contributors (end members in this case are also fundamentally mixtures) of terrigenous detritus to RC11-83: (1) the Agulhas Current, (2) South Atlantic (surface) Current, (3) other parts of the Cape Basin (including local sources from southwestern

Africa, plus eolian dust and possibly contributions from NADW), and (4) AABW, which enters the Cape Basin in the SE corner and travels westward in the clockwise deep gyre. It is possible that some terrigenous sediment from south of the basin is brought into the basin in this manner. We expect the provenance should be mostly a mix of 1 and 3.

Among these possible detritus sources, we believe the one most likely to contribute the high $^{87}Sr/^{86}Sr$ signal is the Agulhas Current, based on the core top map (Fig.18). At the present time, the core top map is still relatively low resolution, and local sources from SW Africa to the Cape Basin cannot be completely excluded, although the major source of terrigenous detritus, the Orange River, is excluded because Sr isotope ratios are too low. The Sr isotope ratios of Agulhas particulates have not been measured previously. We are collecting, for Sr isotope analysis, particulates with SAPS from depths corresponding to the Agulhas Current, as well as AAIW, and NADW for comparison. In addition, we plan to analyze Holocene samples from core tops at the same sites.

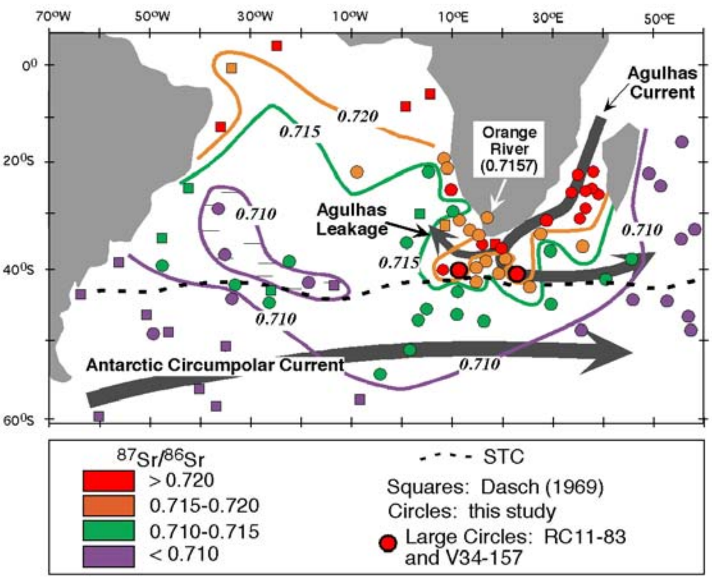

Figure 18. *$^{87}Sr/^{86}Sr$ of core top detritus in the South Atlantic and western Indian Oceans, and respective sectors of the Circum-Antarctic.* The east coast of Africa is the regional source with the high Holocene $^{87}Sr/^{86}Sr$ ratios of RC11-83 in the Cape Basin and V34-257 south of the Retroflection. The regional pattern shows that the high $^{87}Sr/^{86}Sr$ detritus is transported to the SE Atlantic via the Agulhas Leakage. Symbols are color coded, with $^{87}Sr/^{86}Sr$ >0.720 red; 0.715-0.720 orange, 0.710-0.715 green, and <0.710 violet. Isolines are shown for 0.720, 0.715, 0.710. Squares are data from Dasch (1969); circles, this study. Locations of RC11-83, and V34-157 are shown by the large red circles from left to right, respectively.

Beyond our goal of characterizing terrigenous sediment contributions to the Cape Basin, the provenance of sediment along the Natal Valley has potential for constraining relative transport vigour of northward-flowing currents. It appears that there is a trend of generally decreasing Sr isotope ratios along the eastern South African margin. If this is confirmed with additional data, then $^{87}Sr/^{86}Sr$ values in down core records from the Natal Valley might be taken to reflect increased vigour of deep currents. The cores collected during this cruise are ideal for determining if a systematic pattern exists, In order to begin the core-top survey immediately, we have sampled the surface sediments of most of the cores collected on CD154.

Nd isotopes as water mass tracers. Nd isotope ratios in seawater and marine precipitates have characteristics that make them potentially powerful palaeoceanographic tracers. Studies of Fe-Mn crusts and nodules and direct measurements of seawater have shown that they are distinct in different ocean basins, with the highest values in the Pacific (ε_{Nd} =0 to –4) and low values in the north Atlantic (ε_{Nd}= –13 to –14), broadly reflecting the ages of the surrounding continents (c.f. Albarède and Goldstein, 1992; Goldstein and Hemming, 2003; Frank, 2002, and references therein). Circum-Antarctic and Indian deep waters have intermediate values (ε_{Nd}= −7 to −9), consistent with mixing of Atlantic- and Pacific-derived deep waters. Two observations demonstrate the utility of Nd isotopes as water mass tracers. (1) Globally, Nd isotope ratios in seawater strongly correlate with silica, indicating that the Nd isotope ratios conserve the characteristics of major water masses (Fig. 19). (2) In depth profiles from the South Atlantic and western Indian Ocean, Nd isotope ratios show a zig-zag pattern (Fig. 20), higher at intermediate depths dominated by AAIW, lower at greater depths dominated by NADW, and higher at deepest levels dominated by AABW.

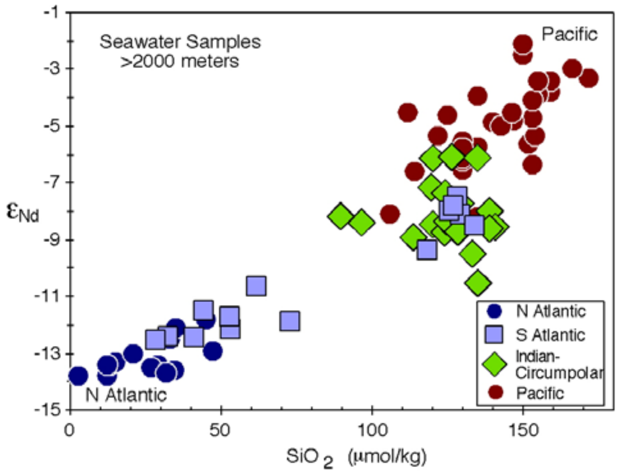

Figure 19. *Nd isotope ratios vs silicate in deep seawater.* Throughout the oceans there is a very good covariation of ε_{Nd} and SiO2 with most data plotting between the North Atlantic and Pacific endmembers. Plotted data are from >2500 mbsl, except two Drake Passage data from 1900 and 2000 m. Data are from the literature, listed in Goldstein and Hemming (2003). Where salinity or silicate were not available in the publication they were estimated from Levitus (1994), using location and depth.

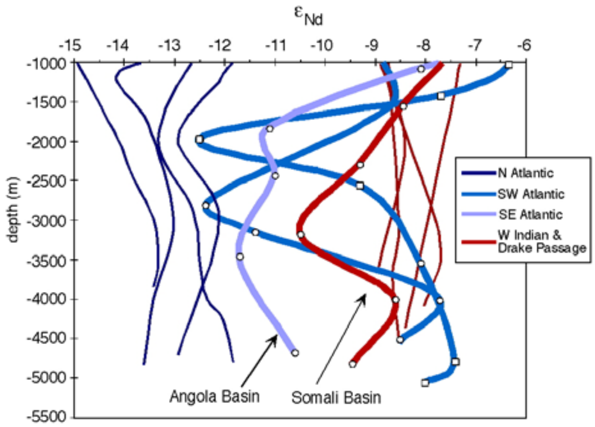

Figure 20. *Nd isotope ratios vs depth in the Atlantic and western Indian and Circum-Antarctic oceans.* Profiles from the North Atlantic are generally uniform with depth and have low values, while most from the western Indian and Circum-Antarctic are also generally uniform with high values. Profiles from the South Atlantic and one from the West Indian ocean show large variations with depth, which can range from near North Atlantic values, reflecting NADW, to near Circumpolar-West Indian values, reflecting AABW and AAIW in individual profiles. The zig-zag profiles show that the Nd isotopic signature of water masses is conserved over the transport path in the Atlantic and into the western Indian oceans. Zig-zag patterns are from Bertram and Elderfield (1993) and Jeandel (1993), the rest are from the literature and listed in Goldstein and Hemming (2003).

Thus, like stable isotope and trace element proxies, Nd isotope variations in seawater can be directly related to water masses in depth profiles. However, unlike nutrient proxies, Nd isotope ratios are not measurably fractionated either by biological processes or by temperature. Therefore, in situations where these effects may cause complications with conventional tracers, the Nd isotopic signature of the source waters is conserved. Indeed, recent applications by our group at LDEO demonstrated that Nd isotope ratios in the authigenic Fe-Mn component of deep Cape Basin cores (assumed to represent the deep water) show temporal variability indicating changes in global overturning circulation on glacial-interglacial and millennial time-scales (Rutberg et al., 2000; Piotrowski et al., submitted). While the value of Nd isotopes is being increasingly recognized as a palaeoceanographic tracer, it is still a "fringe" tool and we believe that the samples taken during CD154 will be important for giving it further legitimacy.

In CD154 we have a two-fold set of objectives for applying Nd isotopes as an ocean circulation tracer. (1) The samples taken during CD154 give us an excellent opportunity to calibrate the present-day Nd isotope ratios of major water masses in a key region of inter-ocean exchange. In this context it is also an opportunity to further ground-truth the utility of Nd isotope ratios as water mass tracers, which is important for reasons given below. (2) We plan to use Nd isotopes as palaeoceanographic tracers in the collected deep sea cores for further investigations of changes in deep ocean circulation. The core samples collected on CD154 are key for sorting out various scenarios on its history through warm and cold climate cycles using Nd isotopes.

Nd isotopes in CD154 water column samples

Although the South Atlantic and western Indian Ocean depth profiles have been among the most important evidence showing that Nd isotope ratios are conservative deep water mass tracers, there are only four such profiles in the literature (Fig. 4), and none are from the Agulhas region. Two profiles are from the southwest Atlantic, one is from the southeast Atlantic in the Angola Basin north of the Walvis Ridge, and one is from the western Indian Ocean in the Somali Basin north of Madagascar.

On the basis of the sparse available data we expect that Nd isotope ratios in the water column will reflect the water masses, however, it is very important to calibrate the present-day variability through measurements. For example, southeast of the Somali Basin zig-zag profile, there are other water profiles in the Mozambique Basin that show no indication of a NADW Nd isotope signal (Bertram and Elderfield, 1993), and the extent that water masses retain the Nd isotopic signal of the sources is a matter of current debate (c.f. Bertram and Elderfield, 1993; Jeandel, 1993; Jeandel et al., 1995; Goldstein and Hemming, 2003). The southwest flowing Agulhas Current is underlain by northeast flowing AAIW, NADW, and AABW. If Nd isotopes behave conservatively in the Agulhas region, then AAIW and AABW will have higher values and NADW lower values. Agulhas Current samples are likely to be different from the deeper water masses. In effect, the samples taken in this cruise will either show that the Nd isotope ratios are modified over this portion of the water mass transport path, or they will demonstrate their utility as isotopes to trace the northeastward movement of AAIW, NADW, and AABW from the South Atlantic to the Indian Ocean.

Cores taken from different depths associated with the major intermediate and deep water masses on CD154 (Fig. 21) give us a unique opportunity to calibrate the relationships between Nd in the water column and Nd isotope ratios in the authigenic fraction of deep sea sediments. In our work we have been using the following criteria to test the integrity of the marine signal for Nd isotope ratios of the authigenic Fe-Mn component of deep sea cores. (1) The Sr isotope ratios of all samples must be marine. (2) Nd isotope ratios of Holocene core top samples, plotted against the SiO_2 abundance of the overlying water (taken from Levitus 1994), must lie on the global dissolved ε_{Nd}-SiO_2 correlation (Fig. 3). In CD154 we are sampling waters representing AAIW, NADW, and NADW-AABW mixtures (Fig. 21), as well as cores taken from water depths that are bathed in these water masses. Thus we have a unique opportunity to directly compare Nd isotope ratio of the authigenic fraction of the sediments with the ambient water mass. This comparison will be a crucial component for testing the utility of Nd isotope ratios as palaeo-circulation tracers.

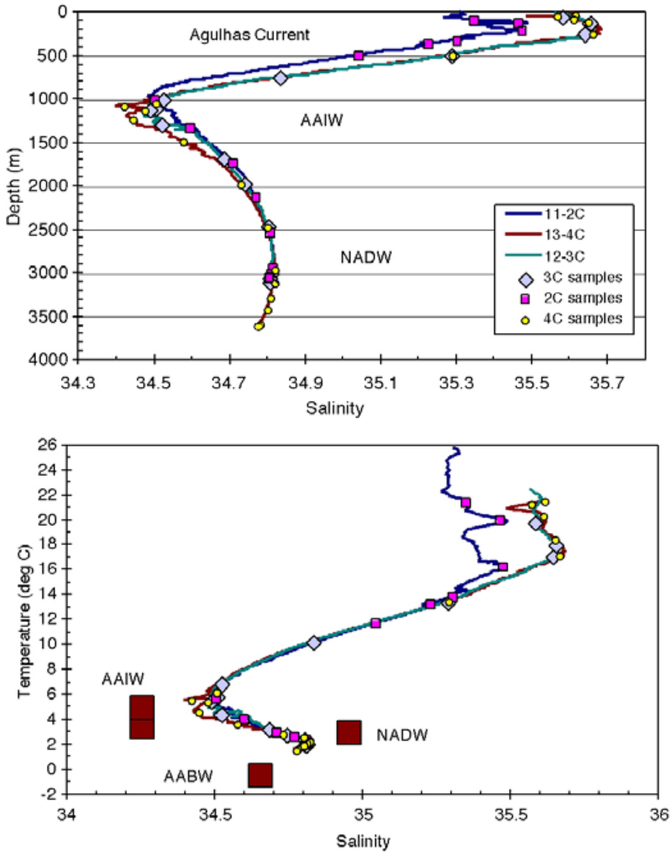

Figure 21. *Depth-salinity and temperature-salinity profiles of the first three CD154 CTD sites*. The samples for each site are also shown, and they cover the Agulhas Current, AAIW, NADW, and intermediate compositions. Deepest samples are NADW-AAIW mixtures.

Nd isotope ratios and palaeocirculation

The deep sea cores sampled during CD154 afford a great opportunity to use Nd isotope ratios as a proxy to address current issues in palaeocirculation. We have a uniquely controlled experiment to determine temporal changes in the NADW signal in Circumpolar and Indian Ocean waters. Cores are being systematically taken from water depths of ~1000-1500, 2000-2500, and >3000 mbsl along transects across the continental margin, and surfaces are currently bathed in dominantly AAIW, AAIW to NADW mixtures, and NADW-AABW mixtures, respectively (c.f. Fig. 5). The Nd isotope ratios of the authigenic Fe-Mn oxide fractions of core tops bathed in AAIW- (or AABW-) dominated waters are expected to show (high) ε_{Nd} of about –7 to –8, and those bathed in NADW should show (lower) ε_{Nd} of about –10 to –11. We fully expect that sedimentation rates will allow us to map the geometry of changes in water mass compositions at least on the time resolution of marine isotope stages. Various scenarios for changes (or the absence thereof) in global overturning circulation can be accommodated, depending on the results:

(1) If there are no substantial changes in the geometry of water masses along the Agulhas "gateway" then the results for the LGM will be the same as for the Holocene.

(2) If northward movement of the STC(?) cut off NADW export to the western Indian Ocean along the Agulhas "gateway", then we expect to see "Circumpolar-type" Nd isotope ratios at all depths during the LGM.

(3) Shoaling of NADW would bring low Nd isotope ratios to shallower core sites, while the coeval incursion of AABW would bring higher Nd isotope ratios to the deeper sites.

(4) If weakening of the NADW (low ε_{Nd}) export flux during cold climate intervals results in a stronger Pacific (high ε_{Nd}) influence on the Circum-Antarctic, then Nd isotope ratios in AAIW and AABW would increase to values higher than observed today. If this is accompanied by shoaling of the weakened NADW flux, then shallower cores should show lower Nd isotope ratios.

Importance of Collaborations. Finally, we emphasize the importance of the collaboration with the Cardiff and Barcelona groups in coordinating multiple proxy studies of these cores, as vital to the success of the Lamont investigations. For example, the expanded sediment sections are the result of contourite depositions by these deep water masses, and accordingly, the sortable silt analyses will be complementary to these analyses. In addition, the stable isotope stratigraphy will be key to the success of the Lamont investigations.

15. Cruise problems

These comments are offered in a constructive spirit with the hope that the scientific operations can be improved to a standard that NERC funded science warrants, i.e. safe, efficient and yielding the highest quality results.

- The cruise suffered from major problems during the mobilisation period. They essentially boiled down the winches being in a very poor condition. This caused a much degraded lifting performance and failure at a routine lifting test carried out for Lloyd's certification prior to our cruise. The eventual solution was to crop 3000 m off the main warp to increase the torque on the drum and so improve the winches lifting capability. This solution resulted in an 8- day loss of sea time and the inability to core beyond ~3500 m water depth. During the cruise the winches remained problematic. This included a near miss incident when the main winch jumped out of gear while a core was on wire being hauled in. The emergency brake fortunately stopped the free-falling core! The main winch problems were exacerbated by the failure of the Rexroth winch which made core handling during deployment and recovery more complicated;
- the ship's stability was very poor and in particular significant acceleration at the end of a roll cycles. This turned out to be caused by the ship's stability tanks being empty (due to rust);
- we were unable to collect any box cores as only the NIOZ box core was available (the UKORS SMBA box corer was lost earlier in the year) and its use necessitated a re-rigging of the deck configuration. Such a re-rig was time consuming and not viable in moderate swell
- the 3.5 kHz profiler was of poor quality and the software/print out was of limited flexibility and "there for use"??. We suggest this system is overhauled and a better more integrated display system either be built in house or sought commercially;
- the measurement of optical transmission has been a long running saga and again during CD154 the transmissometer did not function. These problems should be investigated and taken up with the transmissometer manufactures if necessary;
- the ship GPS was intermittently lost and we are not convinced that there is not a problem with the aerial configuration. The scientific Trimble was more reliable and could be fed into the ship's navigation. There is an urgent need for a unified ships tracker program which is accessible both from bridge and main laboratory.

All of the above problems led to the following losses or operational limits of our sampling campaign:

- limited survey time/water column work due to time lost upon departure. This included the cancellation of our proposed 15-cast hydrographic transect off East London;
- no cores from > ~3500 m water depth, thereby we lost access to valuable key bottom water sites;
- no box core samples;
- loss of work on the South Agulhas Plateau.

In summary, CD154 was blighted by the general infrastructure quality and declined technical state of the *Charles Darwin*. Certainly, it is our view that on this occasion the ship did not compete internationally with the current standard of marine platforms. It is ridiculous given the limited and competitive nature of obtaining NERC research support (i.e. top 10 % internationally) that the *Charles Darwin* as a scientific platform was in such a poor state (α2!).

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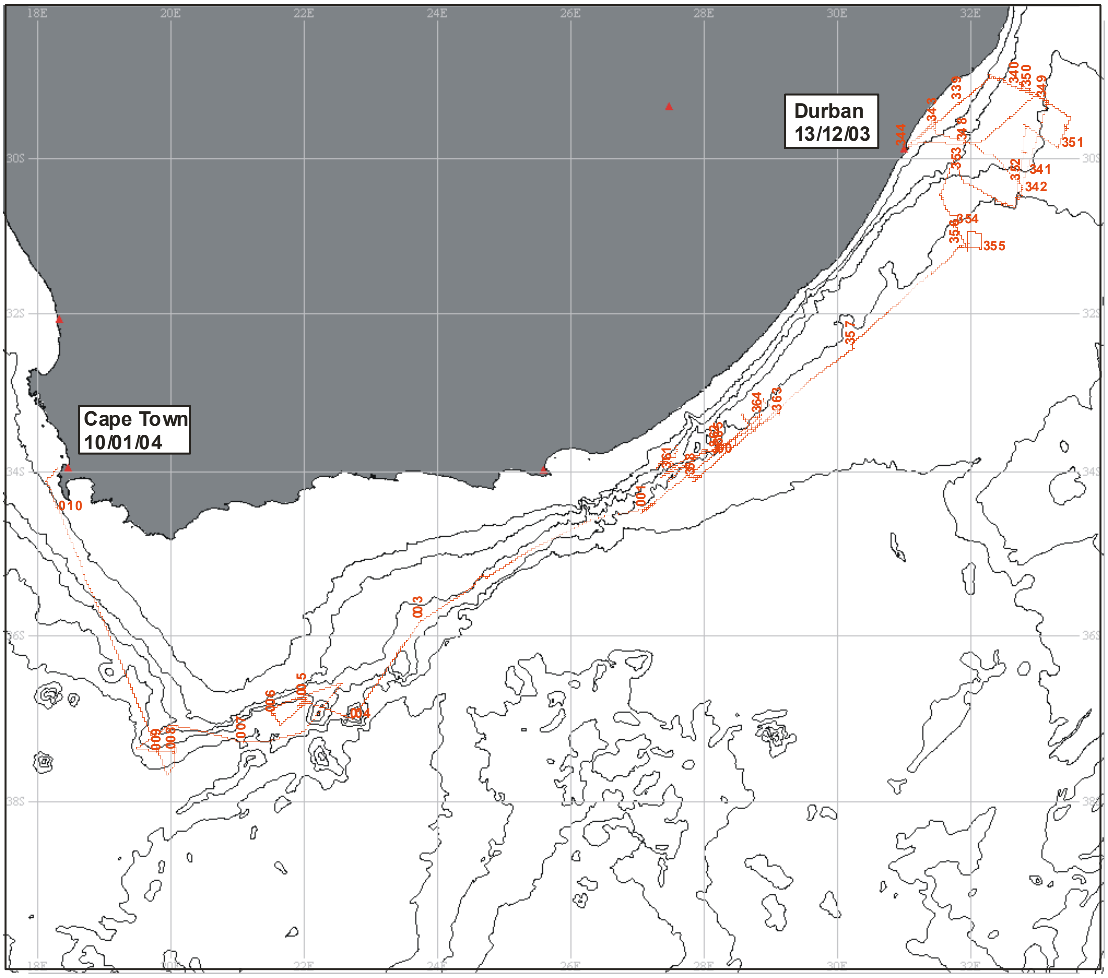
17. CD154 Cruise Track

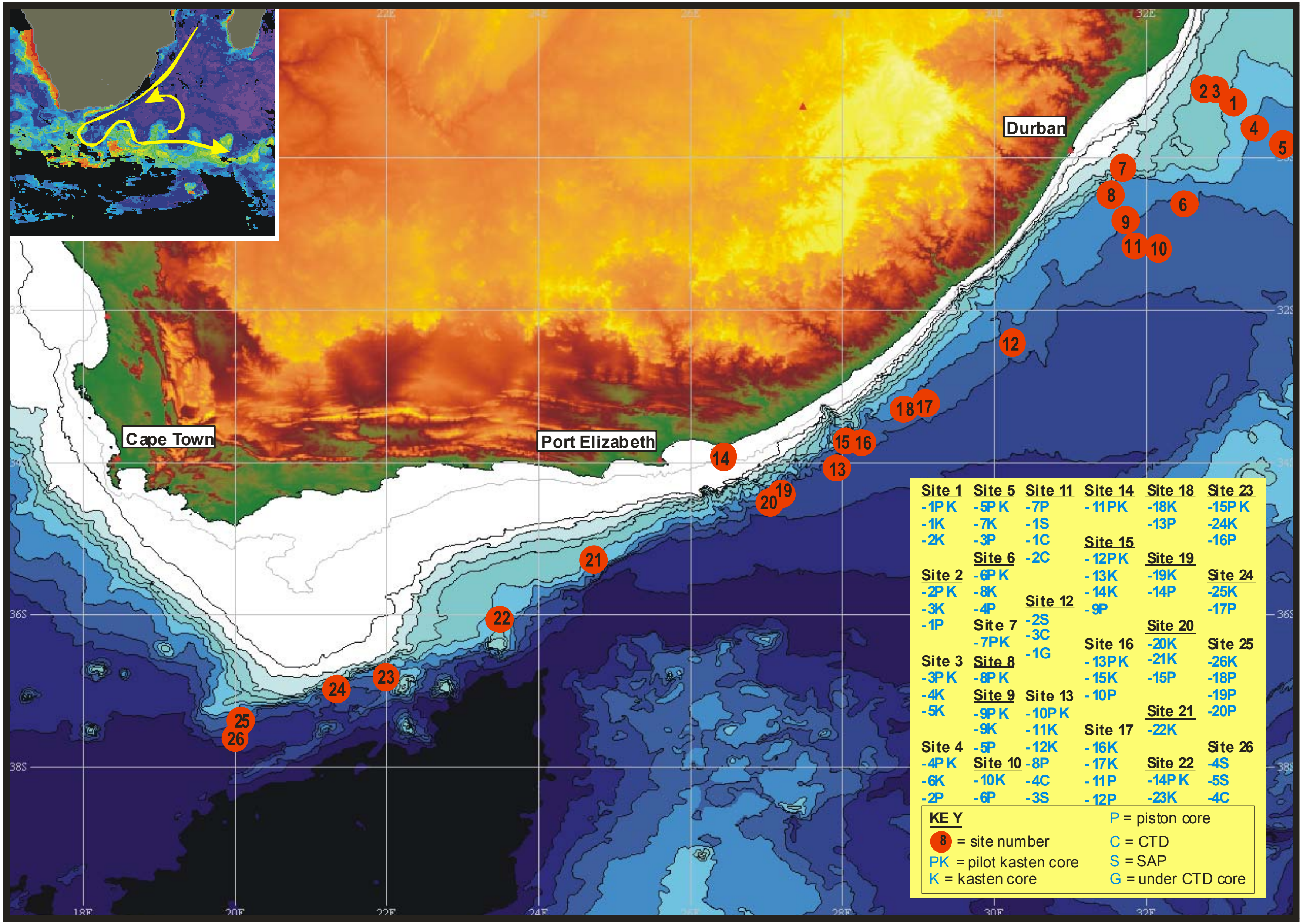


MERCATOR PROJECTION

SCALE 1 TO 2500000 (NATURAL SCALE AT LAT. 0)

INTERNATIONAL SPHEROID PROJECTED AT LATITUDE 0

18. CD154 Station Map (See Station log for further information)



Station No.	Insrument/ 0peration	Core /Cast No.	Date	Time (Z)	Latitude (S)	Longitude (E)	water depth (m)	barrel length (m)	Recovery (cm)	Remarks
1	Pilot Kasten	CD154-01-1PK	14-Dec-03	12:51	29°16.10'	033°09.25'	2010	2	192	
1	Kasten	CD154-01-1K	14-Dec-03	16:51	29°17.46'	033°08.64'	1997	6	183	Core bent at joint
1	Kasten	CD154-01-2K	14-Dec-03	21:08	29°16.41'	033°09.22'	2019	4	357	
2	Pilot Kasten	CD154-02-2PK	15-Dec-03	04:43	29°04.10'	032°46.04'	1623	2	181	
2	Kasten	CD154-02-3K	15-Dec-03	09:02	29°03.86'	032°46.13'	1626	4	242	
2	Piston	CD154-02-1P	15-Dec-03	13:08	29°05.08'	032°45.61'	1613	9	487	Core barrel bent, 121 cm trigger core collected
3	Pilot Kasten	CD154-03-3PK	15-Dec-03	18:47	29°07.63'	032°53.61'	1745	2	174	
3	Kasten	CD154-03-4K	15-Dec-03	21:16	29°06.91'	032°53.37'	1745	6	0	Bottom 2 m section of barrel lost
3	Kasten	CD154-03-5K	16-Dec-03	00:07	29°07.05'	032°53.31'	1747	4	120	
4	Pilot Kasten	CD154-04-4PK	16-Dec-03	10:55	29°36.66'	033°26.77'	2533	2	51	
4	Kasten	CD154-04-6K	16-Dec-03	14:26	29°35.16'	033°26.39'	2469	3	270	
4	Piston	CD154-04-2P	16-Dec-03	19:41	29°37.21'	033°26.46'	2537	6	526	
5	Pilot Kasten	CD154-05-5PK	17-Dec-03	12:15	29°55.26'	033°47.53'	1784	2	93	

19. Station Log

Station No.	Insrument/ 0peration	Core /Cast No.	Date	Time (Z)	Latitude (S)	Longitude (E)	water depth (m)	barrel length (m)	Recovery (cm)	Remarks
5	Kasten	CD154-05-7K	17-Dec-03	14:08	29°56.05’	033°48.91’	1850	4	127	
5	Piston	CD154-05-3P	17-Dec-03	16:50	29°56.35’	033°48.08’	1850			Site abandoned due to bad weather
6	Pilot Kasten	CD154-06-6PK	18-Dec-03	07:47	30°36.51’	032°29.26’	3015	2	185	Over-penetrated, sediment surface lost
6	Kasten	CD154-06-8K	18-Dec-03	10:47	30°35.25’	032°31.14’	2997	4	0	Core catcher lost
6	Piston	CD154-06-4P	18-Dec-03	15:00	30°35.59’	032°30.59’	2998	6	490	
7	Pilot Kasten	CD154-07-7PK	19-Dec-03	03:40	30°07.92'	031°41.84'	1017	2	55	
8	Pilot Kasten	CD154-08-8PK	19-Dec-03	09:25	30°28.67'	031°32.90'	2936	2	0	Sandy sediment, core catcher failed
9	Pilot Kasten	CD154-09-9PK	19-Dec-03	18:30	30°49.39'	031°43.91'	2987	2	181	
9	Kasten	CD154-09-9K	19-Dec-03	21:20	30°50.11'	031°44.56'	2986	4	306	
9	Piston	CD154-09-5P	20-Dec-03	02:00	30°50.07'	031°44.43'	2982	9	705	
10	Piston	CD154-10-6P	20-Dec-03	04:00	31°10.36'	032°08.91'	3076	12	969	
10	Kasten	CD154-10-10K	20-Dec-03	17:50	31°10.21'	032°09.02'	3074	4	363	
11	Piston	CD154-11-7P	21-Dec-03	04:14	31°08.79'	031°52.19'	3072		913	
11	SAP	CD154-11-1S	21-Dec-03	14:24	31°08.73'	031°50.81'	3073			

Station No.	Insrument/ 0peration	Core /Cast No.	Date	Time (Z)	Latitude (S)	Longitude (E)	water depth (m)	barrel length (m)	Recovery (cm)	Remarks
11	CTD	CD154-11-1C	21-Dec-03		sensor failure					
11	CTD	CD154-11-2C	21-Dec-03	20:15	31°09.43'	031°52.24'	3073		24 niskin bottles	
12	SAP	CD154-12-2S	22-Dec-03	17:41	32°25.51'	030°13.92'	3154			
12	CTD	CD154-12-3C	22-Dec-03	21:10	32°25.51'	030°13.92'	3154			
12	mini gravity	CD154-12-1G	22-Dec-03	21:10	32°25.51'	030°13.92'	3154		0	Corer mounted underneath CTD, corer washed out
13	CTD	CD154-13-4C	23-Dec-03	18:35	34°03.19'	027°57.93'	3600		24 Niskin bottles	
13	SAP	CD154-13-3S	24-Dec-03	01:56	34°02.80'	027°58.40'	3600			
13	Pilot Kasten	CD154-13-10PK	24-Dec-03	07:42	34°02.70'	027°57.78'	3596		2	13-42 cm sediment gap in liner
13	Kasten	CD154-13-11K	24-Dec-03	11:50	34°04.08'	027°56.89'	3683		0	
13	Kasten	CD154-13-12K	24-Dec-03	14:48	34°05.70'	027°53.58'	3612		344	Wire at angle, assumed oblique penetration
13	Piston	CD154-13-8P	24-Dec-03	19:36	34°03.04'	027°54.00'	3633		827	
14	Pilot Kasten	CD154-14-11PK	25-Dec-03	06:06	33°52.36'	027°23.72'	1534	2	0	Corer fell over
15	Pilot Kasten	CD154-15-12PK	27-Dec-03	08:51	33°43.09'	028°14.47'	3152	2	183	
15	Kasten	CD154-15-13K	27-Dec-03	12:28	33°41.27'	028°14.82'	3145	4	110	

Station No.	Insrument/ 0peration	Core /Cast No.	Date	Time (Z)	Latitude (S)	Longitude (E)	water depth (m)	barrel length (m)	Recovery (cm)	Remarks
15	Piston	CD154-15-9P	27-Dec-03	16:35	33°42.82'	028°11.37'	3182	12	758	
15	Kasten	CD154-15-14K	27-Dec-03	22:50	33°43.61'	028°12.16'	3236	4	355	
16	Pilot Kasten	CD154-16-13PK	28-Dec-03	05:40	33°42.21'	028°14.45'	3215	2	43	
16	Kasten	CD154-16-15K	28-Dec-03	08:00	33°42.07'	028°14.57	3166	4	106	
16	Piston	CD154-16-10P	28-Dec-03	11:30	33°41.69'	028°14.72	3173	6	569	79 cm trigger core
17	Piston	CD154-17-11P	29-Dec-03	00:09	33°16.28'	029°07.30'	3333	12	1178	100 cm trigger core
17	Piston	CD154-17-12P	29-Dec-03	05:37	33°16.05'	029°07.37'	3335	15	1384	
17	Kasten	CD154-17-16K	29-Dec-03	13:05	33°15.90'	029°07.66'	3344	8	0	Bottom section bent
17	Kasten	CD154-17-17K	29-Dec-03	16:32	33°16.13'	029°07.29'	3333	4	363	
18	Piston	CD154-18-13P	30-Dec-03	10:39	33°18.31'	028°50.82'	3090	12	1121	Bent barrel, trigger core empty
18	Kasten	CD154-18-18K	30-Dec-03	17:57	33°18.69'	028°51.00'	3037	4	383	
19	Kasten	CD154-19-19K	31-Dec-03	17:30	34°24.19'	027°12.64'	3544	4	382	Repenetration of top 1 m sediment section
19	Piston	CD154-19-14P	01-Jan-04	01:35	34°24.69'	027°13.01'	3572	9	841	Bent barrel
20	Kasten	CD154-20-20K	01-Jan-04	08:20	34°27.02'	027°08.85'	3512	4	338	

Station No.	Insrument/ 0peration	Core /Cast No.	Date	Time (Z)	Latitude (S)	Longitude (E)	water depth (m)	barrel length (m)	Recovery (cm)	Remarks
20	Kasten	CD154-20-21K	01-Jan-04	12:00	34°27.10'	027°08.29'	3561	7	130	wire at angle, ship's drift off site
20	Piston	CD154-20-15P	01-Jan-04	17:45	34°27.38'	027°08.50'	3583	9	875	80 cm trigger core
21	Kasten	CD154-21-22K	02-Jan-04	15:37	35°17.02'	024°42.82'	2190	4	0	
22	Pilot Kasten	CD154-22-14PK	03-Jan-04	08:10	36°06.99'	023°30.94'	2120	2	28	Sediment bagged
22	Kasten	CD154-22-23K	03-Jan-04	21:09	36°00.72'	023°30.37'	2180	4	342	
23	Pilot Kasten	CD154-23-15PK	04-Jan-04	11:54	36°49.25'	022°59.46'	3175	2	180	Overpenetrated, sediment surface lost
23	Kasten	CD154-23-24K	04-Jan-04	16:19	36°48.23'	022°00.59'	3173	4	343	
23	Piston	CD154-23-16P	05-Jan-04	00:32	36°49.08'	022°00.02'	3189	12	1103	96 cm trigger core
24	Kasten	CD154-24-25K	05-Jan-04	16:50	36°57.73'	021°32.91'	3417	4	382	
24	Piston	CD154-24-17P	05-Jan-04	21:00	36°57.78'	021°33.07'	3429	9	804	99 cm trigger core
25	Kasten	CD154-25-26K	07-Jan-04	16:04	37°24.57'	020°03.01'	3692	4	0	
25	Piston	CD154-25-18P	07-Jan-04	21:26	37°24.53'	020°03.00'	3692	6	481	Water saturated foram sand, top ~1 m liquified
25	Piston	CD154-25-19P	08-Jan-04	02:22	37°24.54'	020°03.24'	3691	12	981	Water saturated foram sand, top ~1 m liquified
25	Piston	CD154-25-20P	08-Jan-04	08:00	37°24.49'	020°03.07'	3692	15	1153	Water saturated foram sand, top ~1 m liquified

Station No.	Insrument/ 0peration	Core /Cast No.	Date	Time (Z)	Latitude (S)	Longitude (E)	water depth (m)	barrel length (m)	Recovery (cm)	Remarks
26	SAP	CD154-26-4S	08-Jan-04	13:15	37°35.58'	020°02.49'	4139			
26	CTD	CD154-26-5C	08-Jan-04	14:02	37°36.12'	020°01.05'	4126			
26	SAP	CD154-26-5S	08-Jan-04	21:20	37°40.31'	019°58.59'	4352			

Total sediment recovery 234.59 m

20. Operation log sheets

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-01-1PK Date: 14/12/03 (348)
Position: 29°15.59'S 033°09.05'E
Time start: 11:54 Time end:
Instrument: Box/Kasten/Piston/Multi
Barrel Length: 2m pilot

Station water depth: 1977m

	Time (GMT)	Position Latitude	Longitude
In water:	11:58	029°15.93'S	033°09.12'E
On seafloor:	12:51	029°16.10'S	033°09.25'E
On deck:			

On seafloor water depth: 2010m
Wire out Length: 2017m
Pull-out load (tonnes): ~4.2
Core length recovered: 1.92cm
Remarks: Reasonably intact sediment surface

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-01-1k Date: 14/12/03 (348)
Position: 29°16.61'S 033°08.49'E
Time start: 15:58 Time end: 17:40

Instrument: Box/Kasten/Piston/Multi

Barrel Length: 6m

Station water depth: 1987m

	Time (GMT)	Position Latitude	Longitude
In water:	16:02	029°16.73'S	033°08.40'E
On seafloor:	16:51	029°17.46'S	033°08.64'E
On deck:	17:40	029°18.42'S	033°08.93'E

On seafloor water depth: 1997m
Wire out Length: 2017m
Pull-out load (tonnes): 4.5
Core length recovered: 1.83cm
Remarks: Moved ship slightly in order to catch less condensed section
Join between bottom and mid-section (at ~2m) is bent/snapped

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-01-1PK Date: 14/12/03 (348)
Position: 29°15.59'S 033°09.05'E
Time start: 11:54 Time end:
Instrument: Box/Kasten/Piston/Multi
Barrel Length: 2m pilot

Station water depth: 1977m

	Time (GMT)	Position Latitude	Longitude
In water:	11:58	029°15.93'S	033°09.12'E
On seafloor:	12:51	029°16.10'S	033°09.25'E
On deck:			

On seafloor water depth: 2010m
Wire out Length: 2017m
Pull-out load (tonnes): ~4.2
Core length recovered: 1.92cm
Remarks: Reasonably intact sediment surface

Core Number: CD154-02-3K Date: 15/12/03 (349)
Position: 29° 03.3156'S 032° 45.4386'E
Time start: 08:13 Time end:
Instrument: Box/Kasten/Piston/Multi
Barrel Length: 4m

Station water depth: 1616m

	Time (GMT)	Latitude	Position	Longitude
In water:	08:17	29° 03.377'S		032° 45.499'E
On seafloor:	09:02	29° 03.857'S		032° 46.126'E
On deck:	09:51	29° 04.637'S		032° 46.691'E

On seafloor water depth: 1626m
Wire out Length: 1649m
Pull-out load (tonnes): 4.3
Core length recovered: 242cm
Remarks: 2 sets of green layers at 145cm and 208cm

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-02-2PK Date: 15/12/03 (349)
Position: 29° 02.0964'S 032° 45.222'E
Time start: 04:28 Time end: 07:00
Instrument: Box/Kasten/Piston/Multi (PILOT)
Barrel Length: 2m

Station water depth: 1614m

	Time (GMT)	Latitude	Position	Longitude
In water:	04:43	29° 02.397'S		032° 45.134'E
On seafloor:	05:40	29° 04.099'S		032° 46.039'E
On deck:	06:29	29° 05.017'S		032° 47.169'E

On seafloor water depth: 1623m
Wire out Length: 1649m
Pull-out load (tonnes): 4.2
Core length recovered: 181cm
Remarks: 181cm in the barrel and 20cm at the top that could not be recovered

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-02-1P Date: 15/12/03 (349)
Position: 29° 05.08'S 032° 45.61'E
Time start: 12:20 Time end:
Instrument: Box/Kasten/Piston/Multi
Barrel Length: 9m
Station water depth: 1613m

	Time (GMT)	Latitude	Position	Longitude
In water:	13:08	29° 04.150'S		032° 45.230'E
On seafloor:	14:00	29° 05.081'S		032° 45.608'E
On deck:	15:18	29° 05.923'S		032° 45.564'E

On seafloor water depth: 1622m
Wire out Length: 1621m
Pull-out load (tonnes): 3.97
Core length recovered: 487cm
Remarks: core barrel bent
Trigger core, 121cm
Section 1: 0-98cm
Section 2: 98cm-194cm
Section 3: 194cm-197cm (bagged sample 194-197cm attached to core section)
Section 4: 197cm-308cm
Section 5: 308cm-419cm
Section 6: 419cm-487cm

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-03-3PK Date: 15/12/03 (349)
Position: 29° 06.9055'S 032° 53.424'E
Time start: 18:10 Time end: 19:26
Instrument: Box/Kasten/Piston/Multi (PILOT)
Barrel Length: 2m

Station water depth: 1745m

	Time (GMT)	Latitude	Position	Longitude
In water:	~18:10			
On seafloor:	18:47	029° 07.6305'S		032° 53.614'E
On deck:	19:26	029° 08.079'S		032° 53.885'E

On seafloor water depth: 1750m
Wire out Length: 1765m
Pull-out load (tonnes): 4.7
Core length recovered: 174cm
Remarks: Excellent core, green layer is sloping

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-03-4K Date: 15/12/03 (349)
Position: 29° 06.3687'S 032° 53.2608'E
Time start: 20:38 Time end:
Instrument: Box/Kasten/Piston/Multi
Barrel Length: 6m

Station water depth: 1745m

	Time (GMT)	Position Latitude	Longitude
In water:	20:38	29° 06.3687'S	032° 53.2608'E
On seafloor:	21:16	29° 06.907'S	032° 53.368'E
On deck:			

On seafloor water depth: 1746.5m
Wire out Length: 1775m
Pull-out load (tonnes): 4.3
Core length recovered:
Remarks: Entry signal clean
No pull out in excess of tool weight
Lost bottom 2m

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-03-5K Date: 15/12/03 (349)
Position: 29° 06.1305'S 032° 53.2197'E
Time start: 23:18 Time end:
Instrument: Box/Kasten/Piston/Multi
Barrel Length: 4m

Station water depth: 1747m

	Time (GMT)	Position Latitude	Longitude
In water:	23:24	029° 06.3560'S	032° 53.3361'E
On seafloor:	00:07	029° 07.046'S	032° 53.3082'E
On deck:	00:48	029° 07.7444'S	032° 53.6878'E

On seafloor water depth: 1744m
Wire out Length: 1764m
Pull-out load (tonnes): 4
Core length recovered: 120cm
Remarks: recore after loss of the 2m section from the 6m barrel (see CD154-03-4K)

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-04-4PK Date: 16/12/03 (350)
Position: 29° 35.3625'S 033° 26.2826'E
Time start: 09:43 Time end:
Instrument: Box/Kasten/Piston/Multi (PILOT)
Barrel Length: 2m

Station water depth: 2518m

	Time (GMT)	Position Latitude	Longitude
In water:	09:47	029° 35.3625'S	033° 26.2526'E
On seafloor:	10:55	029° 36.6632'S	033° 26.7688'E
On deck:	11:45	029° 37.4520'S	033° 27.1830'E

On seafloor water depth: 2532.5m (2551m on 3.5KHz)
Wire out Length: 2563m
Pull-out load (tonnes): 4.4
Core length recovered: 51cm
Remarks:

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-04-6K Date: 16/12/03 (350)
Position: 29° 34.547'S 033° 24.959'E
Time start: 13:36 Time end: 15:45
Instrument: Box/Kasten/Piston/Multi
Barrel Length: 3m

Station water depth: 2426m

	Time (GMT)	Position Latitude	Longitude
In water:	13:36	29° 34.547'S	033° 24.959'E
On seafloor:	14:26	29° 35.156'S	033° 26.393'E
On deck:	15:24	29° 35.553'S	033° 25.771'E

On seafloor water depth: 2469m

Wire out Length: 2503m
Pull-out load (tonnes): 5.4
Core length recovered: 270cm
Remarks: 40m/min penetration speed
Impact looked very good on "chart record" readout –predict a good load

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-04-2P Date: 16/12/03 (350)
Position: 29° 36.60919'S 033° 27.4458'E
Time start: 17:52 Time end:
Instrument: Box/Kasten/Piston/Multi
Barrel Length: 6m

Station water depth: 2540m

	Time (GMT)	Position Latitude	Longitude
In water:	18:40	29° 36.9732'S	033° 27.3904'E
On seafloor:	19:41	29° 37.2135'S	033° 26.455'E
On deck:			

On seafloor water depth: 2537m
Wire out Length: 2575m
Pull-out load (tonnes): 4.2
Core length recovered: 526cm
Remarks: noisy entry signal, no extra pull out load

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-05-5PK Date: 17/12/03 (351)
Position: 29° 55.213'S 033° 47.399'E
Time start: 11:40 Time end:

Instrument: Box/Kasten/Piston/Multi (PILOT)
Barrel Length: 2m

Station water depth: 1780m

	Time (GMT)	Position Latitude	Longitude
In water:			
On seafloor:	12:15	29° 55.2637'S	033° 47.5270'E
On deck:	12:49	29° 55.3574'S	033° 47.8095'E

On seafloor water depth: 1784m
Wire out Length: 1796m
Pull-out load (tonnes): 4.8
Core length recovered: 93cm
Remarks:

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-05-7K Date: 17/12/03 (351)
Position: 29° 55.5756'S 033° 48.2757'E
Time start: 13:14 Time end: 14:56
Instrument: Box/Kasten/Piston/Multi
Barrel Length: 4m

Station water depth: 1830m

	Time (GMT)	Position Latitude	Longitude
In water:	13:20	29° 55.6466'S	033° 48.4669'E
On seafloor:	14:08	29° 56.045'S	033° 48.909'E
On deck:	15:24	29° 56.486'S	033° 49.370'E

On seafloor water depth: 1850m
Wire out Length: 1859m
Pull-out load (tonnes): 4.3
Core length recovered: 127cm
Remarks: no extra pull out load

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-05-5PK Date: 17/12/03 (351)
Position: 29° 55.213'S 033° 47.399'E
Time start: 11:40 Time end:
Instrument: Box/Kasten/Piston/Multi (PILOT)
Barrel Length: 2m

Station water depth: 1780m

	Time (GMT)	Position Latitude	Longitude
In water:			
On seafloor:	12:15	29° 55.2637'S	033° 47.5270'E
On deck:	12:49	29° 55.3574'S	033° 47.8095'E

On seafloor water depth: 1784m
Wire out Length: 1796m
Pull-out load (tonnes): 4.8
Core length recovered: 93cm
Remarks:

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-06-6PK Date: 18/12/03 (352)
Position: 30° 36.194'S 032° 30.305'E
Time start: 06:34 Time end: 08:53
Instrument: Box/Kasten/Piston/Multi (PILOT)
Barrel Length: 2m

Station water depth: 3009.5m

	Time (GMT)	Position Latitude	Longitude
In water:			
On seafloor:	07:47	30° 36.5056'S	032° 29.260'E
On deck:	08:53	30° 36.29169'S	032° 28.94412'E

On seafloor water depth: 3015m
Wire out Length: 3043m
Pull-out load (tonnes): 5.6
Core length recovered: 185cm
Remarks: over penetrated, lost core top

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-06-8K Date: 18/12/03 (352)
Position: 30° 35.3975'S 032° 31.2711'E
Time start: 10:00 Time end:
Instrument: Box/Kasten/Piston/Multi
Barrel Length: 4m

Station water depth: 2997m

	Time (GMT)	Position Latitude	Longitude
In water:			
On seafloor:	10:47	30° 35.253'S	032° 31.141'E
On deck:	11:42	30° 35.2734'S	032° 30.9840'E

On seafloor water depth: 2994m
Wire out Length: 3020m
Pull-out load (tonnes): 6.2
Core length recovered: 0cm
Remarks: catcher doors broke off in sediment

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-06-4P Date: 18/12/03 (352)
Position: 30° 35.590'S 032° 30.588'E
Time start: 13:16 Time end: 16:05
Instrument: Box/Kasten/Piston/Multi
Barrel Length: 6m

Station water depth: 2990m

	Time (GMT)	Position Latitude	Longitude
In water:	13:35	30° 35.191'S	032° 30.688'E
On seafloor:		30° 35.590'S	032° 30.588'E
On deck:		30° 35.988'S	032° 29.899'E

On seafloor water depth: 3001m
Wire out Length: 3009m
Pull-out load (tonnes): 6.4
Core length recovered: 490cm
Remarks: stiff, clay sediments at core base – no longer barrel, abandon site
Section 1: 0-100cm
Section 2: 100-199cm
Section 3a: 199-200cm
Section 3b: 200-345cm
Section 4: 345-490cm

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-07-7PK Date: 19/12/03 (353)
Position: 30° 08.300'S 031° 42.370'E
Time start: 03:40 Time end: 05:20
Instrument: Box/Kasten/Piston/Multi (PILOT)

Barrel Length: 2m

Station water depth: 1017m (water depth "on depth" 1005m)

	Time (GMT)	Position Latitude	Longitude
In water:	04:03	30° 07.861'S	031° 42.209'E
On seafloor:	04:35	30° 07.918'S	031° 41.842'E
On deck:	05:06	30° 08.0482'S	031° 41.1980'E

On seafloor water depth: 1010m
Wire out Length: 1021m
Pull-out load (tonnes): 3.5
Core length recovered: 55cm
Remarks: seemed to hit at 1016m but tension increased and decreased again at 1021m to clean impact

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-08-8PK Date: 19/12/03 (353)
Position: 30° 29.130S 031° 33.0557'E
Time start: 09:25 Time end: 11:30
Instrument: Box/<u>Kasten</u>/Piston/Multi (PILOT)
Barrel Length: 2m

Station water depth: 2936m

	Time (GMT)	Position Latitude	Longitude
In water:	09:24	30° 29.0822'S	031° 33.0337'E
On seafloor:	10:22	30° 28.674'S	031° 32.4184'E
On deck:	11:25	30° 28.198'S	031° 32.933'E

On seafloor water depth: 2934m
Wire out Length: 2950m
Pull-out load (tonnes): 5.18
Core length recovered: empty
Remarks: sandy sediment
Shutter springs probably too weak
305KHz not too convincing
site abandoned

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-09-9PK Date: 19/12/03 (353)
Position: 30° 51.077'S 031° 45.365'E
Time start: 18:30 Time end: 20:45
Instrument: Box/<u>Kasten</u>/Piston/Multi (PILOT)
Barrel Length: 2m

Station water depth: 2987m

	Time (GMT)	Position Latitude	Longitude
In water:			
On seafloor:	19:41	30° 50.131'S	031° 44.557'E
On deck:	20:45	30° 49.393'S	031° 43.907'E

On seafloor water depth: 2983m
Wire out Length: 3049m
Pull-out load (tonnes): 5.6
Core length recovered: 181cm
Remarks:

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-09-9K Date: 19/12/03 (353)
Position: 30° 50.9887'S 031° 45.10446'E
Time start: 21:20 Time end:
Instrument: Box/<u>Kasten</u>/Piston/Multi
Barrel Length: 4m

Station water depth: 2986m

	Time (GMT)	Position Latitude	Longitude
In water:			
On seafloor:	22:19	30° 50.9887'S	031° 45.10446'E
On deck:	20:45	30° 50.1074'S	031° 44.560'E

On seafloor water depth: 2986m
Wire out Length: 3026m
Pull-out load (tonnes): 6
Core length recovered: 306cm
Remarks: sandy layers in top of core that were not seen in PK

CD154
CORING OPERATION LOG SHEET

Core Number:	CD154-09-5P	Date:	20/12/03 (354)
Position:	30° 51.131'S 031° 44.557'E		
Time start:	02:00	Time end:	

Instrument: Box/Kasten/Piston/Multi
Barrel Length: 9m

Station water depth: 2982m

	Time (GMT)	Position Latitude	Longitude
In water:	03:20	30° 50.0841'S	031° 44.3141'E
On seafloor:	04:20	30° 50.0721'S	031° 44.43086'E
On deck:	05:55	30° 49.95614'S	031° 44.43465'E

On seafloor water depth: 2981m
Wire out Length: 3007m
Pull-out load (tonnes): 6.4
Core length recovered: 705cm
Section 1:0-146cm
Section 2:146-296cm
Section 3:296-449cm
Section 4a: 449-451cm
Section 4b: 451-578cm
Section 5:578-705cm
Remarks: sandy layers in top of core that were not seen in PK
[
CD154
CORING OPERATION LOG SHEET

Core Number:	CD154-10-10K	Date:	20/12/03 (354)
Position:	31° 10.708'S 032° 09.791'E		
Time start:	17:50	Time end:	

Instrument: Box/Kasten/Piston/Multi
Barrel Length: 4m

Station water depth: 3074m

	Time (GMT)	Position Latitude	Longitude
In water:	18:02	31° 10.6765'S	032° 09.659'E
On seafloor:	19:08	31° 10.214'S	032° 09.029'E
On deck:	20:15	31° 09.7244'S	032° 08.460'E

On seafloor water depth: 3075m
Wire out Length: 3105m
Pull-out load (tonnes): 6.3
Core length recovered: 363cm
Remarks:

CD154
CORING OPERATION LOG SHEET

Core Number:	CD154-10-6P	Date:	20/12/03 (354)
Position:	31° 10.70852'S 032° 09.66614'E		
Time start:	22:40	Time end:	

Instrument: Box/Kasten/Piston/Multi
Barrel Length: 12m

Station water depth: 3078m

	Time (GMT)	Position Latitude	Longitude
In water:	22:49	31° 10.70004'S	032° 09.64542'E
On seafloor:	23:57	31° 10.35632'S	032° 08.91166'E
On deck:			

On seafloor water depth: 3076m
Wire out Length: 3100m
Pull-out load (tonnes): 7
Core length recovered: 969cm
Remarks:
Section 1:0-76cm
Section 2:76-226cm
Section 3:226-377cm
Section 4:377-527cm
Section 5:527-678cm
Section 6:678-828cm
Section 7:828-696cm

CD154
SAPS OPERATION SHEET

Station Number:	CD154-11-1S	Date:21/12/03 (355)
Position:	31°08.73'S 031°50.81'E	CTD Number:

Water Depth: 3073m CD154-11-1C CD154-11-2C

	Meter	Deployment Depth	Wire out speed	Delay time	Pump time
SAP 1:	0019081 0018705	120m	60	16min	1hr
SAP 2:	0014672 0014175	500m	60	28min	1hr
SAP 3:	0013421 0013029	1000m	60	46min	1hr

Time out water: #1 16:25
#2 16:35
#3 16:45

Remarks:
SAP3 in 14:24 start 15:12 end 16:12
SAP2 in 14:39 start 15:09 end 16:09
SAP1 in 14:52 start 15:10 end 16:10

CD154
CTD OPERATION SHEET

Station Number: CD154-11 2C Date: 21/12/2003 (355)
Position: 31°09.42821'S 031°52.2442'E
Water Depth: 3073m
Time in water: 20:15 Time out water: 00:50

Sampling:

Bottle Number	Depth Fired	Sample Taken				
		$\delta^{18}O$	Nd	Filtered	Pa/Th	Sal
24	failed		Y		Y	
23	3053		Y		Y	
22	3040		Y	Y	Y	
21	3040		Y		Y	
20	3000		Y	Y	Y	
19	3000		Y		Y	
18	2930		Y	Y	Y	
17	2930		Y		Y	
16	2530		Y	Y	Y	
15	2530		Y		Y	
14	2130		Y	Y	Y	
13	2130		Y		Y	
12	1730		Y	Y	Y	
11	1730		Y		Y	
10	1330		Y	Y	Y	
9	1330		Y		Y	
8	1000		Y	Y	Y	
7	1000		Y		Y	
6	500		Y		Y	
5	360		Y		Y	
4	330		Y		Y	
3	215		Y		Y	
2	120		Y		Y	
1	90		Y		Y	

CTD Gravity Core: Taken: Yes / No
Core Number: CD154 11 7PT CD154 11 7P

CD154
OPERATION LOG SHEET

Core Number: CD154-11-7P Date: 21/12/03 (355)

Position: 31° 09.3485'S 031° 52.495'E
Time start: 04:14 Time end:
Instrument: Box/Kasten/Piston/Multi
Barrel Length: 12m

Station water depth: 3073m

	Time (GMT)	Position Latitude	Longitude
In water:	04:45	31° 09.154'S	031° 52.343'E
On seafloor:	05:47	31° 08.7945'S	031° 52.194'E
On deck:	06:55	31° 08.2568'S	031° 51.796'E

On seafloor water depth: 3072m
Wire out Length: 3092m

Pull-out load (tonnes): 6.7
Core length recovered: 913cm
Remarks: impact 25m/m
Haul 5m/m

CD154
SAPS OPERATION SHEET

Station Number:	CD154-12-2S	Date:22/12/03 (356)
Position:	32°25.51'S 030°13.92'E	CTD Number:
Water Depth:	3154m	CD154-12-3C

	Ltr	Meter	Deployment Depth	Wire out speed	Delay time	Pump time
SAP 1:	479	0019560 0019081	120m	60	18min	1hr
SAP 2:	628	0015300 0014672	1000m	60	36min	1hr
SAP 3:	524	0013945 0013421	2000m	60	72min	1hr

Time out water: #1 20:03
#2 20:20
#3 20:54

Remarks:
SAP3 in 17:41 start 18:53 end 19:53
SAP2 in 18:03 start 18:39 end 19:39
SAP1 in 18:23 start 18:41 end 19:41

CD154
CTD OPERATION SHEET

Station Number:	CD154-12 3C	Date: 21/12/2003 (355)
Position:	32°25.5135'S 030°13.915'E	
Water Depth:	3154m	
Time in water:	21:10	Time out water:

Sampling:

Bottle Number	Depth Fired	Sample Taken				
		$\delta^{18}O$	Nd	Filtered	Pa/Th	Sal
24	50					
23	3150			Y		
22	3100					
21	3100			Y		
20	3050					
19	3050			Y		
18	2500					
17	2500			Y		
16	2000					
15	2000			Y		
14	1700			Y		
13	1700					
12	1300			Y		
11	1300					
10	1130			Y		
9	1130					
8	1100			Y		
7	1100					
6	1000					
5	700					
4	500					
3	250					
2	120					
1	3150					

CTD Gravity Core: Taken: Yes / No
Core Number: CD154 12 1G
Remarks: small surface sample collected

CD154
SAPS OPERATION SHEET

Station Number:	CD154-13-3S	Date:24/12/03 (358)
Position:	34°02.7998'S 027°58.396'E	CTD Number: 13-4C
Water Depth:	3600m	

	Meter	Ltr	Deployment Depth	Wire out speed	Delay time	Pump time
SAP 1:	0019932 0019561	371	120m	60	18min	1hr
SAP 2:	0015870 0015300	1000	1000m	60	36min	1hr
SAP 3:						

Time out water: #1 03:40
Remarks:
SAP2 in 01:56 start 02:32 end 03:32
SAP1 in 02:18 start 02:36 end 03:36
SAP2 – one of the plastic water reservoirs came up empty

CD154
CTD OPERATION SHEET

Station Number: CD154-13 4C Date: 23/12/2003 (357)
Position: 34°03.19235'S 027°57.93215'E
Water Depth: 3600m
Time in water: 18:35 Time out water:
Sampling:

Bottle Number	*Depth Fired*	Sample Taken				
		$\delta^{18}O$	Nd	Filtered	Pa/Th	Sal
24	3670					
23	3670			Y		
22	3640					
21	3480			Y		
20	3480					
19	FAILED					
18	3330					
17	3170					
16	3000					
15	3000			Y		
14	2500					
13	2000			Y		
12	2000					
11	1500					
10	1250					
9	1150					
8	1085					
7	1060					
6	500					
5	250					
4	120					
3	75					
2	50					
1	25					

CTD Gravity Core: Taken: Yes / No
Core Number: Remarks: Filtered odds

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-13-10PK Date: 24/12/03 (358)
Position: 34° 02.67142'S 027° 57.996'E
Time start: 07:42 Time end:
Instrument: Box/Kasten/Piston/Multi (PILOT)
Barrel Length: 2m
Station water depth: 3596m

	Time (GMT)	Position Latitude	Longitude
In water:	07:57	34° 02.67142'S	027° 57.996'E
On seafloor:	09:29	34° 02.89595'S	027° 56.324'E
On deck:			

On seafloor water depth: 3596m
Wire out Length: 3779m
Pull-out load (tonnes): 6
Core length recovered: 202 cm (gap from 13cm – 42cm)
Remarks:

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-13-11K Date: 24/12/03 (358)

Position: 34° 03.0541'S 027° 58.1909'E
Time start: 11:50 Time end:
Instrument: Box/Kasten/Piston/Multi
Barrel Length: 4m

Station water depth: 3683m

	Time (GMT)	Position Latitude	Longitude
In water:	11:52	34° 03.054'S	027° 58.191'E
On seafloor:	13:06	34° 04.077'S	027° 56.8907'E
On deck:			

On seafloor water depth: 3683m
Wire out Length: 3711m
Pull-out load (tonnes): 5.9
Core length recovered: empty
Remarks:

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-13-12K Date: 24/12/03 (358)

Position: 34° 04.859'S 027° 55.093'E
Time start: 14:48 Time end: 18:30
Instrument: Box/Kasten/Piston/Multi
Barrel Length: 4m

Station water depth: 3630m

	Time (GMT)	Position Latitude	Longitude
In water:	14:48	34° 04.991'S	027° 54.857'E
On seafloor:	15:55	34° 05.696'S	027° 53.575'E
On deck:	17:08	34° 06.626'S	027° 52.045'E

On seafloor water depth: 3612m
Wire out Length: 3670m
Pull-out load (tonnes): 7.05
Core length recovered: 344cm
Remarks: Bedding planes change from horizontal to ~40° oblique angle – diagonal penetration?
IMPORTANT – core may have been labelled 13-13K

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-13-8P Date: 24/12/03 (358)

Position: 34° 02.83'S 027° 57.358'E
Time start: 19:36 Time end:
Instrument: Box/Kasten/Piston/Multi
Barrel Length: 12m

Station water depth: 3603m

	Time (GMT)	Position Latitude	Longitude
In water:	19:48	34° 02.942'S	027° 56.705'E
On seafloor:	21:29	34° 03.039'S	027° 53.955'E
On deck:			

On seafloor water depth: 3633m
Wire out Length: 3690m
Pull-out load (tonnes): 7.43
Core length recovered: 827cm
Remarks:
Section 1: 0-113cm
Section 2: 113-227cm
Section 3: 227-378cm
Section 4: 378-529cm
Section 5: 529-679cm
Section 6: 679-827cm

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-14-11PK Date: 25/12/03 (359)

Position: 33° 52.36197'S 027° 23.722'E
Time start: 06:06 Time end:
Instrument: Box/Kasten/Piston/Multi (PILOT)

Barrel Length: 2m

Station water depth: 1534m

	Time (GMT)	Position Latitude	Longitude
In water:	06:28	33° 53.365’S	027° 22.453’E
On seafloor:	07:32	33° 55.371’S	027° 20.307’E
On deck:			

On seafloor water depth: 1543m
Wire out Length: 1650m
Pull-out load (tonnes): 3.5
Core length recovered: empty
Remarks: appeared to drag along seafloor

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-15-12PK Date: 27/12/03 (361)
Position: 33° 41.352’S 028° 14.984’E
Time start: 08:51 Time end:
Instrument: Box/Kasten/Piston/Multi (PILOT)
Barrel Length: 2m

Station water depth: 3152m

	Time (GMT)	Position Latitude	Longitude
In water:	09:01	33° 41.61145’S	028° 14.94152’E
On seafloor:	10:14	33° 43.088’S	028° 14.471’E
On deck:			

On seafloor water depth: 3273m
Wire out Length: 3330m
Pull-out load (tonnes): 6.3
Core length recovered: 183cm
Remarks

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-15-13K Date: 27/12/03 (361)
Position: 33° 41.2654’S 028° 14.81575’E
Time start: 12:28 Time end: 01:40
Instrument: Box/Kasten/Piston/Multi
Barrel Length: 4m

Station water depth: 3145m

	Time (GMT)	Position Latitude	Longitude
In water:	12:30	33° 41.373’S	028° 14.761’E
On seafloor:	13:57	33° 42.812’S	028° 14.322’E
On deck:	14:58	33° 43.601’S	028° 13.73484’E

On seafloor water depth: 3257m
Wire out Length: 3305m
Pull-out load (tonnes): 5.3
Core length recovered: 110cm

Remarks: Tubed like a pilot, CD154-15-12PK processed as Kasten

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-15-14K Date: 27/12/03 (361)
Position: 33° 42.70695’S 028° 14.12696’E
Time start: 22:50 Time end: 01:40
Instrument: Box/Kasten/Piston/Multi
Barrel Length: 4m

Station water depth: 3236m

	Time (GMT)	Position Latitude	Longitude
In water:	23:01	33° 42.92496’S	028° 13.80133’E
On seafloor:	00:08	33° 43.61080’S	028° 12.15924’E
On deck:	01:18	33° 43.6008’S	028° 11.53637’E

On seafloor water depth: 3272m
Wire out Length: 3349m
Pull-out load (tonnes): 6.67
Core length recovered: 355cm
Remarks:

CD154
CORING OPERATION LOG SHEET

Core Number:	CD154-15-9P	Date:	27/12/03 (361)
Position:	33° 42.82'S 028° 11.369'E		
Time start:	16:35	Time end:	

Instrument: Box/Kasten/Piston/Multi
Barrel Length: 12m

Station water depth: 3182m

	Time (GMT)	Position Latitude	Longitude
In water:	17:46	33° 41.997'S	028° 13.08'E
On seafloor:	21:29	33° 42.82034'S	028° 11.36937'E
On deck:	20:41	33° 43.4321'S	028° 09.39808'E

On seafloor water depth: 3242m
Wire out Length: 3265m
Pull-out load (tonnes): 6.9
Core length recovered: 758cm
Remarks: Problem during deployment due to use of hydrographic winch

CD154
CORING OPERATION LOG SHEET

=Core Number:	CD154-16-13PK	Date:	28/12/03 (362)
Position:	33° 40.01244'S 028° 15.31296'E		
Time start:	05:40	Time end:	

Instrument: Box/Kasten/Piston/Multi (PILOT)
Barrel Length: 2m

Station water depth: 3092m

	Time (GMT)	Position Latitude	Longitude
In water:			
On seafloor:	05:48	33° 42.20586'S	028° 14.44713'E
On deck:	07:03	33° 43.700'S	028° 13.399'E

On seafloor water depth: 3215m
Wire out Length: 3368m
Pull-out load (tonnes): 5.1
Core length recovered: 43cm
Remarks:

CD154
CORING OPERATION LOG SHEET

Core Number:	CD154-16-15K	Date:	28/12/03 (362)
Position:	33° 40.70'S 028° 15.45'E		
Time start:	08:00	Time end:	

Instrument: Box/Kasten/Piston/Multi
Barrel Length: 4m

Station water depth: 3120m

	Time (GMT)	Position Latitude	Longitude
In water:	08:00	33° 40.70'S	028° 15.45'E
On seafloor:	09:14	33° 42.070'S	028° 14.566'E
On deck:			

On seafloor water depth: 3166m
Wire out Length: 3260m
Pull-out load (tonnes): 5.8
Core length recovered: 106cm
Remarks:

CD154
CORING OPERATION LOG SHEET

Core Number:	CD154-16-10P	Date:	28/12/03 (362)
Position:	33° 40.62735'S 028° 15.32447'E		
Time start:	11:30	Time end:	

Instrument: Box/Kasten/Piston/Multi
Barrel Length: 6m

Station water depth: 3115m

	Time (GMT)	Position Latitude	Longitude
In water:	12:02	33° 40.63736'S	028° 15.32404'E
On seafloor:	13:13	33° 41.68855'S	028° 14.71592'E
On deck:	14:22	33° 42.36618'S	028° 13.92213'E

On seafloor water depth: 3173m
Wire out Length: 3213m

Pull-out load (tonnes): 6
Core length recovered: 569cm
Remarks: Trigger 0-79cm
Section 1: 0-137cm
Section 2:137-273cm
Section 3:273-421cm
Section 4:421-569cm

CD154
CORING OPERATION LOG SHEET

Core Number:	CD154-17-16K	Date:	29/12/03 (363)
Position:	33° 15.5662'S 029° 07.74182'E		
Time start:	13:05	Time end:	

Instrument: Box/Kasten/Piston/Multi
Barrel Length: 8m

Station water depth: 3337m

	Time (GMT)	Position Latitude	Longitude
In water:	13:11	33° 15.54566'S	029° 07.644'E
On seafloor:	14:16	33° 15.897'S	029° 07.658'E
On deck:	15:20	33° 16.079'S	029° 07.397'E

On seafloor water depth: 3344m
Wire out Length: 3399m
Pull-out load (tonnes): 5.9
Core length recovered: empty
Remarks: Kasten bent at 2m from base

CD154
CORING OPERATION LOG SHEET

Core Number:	CD154-17-17K	Date:	29/12/03 (363)
Position:	33° 16.131'S 029° 07.284'E		
Time start:	16:32	Time end:	

Instrument: Box/Kasten/Piston/Multi
Barrel Length: 4m

Station water depth: 3337m

	Time (GMT)	Position Latitude	Longitude
	16:32	33° 15.64'S	029° 07.45'E
	17:39	33° 16.131'S	029° 07.284'E
	18:47	33° 16.229'S	029° 07.3029'E

On seafloor water depth: 3333m
Wire out Length: 3384m
Pull-out load (tonnes): 6.6
Core length recovered: 363cm
Remarks:

CD154
CORING OPERATION LOG SHEET

Core Number:	CD154-17-11P	Date:	29/12/03 (363)
Position:	33° 15.171'S 029° 08.8517'E		
Time start:	00:09	Time end:	03:31

Instrument: Box/Kasten/Piston/Multi
Barrel Length: 12m

Station water depth: 3382m

	Time (GMT)	Position Latitude	Longitude
In water:	00:48	33° 15.5989'S	029° 08.3584'E
On seafloor:	02:07	33° 16.27812'S	029° 07.298'E
On deck:	03:31	33° 16.6627'S	029° 07.42369'E

On seafloor water depth: 3333m
Wire out Length: 3371m
Pull-out load (tonnes): 6.6
Core length recovered: 1178cm
Remarks: Trigger 0-100cm
Section 1: 0-146cm
Section 2: 146-292cm
Section 3: 292-443cm
Section 4: 443-594cm
Section 5: 594-746cm
Section 6: 746-896cm
Section 7: 896-1037cm
Section 8: 1037-1178cm

CD154
CORING OPERATION LOG SHEET

Core Number:	CD154-17-12P	Date:	29/12/03 (363)

Position: 33° 14.62166'S 029° 07.97223'E
Time start: 05:37 Time end: 03:31
Instrument: Box/Kasten/Piston/Multi
Barrel Length: 15m

Station water depth: 3366m

	Time (GMT)	Position Latitude	Longitude
In water:	06:09	33° 14.907'S	029° 08.002'E
On seafloor:	09:01	33° 16.049'S	029° 07.369'E
On deck:	10:14	33° 16.2782'S	029° 07.55116'E

On seafloor water depth: 3335m
Wire out Length: 3364m
Pull-out load (tonnes): 6.2 tonnes
Core length recovered: 1384cm
Remarks:
Section 1: 0-81cm
Section 2: 81-196cm
Section 3: 196-347cm
Section 4: 347-498cm
Section 5: 498-649cm
Section 6: 649-800cm
Section 7: 800-951cm
Section 8: 951-1102cm
Section 9: 1102-1243cm
Section 10: 1243-1384cm

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-18-18K Date: 30/12/03 (364)

Position: 33° 17.44'S 028° 52.63'E
Time start: 17:57 Time end:
Instrument: Box/Kasten/Piston/Multi
Barrel Length: 4m

Station water depth: 3111m

	Time (GMT)	Position Latitude	Longitude
In water:	17:57	33° 17.44'S	028° 52.65'E
On seafloor:	19:31	33° 18.69'S	028° 51.0'E
On deck:	20:28	33° 19.47974'S	028° 50.072'E

On seafloor water depth: 3097m
Wire out Length: 3147m
Pull-out load (tonnes): 6.4
Core length recovered: 383cm
Remarks:

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-18-13P Date: 30/12/03 (364)

Position: 33° 17.399'S 028° 51.8034'E
Time start: 10:39 Time end: 14:00
Instrument: Box/Kasten/Piston/Multi
Barrel Length: 12m

Station water depth: 3090m

	Time (GMT)	Position Latitude	Longitude
In water:	10:58	33° 17.4041'S	028° 51.794'E
On seafloor:	12:14	33° 18.3129'S	028° 50.81614'E
On deck:			

On seafloor water depth: 3091m
Wire out Length: 3127m
Pull-out load (tonnes): 6
Core length recovered: 1121cm
Remarks: Core bent, but full recovery
Section 1: 0-70cm
Section 2: 70-220cm
Section 3: 220-371cm
Section 4a: 371-522cm
Section 4b: 522-523cm (bagged)
Section 5: 523-674cm
Section 6: 674-825cm
Section 7: 825-973cm
Section 8: 993-1121cm

CD154
CORING OPERATION LOG SHEET

Core Number:	CD154-19-19K	Date:	31/12/03 (365)
Position:	34° 24.50'S 027° 12.69'E		
Time start:	17:30	Time end:	

Instrument: Box/<u>Kasten</u>/Piston/Multi
Barrel Length: 4m

Station water depth: 3402m

	Time (GMT)	Position Latitude	Longitude
In water:	18:00	34° 22.92'S	027° 16.13622'E
On seafloor:	20:57	34° 24.188'S	027° 12.63741'E
On deck:	22:25	34° 25.8698'S	027° 10.45798'E

On seafloor water depth: 3544m
Wire out Length: 3706m
Pull-out load (tonnes): 6.5
Core length recovered: 382cm
Remarks: repenetrated with top 1m repeated

CD154
CORING OPERATION LOG SHEET

Core Number:	CD154-19-14P	Date:	01/01/04 (001)
Position:	34° 24.6863'S 027° 13.0118'E		
Time start:	01:35	Time end:	

Instrument: Box/Kasten/<u>Piston</u>/Multi
Barrel Length: 9m

Station water depth: 3560m

	Time (GMT)	Position Latitude	Longitude
In water:	02:40	34° 23.420'S	027° 15.046'E
On seafloor:	04:08	34° 24.68635'S	027° 13.0118'E
On deck:	05:54	34° 25.999'S	027° 11.185'E

On seafloor water depth: 3572m
Wire out Length: 3628m
Pull-out load (tonnes): 6.7
Core length recovered: 841cm
Remarks: Core bent, but full recovery
Section 1: 0-108cm
Section 2: 108-259cm
Section 3: 259-410cm
Section 4: 410-561cm
Section 5: 561-711cm
Section 6: 711-841cm

CD154
CORING OPERATION LOG SHEET

Core Number:	CD154-20 20K	Date:	01/01/2004(001)
Position:	34° 26.12'S 027° 10.84'E		
Time start:	08:20	Time end:	

Instrument: Box/<u>Kasten</u>/Piston/Multi
Barrel Length: 4m

Station water depth: 3512m

	Time (GMT)	Position Latitude	Longitude
In water:	08:20	34° 26.12'S	027° 10.84'E
On seafloor:	09:48	34° 27.02'S	027° 08.85'E
On deck:	11:14	34° 27.85068'S	027° 06.90372'E

On seafloor water depth: 3512m
Wire out Length: 3605m
Pull-out load (tonnes):
Core length recovered: 338cm
Remarks:

CD154
CORING OPERATION LOG SHEET

Core Number:	CD154-20 21K	Date:	01/01/2004 (001)
Position:	34° 26.11161 027° 10.66458'E		
Time start:		Time end:	

Instrument: Box/<u>Kasten</u>/Piston/Multi
Barrel Length: 7m

Station water depth: 3366m

	Time (GMT)	Position Latitude	Longitude
In water:	12:33	34° 26.11082'S	027° 10.65252'E
On seafloor:	14:03	34° 27.10219'S	027° 08.28904'E

On deck:	15:12	34° 27.561'S	027° 06.232'E

On seafloor water depth: 3561m
Wire out Length: 3652m
Pull-out load (tonnes):
Core length recovered:
Remarks: unable to cable angle correct, drifted past site

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-20-15P Date: 01/01/04 (001)
Position: 34° 27.22'S 027° 08.78'E
Time start: 17:46 Time end:
Instrument: Box/Kasten/Piston/Multi
Barrel Length: 9m

Station water depth: 3420m

	Time (GMT)	Position Latitude	Longitude
In water:	18:17	34° 26.602'S	027° 10.28149'E
On seafloor:	20:42	34° 27.38236'S	027° 08.50216'E
On deck:	23:19	34° 28.297'S	027° 07.904'E

On seafloor water depth: 3583m
Wire out Length: 3665m
Pull-out load (tonnes): 7
Core length recovered: 875cm
Remarks: Trigger, 80cm
Section 1: 0-139cm
Section 2: 139-279cm
Section 3: 279-429cm
Section 4: 429-580cm
Section 5: 580-728cm
Section 6: 728-875cm

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-21-22K Date: 02/01/04 (002)
Position: 35° 17.017'S 024° 46.800'E
Time start: 15:37 Time end:
Instrument: Box/Kasten/Piston/Multi
Barrel Length: 4m

Station water depth: 2328m

	Time (GMT)	Position Latitude	Longitude
In water:	15:40	35° 17.03'S	024° 46.53'E
On seafloor:	16:59	35° 17.018'S	024° 42.820'E
On deck:	17:50	35° 16.83'S	024° 40.85'E

On seafloor water depth: 2190m
Wire out Length: 2290m
Pull-out load (tonne): 4.9
Core length recovered: 0
Remarks: empty, heavy rolling

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-22-14PK Date: 03/01/04 (003)
Position: 36° 06.34323'S 023° 31.787'E
Time start: 08:10 Time end:
Instrument: Box/Kasten/Piston/Multi (PILOT)
Barrel Length: 2m

Station water depth: 2118m

	Time (GMT)	Position Latitude	Longitude
In water:	08:20	36° 06.34'S	023° 31.77'E
On seafloor:	09:18	36° 06.99'S	023° 30.94'E
On deck:	10:10	36° 07.76681'S	023° 30.74208'E

On seafloor water depth: 2120m
Wire out Length: 2128m
Pull-out load (tonnes): 4.6
Core length recovered: 28cm (bagged)
Remarks: heavy rolling

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-22-23K Date: 03/01/04 (003)
Position: 36° 05.9013'S 023° 31.194'E
Time start: Time end:
Instrument: Box/Kasten/Piston/Multi

Barrel Length: 4m

Station water depth: 2108m

	Time (GMT)	Latitude	Longitude
In water:	21:09	36° 05.93902'S	023° 31.10077'E
On seafloor:		36° 07.24'S	023° 30.37'E
On deck:			

On seafloor water depth: 2180m
Wire out Length: 2220m
Pull-out load (tonnes): 4.8
Core length recovered: 342cm
Remarks:

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-23-15PK Date: 04/01/04 (004)
Position: 36° 48.62'S 022° 05.70'E
Time start: 11:54 Time end:
Instrument: Box/Kasten/Piston/Multi (PILOT)
Barrel Length: 2m

Station water depth: 3063m

	Time (GMT)	Latitude	Longitude
In water:	11:54	36° 45.75127'S	022° 03.0903'E
On seafloor:	13:56	36° 49.081'S	022° 00.629'E
On deck:	15:00	36° 49.2518'S	021° 59.5638'E

On seafloor water depth: 3175m
Wire out Length: 3227m
Pull-out load (tonnes): 5.5
Core length recovered: 180cm
Remarks: over-penetrated significantly

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-23-24K Date: 04/01/04 (004)
Position: 36° 48.226'S 022° 00.591'E
Time start: 16:19 Time end:
Instrument: Box/Kasten/Piston/Multi
Barrel Length: 4m

Station water depth: 3080m

	Time (GMT)	Latitude	Longitude
In water:	16:20	36° 46.22'S	022° 01.779'E
On seafloor:	17:58	36° 48.226'S	022° 00.591'E
On deck:	19:13	36° 49.885'S	021° 58.978'E

On seafloor water depth: 3173m
Wire out Length: 3228m
Pull-out load (tonnes): 6.2
Core length recovered: 343cm
Remarks:

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-23-16P Date: 05/01/2004 (005)
Position: 36° 45.99957'S 022° 01.25241'E
Time start: 00:32 Time end:
Instrument: Box/Kasten/Piston/Multi
Barrel Length: 12m

Station water depth: 3150m

	Time (GMT)	Latitude	Longitude
In water:	02:30	36° 47.39'S	022° 00.34'E
On seafloor:	03:40	36° 49.08'S	022° 00.0201'E
On deck:	05:01	36° 51.507'S	021° 57.7081'E

On seafloor water depth: 3189m
Wire out Length: 3237m
Pull-out load (tonnes): 6.4
Core length recovered: 1103cm
Remarks: Trigger, 96cm
Section 1: 0-50cm
Section 2: 50-200cm
Section 3: 200-350cm
Section 4: 350-502cm
Section 5: 502-653cm
Section 6: 653-804cm

Section 7: 804-954cm
Section 8: 954-1103cm

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-24-25K Date: 05/01/04 (005)

Position: 36° 57.67'S 021° 32.99'E
Time start: 16:50 Time end:
Instrument: Box/Kasten/Piston/Multi
Barrel Length: 4m

Station water depth: 3417m

	Time (GMT)	Position Latitude	Longitude
In water:	16:50	36° 57.683'S	021° 32.88015'E
On seafloor:	18:02	36° 57.728'S	021° 32.913'E
On deck:	15:20	36° 58.16497'S	021° 32.51141'E

On seafloor water depth: 3417m
Wire out Length: 3444m
Pull-out load (tonnes): 6.3
Core length recovered: 382cm
Remarks:

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-24-17P Date: 05/01/2004 (005)

Position: 36° 57.62360'S 021° 33.16344'E
Time start: Time end:
Instrument: Box/Kasten/Piston/Multi
Barrel Length: 9m

Station water depth: 3417m

	Time (GMT)	Position Latitude	Longitude
In water:	21:11	36° 57.68985'S	021° 33.07515'E
On seafloor:	22:17	36° 57.77702'S	021° 33.06953'E
On deck:			

On seafloor water depth: 3429m
Wire out Length: 3439m
Pull-out load (tonnes): 6.4
Core length recovered: 804cm
Remarks: Trigger, 99cm
Section 1: 0-123cm
Section 2: 123-227cm
Section 3: 227-369cm
Section 4: 369-511cm
Section 5: 511-657cm
Section 6: 657-804cm

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-25-26K Date: 07/01/04 (007)

Position: 37° 24.50'S 021° 03.01'E
Time start: 16:04 Time end:
Instrument: Box/Kasten/Piston/Multi
Barrel Length: 4m

Station water depth: 3697m

	Time (GMT)	Position Latitude	Longitude
In water:		37° 24.50'S	020° 03.01'E
On seafloor:	17:20	37° 24.57'S	020° 03.01'E
On deck:	18:32	37° 24.543'S	020° 02.998'E

On seafloor water depth: 3692m
Wire out Length: 3723m
Pull-out load (tonnes): 5.6
Core length recovered: 0cm
Remarks:

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-25-18P Date: 07/01/2004 (007)

Position: 37° 24.56143'S 020° 02.96234'E
Time start: Time end:
Instrument: Box/Kasten/Piston/Multi
Barrel Length: 6m

Station water depth: 3691m

	Time (GMT)	Latitude	Longitude
In water:	20:11	37° 24.558’S	020° 02.964’E
On seafloor:	21:26	37° 24.53219’S	020° 03.00182’E
On deck:			

Position

On seafloor water depth: 3692m
Wire out Length: 3710m
Pull-out load (tonnes): 7.3
Core length recovered: 481cm
Remarks: Trigger empty
Section 1: 0-123cm
Section 2: 123-192cm
Section 3: 192-336cm
Section 4: 336-481cm
Section 5: 511-657cm
Section 6: 657-804cm

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-25-19P Date: 07/01/2004 (007)
Position: 37° 24.54’S 020° 03.2387’E
Time start: Time end:
Instrument: Box/Kasten/<u>Piston</u>/Multi
Barrel Length: 12m

Station water depth: 3694m

	Time (GMT)	Latitude	Longitude
In water:			
On seafloor:	02:22	37° 24.54’S	020° 03.2387’E
On deck:	03:38	37° 24.3326’S	020° 03.0750’E

On seafloor water depth: 3691m
Wire out Length: 3705m
Pull-out load (tonnes): 6.7
Core length recovered: 981cm
Remarks: Trigger empty, top 1m of core liquified
Section 1: 0-118cm
Section 2: 118-260cm
Section 3: 260-402cm
Section 4: 402-549cm
Section 5: 549-695cm
Section 6: 695-838cm
Section 7: 838-981cm

CD154
CORING OPERATION LOG SHEET

Core Number: CD154-25-20P Date: 08/01/2004 (008)
Position: 37° 24.53’S 020° 03.03’E
Time start: 06:50 Time end:
Instrument: Box/Kasten/<u>Piston</u>/Multi
Barrel Length: 15m

Station water depth: 3692m

	Time (GMT)	Latitude	Longitude
In water:	06:50	37° 24.527’S	020° 03.029’E
On seafloor:	08:00	37° 24.491’S	020° 03.073’E
On deck:	09:23	37° 24.32375’S	020° 02.96725’E

On seafloor water depth: 3692m
Wire out Length: 3699m
Pull-out load (tonnes): 7.2
Core length recovered: 1153cm
Remarks: Trigger empty, Much of core liquified
Section 1: 0-77cm
Section 2: 77-216cm
Section 3: 216-356cm
Section 4: 356-488cm
Section 5: 488-620cm
Section 6: 620-765cm
Section 7: 765-910cm
Section 8: 910-1031cm
Section 9: 1031-1153cm

CD154
CTD OPERATION SHEET

Station Number: CD154-26-5C Date: 8/01/2004 (008)
Position: 37°36.11847’S 020°01.04938’E

Water Depth: 4126m
Time in water: 14:02 Time out water:
Sampling:

Bottle Number	Depth Fired	Sample Taken				
		$\delta^{18}O$	Nd	Filtered	Pa/Th	Sal
24	4152 (bottom)	Failed				
23	4152 (bottom)					
22	4050					
21	3950					
20	3850					
19	3750					
18	3600					
17	3600			Y		
16	3400					
15	3200					
14	3000					
13	2800			Y		#53
12	2800					#52
11	2500					#51
10	2200					
9	2000					
8	1500					
7	1000					
6	700					
5	700			Y		
4	500					
3	200					
2	100					
1	50					

CTD Gravity Core: Taken: Yes / No
Core Number:
Remarks: 2 SAP deployments

CD154
SAPS OPERATION SHEET

Station Number: CD154-26-4S Date:08/01/04 (008)
Position: 37°35.583'S 020°02.488'E CTD Number:
Water Depth: 4139m CD154-26-4C

	Ltr	Meter	Deployment Depth	Wire out speed	Delay time	Pump time
SAP 1:	126		50m	60	2	1hr
SAP 2:	496		200m	60	25	1hr
SAP 3:						

Time out water: SAP1: 13:25
SAP2: 13:35

Remarks:
SAP2 in 11:50 start 12:15 end 13:15
SAP1 in 11:59 start 12:01 end 13:01

CD154
SAPS OPERATION SHEET

Station Number: CD154-26-5S Date:08/01/04(008)
Position: 37°40.307'S 019°58.591'E CTD Number:
Water Depth: 4352m CD154-26-4C

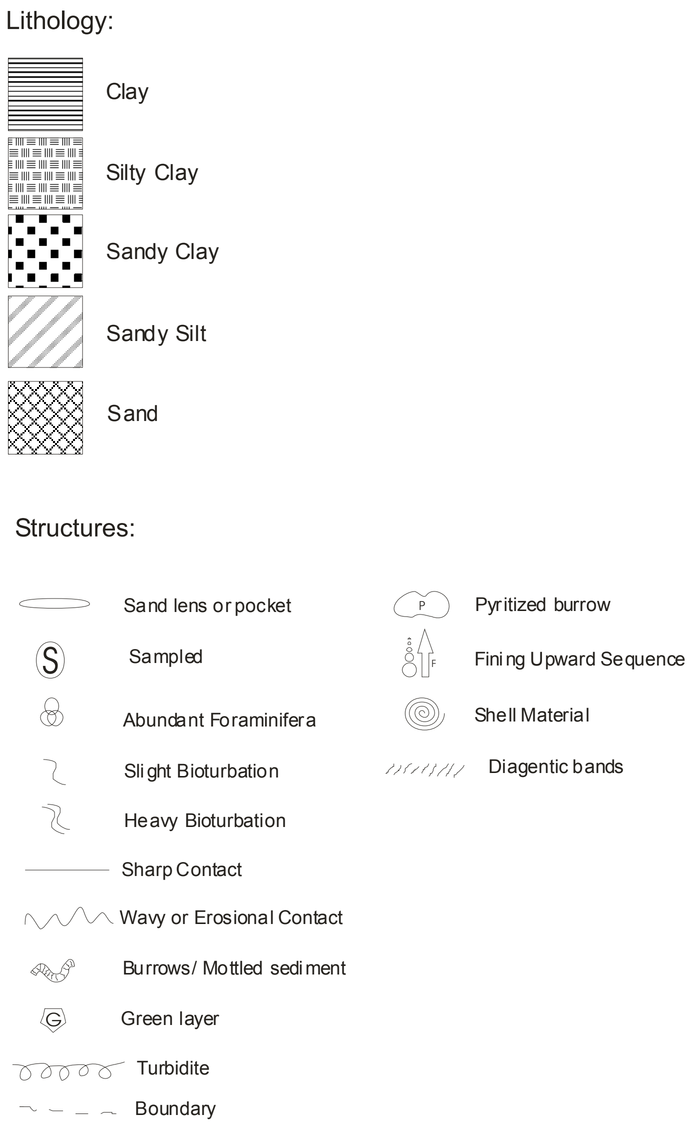
	Ltr	Meter	Deployment Depth	Wire out speed	Delay time	Pump time
SAP 1:	503		500m	60	4	1hr
SAP 2:	563		800m	60	6	1hr
SAP 3:						

Time out water: SAP1: 21:20
SAP2: 21:30

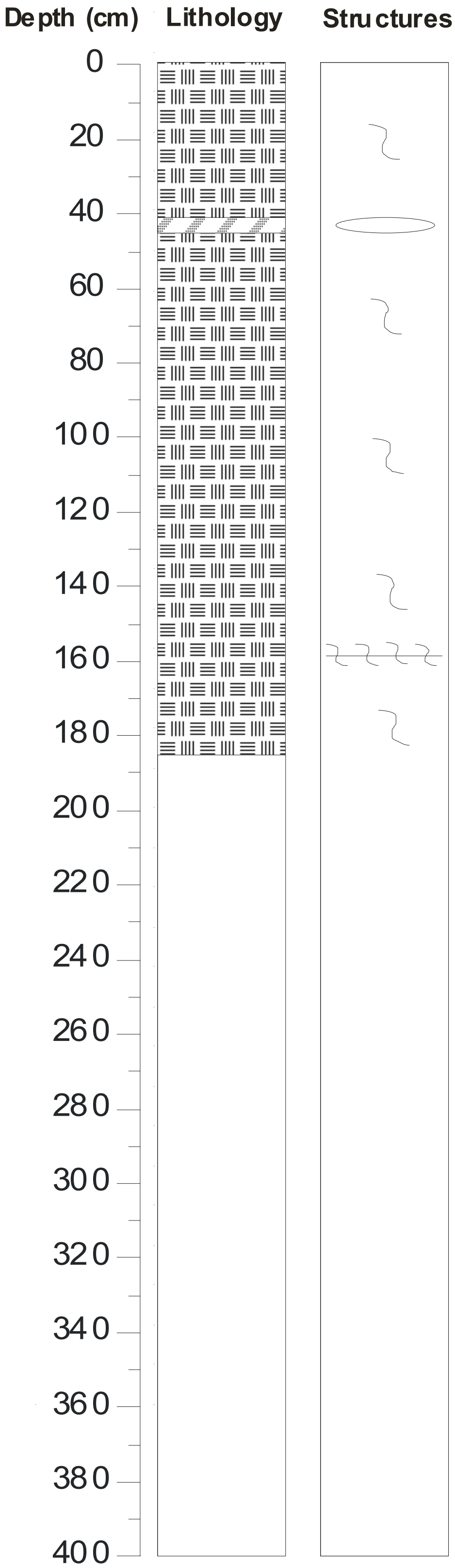
Remarks:
SAP2 in 11:50 start 19:04
SAP1 in 11:59 start 19:18

21. Core descriptions

Legend for Core Description



Core Description: CD154-01-1K



Comments

10 YR 6/2 Light brownish Silty Clay

Sandy silt lens 42-43cm

Gradational colour change

5 Y 6/2 Light Olive grey

Moderate bioturbation throughout

Silty Clay 5 Y 6/2 Light Olive grey

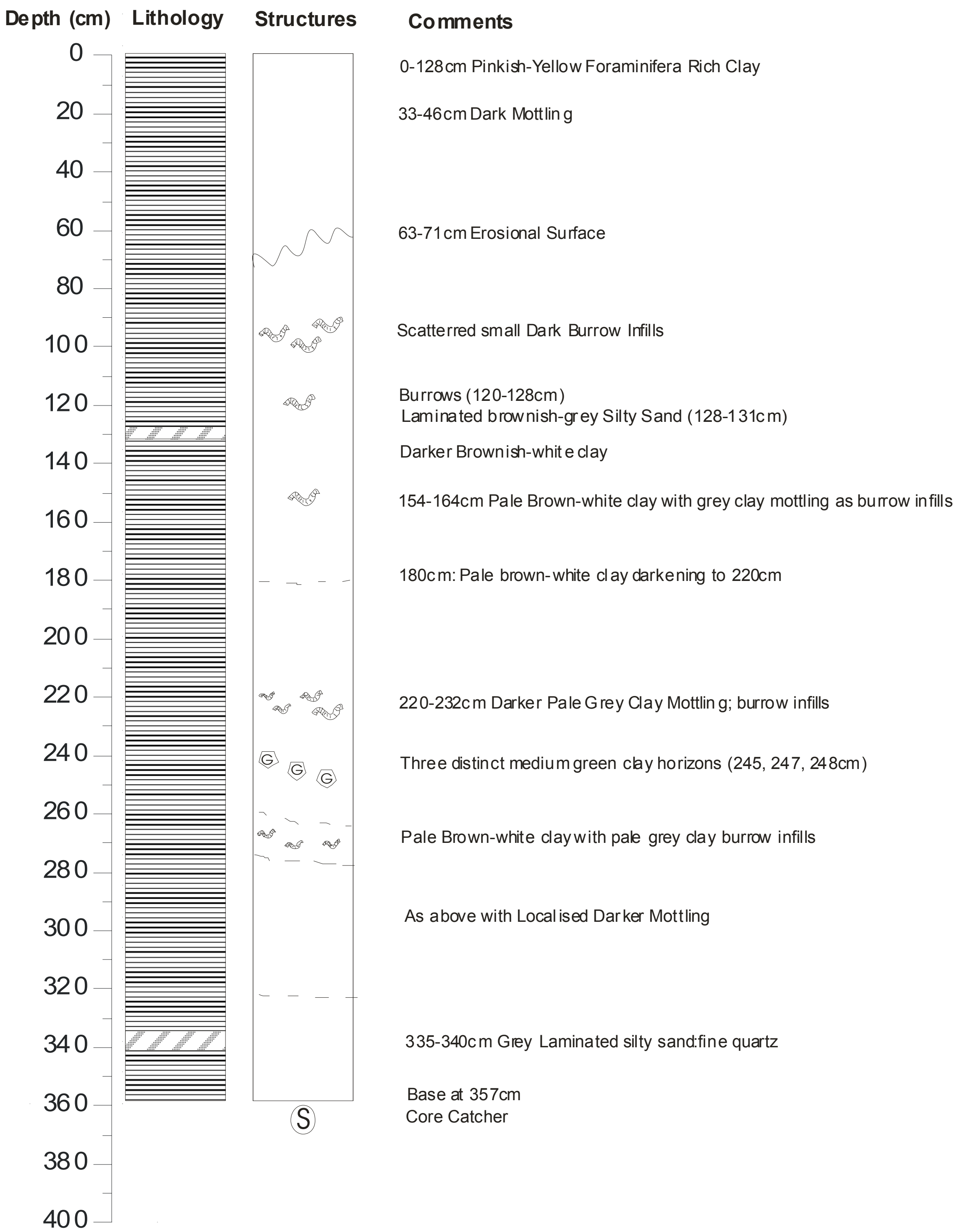
Bioturbated contact grading to lighter colour at 160cm

2.5 Y 6/2 Light Brownish grey

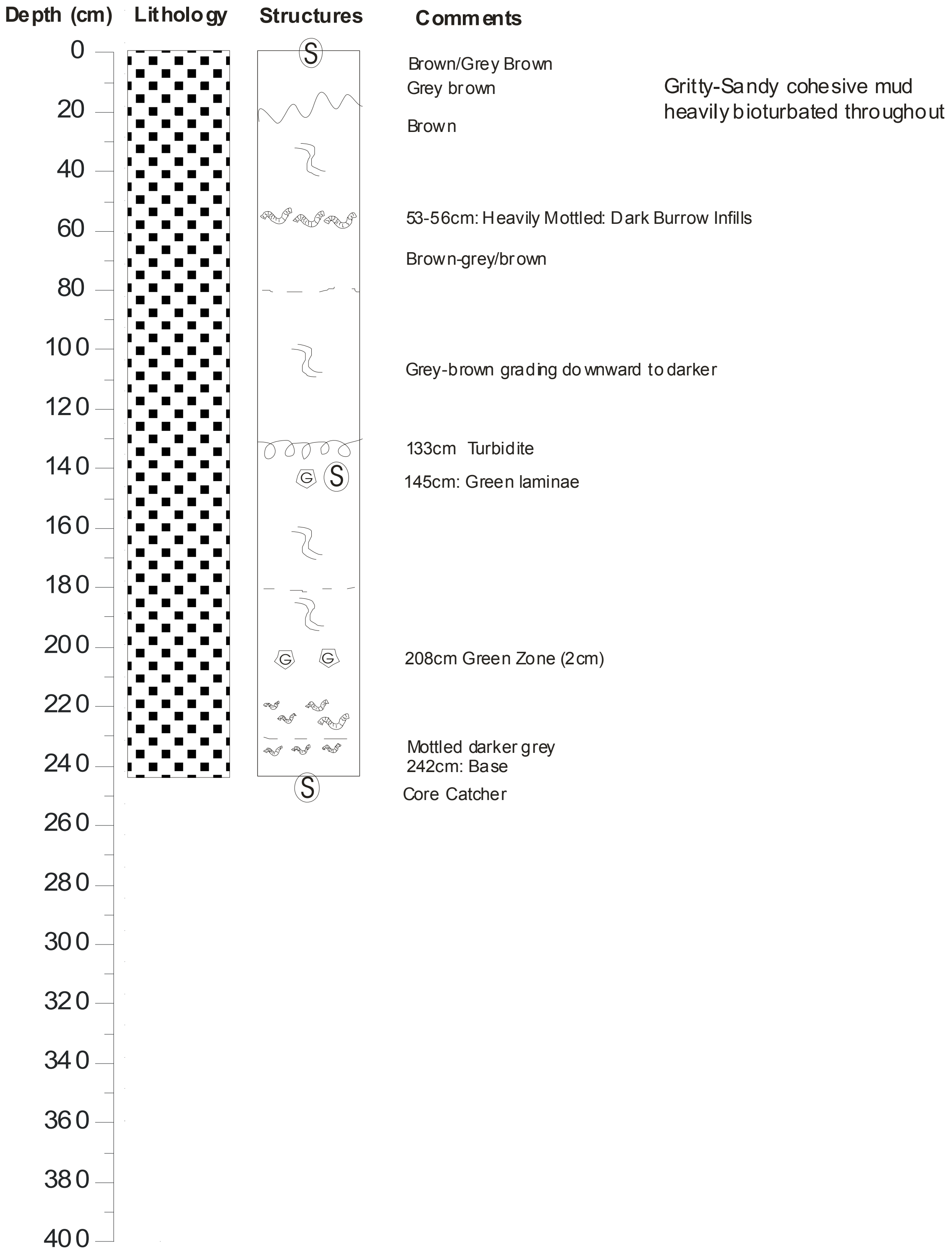
Base at 184cm

Core Catcher

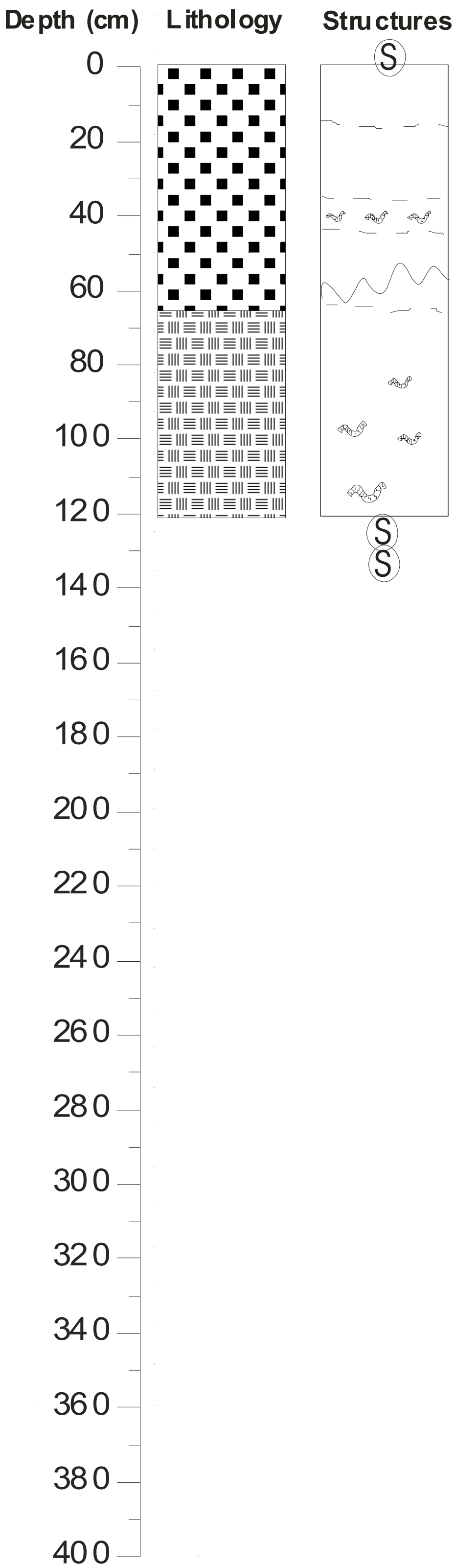
Core Description: CD154-01-2K



Core Description: CD154-02-3K



Core Description: CD154-03-5K



Comments

Orange- Brown light sediments undisturbed for 15cm.

0-65cm: Sandy cohesive clay

As above but with darker streaks

36-46cm: Light brown with dark mottling.

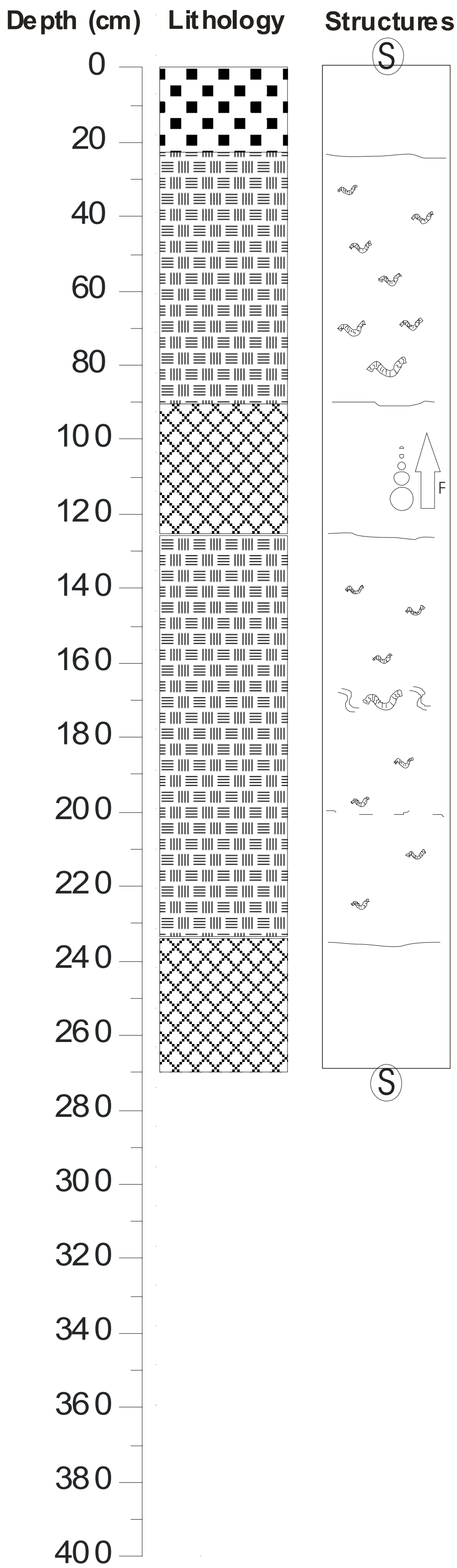
Darker brown unit with diagonal contact at base (56-63cm)

Small Light brown unit repeated to 65cm

65-120cm transition to a grey SILTY CLAY
Numerous mottled patches, more towards the base.

120cm: Base
Core Catcher
Sampled at core catcher and base.

Core Description: CD154-04-6K



Comments

0-22cm:Orange uniform SANDY CLAY

22-90cm: SILTY CLAY interspersed with dark patches, mottled.
Unit appears interbedded in places

90-123cm SAND unit with visual laminations/beds
Coarsening towards base.

123-234cm:
Uniform SILTY CLAY with dark mottled appearance.

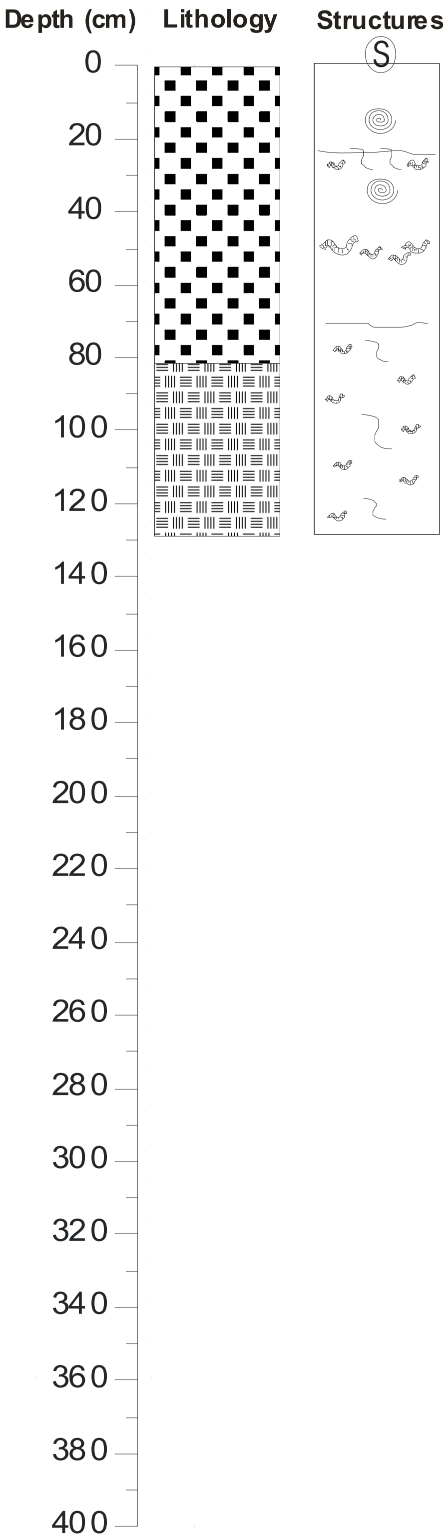
176cm: Heavy bioturbation. Large burrow.

200-234 darker pink-orange appears more clay-rich

234-270cm: Uniform Medium-Coarse pink-orange SAND

270cm: Base
Core Catcher

Core Description: CD154-05-7K



Comments

0-5cm SOUPY

0-81cm Orange-light brown SANDY CLAY.
Bivalves

23-27cm dark mottles - bioturbation
Bivalves

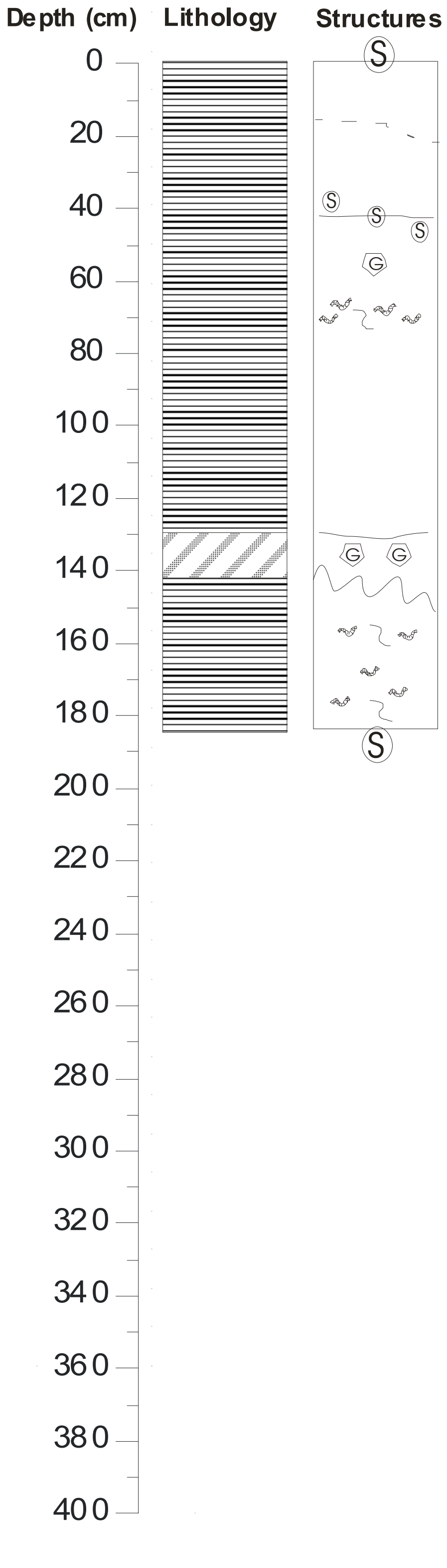
46-53cm: Dark mottled layer

70-71cm thin darker layer

81-127cm Light Grey SILTY CLAY with modrate burrows/mottling.

270cm: Base
Core Catcher

Core Description: CD154-06-6PK



Comments

0-15cm dark pink-brown Foraminiferal Clay

15-38cm Pinkish Pale-brown Foraminiferal Clay

23-27cm dark mottles - bioturbation

43cm: 3mm Laminated Fe crust
Sampled at 43, 43.5, 44cm.

56cm: Olive green layer

65-75cm: Black mottles and burrows

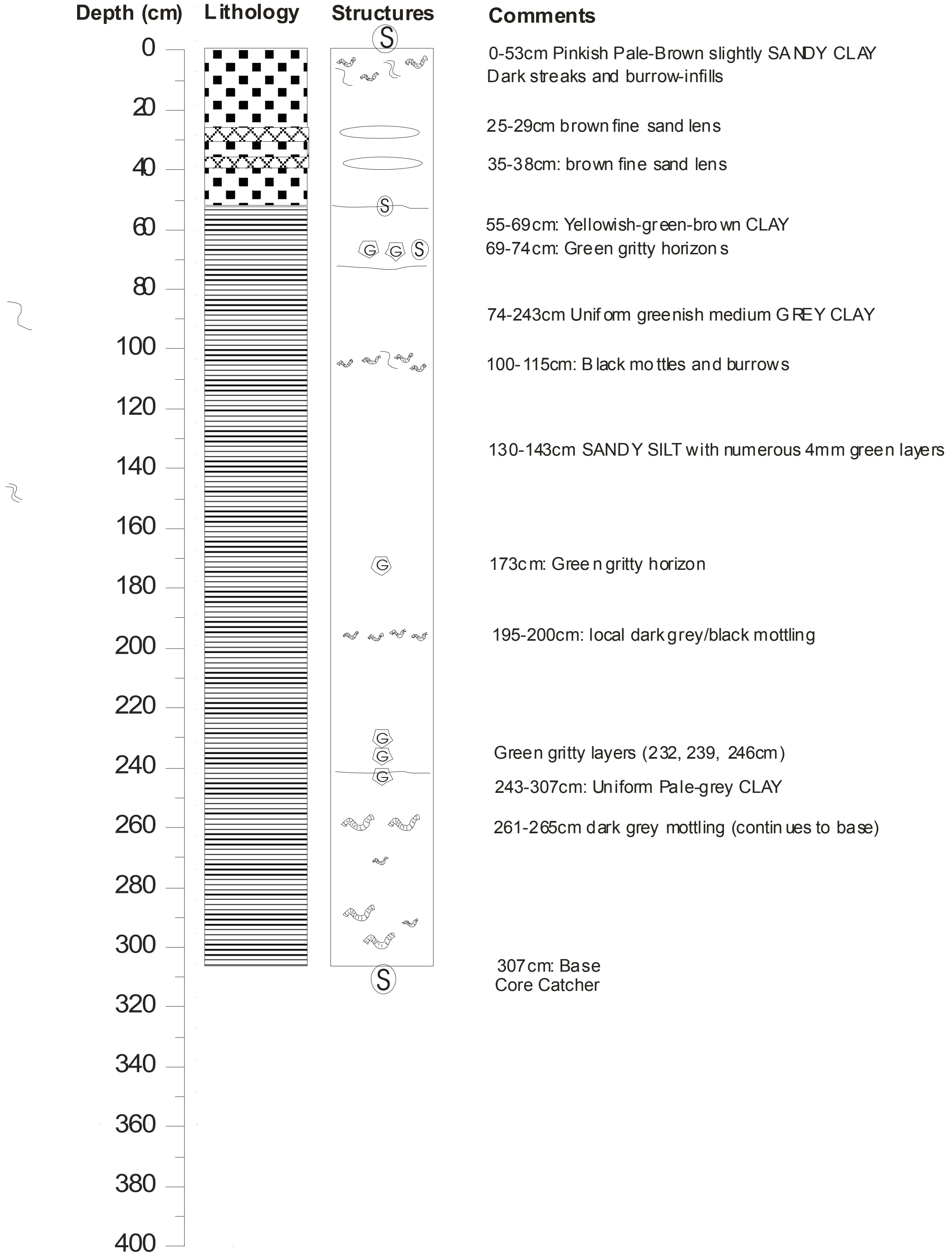
40-130cm: Light grey CLAY

130-143cm SANDY SILT with numerous 4mm green layers

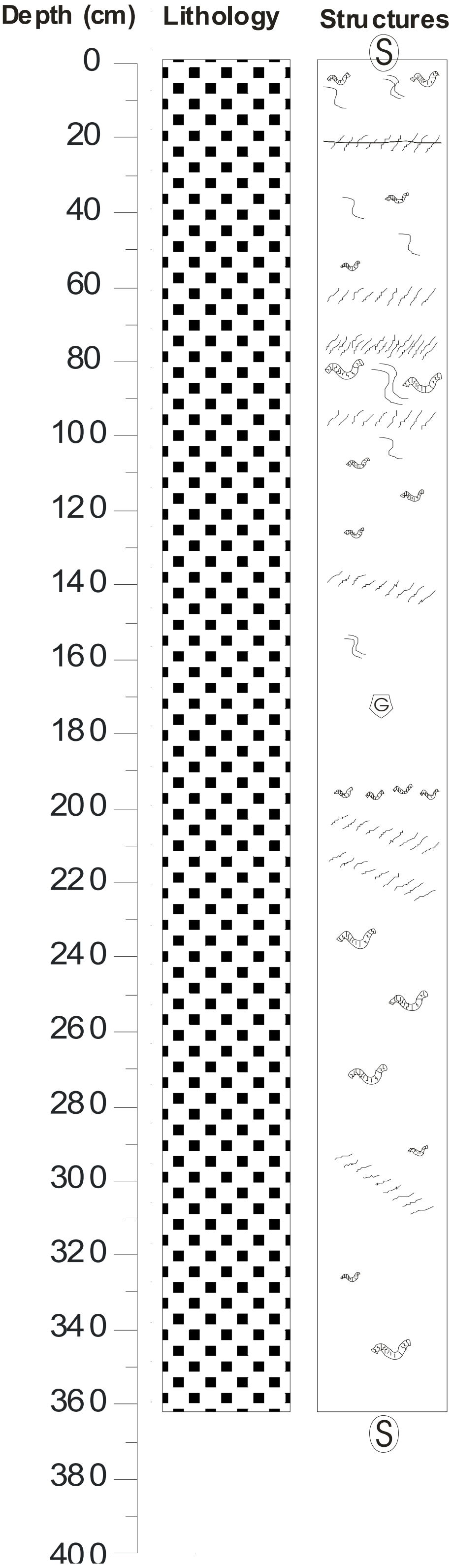
143-183cm Very Light Grey CLAY with moderate burrows/mottling.

183cm: Base
Core Catcher

Core Description: CD154-09-9K



Core Description: CD154-10-10K



Comments

10 YR 4/3 SANDY CLAY
0-22cm SANDY CLAY with pervasive mottling.
Grading from soupy at top to firmer at 22cm.
10 YR 5/3 at 22cm. Boundary marked by diagenetic banding

22-373cm: Heavily bioturbated unit with pervasive mottling

Colour greenish-brownish grey 5Y 5/1 - gley 15/10Y

Numerous 5mm diagentic bands punctuate the otherwise homogenous core. Below 50cm, diagenetic bands dip at an increasing angle;
e.g. Diagenetic band at 208cm spans over 203-210cm interval

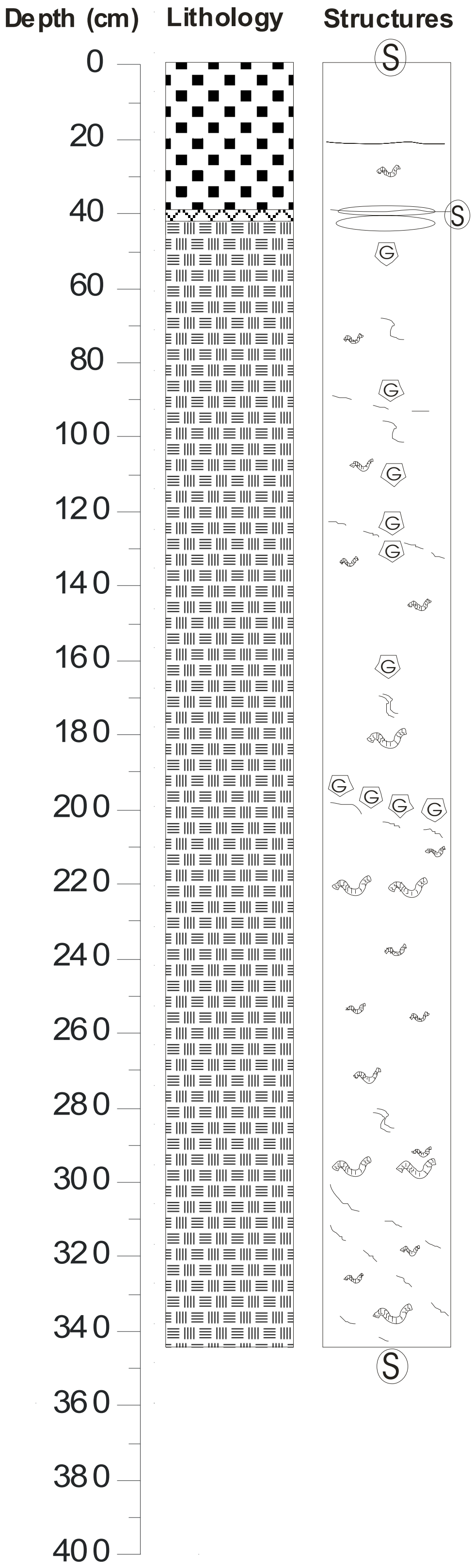
778-107cm Most intense mottling/bioturbation

SANDY CLAY throughout.

363cm: Base

Core Catcher

Core Description: CD154-13-12K



Comments

0-41cm: Orange-Pink SANDY CLAY

39-43cm Grey sandy lenses. Sampled at 39, 41cm.

43-344cm: Grey SILTY CLAY with frequent green layers

Entire unit is heavily mottled and bioturbated.
Ophiomorpha burrowing identified at 221 and 294cm.

Angle of bedding planes shift from near horizontal at top to an oblique angle e.g. 40 degree dip at 160cm
Core penetration at angle?

194cm: Four green layers

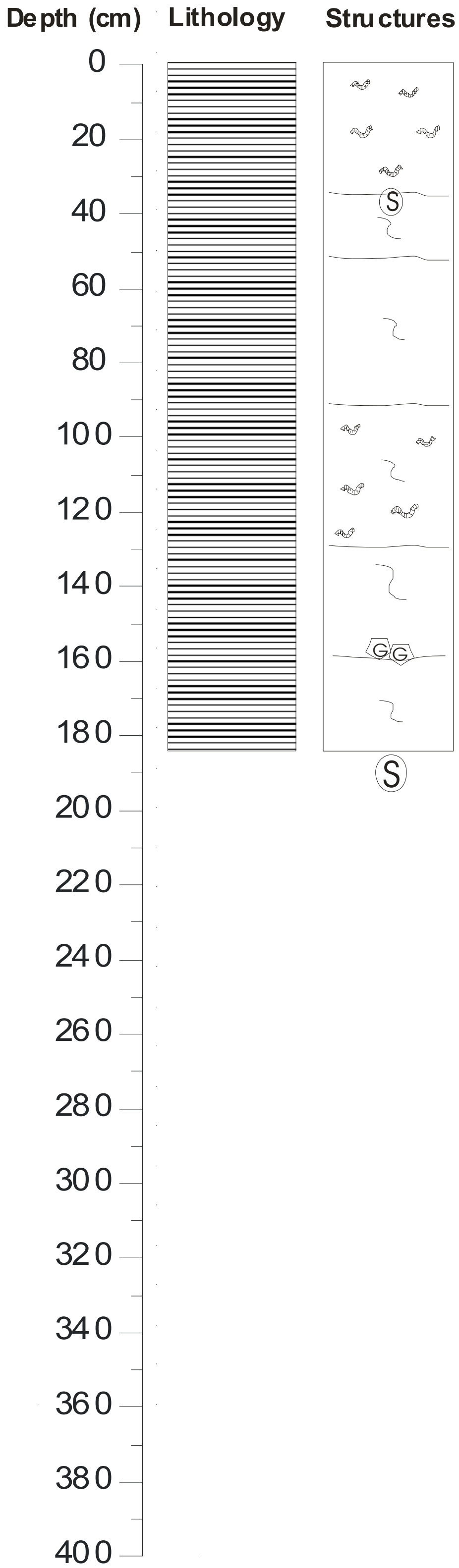
221cm: Ophiomorpa burrow

294cm: Ophiomorpa burrow

Beds steepen towards the base

344cm: Base
Core Catcher

Core Description: CD154-15-12PK



Comments

0-36cm: Pinkish-Brown CLAY with grey mottling.

36-52cm: Strongly greenish Grey CLAY. Sampled at 38, 41cm.

52-90cm: Greenish Pale grey CLAY

90-130cm: Browinish-Grey CLAY with pale GREY patches

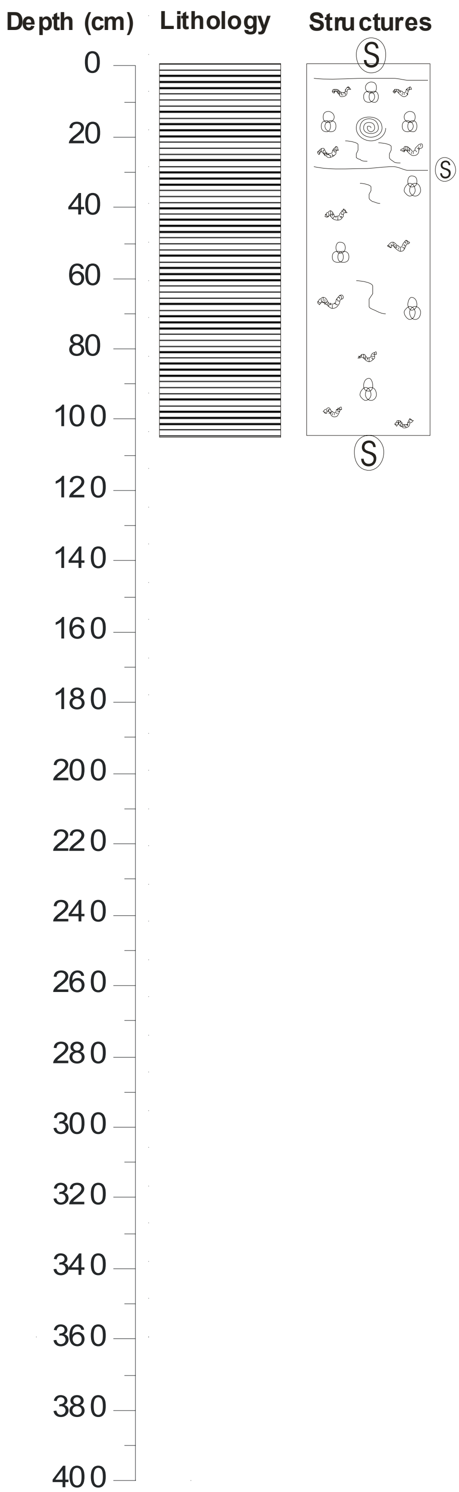
130-158cm: Pale Grey CLAY

158-159cm: Pale Green Band

159-183cm: Sticky Grey CLAY

183cm: Base
Core Catcher

Core Description: CD154-16-15K



Comments

0-5cm SOUPY surface.

5-29cm: Butt Brown firm CLAY
Abundant forams and shells material
Mottled texture. Sampled above and below boundary: 29, 30cm.

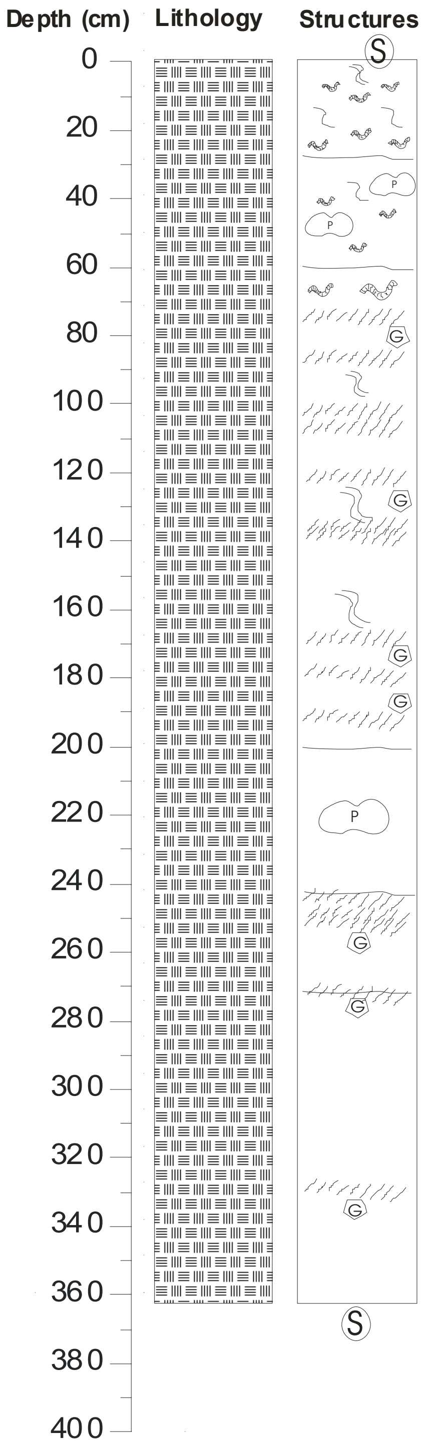
29-106cm: Grey, mottled CLAY with brown and dark grey bioturbation.
Firm, fine abundant forams

56-62cm: Wet, SOUPY area.

106cm: Base
Core Catcher

REPENETRATION inferred.

Core Description: CD154-17-17K



Comments

0-28cm:Light brown SILTY CLAY (10 YR 4/3)
Heavily mottled with some work burrows in top 10cm
Transition to underlying unit sharp although mild gradation in colour visible possibly via bioturbation.

28-60cm: Mildly mottled green-gray SILTY CLAY
Colour 2.5Y 5/1
Small pyritized worm burrows.

60-202cm: Same as above, SILTY CLAY but very heavily MOTTLED
Colour 2.5 Y 5/1, mottles are an olive colour 5Y 4/2.
Several relic and hardened diagenetic fronts between a few mm to 1 cm in thickness. They are marked by an intense green colour.

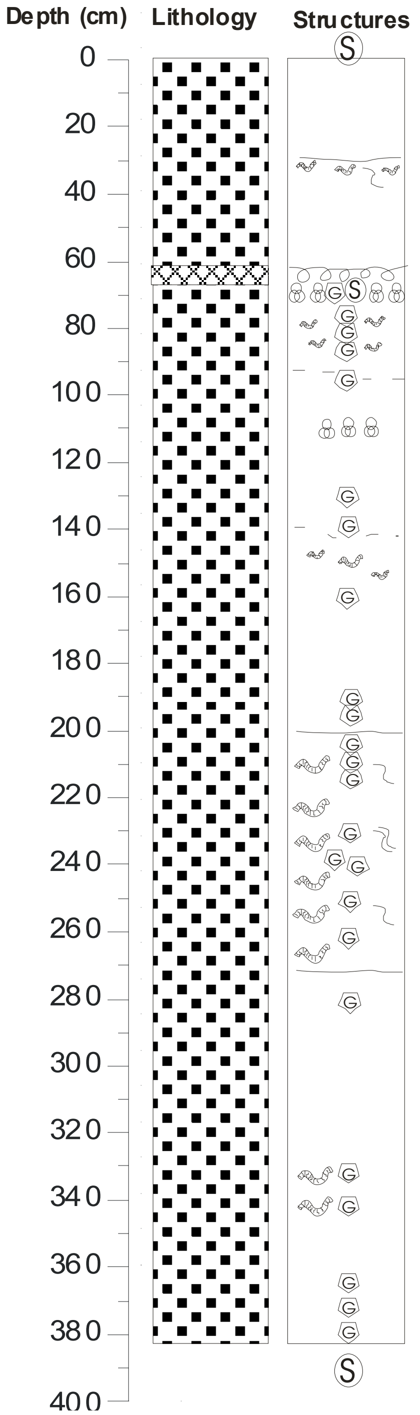
202-244cm: SILTY CLAY Unit with distinct lack of mottling and only small black speckles of pyritized burrows up to a few mm in size.

244-273cm: As above but characterized by 5-6 relic diagenetic fronts.

273-363cm: As above but only one marked 1.5cm think diagenetic front at 329cm.

363cm: Base
Core Catcher

Core Description: CD154-18-18K



Comments

0-5cm: SOUPY top
0-15cm: SANDY CLAY with no burrowing apparent
Colour: 2.5 Y 4/3
Burrows at the unit boundary.

30-60cm: SANDY CLAY with colour GLEY 15/10Y

60-67cm: Poorly laminate, SAND unit with erosional base- turbidite.
Rich in foraminifera with dark green basal contact. Sampled.

67-383cm: SANDY CLAY with colour GLEY 15/10Y
Numerous green layers, with colour GLEY 1 4/5G throughout this final unit. Dark mottled patches thoughout.

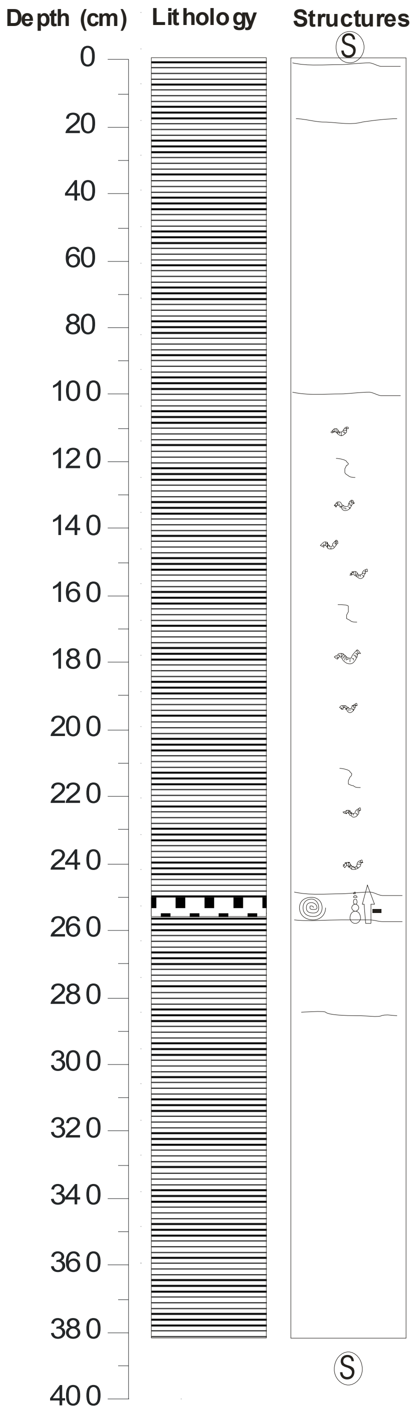
90-140cm: Few burrows, sandy foram clay.

200-290cm: Rich in burrows and green layers

360cm: Possible horizontal burrow: Purple.

383cm: Base
Core Catcher

Core Description: CD154-19-19K



Comments

0-2cm : Very soft, Orange CLAY
2-18cm: Soft Greenish-Grey Uniform CLAY

18-101cm: Soft, pale-GREY uniform CLAY

101cm: Sharp Break - Orange Mud INSIDE core indicates repenetration of core at this level.

102-250cm: Soft Greenish-Grey uniform CLAY with localised slight Mottling and burrowing. Becomes paler grey with depth

250-256cm: Greenish pale Grey CLAY. Sharp basal break is sandy with shell material (Gastropods).

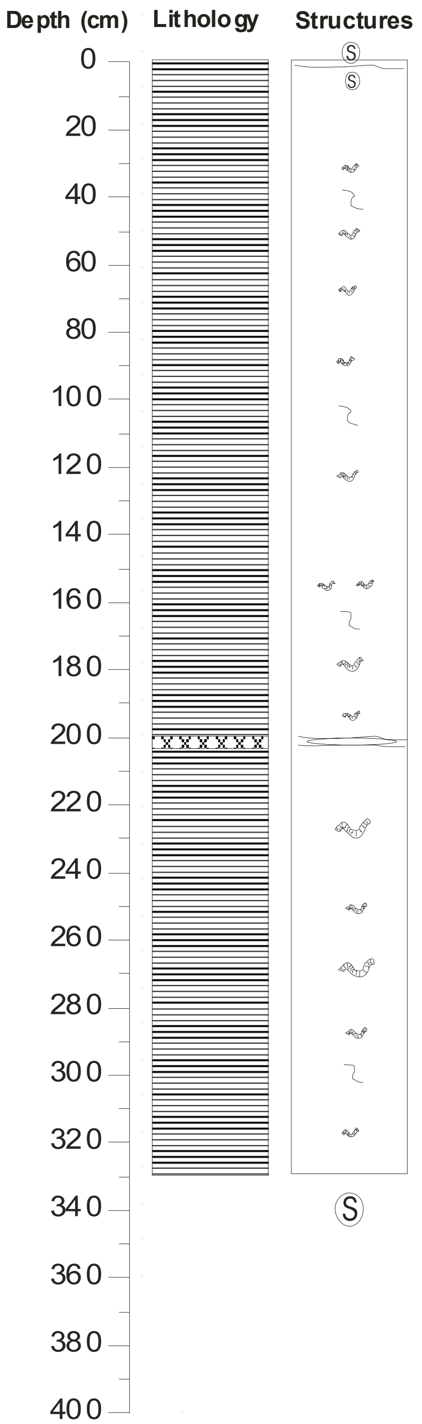
256-286cm: Pale Grey soft Uniform CLAY

286-382cm: Slightly greenish pale Grey soft CLAY with scatterred black carbonised markings (lignite? Wood fragments?)

Interval becomes more greenish and darker in colour below 330cm

382cm: Base
Core Catcher

Core Description: CD154-20-20K



Comments

0-1cm : Very soft, Orange SOUPY CLAY. Sampled above and below (0,2cm)

1-200cm: Greenish-Yellow Grey soft uniform CLAY
with occasional burrows

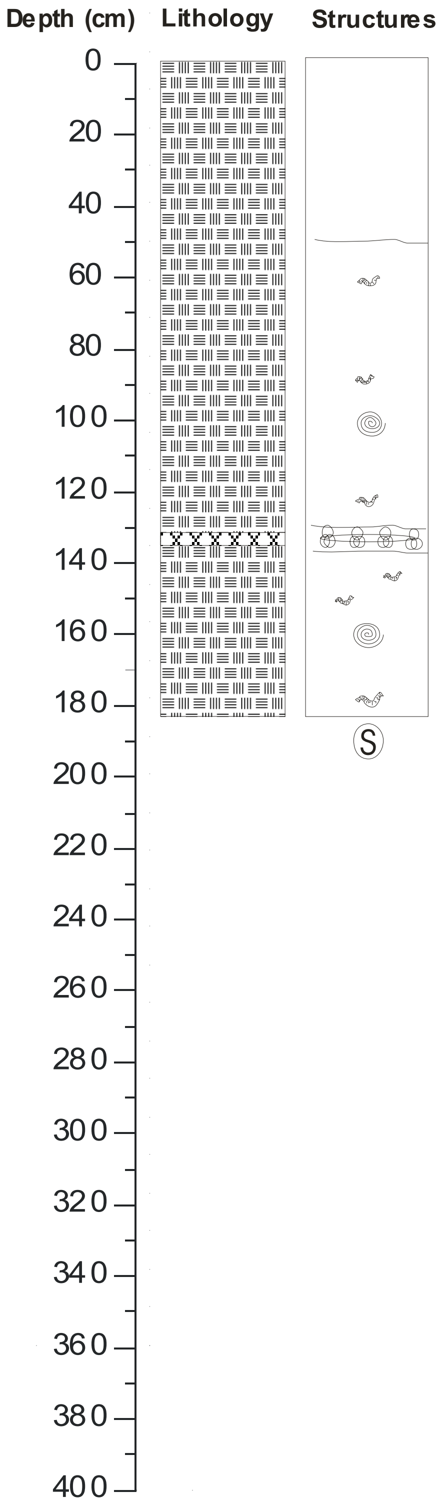
Scatterred black carbonised flecks, especially in lower part
(?plant fragments?, ?Burrow infills?)

201-202cm: Sandy interval

202-339cm: Soft Greenish Pale Grey sticky Uniform CLAY with
occasional burrows infilled with silty grey clay
Numerous black carbonised flecks (plant fragmnets or infills?)

339cm: Base
Core Catcher

Core Description: CD154-23-15PK



Comments

0-50cm: Homogenous SILTY CLAY

Colour 5Y 5/2 Olive Grey throughout

50-180cm: Lower unit as above but with white flecks, slightly mottled
Colour 5Y 5/2 Olive Grey.

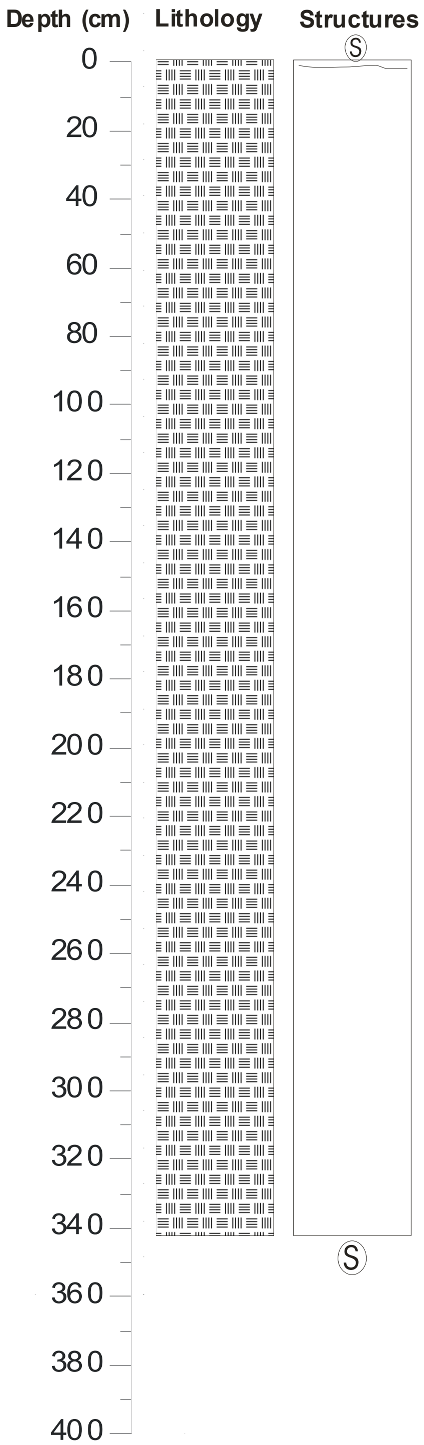
102cm: Shell material visible

133-136cm: Sandy interval with abundant foraminifera

161cm: Shell material visible

180cm: Base
Core Catcher

Core Description: CD154-23-24K



Comments

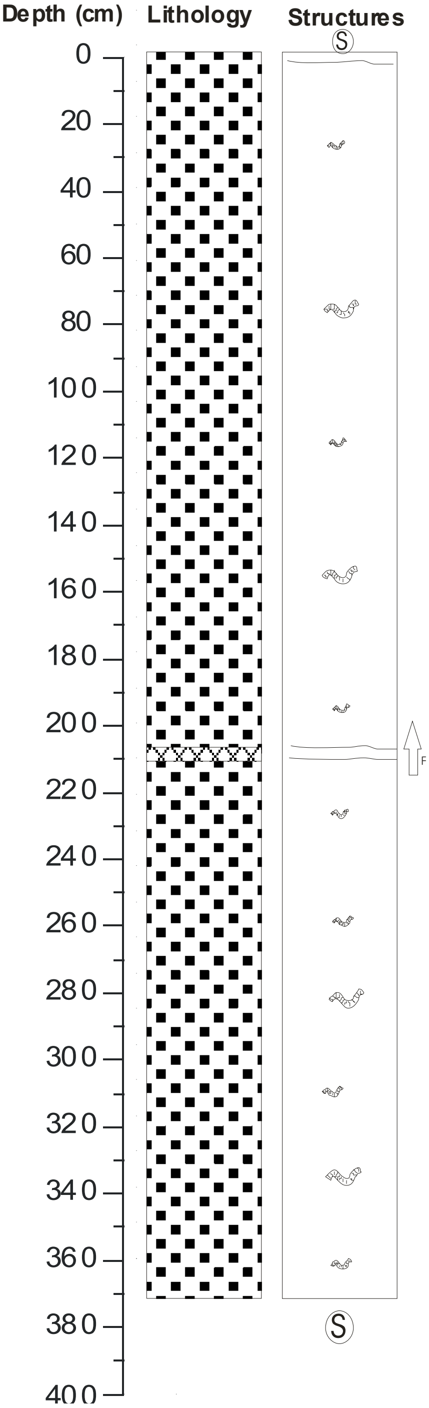
0-2cm: Thin, watery SILTY CLAY light brown colour: 2.5 Y 4/2

2-342cm: Massive unit of greenish grey colour (5Y 5/2)
Interlayered with lighter greenish grey intervals of GLEY1 6/10Y colour.

342cm: Base

Core Catcher

Core Description: CD154-24-25K



Comments

0-2cm: Thin, watery SANDY CLAY light brown colour: 2.5 Y 4/3. Much of this top layer washed away during recovery.

2-371cm: Massive unit of SANDY CLAY, variously mottled intensity. Colour ranges from light greyish green (GLEY1 6/10Y) to darker greenish grey (5Y 5/2). General texture ranges from stiff but soupy sediments to more consolidated mud. Soupy material is sandy/gritty. Stiffer mud is finer grained.

208cm: Erosional surface with ripple-like structure with fining upward sequence. Trough of ripple filled with darker, sandy material.

371cm: Base

Core Catcher