UNIVERSITY OF CAMBRIDGE

DEPARTMENT OF EARTH SCIENCES

R.R.S. CHARLES DARWIN

Cruise 159

1st - 30th July 2004

Fairlie, Scotland to St. John's, Newfoundland

For the *RAPID* Climate Change Research Programme of NERC under grant NER/T/S/2002/00436

Principal Scientist

Professor I.N. McCave

2005

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RRS CHARLES DARWIN : OFFICERS

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Mr G. Slater	3rd Engineer
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TIME BREAKDOWN

Steaming (& surveying)	420 hours
On Station	244 hours
Weather delays	32 hours
Mechanical delays	4 hours

1. ABSTRACT

Cruise Charles Darwin 159 was primarily devoted to coring with ancillary CTD work in the North Atlantic between Scotland and Newfoundland. The sampling program was most successful, due to unusually good weather in July (1-30, 2004), recovering 30 box cores, 19 piston cores, 6 kasten cores, 9 other short gravity cores and 20 CTD casts as well as 28 surface water samples for trace metals, 28 for plankton and isotopes, and 20 filtered for foraminifera. It was undertaken in support of the NERC RAPID Climate Change programme. Objectives are to generate palaeoceanographic records of hydrographic changes (temperature, salinity, nutrients, flow speed) associated with sharp climate transitions of the last 16 ka seen in the Greenland ice cores. Samples and CTD casts were also taken at sites of former current meter deployments to calibrate proxies for flow speed and other hydrographic variables. Sampled areas were north of Rockall, S. Iceland slope and rise, Gardar Drift, S.E. Greenland margin, Eirik Drift, and Hamilton Spur and Orphan Spur off Labrador.

2. INTRODUCTION

Cruise 159 of the RRS Charles Darwin was undertaken in support of the palaeoceanographic component of the NERC programme on Rapid Climate Change, called "*RAPID*".

a). Scientific Aims of *RAPID*

From the outline of what the programme entails:

"The purpose of the Rapid Climate Change programme is to improve our ability to quantify the probability and magnitude of future rapid change in climate. *Studies, using palaeo data, of past climate suggest that large and rapid (as fast as 10-20 years) changes have occurred and that changes in the THC (thermohaline circulation) are a major factor in some of these cases.* Modelling studies show that the THC and the heat that it transports northward in the Atlantic produces a substantially warmer climate in western Europe than would otherwise be the case. They also predict that under a greenhouse gas warming situation the THC might slow down, possibly leading to a cooling of western Europe, which could have significant socio-economic impacts. A limited number of observations of the North Atlantic THC are available and, of the few that are, some suggest that a slow down of the THC might be occurring now.

Therefore the programme aims to investigate and understand the causes of rapid climate change, with a main (but not exclusive) focus on the role of the Atlantic Ocean's THC. Using a novel combination of present day observations, palaeo data and a hierarchy of models (from local process models to global general circulation models) the programme will improve our understanding of the roles of the THC and other processes in rapid climate change, and of the global and regional impacts of such change. As a result, our ability to monitor and predict potential future rapid climate change, particularly in the North Atlantic region, will be enhanced. This will be achieved by undertaking improved observations of the Atlantic THC and the processes that influence it; *by using improved palaeo data to reconstruct past changes; by combining the* *present day and palaeo observations with models,* in order to test and improve them; and finally using the understanding gained to assess the probability and magnitude of future rapid climate change.” (my italics)

Specific objectives of the programme are:

1) To establish a pre-operational prototype system to continuously observe the strength and structure of the Atlantic meridional overturning circulation (MOC).
2) To support long-term direct observations of water, heat, salt, and ice transports at critical locations in the northern North Atlantic, to quantify the atmospheric and other (e.g. river run-off, ice sheet discharge) forcing of these transports, and to perform process studies of ocean mixing at northern high latitudes.
3) *To construct well-calibrated and time-resolved palaeo data records of past climate change, including error estimates, with a particular emphasis on the quantification of the timing and magnitude of rapid change at annual to centennial time-scales.*
4) To develop and use high-resolution physical models to synthesise observational data.
5) To apply a hierarchy of modelling approaches to understand the processes that connect changes in ocean convection and its atmospheric forcing to the large-scale transports relevant to the modulation of climate.
6) To understand, using model experimentation and data (palaeo and present day), the atmosphere’s response to large changes in Atlantic northward heat transport, in particular changes in storm tracks, storm frequency, storm strengths, and energy and moisture transports.
7) *To use both instrumental data and the palaeo data (see 1-3) for quantitative testing of model variability and rapid changes on annual to centennial time-scales. To explore the extent to which these data can provide direct information about the THC and other possible rapid changes in the climate system and their impact.*
8) To quantify the probability and magnitude of potential future rapid climate change, and the uncertainties in these estimates.

The work on this cruise was devoted to italicised objectives 3, (and eventually 7), above.

b). Specific Cruise Objectives

The work focusses on determination of changes in hydrographic properties and flow of water masses along the Scotland–Labrador boundary of the N. Atlantic through late Glacial and Holocene rapid climate changes. The principal objectives were to take seabed and water samples in order:

- To target the sharp warmings at about 14,650 and 11,600 years ago and the cooling at 13,300 yrs B.P. recorded isotopically in the Greenland ice sheet. [We also hoped to obtain material able to resolve the 8.2 ka sharp cool event recorded in GISP and GRIP ice cores, if it existed at sea];
- For each event to determine the *sequence* of changes in water mass properties sea surface and bottom water temperature and nutrient content.

- To determine the phase relationship (leads and lags) between the oceanographic variables both at single sites and between sites to provide a key to assess possible outcomes to changes in these parameters observable today;
- To calibrate with error bounds the proxies required for precise estimation of key hydrographic variables by analysing surface sediments and the water column from the sites of long-term current meter moorings with well characterised present day hydrography in the region.

The areas where sampling for detailed records of the last 16 ka were to be carried out follow the major inputs of water to what becomes North Atlantic Deep Water: (i) South Iceland Rise for Iceland-Scotland Overflow Water (ISOW), (ii) Eirik Drift for the integrated outflow from the Norwegian/Greenland Sea of ISOW plus DSOW (Denmark Strait Overflow Water), and (iii) Labrador Margin for Labrador Sea Water (LSW) at shallower depths and the integrated overflow deeper. The final target was box- or multi-coring of as many as possible of the large number of sites in the N.E. Atlantic where current meters have been set within 100 m of the bed and yielded records of a year or more in length for calibration of the grain-size flow speed and Mg/Ca benthic and planktonic foraminiferal temperature proxies.

c) Narrative of Cruise

At the outset it must be said that the weather was extraordinarily kind to us. Considering that we went to the two worst weather spots in the N. Atlantic, S. Iceland and S. Greenland, to lose only 36 hours in a month due to weather is tantamount to getting off scot free.

The cruise was intended to be in 5 phases:

1. Sail from Clyde visiting former current meter sites on passage to SE Iceland undertaking CTD with under CTD corer stations.

2a. Sample WOCE current meter (CM) (ACM 8-ISOW) Sites with CTD and with under-CTD mini-corer.

2b. Undertake a SWATH and 3.5Khz survey off SE Iceland to locate coring sites.

2c. Obtain piston and/or kasten and box cores on suitable sites located in surveys at 2b above.

3 Transit from SE Iceland to S Greenland visiting van Aken's former current meter sites in S Iceland Basin, WOCE ACM 8-German sites on the Reykjanes Ridge and current meter line off Cape Farewell, sampling each with CTD & undercorer, and possibly piston core southern Snorri Drift (if it exists).

4a Undertake swath and 3.5Khz survey before occupying coring stations in the Eirik Drift area, noting that this area was occupied by RV Maurice Ewing in 2002 and NO Marion Dufresne in 2003.

4b. Take piston/kasten and box cores plus CTD at ~5 stations.

5 a Deploy CTD with under-CTD corer at stations on Canadian Margin along ACM 29 current meter line on the continental slope off Labrador.

5b. 3.5 kHz and Swath survey across Hamilton Spur.

5c. Piston/Kasten and Box cores plus CTD at 2 to 3 sites.

Transit to St Johns, Newfoundland, possibly undertaking more coring at a site on Orphan Spur (around 51° N, 49° 30' W) on passage if there is time.

In the event we managed all this and more, visiting central Gardar Drift and the SE Greenland margin en route to Eirik Drift.

The cruise proceeded very much as originally planned. We sailed from Fairlie at 10.00 BST on Thursday 1st July on a bright summer day. After a sharp little blow going across the Malin Sea, which enabled the novice members of the scientific party to get their sea legs (and stomachs) we visited stations on the area north of Rockall where long-term current meter records are available. These were sampled with the CTD and a mini-corer slung 10 m below it. This did not work well. Details appear later in this report, but the problems appear to relate to (a) hard bottom under fast flow, (b) too shallow penetration and (c) failure of the core-catcher to retain the sample, partly due to (a) and (b). A box core was therefore taken at Station 1, no sample was obtained from Sta.2 and the minicorer worked well at Sta.3.

We then went across to the S. Iceland Basin to start on the current meter location of WOCE line ACM-8B which cross the core of the Iceland-Scotland overflow (Stations 4-9). We didn't have a lot of luck with the mini corer there either and decided at Station 9 to deploy the pilot gravity corer from the piston core on a 4 mm hydrowire as a quick way of sampling. With the benefit of hindsight it might be that the old "boomerang corer", a free-fall device, would serve the purpose best, but more expensively.

This brought us on July 6th to near the top of the S. Iceland slope (Sta. 09 1035 m) which we then descended, taking a series of piston and kasten cores at depths of 1237, 1475, 1751, 1936, 2133 and 2303 m, also with a box core at each site (see table of stations and samples). For most of the time the wind stayed below 20 knots enabling us to complete the S. Iceland coring transect by the 9th of July. Only on the 7th did it get up to 28 knots for a few hours.

Having made good time we decided to go to our next area off Greenland via central Gardar Drift, to a site noted in 3.5 kHz records on Darwin cruise CD 88. This area has extremely high sedimentation rates with what turned out to be very soft sediment. We were beset by the problem throughout the cruise of the piston core over-penetrating, but here at Station 20/21 the corers all over-penetrated (mud on top of the bomb) until we took **all** the lead out of the kasten core bomb.

We left Gardar Drift on the evening of the 12th, making course for two WOCE ACM-8C sites on the flanks of the Reykjanes Ridge/ eastern Irminger Sea (sta 22,23). Here we encountered our only testing patch of weather with winds up to force 9 (42 knots) for a day or so. By late on the 14th we were back in business, taking two ACM-8C stations before crossing the Irminger Sea to core the S.E. Greenland Rise. The Denmark Strait overflow is very strong and previous investigators have found the Holocene to be absent from cores taken at mid-slope (e.g. SU 90-24 at 2085m of Elliot et al (2003)), so we targeted the downstream part of what might be a levee at ~ 2750 m. The bottom of the Irminger Sea (~ 3000 m at our latitude) is occupied by a turbidity current channel. So one has to be shallow enough to avoid turbidites but not so shallow as to be in the scour zone and have the record removed.

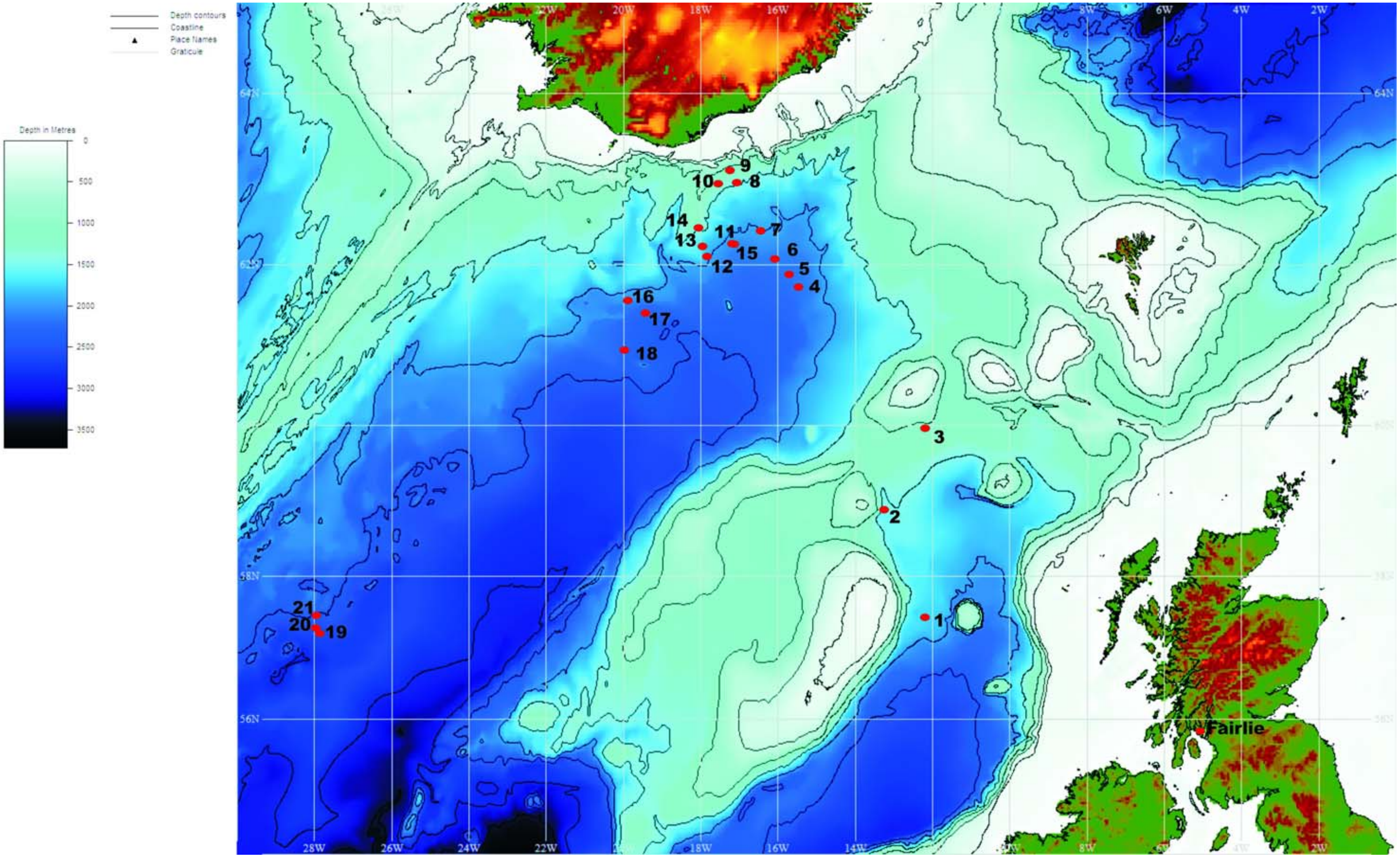
We shall see! We proceeded up the S.E. Greenland slope via a further two ACM-8C sites (Sta 25, 26) and took a core high on the slope at ~ 750 m, hoping to get records of the E. Greenland Current. The bed was covered by a siliceous mat and living sponges with large IRD rocks, so the prospects of a good record appear slim, but the foraminifera may reveal something.

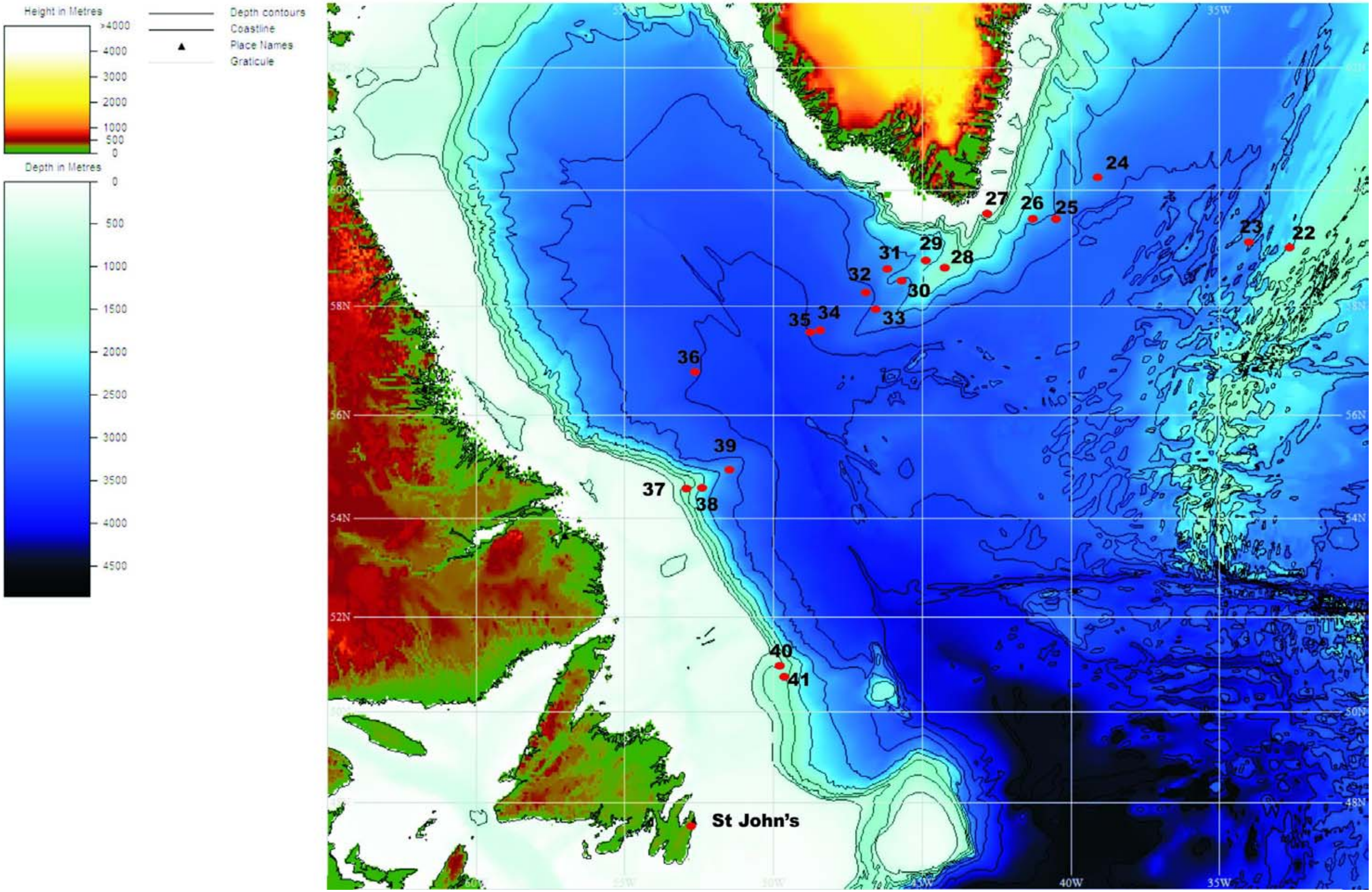
We now moved (on 19th July) into the final third of the cruise on Eirik Drift and the Labrador Sea. Approaching Eirik Drift the weather blew up to Force 8, but on 19th abated so that we were able to start our coring stations without delay. Eirik Drift has two principal ridges including a subsidiary lying to the north west of the main ridge. We took a zigzag course allowing us to cross both ridges and occupy 8 stations between water depths of 1,600 and 3,500m. The sampling proceeded without many hitches, the principal one being that we bent the lower 3m section of the Kasten core barrel at Station 33. In the middle of Station 34 the wind again got up to Force 8, but this was short lived and we were able to complete sampling of Eirik Drift by 24th July.

We then crossed the Labrador Sea in traditional conditions for the area, that is to say intermittently thick fog, and took our first station on the Labrador Margin (Station 36) at the site of WOCE current meter ACM 29 No.1 at a water depth of about 3,000m. We did not follow up the slope to the shallower ACM current meter stations because the velocities recorded there suggested that the conditions were unlikely to be depositional, so we proceeded straight to the shallow margin of Hamilton Spur. Here we took 3 stations on this projection from the Labrador Margin which shows an asymmetrical bathymetric profile, suggesting excess deposition on its south-eastern down-current side. Our stations here lay between 1,400 and 2,900m water depth. At the deepest station (Station 39) we took both a piston and a Kasten core in order to compare corer performance and recovery. For this purpose we were able to assemble a 6m Kasten comprising a 4 and a 2m section strapped together. We left Hamilton Spur on 26th and had a day's passage to the south east for our final set of sites, which were just to the west of a projection on the continental margin which has the appearance of being current constructed. There is no good seismic profile over this feature, which we informally call Orphan Spur (because it lies close to the well known Orphan Knoll). Here we took our final 2 stations designed to sample the upper part of Labrador Sea water at water depths 1,100 and 1,300m. These we completed on 29th in the early morning, and then made good passage for St. John's where the cruise ended on the morning of 30th. Although we were accompanied by some icebergs all the way from Hamilton Spur down past Orphan Spur, they presented no danger and caused no delay for our programme, because they were rather too far away for either good viewing or serious interference. The statistics of the recovery on this cruise are listed below and represent an extremely successful acquisition of material and data for ocean history and proxy calibration in the RAPID programme.

Material recovered: 30 box cores (total length 8.55 m), 19 piston cores (total length 224.27 m + 5.72 m pilot cores), 4 mini cores under the CTD, 5 gravity cores, 6 kasten cores (total length 29.79 m), 20 full-depth CTD casts, surface water samples at most stations for phosphate and trace metal analysis, and 29 surface and plankton net samples filtered for forams.

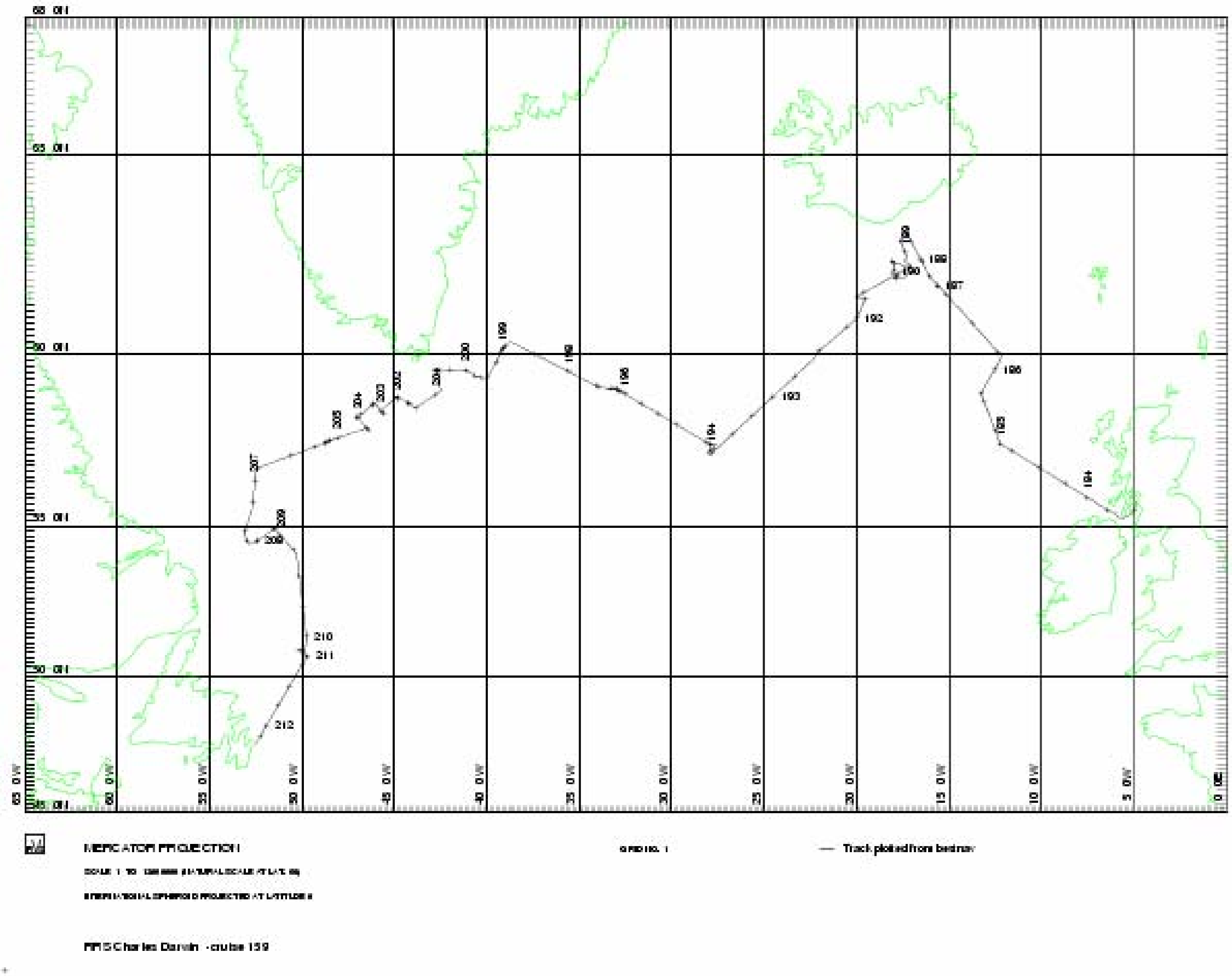
3. STATION MAPS AND TRACK CHART





Height in Metres
>4000
4000
3000
2000
1000
500
0
Depth in Metres
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Depth contours
Coastline
Place Names
Graticule
24
27
26
25
23
22
31
29
28
32
30
33
35
34
36
39
37
38
40
41
St John's
58N
56N
54N
52N
50N
48N
40W
35W

Ship's track (with Julian Day markers)

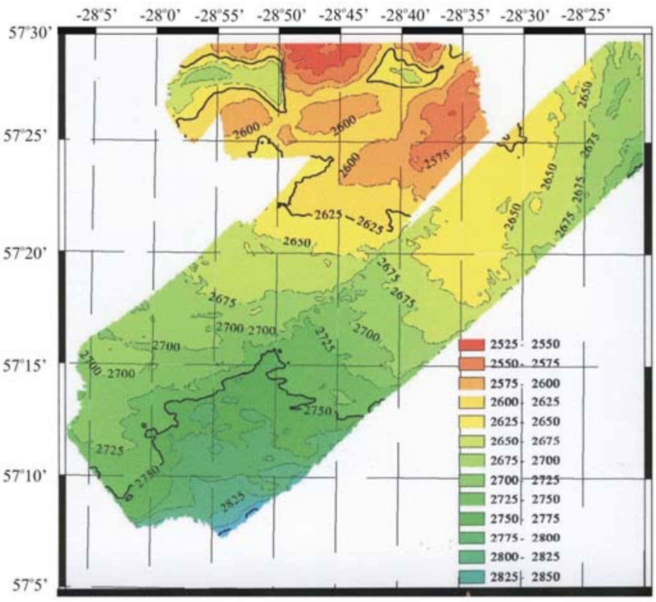


Scaled to fit media

3. TOPOGRAPHY and 3.5kHZ PROFILING

a. Topography

The swath echo sounding system was run continuously and much of the output was processed, especially around the coring sites. CTD deployments were sufficiently numerous that most processed swath has accurate sound velocity profiles. The principal areas covered were (1) tracks across North Rockall Plateau, (2) tracks up and down the south east Iceland Continental Rise, (3) a brief survey of mid-Gardar Drift around Stations 19 to 21 (see fig. below), (4) traverse of the west side of Rejkjanes Ridge and the South East Greenland Margin, (5) a zig-zag track across Eirik Drift and 6 tracks up and over Cartwright Spur, and a small part of the Continental Margin down to Orphan Spur off Labrador. An example of the swath coverage is given here for the mid-Gardar sites, and the listing of the areas within which there is some swath coverage is given in the table containing the records of processed swath stored on CD.

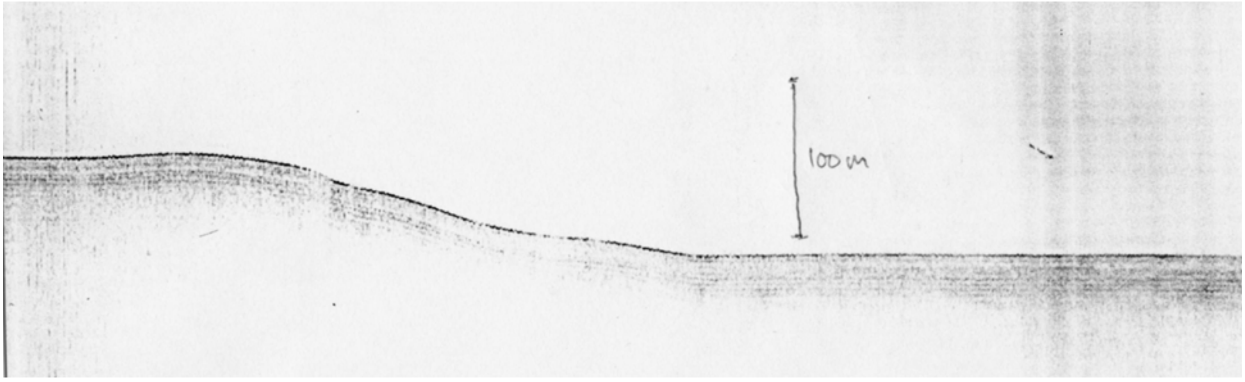


Swath bathymetry,region of Stations 19-21.

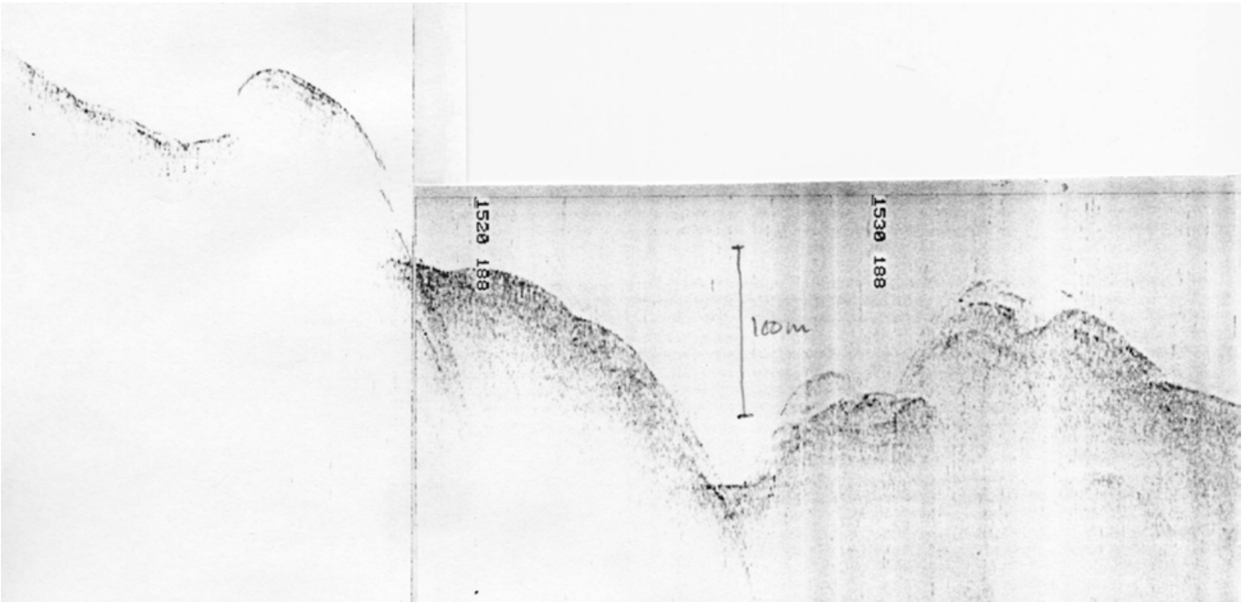
b. 3.5 kHz Profiling

The 3.5 was run continuously from the beginning of the cruise. Early results over Rockall trough were poor until settings were determined to give the best results. However the results on the Raytheon recorder up to the Iceland Rise were very faint though this may be recoverable from the digitally recorded data. (The 3.5 was recorded on the new 'Octopus' system.)

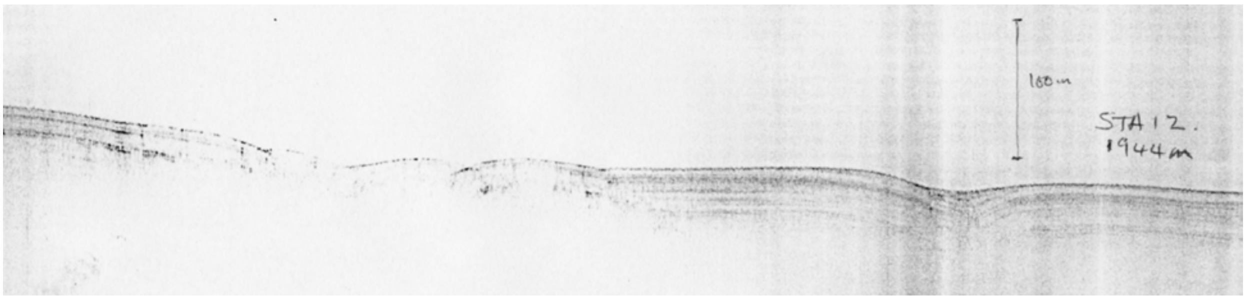
No recording paper was supplied for the 3.5 kHz Raytheon recorder. This was potentially catastrophic as the 3.5 is the single most important tool for deciding on core site locations. Luckily a (substandard) substitute was located in a cupboard on the Bridge. It is absolutely necessary to have an immediate continuous paper record so that one can review long stretches of sub-seabed conditions where changes can be rather subtle over long distances. Printing out single A4 sheets from a computer screen (not in real time) is absolutely not a satisfactory substitute. Examples of 3.5 records of conditions encountered are shown below.



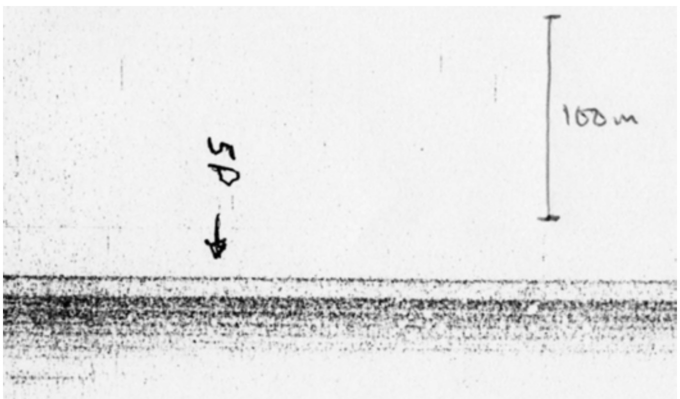
Between stas 7 & 8, 1420 m, S Iceland Rise. Ship travels L to R. 0400 JD188



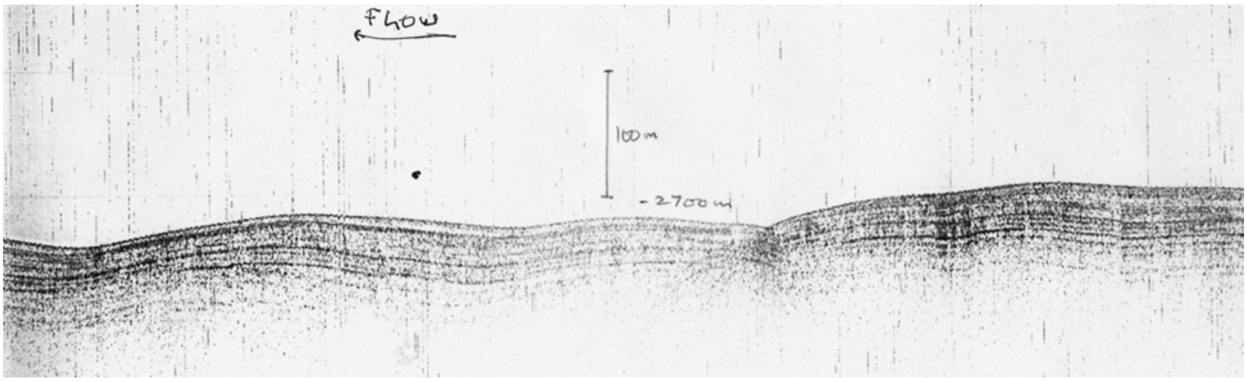
Near Sta 9, S Iceland Rise, rough topography, difficult coring. 1530 JD188



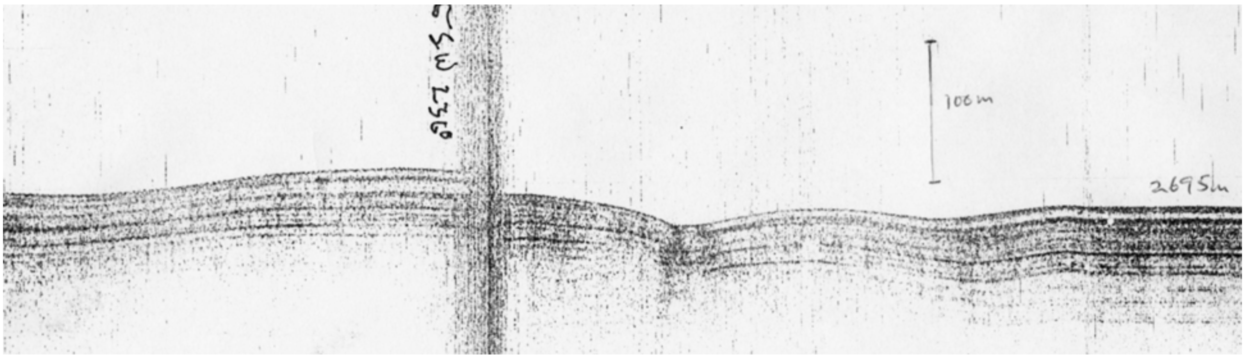
Foot of S Iceland Rise, low mud waves approaching Sta 12. 1330 JD189



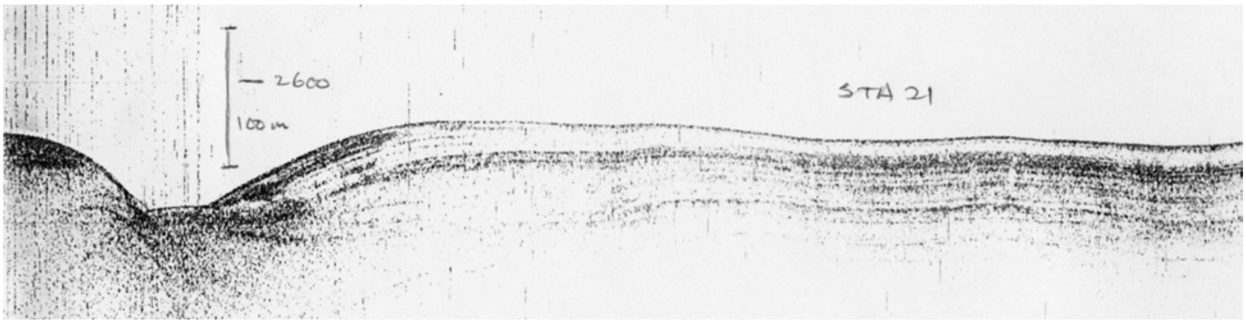
Foot of S. Iceland Rise, 2300 m, possibly thick Holocene section at Sta 17 (~ 10 m), core 5P.



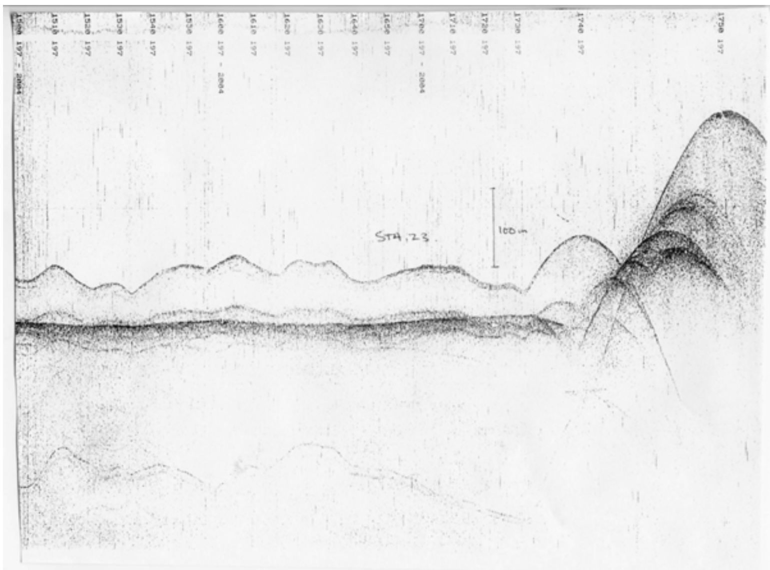
Mud waves migrating upflow, mid-Gardar Drift. 2330 JD193



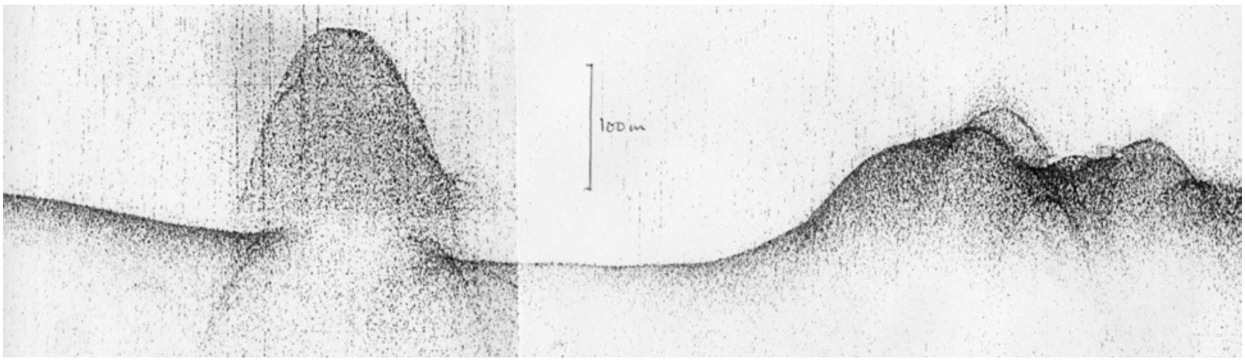
Mud waves coming onto Sta 20, mid Gardar. 0030 JD194



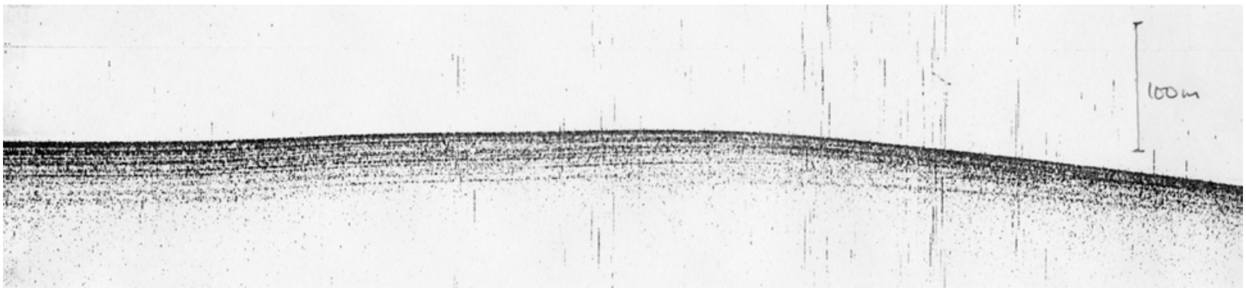
Very thick Holocene section, Sta 21, mid-Gardar (JD194). Near site located by McCave (1995) on CD 88 and later cored by Marion Dufresne (MD99-2251).



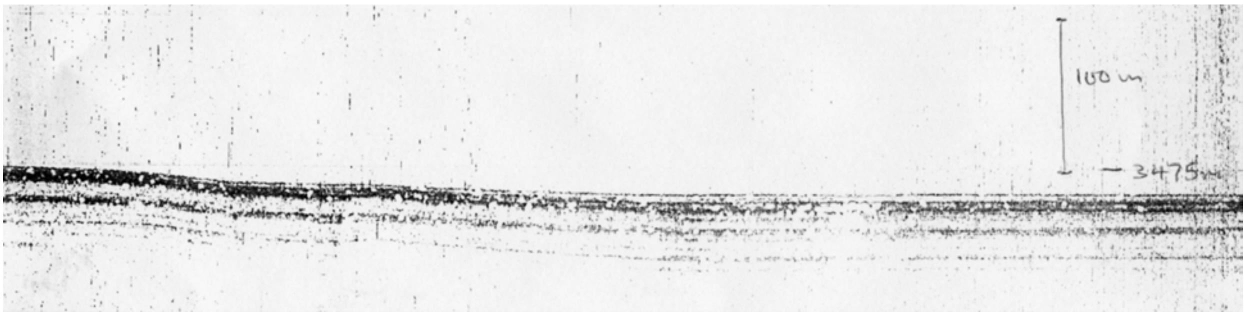
Station 23, between a rock and a hard place. W Reykjanes Ridge, site of WOCE current meter mooring of line ACM 8c at ~2600 m. Mountainous topography, gravelly bottom, unknown topographic influences on flow speeds!



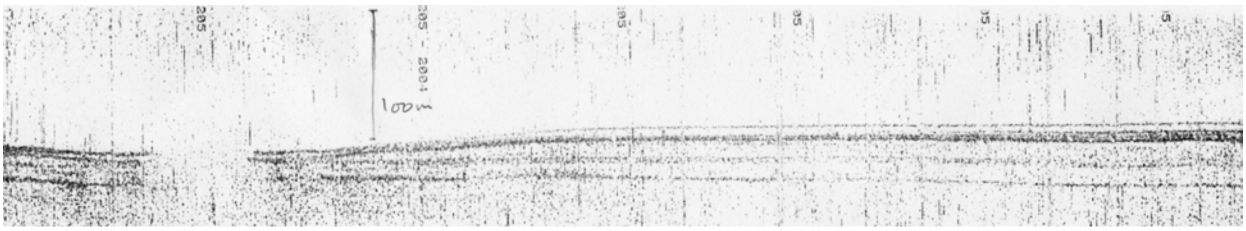
E side of northern Eirik Drift, current scoured hard bottom, 1770m 1900 JD200



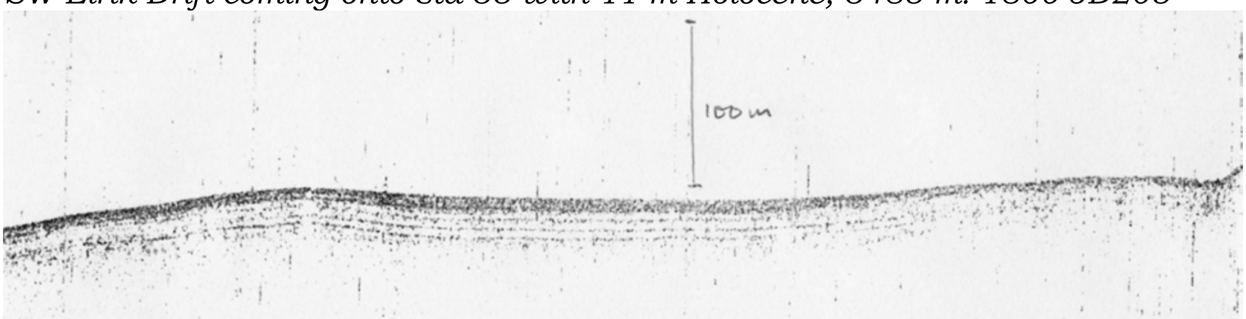
NW Eirik Drift between Sta 31-32, 2545 m 1500 JD203



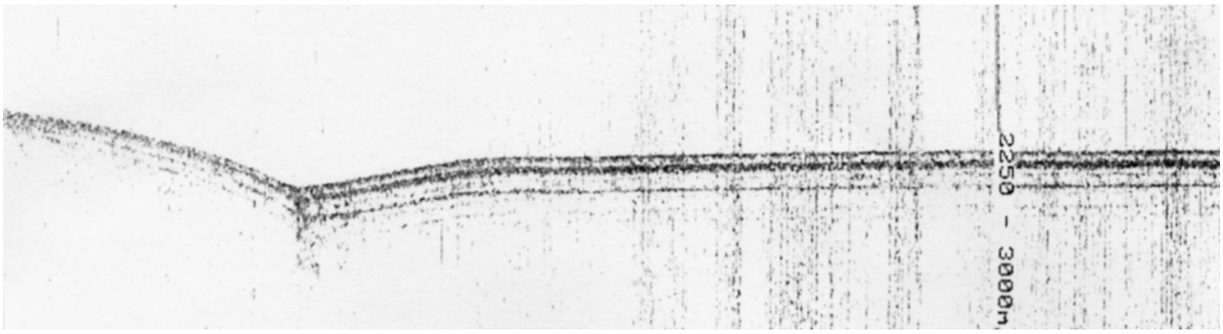
SW Eirik Drift coming onto sta 34 with 7 m Holocene, 3495 m. 0400 JD205



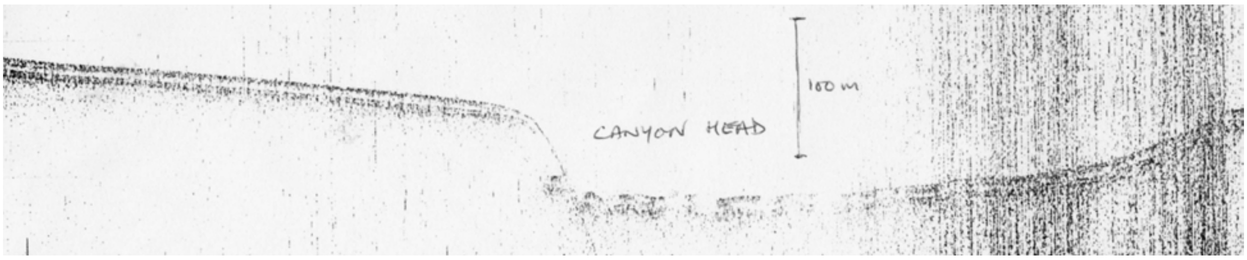
SW Eirik Drift coming onto sta 35 with 11 m Holocene, 3485 m. 1800 JD205



Mid depth Hamilton Spur cored perched sediment pod, Sta 38. 2330 JD207



Deep Hamilton Spur, double cored (K+P) Sta 39, 2862 m. 1300 JD208



Head of a canyon seen on the swath just downslope from Sta 40, break in slope at 1150 m. 2110 JD210

CD 159: Postscript files on CD ('**error**' signifies a corrupted file, but does not contain a map, only a depth scale). CD is held by INMcC and IRH and Miss S. Hunter at SOC (supervisor Prof DAV Stow), and BODC also has a copy.

File title	Latitude	Longitude	Station
Set 1 Box 9a 4	57° 22' - 57° 50'	11° 49' - 12° 32'	1
Box 5a 4	58° 52' - 59° 14'	12° 55' - 13° 20'	2
Box 12a 4	59° 43' - 60° 08'	12° 02' - 12° 30'	3
Box 2	**Error**		-
Set 2 Box 10a 4	61° 40' - 61° 50'	15° 11' - 15° 31'	4
Box 7a 4	61° 45' - 61° 57'	15° 37' - 15° 56'	5
Box 8a 4	61° 47' - 62° 11'	15° 46' - 16° 07'	6
Box 5a 4	62° 16' - 62° 34'	16° 13' - 16° 40'	6-7
Box 3a 4	62° 52' - 63° 54'	16° 54' - 17° 19'	8-9
Set 3 set 3a 4	62° 00' - 63° 10'	17° 00' - 18° 10'	10-11-12
Box 3da 4	? negative of grid.		-
areaset 3alla4	**Error**		-
Set 4 Box 38a 4	62° 05' - 62° 23'	17° 10' - 17° 47'	15
Box 8	57° 52' - 58° 16'	25° 45' - 26° 30'	18-19, Marietta/Franklin
Box 2	57° 07' - 57° 30'	27° 22' - 28° 06'	19-21
Box 2a 4	**Error**		-
dense (same as Box 2)	57° 07' - 57° 30'	27° 22' - 28° 00'	-
test (same as Box 2)	different colours!		-
Set 5 Hove	58° 55' - 59° 10'	32° 25' - 33° 52'	22-23
Box 3839	**Error**		-
Set 6 Greenland	59° 26' - 59° 37'	42° 25' - 42° 50'	27
Ridge	59° 29' - 59° 37'	42° 36' - 42° 46'	27
Set 7 area 7 box 11-12	58° 35' - 58° 45'	44° 10' - 44° 23'	28-29
area 7 box 6	58° 47' - 58° 52'	44° 50' - 45° 03'	29
Set 8 Box 3738	59° 26' - 59° 32'	40° 29' - 40° 36'	25
easteirik	59° 30' - 58° 30'	40° 00' - 44° 45'	25-29
eirik_all	59° 50' - 57° 30'	40° 00' - 49° 00'	25-35
Box 3638	59° 20' - 59° 45'	40° 30' - 41° 30'	26
Box 31 (see set 6)	59° 25' - 59° 38'	42° 35' - 42° 45'	27
Box 23	58° 37' - 58° 45'	44° 10' - 44° 40'	28-29
Box 22	58° 46' - 58° 52'	44° 40' - 45° 05'	29
Box 1718920	58° 19' - 58° 41'	45° 15' - 46° 15'	29-30
westeirik	58° 50' - 57° 30'	44° 50' - 48° 50'	29-35
Box 1415	57° 52' - 58° 25'	46° 20' - 46° 50'	31-33
Box 13	58° 02' - 58° 23'	46° 49' - 47° 07'	32
Box 14	57° 53' - 58° 06'	46° 20' - 46° 50'	33 (depths + 3,000 m)
Box 7	57° 26' - 57° 39'	48° 25' - 48° 55'	34-35
seamount 1	57° 32' - 57° 38'	48° 30' - 48° 48'	34-35
Box 36	**Error**		-
Set 9 cd159_9all	54° 40' - 57° 25'	48° 45' - 53° 08'	35-36-37
Box 4	56° 59' - 56° 34'	51° 40' - 52° 35'	36
Box 2	54° 35' - 55° 35'	52° 35' - 53° 10'	36-37
Set 10 Box 2	54° 23' - 54° 40'	52° 34' - 53° 05'	37-38
Box 2a 4 (repeat 2)	54° 23' - 54° 40'	52° 34' - 53° 05'	37-38
Box 4a 4	54° 26' - 54° 39'	52° 02' - 52° 33'	38
Set 11 Box 3	54° 47' - 54° 57'	51° 19' - 51° 36'	39
cd159_11_all	? 52° 30' - 55°	49° 55' - 51° 30'	39-SSE
Set 12 Box 19203031	50° 49' - 51° 03'	49° 48' - 50° 05'	40
Box 4445	**Error**		-
cd159_12	depth colour scale		-

4. CORING OPERATIONS

a. Box Coring

The box corer proved reliable as ever. The instrument was the standard "Sandia Mark 3" 50 x 50 x 50-60 cm spade corer after Hessler & Jumars (1974). Many cores were taken in areas littered with glacial and modern ice-rafted debris, some of it tens of cm in diameter, yet we rarely failed to obtain a sample and bent the box only once, despite landing frequently on stony and current-scoured ground.

The sub-sampling procedure was as follows:

1. Two 110 mm (i.d.) core liner tubes were first inserted in the mud.
2. The topmost 2 cm of the remainder of the box core surface was scraped and bagged for sedimentological and geochemical determinations.
3. The 330 mm long x 150 mm wide x 25 mm thick styrene trays employed for kasten core sub-sampling were routinely used to obtain a vertical sub-sample from the top section of each box core once the side panel had been removed and before the extraction of the sub-cores of operation 1 above. These will be X-rayed to examine sedimentary structure.

CD 159 BOX CORE LOG

Activity No.	Latitude (N)	Longitude (W)	Depth (PDR)	Location	Remarks
RAPiD-01-1B	57° 29.15'	12° 14.23'	1805	N. Rockall	35 cm
RAPiD-05-2B	61° 49.98'	15° 37.71'	2278	S. Iceland	19 cm
RAPiD-06-3B	62° 03.80'	16° 03.34'	2228	S. Iceland	22 cm
RAPiD-07-4B	62° 26.36'	16° 27.98'	2050	S. Iceland	18 cm
RAPiD-08-5B	62° 58.10'	17° 04.40'	1421	S. Iceland	Surface scrape only, ACM8 Site 503. .
RAPiD-10-6B	62° 58.39'	17° 35.75'	1249	S. Iceland	49 cm
RAPiD-11-7B	62° 17.89'	17° 09.06'	2126	S. Iceland	39 cm. near AII-94-4PC site, and Sta. 15.
RAPiD-12-8B	62° 05.60'	17° 48.97'	1944	S. Iceland	38 cm
RAPiD-13-9B	62° 12.71'	17° 59.37'	1755	S. Iceland	33 cm
RAPiD-14-10B	62° 27.18'	18° 05.04'	1488	S. Iceland	Crooked, 17 cm in one corner, gravelly
RAPiD-14-11B	62° 27.24'	18° 04.99'	1487	S. Iceland	Similar (worse); bagged sample.
RAPiD-21-12B	57° 27.09'	27° 54.53'	2630	Cent. Gardar	58 cm, overfull but top is v. near top.
RAPiD-24-13B	60° 10.36'	39° 07.49'	2748	SE Greenl'd	48 cm
RAPiD-26-14B	59° 34.98'	41° 10.01'	2302	SE Greenl'd	39 cm
RAPiD-27-15B	59° 36.18'	42° 42.47'	768	SE Greenl'd	Sponge mat at surface & below, big IRD
RAPiD-28-16B	58° 39.17'	44° 12.98'	1627	Eirik	Thin slice, rocky.
RAPiD-28-17B	58° 39.35'	44° 12.48'	1628	Eirik	" " "
RAPiD-29-18B	58° 48.01'	44° 51.82'	2145	Eirik	23 cm, crooked hit (23 to 0 on one side).
RAPiD-30-**20B**	58° 26.04'	45° 44.99'	2439	Eirik	33 cm. Numbering error; **no #19B.**
RAPiD-31-21B	58° 36.65'	46° 11.41'	2570	Eirik	32 cm
RAPiD-32-22B	58° 14.92'	47° 00.74'	3096	Eirik	33 cm
RAPiD-33-23B	57° 56.10'	46° 30.66'	3016	Eirik	34 cm
RAPiD-34-24B	57° 35.14'	48° 30.62'	3496	Eirik	28 cm
RAPiD-35-25B	57° 30.47'	48° 43.40'	3486	Eirik	43 cm
RAPiD-37-26B	54° 30.84'	52° 57.12'	1380	Hamilton Sp	38 cm
RAPiD-38-27B	54° 31.97'	52° 25.94'	2152	Hamilton Sp	35 cm
RAPiD-39-28B	54° 54.76'	51° 28.89'	2863	Hamilton Sp	35 cm
RAPiD-40-29B	50° 57.48'	49° 57.54'	1044	Orphan Sp.	33 cm
RAPiD-41-30B	50° 42.65'	49° 42.82'	1271	Orphan Sp.	39 cm

b. Kasten Coring

Kasten cores were taken using the 1.5 tonne variable weight core-head ('bomb') with an adaptor to take the square barrel. The intention was wherever possible to take 7 m cores made up of 4 m and 3 m barrels fish-plated together. We did not make extensive use of the Kasten corer because, (a) the piston corer appeared to be working pretty well, and (b) if our wildest dreams were attained (sedimentation rates of > 50 cm/ka), then 6.5 m, the usual recovery, would not get us down to the 16 ka lower limit for RAPID. As it turned out, Kasten performance was somewhat chequered.

The first on the S. Iceland Rise at 1936 m depth (see table) was an excellent core of 6.4 m length. The next site (Sta. 21) was at the point located during cruise CD 88 (McCave, 1995) and later cored by Mark Chapman on Marion Dufresne (MD99-2251). My estimate then (1994) was that this site could contain up to 16 m of Holocene. It proved to be very soft sediment and the Kasten over-penetrated by over a metre (mud on top of the bomb). We then took a box core (which also over-penetrated) while we removed all the lead from the Kasten bomb. This reduced its weight to ~ 200 kg and a 4 m barrel was attached. This obtained a good 3.6 m core with brown mud at the top (but the top is always disturbed because of the need to lay the core horizontal).

Core 4K on Eirik drift also over-penetrated so, in a perfect demonstration of the accuracy of Sods Law, at the next (deeper) station where the bed was anticipated to be even softer, we put the corer in very slowly (20 m/min). It stopped on a harder layer at 2 m, fell over and bent the (brand new) barrel. The final core (RAPiD-39-6K) was taken at the same site as 18P in order to compare piston and kasten recovery.

KASTEN CORE LOG

Core No.	Latitude (N)	Longitude (W)	Depth (m)	Barrel		
(m)	Location	Length (cm)/ comments				
RAPiD-12-1K	62° 05.43′	17° 49.18′	1936	7	S. Iceland	641
RAPiD-21-2K	57° 26.99′	27° 54.24′	2622	7	Gardar	690. <u>very</u> overpenetrated
RAPiD-21-3K	57° 27.09′	27° 54.70′	2630	4	Gardar	~360; 200 kg bomb
RAPiD-31-4K	58° 36.61′	46° 11.48′	2570	7	Eirik	678; overpenetrated by ~25 cm
RAPiD-33-5K	57° 56.18′	46° 29.65′	3008	7	Eirik	42 cm recov^{d}. Stopped @ 2 m, fell over, bent barrel,
RAPiD-39-6K	54° 54.71′	51° 28.77′	2863	6	Hamilton Sp.	641; overpenetrated by ~20 cm, also site of kasten 39-6K.

c. Piston Coring

CD159 was the first cruise to use UKORS new NIOZ-type piston corer, and a number of problems with the manufacture and operation of the system were encountered.

The biggest of these problems was the fact that the corer over-penetrated on every deployment except one. This was essentially due to the fact that the 1.5 Tonne bomb weight was too large for the soft sediment types being cored. As there was no means of reducing the weight of the bomb, other methods of slowing the corer down were employed, but with little success. Extra barrels were added to the corer to increase the barrel length to a maximum of 21 m. The free-fall distance was reduced to 1m and the winch speed was reduced to 10m/min on triggering. The amount of 'rebound' wire in the system was also reduced to the point that large shock loads were recorded at the block upon triggering. These adjustments had a slight effect, but nowhere near enough to stop the corer over-penetrating. For future cruises, a bomb weight with removable 0.25 Tonne weights would be recommended.

It was noticed at an early stage in the cruise that the barrel adaptor, used to connect the 110mm diameter barrels to the bomb weight, did not have a constriction in its centre to act as a piston stop (as the Dutch corer hired from NIOZ on previous cruises did). This meant that the 'nose' of the core bomb was acting as the piston stop on recovery of the corer. As this 'nose' was only 1mm smaller in diameter than the top of the piston, a 10mm thick steel washer had to be manufactured on board to insert at the top of the liner, to provide a larger area for the piston to stop against.

On most stations, the liner at the very top of the corer was shattered. This was due to the fact that the 4 piston seals were an extremely tight fit inside the liner. On triggering, the rebound in the wire caused the piston to jerk the liner upwards and shatter it against the piston stop. It was thought that this was because the liner purchased by UKORS has a slightly smaller internal diameter than that used by NIOZ on previous cruises. Various combinations of the number and placement of seals were tried with little or no effect. Only the removal the seals altogether ('soft' piston) alleviated the problem during the cruise. It has since been found that the profile of the plastic spacers between the piston seals were manufactured incorrectly, causing the seals to expand against the liner too tightly. This problem has now been remedied.

Due to the problems being encountered with the over-penetration of the corer, it was decided to attempt to use the system as a gravity corer. Unfortunately, neither the 90mm nor the 110mm one-way valves needed for gravity coring were supplied with the system. The 160mm valves were supplied, but it was found that the 160mm barrel adaptor would not fit onto the core bomb weight. We therefore had no gravity coring capability whatsoever during the cruise, other than the Kasten corer.

The aft winch davit assembly is prone to rotate in its mounting bracket when recovering the corer and launch frame in anything but flat calm conditions. An alternative method of clamping the davit to the bulwark should be found.

The table below shows the locations, depths, corer setup, recovery and comments for each of the 19 piston cores taken during CD159. These had a total length of 224 m plus 5 m of pilot gravity (PG) core, representing a fair degree of success.

PISTON CORE LOG

Core No.	Latitude (N)	Longitude (W)	Depth m	Barrel/ liner m/mm	Free-fall (m)	Re-bound (m)	Pullout (T)	Location	Remarks Core length/ pilot gravity core length/ comment
RAPiD-10-1P+PG	62° 58.53’	17° 35.37’	1237	9/110	3	3	4.9	S. Iceland	616 cm/23 cm PG;
RAPiD-13-2P+PG	62° 12.93’	17° 59.58’	1751	12/110	2	1	4.3	S. Iceland	856 cm/ 60 cm PG
RAPiD-14-3P+PG	62° 27.26’	18° 05.49’	1475	12/110	1	1	4.6	S. Iceland	850 cm; PG empty;
RAPiD-15-4P+PG	62° 17.58’	17° 08.04’	2133	15/110	1	1	4.8	S. Iceland	1121cm/ 20 cm PG. Near Johnson-Shor pos^{n}.
RAPiD-17-5P+PG	61° 28.90’	19° 32.16’	2303	18/110	1	4	6.0	S. Iceland	1441 cm/ 75 cm PG – overpen^{d}.
RAPiD-20-6P+PG	57° 16.25’	27° 56.25’	2695	18/110	1	4	6.2	Gardar	1471 cm/ 47 cm PG. Section 6 imploded.
RAPiD-24-7P+PG	60° 10.43’	39° 07.39’	2744	18/110	1	4	6.7	SE Greenland	1425 cm/ 61 cm PG, overpen^{d}.
RAPiD-27-8P+PG	59 35.92	42 41.82’	742	9/110	1	2.5	4.0	SE Greenland	548 cm/PG empty
RAPiD-28-9P+PG	58 39.03’	44 12.75’	1625	9/110	1	3	5.2	Eirik	686 cm/ PG overpen^{d}; sample only in CC, bagged.
RAPiD-29-10P+PG	58 48.00’	44 51.92’	2145	18/110	1	2.5	5.6	Eirik	1362 cm, PG empty
RAPiD-30-11P+PG	58 35.93’	45 45.00’	2440	18/110	1	2	6.0	Eirik	1466 cm/ 25 cm PG
RAPiD-32-12P+PG	58 15.00’	46 59.86’	3072	18/110	1	2.5	6.5	Eirik	1463 cm/45 cm PG
RAPiD-34-13P+PG	57 35.19’	48 29.91’	3494	21/110	1	3	6.7	Eirik	1740 cm/45 cm PG
RAPiD-35-14P+PG	57 30.25’	48 43.34’	3484	18/110	1	3	6.5	Eirik	1561 cm/bag top PG. 9.3 t shock tension @ trigger
RAPiD-37-15P+PG	54 31.51’	52 57.65’	1409	18/110	1	2.5	4.9	Hamilton Spur	1006 cm/ 74 cm PG.
RAPiD-38-16P+PG	54 31.95’	52 25.55’	2159	18/**90**	1	3	5.2	Hamilton Spur	1181 cm/18 cm PG.
RAPiD-39-17P+PG	54 54.79’	51 28.99’	2864	18/90	1	3	5.9	Hamilton Spur	1343 cm/ 71 cm PG (overpen^{d}, top bagged),(+6K)
RAPiD-40-18P+PG	50 57.14’	49 57.80’	1051	18/90	1	1.5	4.6	Orphan Spur	1096 cm/ PG bagged
RAPiD-41-19P+PG	50 42.86’	49 43.12’	1266	18/90	1	1.5	5.0	Orphan Spur	1195 cm/ 51.6 cm PG
									224.27 m/ 5.72 m total lengths

d. Coring with 'under-CTD' corer

The performance of the under-CTD mini-corer was rather chequered due to a combination of corer design and environmental conditions. The corer was suspended on 20 m of 4 mm wire attached to the CTD frame by a 3-point suspension. The corer has a miniature oil-drum shape holding weights, with a 30 cm plastic, 6 cm diameter core tube below. The flat base of the drum prevents over-penetration. A core cutter and orange-peel catcher are fitted to the nose, and a ball valve at the top of the core tube inside the drum is intended to prevent fall-out when the corer is raised above the sea surface. The performance is detailed in the table below. Of 13 deployments only 3 recovered good cores ranging from 8.5 to 19 cm long. Material was salvaged after partial wash-out from a further two. Three are recorded as having penetrated and lost their (sandy) samples. In these cases penetration was not great, 5-7 cm, and the ball valve was not effective. In five cases the corer failed and this was due to hard bottom in three cases, one of which was marked by recovery of a few pebbles.

Overall, in eight cases the bottom was rather sandy or even pebbly and the corer had difficulty either penetrating or retaining the sand. The retention problem is partly down to the ball valve and the fact that the drum is full of water, which decreases the pressure exerted by the ball on the core tube top because of buoyancy. There is an associated problem of insufficient penetration.

Suggestions for remedies are:

(i) cut holes in the bottom of the drum to let water out quickly at the sea surface.
(ii) get a better, tighter fitting valve.
(iii) increase corer weight (but at present we haul this up manually, so greater weight is not optimal).
(iv) suspend the corer under the CTD on an arm which is released by firing one of the CTD bottles at 5-10 m above the bed. To ensure it flies true and enters vertically put a fin on top of the corer.

The fact is that physical oceanographers frequently set their current meters at locations where the flow is fast (to monitor, for example, DWBC flux) leading to sandy or pebbly beds that are hard to core. Thus many current meter sites will present coring difficulties.

CTD Stations: Under-CTD Mini-Corer Performance

STATION	CTD	# MINI-C	MINI-CORER PERFORMANCE
1	1	X/B	Penetrated, did not retain sample. Box cored (35 cm)
2	2	X	Did not retain sample (sandy).
3	3	**1C**	Good, 19 cm.
4	4	**2C**	Salvaged; washed sandy sample.
5	5	X/B	Did not retain sample: Box cored (22 cm).
6	6	-/B	Box cored first, no Mini-C.

7	7	X/B	Mini-C failed. Box core (18 cm).
8	8	-/B	Box cored (surface scrape). Mini-C not deployed.
9	9	X/G	Mini-C failed, used PG as Gravity core (67 cm).
16	10	X/G	Mini-C failed, bottom hardish, used PG as GC (13 cm).
18	11	**3C**	OK; 8.5 cm.
19	12	**4C**	Salvaged washed sample.
22	13	X/G	Mini-C failed, GC taken (30 cm).
23	14	X	Few pebbles in Mini-C, hard bottom.
24	15	-/B	Box cored first, Mini-C not deployed.
25	16	-/G	Took GC, lost core, but over pen. of 2 cm above valve.
26	17	-/B	Box cored first, Mini-C not deployed.
27	18	-/B	Mini-C not deployed, Box core sponge mat & rocks.
32	19	-/B	Mini-C not deployed, Box cored.
36	20	**5C**	Good core, 12 cm.

X = no core, B = Box, G = Gravity, - not deployed

5. CTD OPERATIONS AND WATER SAMPLING

Operations

A seabird CTD, multi sensor, and 24-Niskin bottle rosette package was used on 20 stations: CD 159 – 1, 2, 3, 4, 5, 6, 7, 8, 9, 16, 18, 19, 22, 23, 24, 25, 26, 27, 32 and 36. Two bottles (duplicates in case of malfunction) were tripped at each of twelve depths, one of which was close to the sea floor. The system performed perfectly at all stations apart from on Station CD159-022 when the transmissometer sensor produced unusable data.

Data on station locations and depths of samples are listed in the CTD Data Reports compiled for each station.

100 cm^3 samples were drawn in glass bottles for (i) alkalinity, (ii) $\delta^{18}O$ and (iii) $\delta^{13}C$ (see table below for samples). The $\delta^{18}O$ samples were stored untreated. Measurement of pH was made on the alkalinity samples before storage untreated. The pH meter was calibrated with pH = 4 and = 9 buffers before and after each set of measurements. The $\delta^{13}C$ samples were filtered through disposable 0.4 μm Nuclepore filters, poisoned with a few drops of saturated mercuric chloride solution and sealed in glass ampoules using a blow torch.

One or two 1 litre samples were drawn, usually from the deepest water samples and filtered through 0.4 μm Nuclepore filters before storage.

Two or three samples were drawn from each cast for determination of salinity for calibration purposes.

Surface sea water samples were collected for trace element work from forward starboard as the ship slowed to reach station, using the “Greaves surface sampler” (a weighted sheath holding a 1 litre polypropylene bottle). The sampler did not survive the cruise intact, suffering terminal damage from striking the bows of the ship. Samples were filtered through 0.4 μm Nuclepore filters before storage.

CTD Water samples for stable isotope and approximate alkalinity analysis:

There are three bottles for each sample: δ18O, alkalinity, and a heat sealed poisoned vial forδ13C.

CD159/1 - CTD1 - $\delta^{18}O$/ $\delta^{13}C$/Alk	
Bottle #:	Depth (m):
24	5
22	10
20	20
18	50
16	100
14	200
12	250
10	500
8	800
6	1000
4	1250
2	1600
1	1789

CD159/2 – CTD2 - $\delta^{18}O$/$\delta^{13}C$/Alk	
Bottle #:	Depth (m):
1	1596
3	1450
5	1400
7	1200
9	1000
11	750
13	500
15	250
17	100
19	50
21	25
23	10

CD159/3 – CTD3 - $\delta^{18}O$/ $\delta^{13}C$/Alk	
Bottle #:	Depth (m):
1	1179
3	1150
5	1000
7	900
9	800
11	600
13	500
15	250
17	100
19	50
21	23
23	10

CD159/4 – CTD4 - $\delta^{18}O$/ $\delta^{13}C$/Alk	
Bottle #:	Depth (m):
1	2270
3	2000
5	1600
7	1200
9	800
11	750
13	650
15	530
17	200
19	50
21	30
23	5

CD159/5 – CTD5 - $\delta^{18}O$/ $\delta^{13}C$/Alk	
Bottle #:	Depth (m):
1	2270
3	2000
5	1700
7	1100
9	850
11	800
13	650
15	500
17	300
19	100
21	50
23	10

CD159/6 – CTD6 - $\delta^{18}O$/ $\delta^{13}C$/Alk	
Bottle #:	Depth (m):
1	2206
3	2190
5	2080
7	1800
9	1200
11	750
13	650
15	400
17	200
19	75
21	50
23	10

CD159/7 – CTD7 - $\delta^{18}O$/ $\delta^{13}C$/Alk	
Bottle #:	Depth (m):
1	2035
3	1900
5	1750
7	1200
9	1100
11	900
13	700
15	500
17	300
19	100
21	50
23	10

CD159/8 – CTD8 - $\delta^{18}O$/ $\delta^{13}C$/Alk	
Bottle #:	Depth (m):
1	1285
3	1050
5	830
7	810
9	780
11	750
13	660
15	590
17	200
19	100
21	70
23	35

CD159/9 – CTD9 - $\delta^{18}O$/ $\delta^{13}C$/Alk	
Bottle #:	Depth (m):
1	1123
3	1000
5	900
7	690
9	650
11	600
13	450
15	200
17	85
19	35
21	20
23	5

CD159/9 – CTD9 - $\delta^{18}O$/ $\delta^{13}C$/Alk	
Bottle #:	Depth (m):
1	2121
3	1900
5	1750
7	1700
9	1675
11	1625
13	1500
15	1000
17	900
19	870
21	800
23	500

CD159/18 – CTD11 – $\delta^{18}O$/ $\delta^{13}C$/Alk	
Bottle #:	Depth (m):
1	2390
3	2330
5	1850
7	1500
9	1200
11	825
13	780
15	690
17	500
19	300
21	280
23	100

CD159/19 – CTD12 – $\delta^{18}O$/ $\delta^{13}C$/Alk	
Bottle #:	Depth (m):
1	2766
3	2650
5	2200
7	1500
9	1100
11	750
13	550
15	350
17	300
19	221
21	150
23	50

CD159/22 – CTD13 – δ18O/ δ13C/Alk	
Bottle #:	Depth (m):
1	2095
3	1500
5	1150
7	900
9	800
11	610
13	570
15	390
17	350
19	230
21	190
23	50

CD159/23 – CTD14 – δ18O/ δ13C/Alk	
Bottle #:	Depth (m):
1	2591
3	2000
5	1600
7	1250
9	1050
11	700
13	550
15	400
17	300
19	180
21	60
23	5

CD159/24 – CTD15 – δ18O/ δ13C/Alk	
Bottle #:	Depth (m):
1	2724
3	2650
5	2550
7	2450
9	1500
11	1150
13	750
15	550
17	450
19	160
21	120
23	50

CD159/25 – CTD16 – δ18O/ δ13C/Alk	
Bottle #:	Depth (m):
1	2685
3	2600
5	2540
7	2440
9	2300
11	1750
13	800
15	450
17	250
19	150
21	120
23	40

CD159/26 – CTD17 – δ18O/ δ13C/Alk	
Bottle #:	Depth (m):
1	2276
3	2190
5	2150
7	2120
9	2080
11	1800
13	1300
15	900
17	550
19	370
21	80
23	30

CD159/26 – CTD18 – δ18O/ δ13C/Alk	
Bottle #:	Depth (m):
1	761
3	700
5	600
7	500
9	400
11	300
13	200
15	100
17	50
19	20
21	10
23	5

CD159/32 – CTD19 – δ18O/ δ13C/Alk	
Bottle #:	Depth (m):
1	3050
3	2830
5	2800
7	2570
9	2470
11	2400
13	1900
15	1500
17	1200
19	800
21	100
23	50

Hydrographic data processing

Initial processing of the hydrographic data was carried out by the UKORS staff. Two sets of data were taken from the shipboard data base:

(i) ASCI files of data in 1 m bins and these were converted to Excel .txt files for convenience, This file type stores data for ten sensors as given in UKORS documentation. Of these, DepSM (water depth in m), PrDM (pressure in decibars), T090C (temperature in ^{o}C), Sa100 (salinity), Densityoo (density in kg m^{-3}), Sbeox)Mm/kgcan (dissolved O_2 in μmol/kg) were selected and transferred to an Excel Workbook “CD159_CTD_Data.xls” for ease of use.

(ii) Excel workbooks of the form “trans001_lowgain.xls”, where 001 etc. is the sequential CTD cast (not the station number), which contain 1 m binned data under a number of headers of which Att Coeff (Attenuation Coefficient), Potemp090C (potential temperature)and Sigma-e00 (σ_o) were also transferred to the Excel Workbook “CD159_CTD_Data.xls”. No Attenuation data were recovered for trans013 (CTD-022) because of technical difficulties.

Salinity Calibrations

Samples were drawn from bottles for determination of salinity onboard using the ‘Portasal’ salinometer. The secondary salinity sensor is preferred as it has the lowest mean difference from the salinometer (0.0013). Standard Seawater Batch no.P137 was used as the standard.

SEABIRD C.T.D. and Portasal SALINITY DATA

CAST NO	BOTTLE	SAMPLE	SAL primary	SAL 2ndary	2nd-prim	PORTASAL	primary - portasal	2ndy-portasal
1	1	193	34.937	34.9350	-0.002	34.938	-0.0010	-0.0030
1	2	194	34.955	34.9540	-0.001	34.955	0.0000	-0.0010
1	3	195	34.955	34.9540	-0.001	34.957	-0.0020	-0.0030
2	5	196	35.1335	35.1335	0	35.139	-0.0055	-0.0055
2	6	197	35.1331	35.1322	-0.0009	35.138	-0.0049	-0.0058
2	9	198	35.252	35.2510	-0.001	35.253	-0.0010	-0.0020
2	10	199	35.252	35.2510	-0.001	35.254	-0.0020	-0.0030
3	1	200	35.0938	35.0953	0.0015	35.097	-0.0032	-0.0017
3	2	201	35.0938	35.0953	0.0015	35.097	-0.0032	-0.0017
3	9	202	35.282	35.2834	0.0014	35.284	-0.0020	-0.0006
3	10	203	35.2819	35.2834	0.0015	35.283	-0.0011	0.0004
4	3	204	34.9108	34.9115	0.0007	34.912	-0.0012	-0.0005
4	4	205	34.9107	34.9115	0.0008	34.914	-0.0033	-0.0025
4	7	206	34.9797	34.9809	0.0012	34.982	-0.0023	-0.0011
4	8	207	34.9798	34.9809	0.0011	34.982	-0.0022	-0.0011
5	4	209	34.9106	34.9117	0.0011	34.914	-0.0034	-0.0023
5	5	210	34.9081	34.9092	0.0011	34.911	-0.0029	-0.0018
5	6	211	34.908	34.9093	0.0013	34.91	-0.0020	-0.0007
6	7	212	34.9028	34.9039	0.0011	34.906	-0.0032	-0.0021
6	8	213	34.9029	34.9038	0.0009	34.906	-0.0031	-0.0022
6	15	214	35.2555	35.2576	0.0021	35.258	-0.0025	-0.0004
6	16	215	35.2556	35.2577	0.0021	35.259	-0.0034	-0.0013
7	1	216	34.9759	34.9771	0.0012	34.98	-0.0041	-0.0029
7	5	49	35.0079	35.0089	0.001	35.011	-0.0031	-0.0021
7	6	50	35.008	35.0090	0.001	35.011	-0.0030	-0.0020
8	1	51	35.0185	35.0203	0.0018	35.02	-0.0015	0.0003
8	2	52	35.0184	35.0195	0.0011	35.02	-0.0016	-0.0005
8	3	53	35.018	35.0189	0.0009	35.02	-0.0020	-0.0011
8	4	54	35.0179	35.0192	0.0013	35.021	-0.0031	-0.0018
9	3	55	35.0417	35.0435	0.0018	35.044	-0.0023	-0.0005
9	4	56	35.0419	35.0426	0.0007	35.045	-0.0031	-0.0024

9	5	57	35.0477	35.0497	0.002	35.051	-0.0033	-0.0013
9	6	58	35.0475	35.0497	0.0022	35.051	-0.0035	-0.0013
10	1	59	34.9954	34.9957	0.0003	34.999	-0.0036	-0.0033
10	2	60	34.9956	34.9959	0.0003	34.999	-0.0034	-0.0031
10	3	61	35.005	35.0054	0.0004	35.007	-0.0020	-0.0016
10	4	62	35.0052	35.0055	0.0003	35.007	-0.0018	-0.0015
12	7	193	34.9007	34.9015	0.0008	34.902	-0.0013	-0.0005
12	8	194	34.9009	34.9016	0.0007	34.902	-0.0011	-0.0004
12	9	195	34.9184	34.9193	0.0009	34.919	-0.0006	0.0003
12	10	196	34.9184	34.9193	0.0009	34.92	-0.0016	-0.0007
13	1	197	34.9499	34.9507	0.0008	34.951	-0.0011	-0.0003
13	2	198	34.95	34.9506	0.0006	34.951	-0.0010	-0.0004
13	3	199	34.9476	34.9487	0.0011	34.948	-0.0004	0.0007
13	4	200	34.9477	34.9487	0.001	34.95	-0.0023	-0.0013
14	1	201	34.9342	34.9349	0.0007	34.936	-0.0018	-0.0011
14	2	202	34.9343	34.9348	0.0005	34.936	-0.0017	-0.0012
14	3	203	34.9324	34.9333	0.0009	34.933	-0.0006	0.0003
14	4	204	34.9323	34.9333	0.001	34.933	-0.0007	0.0003
15	1	205	34.846	34.8465	0.0005	34.848	-0.0020	-0.0015
15	2	206	34.8459	34.8465	0.0006	34.847	-0.0011	-0.0005
15	9	207	34.8987	34.8998	0.0011	34.901	-0.0023	-0.0012
15	10	208	34.8987	34.8998	0.0011	34.904	-0.0053	-0.0042
16	9	49	34.9185	34.9191	0.0006	34.92	-0.0015	-0.0009
16	10	50	34.9185	34.9190	0.0005	34.922	-0.0035	-0.0030
16	11	51	34.9026	34.9037	0.0011	34.904	-0.0014	-0.0003
16	12	52	34.9027	34.9037	0.001	34.904	-0.0013	-0.0003
17	11	53	34.9177	34.9188	0.0011	34.918	-0.0003	0.0008
17	12	54	34.9177	34.9187	0.001	34.918	-0.0003	0.0007
17	13	55	34.9029	34.9042	0.0013	34.905	-0.0021	-0.0008
17	14	56	34.9029	34.9043	0.0014	34.904	-0.0011	0.0003
18	3	57	34.9403	34.9422	0.0019	34.942	-0.0017	0.0002
18	4	58	34.9402	34.9422	0.002	34.942	-0.0018	0.0002
18	5	59	34.9349	34.9369	0.002	34.937	-0.0021	-0.0001
18	6	60	34.9348	34.9369	0.0021	34.937	-0.0022	-0.0001
						Sum	-0.1410	-0.0830
						Mean	-0.0022	**-0.0013**

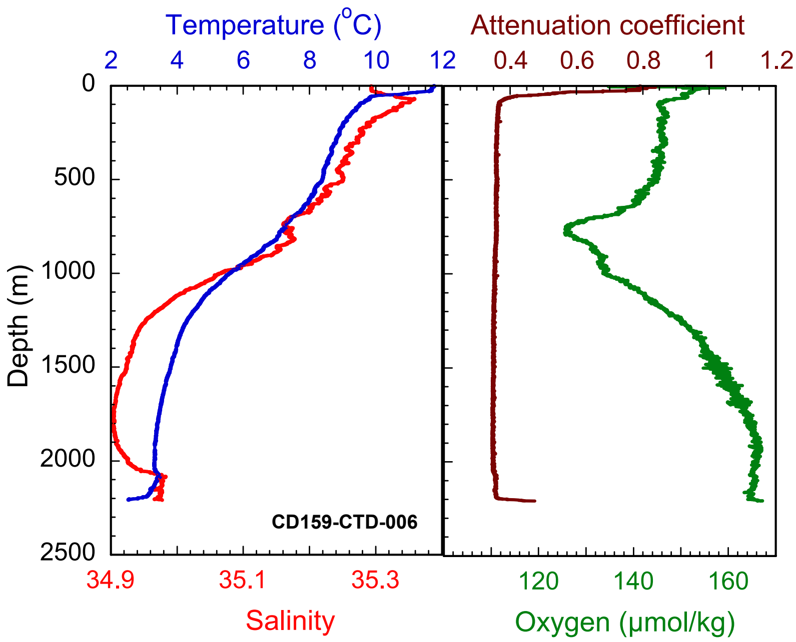


Figure 1 *Temperature, salinity, dissolved oxygen and particle attenuation coefficient versus water depth for Station CD159-CTD-006.*

TheExcel Workbook **CD159_CTD_Data.xls** is the prime data source used for this report. Sets of the Excel .txt (but not trans_lowgain.xls) files have also been stored for reference, as they contain additional sensor data, in the folder **CD159_CTD_Excel.txt**. Kaleidagraph version 3.6 has been used to generate .qpc plots and data were transferred to ,qda files for this purpose and have been stored in the folder **CD159_CTD_Plotsfolders/Kgraph_Data**.

A set of "thumbnail" depth plots for temperature, salinity, dissolved oxygen and particle attenuation coefficient have been produced for each station (see **Figure 1** for an example) and are given in the **Appendix** to this report; electronic copies have also been stored as Kaleidagraph .qpc files in the folder **CD159_CTD_Plotsfolder,** as CD159-Tsz-001.qpc etc showing temperature and salinity versus depth or CD159-AOz-001.qpc etc. showing Attenuation Coefficient and dissolved oxygen versus depth. Other plots are given within the text and copies also stored in the plots folder.

Summary of hydrographic properties of the cruise area

(i) Introduction

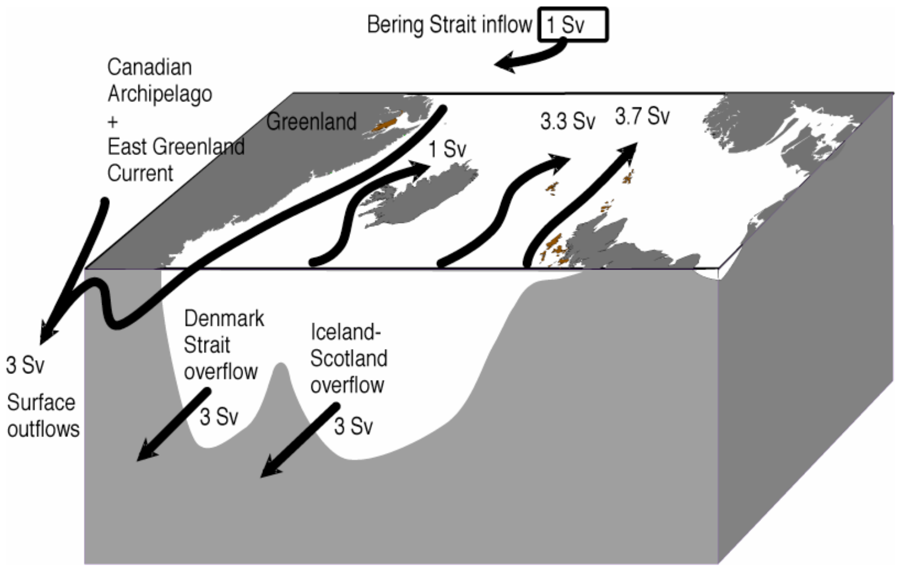


Figure 2 *The water balance for the Arctic Mediterranean*

The essential hydrographic features of the cruise area are illustrated in **Figures 2 and 3**. The meridional overturning circulation comprises the generic North Atlantic Current entering the Nordic Seas with return flow as the Iceland Scotland and Denmark Straits overflow (**Figure 2**). Additionally, the North Atlantic Current entering the Labrador Sea together with southward flowing surface outflow from the Nordic Seas produces deep water formation in the Labrador Sea (**Figure 3**, after Mauritzen, C., 1996, *Deep-Sea Res.*, 43: 769-806; Mauritzen C. and Hakkinen, S.,1999, *Deep-Sea Res.*, 46: 877-9).

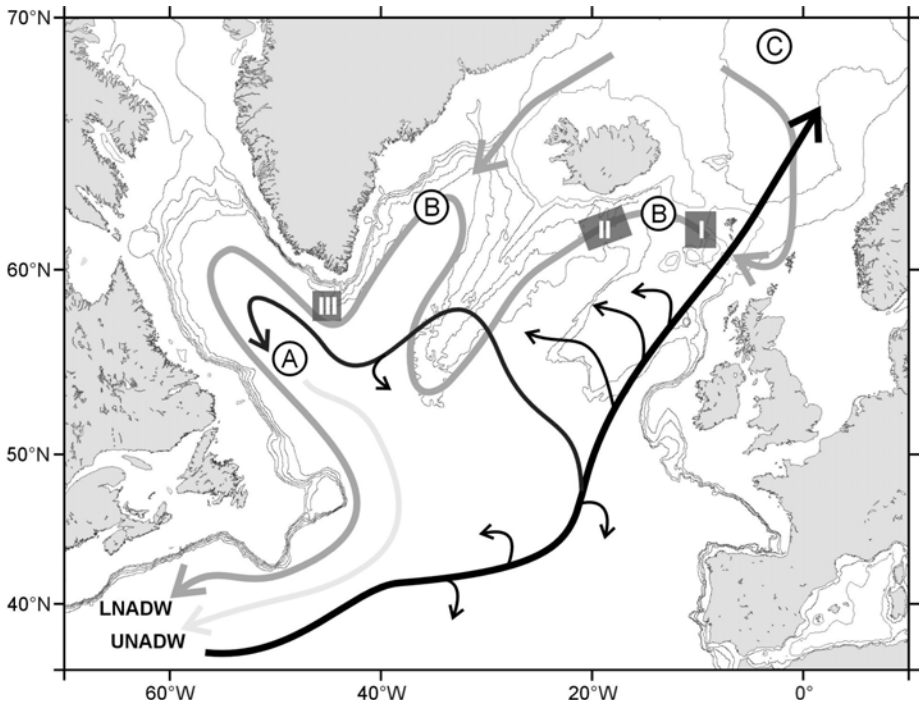


Figure 3 *Schematic of the 3-D MOC. Dense water in grey. Arrows indicate both diapycnal transfers and flow direction. "A" represents deep water formation in the Labrador Sea, "B" entrainment by overflowing waters, and "C" dense water formation in the Nordic seas. Squares I-III denote main study areas.*

The water masses referred to below are as follows:

Water mass/type	Abbreviation
North Atlantic Current	NAC
East North Atlantic Water	ENAW
West North Atlantic Water	WNAW
Iceland-Scotland Overflow Water	ISOW
Denmark Strait Overflow Water	DSOW
Labrador Sea Water	LSW
Subarctic Intermediate Water	SAIW

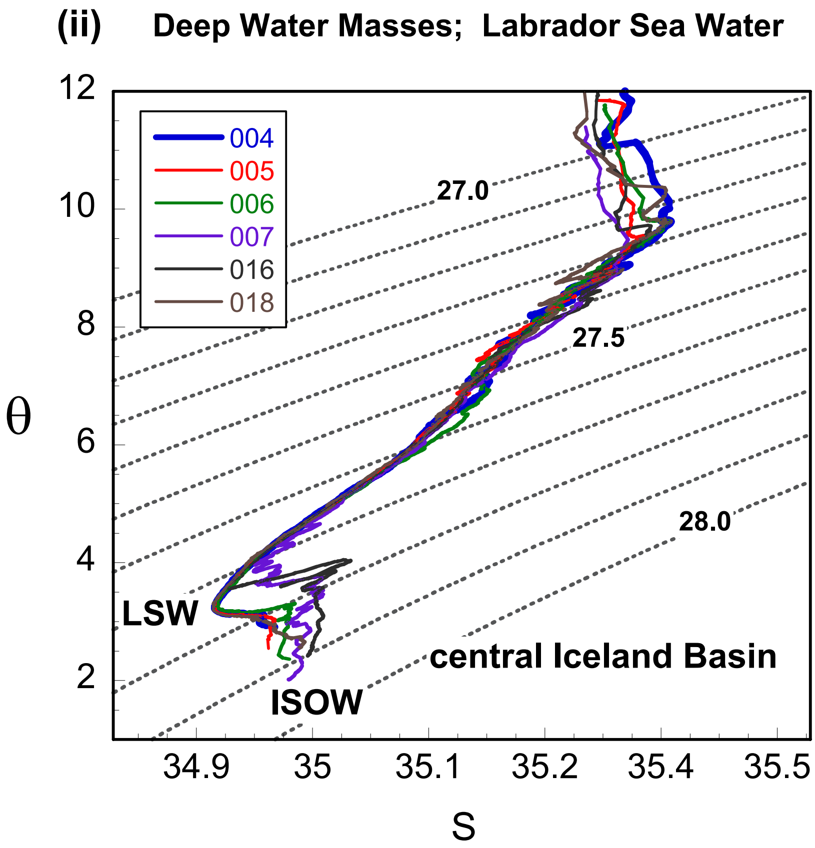


Figure 4 Potential temperature-salinity diagram for Stations CD159-004,005,006,007,016,018. Contours show σ_o

LSW is present on the σ_o = 27.75 surface at six stations within the Iceland Basin (**Figure 4**). Two stations in the east of the basin (CD159-002,003) are too shallow (1597 and 1181 m) to have intercepted LSW, and one (CD159-001 at 1790 m) only just reaches LSW (**Figure 5A**). However, the θ-S plots clearly show its influence at all these three stations. In the north of the basin (**Figure 5B**). CD159-009 shows no influence of LSW and CD159-008 a minor influence. CD159-019 to the east of the Reykjanes Ridge also only just reaches LSW (**Figure 6**) despite a depth of 1886m. In other respects, CD159-019 shows characteristics of sites west of the Reykjanes Ridge.

***Figure 5** Potential temperature-salinity diagram (A) for Stations CD159-001,002,003,004 (B) for, 007,008,009; Contours show σ_o*

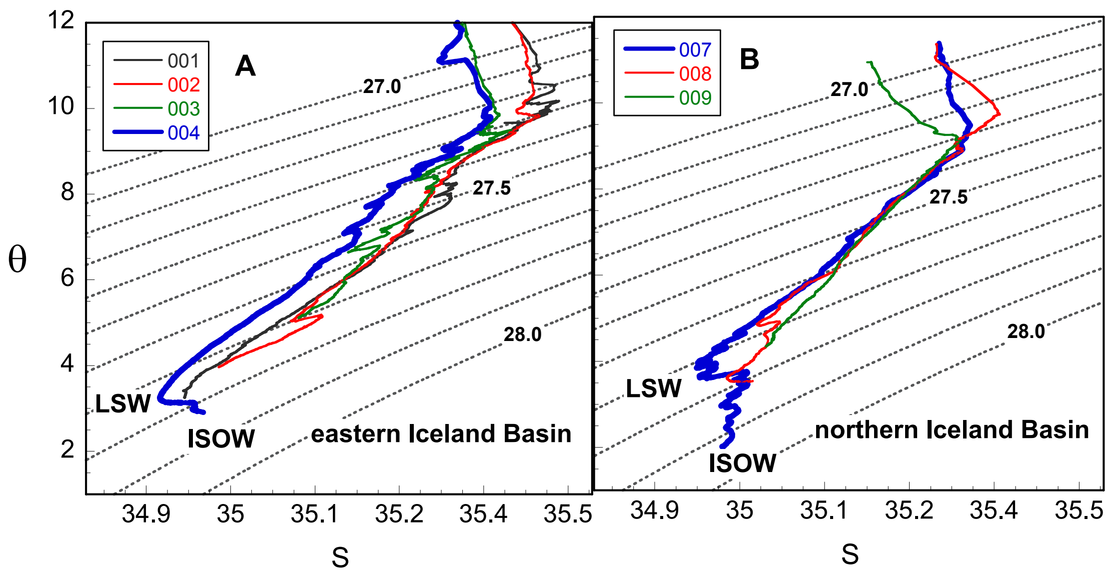
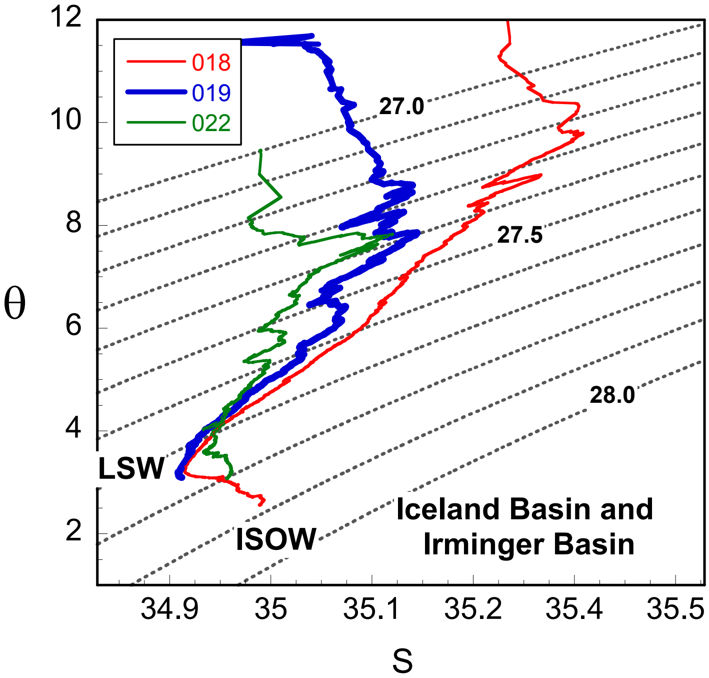


Figure 6 *Potential temperature-salinity diagram for Stations CD159-018 and –019 (Iceland Basin), and –022 (Irminger Basin); Contours show* σ_o



A useful recent paper on upper ocean water masses and circulation pathways through the Iceland Basin with references to earlier literature is Pollard R.T. et al (*J. Geophys. Res.* 109, C04004, doi 10.1029/2003JC002067,2004).

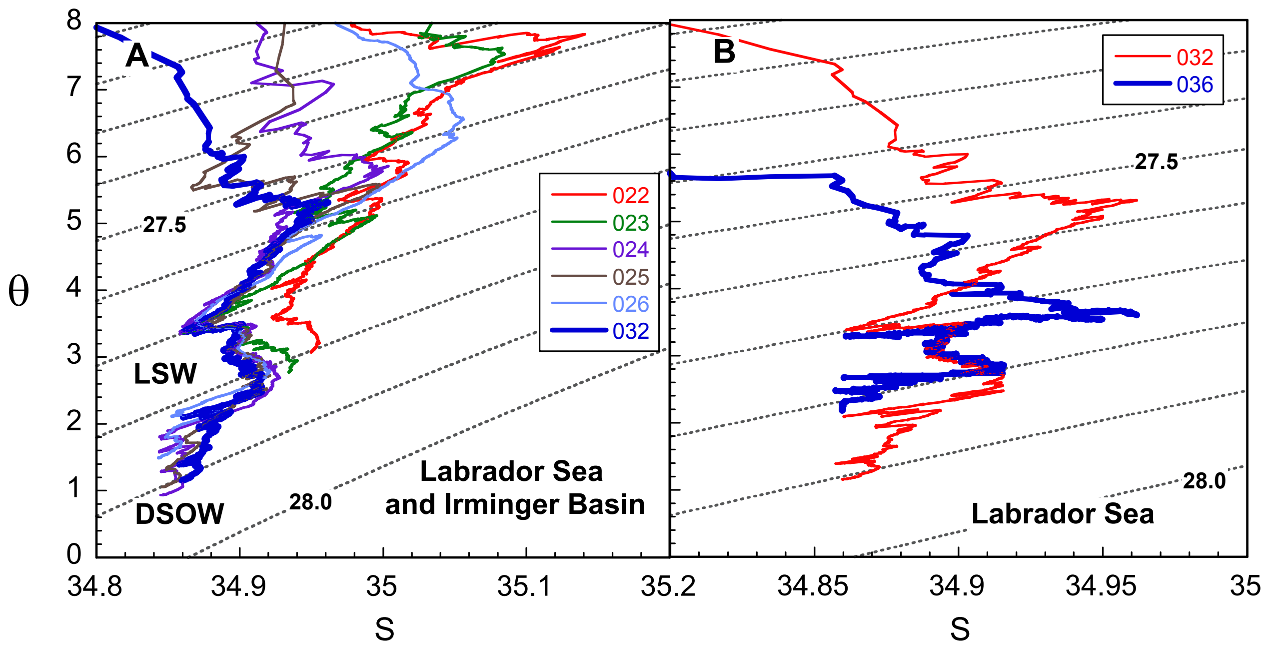


Figure 7 *Potential temperature-salinity diagram for Labrador Sea and Irminger Basin: (A) Stations CD159- 022, 023, 024, 025, 026, 032, (B)- 032, 036; Contours show* σ_o

The characteristics of LSW in the Irminger Basin (**Figure 7A**) are more complex than in the Iceland Basin given that the core of LSW in the Iceland Basin is on the σ_o = 27.75 kg m^{-3} surface at θ = 3^o, S = 34.95. Salinities up to nearly S = 35 are seen in the Labrador Sea stations (**Figure 7B**) and, in the Irminger Basin, the σ_o = 27.75 surface is more saline than waters above and below.

The Overflow Waters

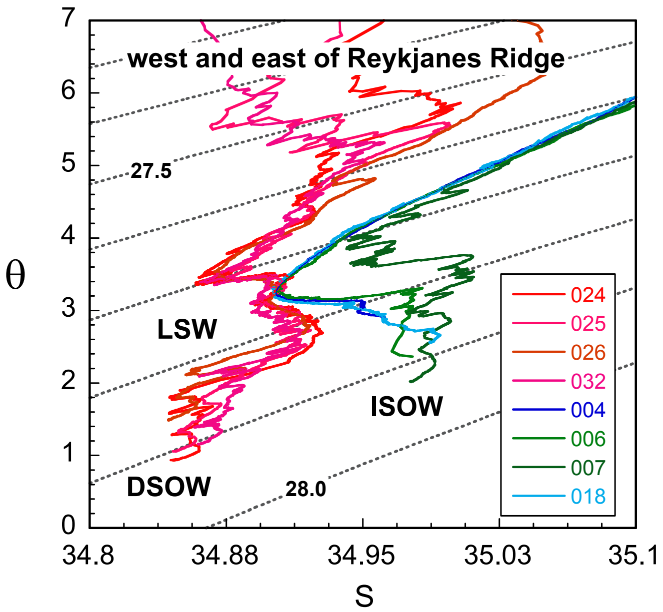


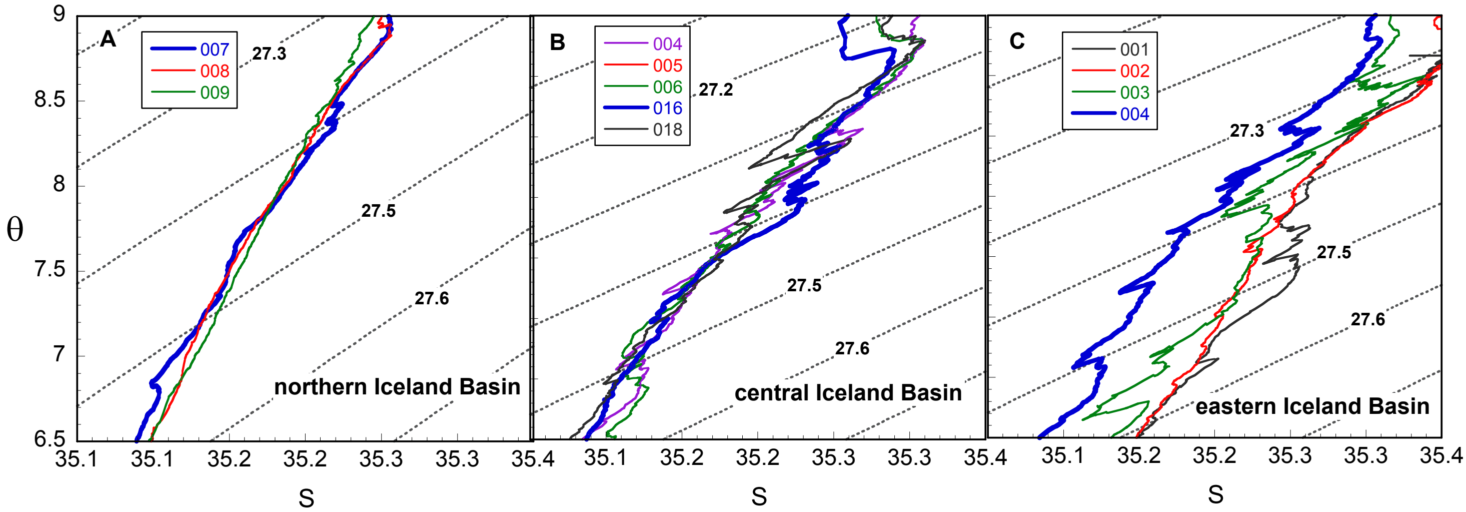
Figure 8 *Potential temperature-salinity diagram for deep waters west (in red colours) and east (in blue-green colurs) of the Reykjanes Ridge; Contours show* σ_o

The difference in characteristic θ-S features of LSW occurs because the properties of the overflow waters to the west and east of the Reykjanes Ridge are different (**Figure 8**). DSOW is fresher than both LSW and ISOW at the stations sampled and therefore induces a salinity maximum in the θ-S diagram west of the Ridge.

(iii) Near Surface Waters

θ-S diagrams spanning the North Atlantic Current (ignoring surface waters) between the σ_o = 27.3 and 27.6 surfaces are shown in **Figure 9** for the Iceland Basin and **Figure 10** for the Irminger Basin. According to Pollard et al. (2004) two conspicuous features are present on the σ_o = 27.4 surface: (i) Subarctic Intermediate Water, a cold fresh water at S < 34.9 , formed in the Labrador Sea and inserted into WNAW, and (ii) saline (S > 35.1) East North Atlantic Water identified with the Rockall-Hatton branch of the NAC.

Figure 9 *Potential temperature-salinity diagram for waters of the North Atlantic Current in the Iceland Basin; Contours show* σ_o



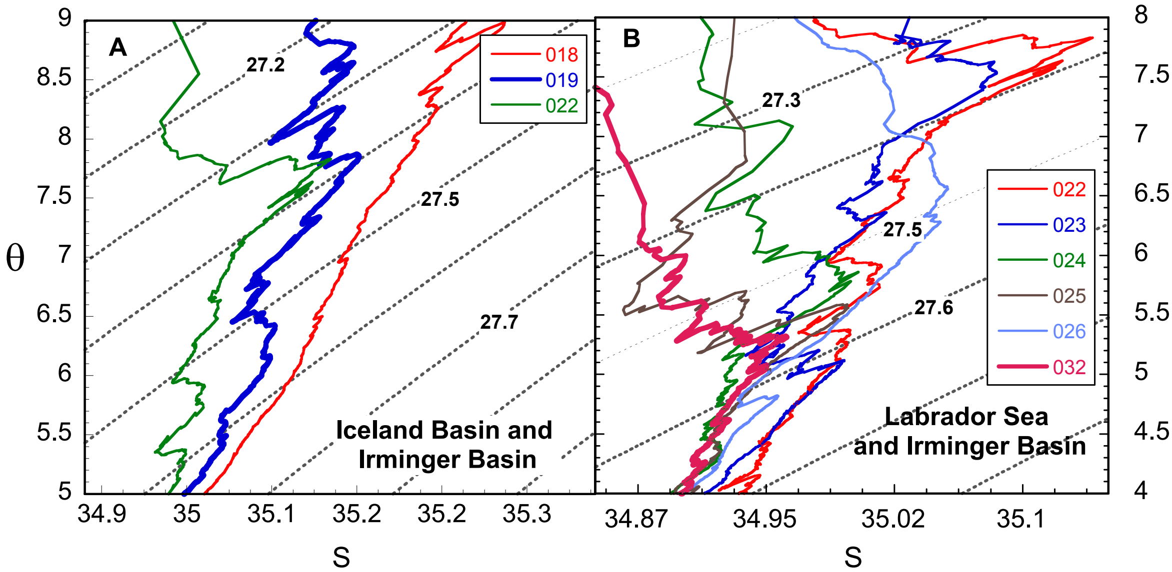


Figure10 *Potential temperature-salinity diagram for waters of the North Atlantic Current in the Irminger Basin compared with some Iceland Basin stations; Contours show* σ_o

These features seem to be absent from sites in the northern Iceland Basin but the more saline water may be present, with others, in the central and eastern Iceland Basin but not, obviously, associated with stations closest to Rockall and Hatton Banks. The presence of SAIW is similarly difficult to identify from Figure 10. Comparison of stations west and east of the Reykjanes Ridge

(**Figure 10A**) suggest that saline water present on the σ_o = 27.4 surface is originating from the west rather than the east.

(iii) Dissolved oxygen

A σ_o - O_2 diagram for all stations (**Figure11**) shows a strong regional hydrographic control on dissolved O_2. Waters of the Iceland Basin show the strongest (although weak in absolute terms) oxygen minimum with a weaker minimum to the west in the Irminger Basin and Labrador Sea. A weak O_2 maximum is seen in the core of Labrador Sea water. There is a clear difference between the oxygen content of the overflow waters with DSOW (~190 µmol/kg) higher than ISOW (~165 µmol/kg). A comparison of σ_o – AOU would be needed to determine the extent to which this is a function of temperature.

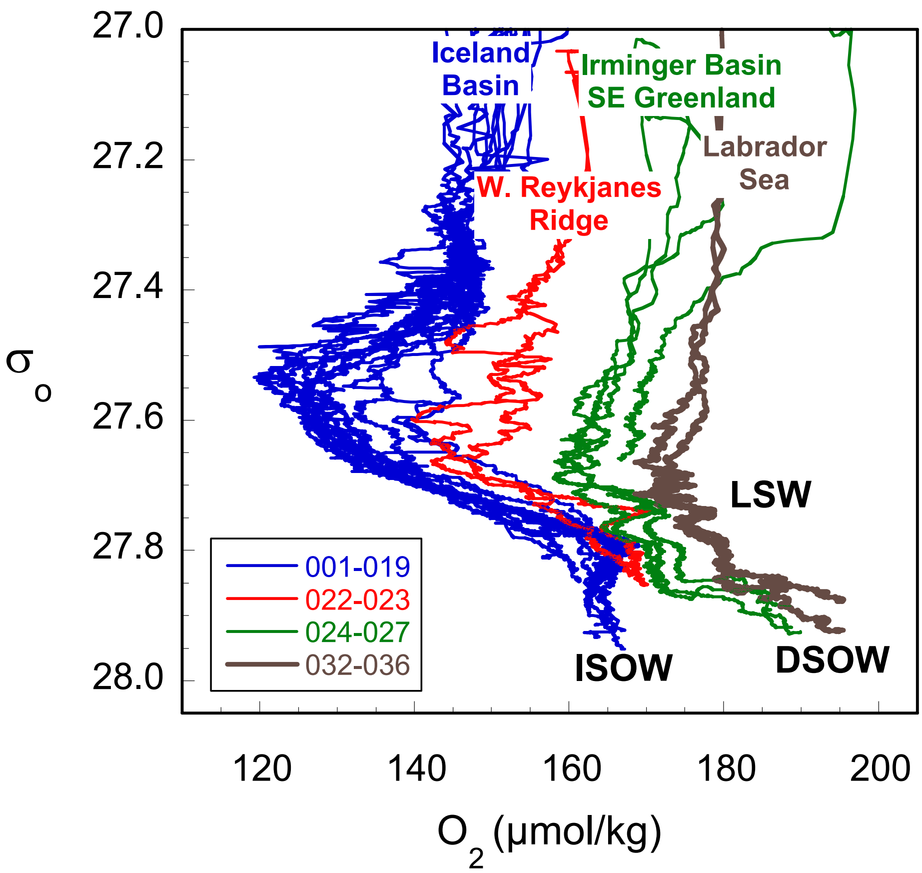


Figure 11 σ_o - O_2 *diagram for all CD159; four geographical areas are distinguished.*

6. PLANKTON SAMPLING

(i) Genetics

Samples of foraminifera were taken for genetic investigations. Under 'Method' below in the table 'PLANKTON SAMPLING LOG', "Deck" refers to the plankton net set up on deck with the hose from the ship's 'non-toxic' water supply pumped from a depth of ~6m run through it. Mesh size was 200 microns. "Sieved" was when the weather deteriorated and the indoor NT supply was run through a sieve (150 micron) in the sink for a couple of hours. This worked well and was contnued thereafter. Bulk plankton refers to samples of total plankton that were collected especially for pickling (i.e. from which all the forams hadn't been removed). There were only 2 vertical tows (with 150 micron mesh) as we found that these were a bit of a waste of time as all we got was a bucketload of jellyfish and no forams.
Samples are being investigated by Mr M. Carroll and Dr K.F. Darling (Institute of Geosciences, University of Edinburgh).

(ii) Geochemistry

Samples of living foraminifera were also taken for geochemical analyses and proxy calibration work listed below in the table 'Plankton and water samples'. These samples were obtained by filtering the ship's 'non-toxic' water supply (taken from ~ 6m water depth) through a 150 μm nylon mesh, housed in a 'Greaves Filtration Device'. Filtrates were stored in petri dishes, which were sealed in ziploc bags and frozen onboard the Darwin. These samples will remain frozen until the time of analysis, and are currently stored in the Godwin Laboratory. Samples are being investigated by Dr. L.C. Skinner and Prof. H. Elderfield (University of Cambridge).

PLANKTON SAMPLING LOG

Sample	Date	Time (GMT)		Location			Specimens	Material collected	
		Start	End	Start	End	Method	tot forams	Bulk plankton	foram abundance
1	02-Jul-04	16:00	17:00	57°07'N 11°09'W	57°13'N 11°25'W	Deck	30	in Formalin	common
2	03-Jul-04	03:30	04:30	57°32'N 12°17'W	57°40'N 12°23'W	Deck	30	in Formalin	common
3	03-Jul-04	17:30	18:00	58°55'N 13°16'W	N/A	200m vert. tow	20	in Formalin	common
4	04-Jul-04	15:00	17:30	61°16'N 14°31'W	61°33'N 15°04'W	Deck	5		rare
5	05-Jul-04	?	13:38	62°04'N 16°03'W	N/A	200m vert. tow	0	in Formalin	almost barren
6	06-Jul-04	00:00	02:00	62°30'N 16°32'W	62°52'N 16°57'W	Deck	34	in Formalin	common
7	06-Jul-04	15:40	17:10	63°02'N 17°29'W	62°58'N 17°35'W	Deck	45		abundant
8	07-Jul-04	19:15	22:00	62°06'N 17°49'W	62°12'N 17°59'W	Deck	9		rare
9	08-Jul-04	15:15	17:30	62°24'N 17°49'W	62°17'N 17°09'W	Deck	33		common
10	09-Jul-04	21:00	23:30	61°23'N 19°37'W	61°00'N 19°58'W	Deck	1		almost barren
11	10-Jul-04	18:45	20:50	59°20'N 23°28'W	59°01'N 23°56'W	Deck	8	in Formalin	rare
12	11-Jul-04	12:15	16:45	57°44'N 26°45'W	57°16'N 27°43'W	Deck	93		abundant
13	13-Jul-04	01:55	04:45	57°42'N 28°42'W	57°56'N 29°25'W	Sieved	30	in Ethanol	common
14	13-Jul-04	17:10	19:30	58°36'N 31°30'W	58°42'N 31°52'W	Sieved	59		abundant
15	15-Jul-04	06:50	08:00	59°00'N 32°50'W	59°03'N 33°19'W	Sieved	31		abundant
16	16-Jul-04	03:40	04:15	59°50'N 36°42'W	59°57'N 37°11'W	Sieved	45		abundant
17	17-Jul-04	02:30	04:30	60°10'N 39°07'W	59°58'N 39°20'W	Sieved	30		common
18	18-Jul-04	22:50	00:55	58°58'N 42°34'W	58°50'N 42°57'W	Sieved	30	in Ethanol	common
19	19-Jul-04	19:30	20:30	58°43'N 44°25'W	58°44'N 44°33'W	Sieved	30		common
20	20-Jul-04	17:45	20:05	58°23'N 45°33'W	58°27'N 45°48'W	Sieved	30		common
21	22-Jul-04	02:35	05:00	58°14'N 46°59'W	58°14'N 46°59'W	Sieved	30		common
22	23-Jul-04	06:50	09:30	57°34'N 48°26'W	57°29'N 48°44'W	Sieved	30		common
23	24-Jul-04	03:40	07:25	57°27'N 49°00'W	57°21'N 49°30'W	Sieved	30		common
24	24-Jul-04	23:40	02:00	56°26'N 52°30'W	56°05'N 52°35'W	Sieved	30	in Ethanol	common
25	25-Jul-04	23:00	00:40	54°28'N 52°26'W	54°32'N 52°26'W	Sieved	21		common
26	26-Jul-04	07:50	10:10	54°35'N 52°16'W	54°49'N 51°41'W	Sieved	30		common
27	26-Jul-04	01:15	03:55	54°33'N 50°56'W	54°22'N 50°40'W	Sieved	30	in Ethanol	common
28	27-Jul-04	18:20	21:45	52°20'N 49°56'W	51°42'N 49°49'W	Sieved	30		common
29	28-Jul-04	18:30	21:30	50°53'N 49°54'W	50°39'N 49°41'W	Sieved	30		common

Note that numbers of forams sampled are not always related to abundance; often just 30 were selected though more were available

Plankton & Water Samples

Site/Locn	Sample Label	Day	Time on	Lat (N)	Long (W)	Day	Time off	Lat (N)	Long (W)	Sample Label	Day	Time Z	Lat (N)	Long (W)
1	CD159/1 - NT1	184	21.33	57°29.56’	12°14.69’	185	7.01	58°01.10’	12°37.01’	none				
2	CD159/2 - NT2	185	13.48	58°55.08’	13°16.07’	185	19.42	58°58.08’	13°12.90’	none				
4	CD159/4 - NT3	186	19.12	61°44’29’	15°24’06	186	21.5	61°45.17’	15°24.26’	CD159/4 - NTW3	186	20.14	61°44’29’	15°24’06
5	CD159/5 - NT4	186	23.18	61°49.82’	15°37.55’	187	7.58	62°03.81’	16°03.4’	CD159/5 - NTW4	186	23.56	61°49.82’	15°37.55’
6	CD159/6 - NT5	187	8.09	63°03.8’	16°03.4’	187	14.07	63°03.90’	16°02.8’	CD159/6 - NTW5	187	11.12	61°49.82’	15°37.55’
7	CD159/7 - NT6	187	16.58	62°26.42’	16°28.17’	187	23.19	62°26.42’	16°28.17’	CD159/7 - NTW6	187	19.54	62°26.42’	16°28.17’
8	CD159/8 - NT7	188	4.06	62°58.12’	17°04.27’	188	9.32	62°59.74’	17°06.98’	CD159/8 - NTW7	188	8.08	62°59.74’	17°06.98’
9	CD159/9 - NT8	188	11.01	62°08.64’	17°17.54’	188	14.28	63°08.64’	17°17.11’	CD159/9 - NTW8	188	13.05	63°08.64’	17°17.11’
10	CD159/10 - NT9	188	18.1	62°58.61’	17°35.64’	188	22.35	62°58.61’	17°35.64’	none				
11	CD159/11 - NT10	189	5.35	62°17.85’	17°09.11’	189	8.17	62°15.85’	17°10.94’	none				
11 - 13	CD159/12-13 - NT11	189	12.5	62°07.86’	17°57.49’	190	1.52	62°12.99’	17°59.45’	CD159/12 - NTW11	189	17.01	62°05.35’	17°49.35’.
16 - 18	CD159/16-18 - NT12	191	9.51	61°34.20’	19°58.86’	191	0.04	60°59.22’	19°59.27’	CD159/16 - NTW12	191	10.08	61°34.22’	19°57.89’
18	CD159/18 - NT13	192	10.54	60°13.96’	21°44.40’	193	1.41	58°41.01’	24°50.68’	CD159/18 - NTW13a	192	16.38	59°33.80’	23°0.1.10’
										CD159/18 - NTW13b	192	21.54	59°01.76’	24°08.19’
19	CD159/19 - NT14	193	19.3	57°11.93’	27°51.06’	193	3.49	57°15.94’	27°56.44’	CD159/19 - NTW14	193	23.06	57°16.52’	27°55.90’
21	CD159/21 - NT15	194	9.08	57°26.88’	27°54.37’	195	1.18	57°39.66’	28°31.88’	CD159/21 - NTW15	194	9.24	52°26.90’	27°54.43’
22	CD159/22 - NT16	197	1.05	58°59.90’	32°47.77’	197	6.32	59°00.06’	32°47.88’	none				
23	CD159/23 - NT17	197	13.07	59°08.11’	34°04.47’	197	17.4	59°08.11’	34°04.47’	CD159/23 - NTW17	197	15.16	59°08.16’	34°04.11’
23 - 24	CD159/23-24 - NT18	198	10.49	60°21.31’	38°46.32’	199	1.45	60°10.33’	39°07.67’	CD159/24 - NTW18	198	12.5	60°11.31’	39°06.21’
										CD159/24 - NTW19	198	22.03	60°10.53’	39°07.36’
25	CD159/25 - NT19	199	10.19	59°20.65’	39°58.43’	198	17.55	59°25.09’	40°36.54’	CD159/25 - NTW20	199	15.28	59°25.21’	40°35.96’
27	CD159/27 - NT20	200	11.04	59°36.06’	42°42.15’	200	16.29	59°36.34’	42°41.78’	CD159/27 - NTW21	200	12	59°36.06’	42°42.15’
27-28	CD159/27-28 - NT21	200	19.56	59°16.47’	42°35.70’	201	0.31	58°51.77’	42°52.57’	CD159/27-28 - NTW22	200	22.48	58°58.51’	42°33.65’
28	CD159/28 - NT22	201	11.22	59°39.27’	42°12.14’	202	0.13	58°47.96’	44°50.71’	CD159/28 - NTW23	201	19.27	58°43.71’	44°25.91’
29 - 31	CD159/29-31 - NT23	202	11.04	59°36.06’	42°42.15’	203	9	58°36.64’	46°11.31’	CD159/29-31 - NTW24	202	13.51	58°42.32’	45°06.86’
										CD159/29-31 - NTW25	202	22.24	58°26.02’	45°44.98’
31	CD159/31 - NT24	203	10.2	58°36.72’	46°11.19'	203	15.1	58°32.22’	46°20.99'	CD159/31 - NTW26	203	12.56	58°36.69’	46°11.22’
32	CD159/32 - NT25	203	19.33	58°14.82’	47°00.58'	204	0.52	58°14.86’	47°01.33'	CD159/32 - NTW27	204	0.1	58°14.88’	47°00.58’
37	CD159/37 - NT26	207	17.47	54°31.65’	52°57.53'	207	22.54	54°28.55’	52°25.08'	CD159/37 - NTW28	207	22.52	54°28.62’	52°25.08'
39	CD159/39 - NT27	208	10.41	54°52.16’	51°34.98'	208	23.26	54°45.80’	51°15.29'	CD159/39 - NTW29	208	23.28	54°45.80’	51°15.29'

7. EQUIPMENT PROBLEMS

The cruise was remarkably free of problems with equipment either from the ship or our own. Problems with the new piston corer system are recorded in that section, but it may be noted that our preliminary comparison of Piston and Kasten corer retrieval (Sta. 39) reveals no loss in the piston cores due to overpenetration or gain by excess stretching due to the strong cable rebound felt at most deployments. As described above, the bomb weight was too heavy and inflexible and needs to be variable in ~ 0.25t steps. The lack of one-way valves needed for gravity coring, plus the fact that the 160mm barrel adaptor would not fit onto the bomb, meant that we had no gravity coring capability during the cruise, other than the Kasten corer. The rotation of the aft winch davit assembly in its mounting bracket gave us a few problems in any sea states above moderate (>5).

Problems with the 'under CTD mini-corer are detailed in Section 4(d).

The 3.5 kHz system is most unfriendly to a Chief Scientist looking for coring sites. The lack of a large size paper output (and on this occasion even of paper for the small Raytheon recorder) do not allow one to see the top 10-20 metres with sufficient resolution, and the one page at a time computer output does not allow one to see the record of the previous several hours' survey to assess thickening/thinning trends. This is all important when trying to core the Holocene at highest resolution.

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CD 159 STATION LOG

Cores: B = Box, C = CTD mini-corer, G = Gravity, K = Kasten, P = Piston, PG = Pilot gravity

WS = surface water sample, CTD = CTD!, Net = Vertical haul net 200-0 m

Station No.	Activity No.	Day	Date July	Time (Z)	Latitude (N)	Longitude (W)	Depth (PDR)	Remarks
CD 159 - 01	01WS	184	2nd	20.45	57° 29.43	12° 14.62’		
	CTD 01			21.05	57° 29.43	12° 14.62’	1805	Mini corer did not retain sample
	RAPiD-01-1B	185	3rd	01.11	57° 29.15’	12° 14.23’	1805	35 cm
CD 159 – 02	02WS	185	3rd	13.35	58° 55.22’	13° 16.08’		
	CTD 02			13.55	58° 55.22’	13° 16.08’	1619	Mini corer did not retain sandy sample
	Net 01			17.25	58° 55.42’	13° 16.20’		
CD 159 – 03	03WS	186	4th	02.45	59° 57.68’	12° 09.43’		
	CTD 03			03.14	59° 57.68’	12° 09.43’	1206	
	RAPiD-03-1C			03.45	59° 57.76’	12° 09.73	1206	19 cm
CD 159 – 04	04WS	186	4th	19.15	61° 44.31’	15° 24.10’		
	CTD 04			19.20	61° 44.31’	15° 24.10’	2284	ACM8b site 501
	RAPiD-04-2C			20.15	61° 44.60’	15° 24.31’	2284	Sample salvaged, sandy, washed
CD 159 – 05	CTD 05	186	4th	22.55	61° 49.90’	15° 37.52’	2280	ACM8b Site 507. Mini corer failed, sandy
	RAPiD-05-2B	187	5th	04.45	61° 49.98’	15° 37.71’	2278	19 cm
CD 159 – 06	06WS	187	5th	08.00	62° 03.80’	16° 03.34’	2229	ACM8b Site 506
	RAPiD-06-3B			09.00	62° 03.80’	16° 03.34’	2228	22 cm
	CTD 06			10.50	62° 03.82’	16° 03.30’	2228	
	Net 02			13.38	62° 03.82’	16° 03.30’		

Station No.	Activity No.	day	Date July	Time (Z)	Latitude (N)	Longitude (W)	Depth	Remarks
CD 159 – 07	CTD 07	187	5th	16.58	62° 26.42’	16° 28.26’	2048	ACM8b Site 505. Mini corer failed
	RAPiD-07-4B			20.30	62° 26.36’	16° 27.98’	2050	18 cm
	07WS			23.30				
CD 159 – 08	RAPiD-08-5B	188	6th	06.13	62° 58.10’	17° 04.40’	1421	ACM8b Site 503. Surface scrape only.
	CTD 08			07.52	62° 59.82’	17° 06.47’	1297	
	08WS			09.32	62° 59.4’	17° 07.15’		
CD 159 – 09	09WS	188	6th	10.40	63° 08.30’	17° 17.73’	1035	ACM8b Site 502
	CTD09			11.03	63° 08.39’	17° 17.65’	1038	Minicorer failed
	RAPiD-09-1G			14.15	63° 08.39’	17° 17.66’	1038	Used pilot as GC. 67 cm, overfilled, bagged top
	Net 03			14.54	63° 08.69’	17° 17.54’	1049	
CD 159 – 10	10WS	188	6th	16.40	62° 58.4’	17° 35.75’		
	RAPiD-10-6B			17.14	62° 58.39’	17° 35.75’	1249	49 cm
	RAPiD-10-1P+PG			19.30	62° 58.53’	17° 35.37’	1237	616 cm/23 cm; 9m barrel
CD 159 – 11	RAPiD-11-7B	189	7th	06.19	62° 17.89’	17° 09.06’	2126	39 cm. Near Johnson-Shor site, see also Sta 15
	11 WS			06.31	62° 17.84’	17° 09.08’		
CD 159 – 12	12WS	189	7th	14.00	62° 05.60’	17° 48.83’		
	RAPiD-12-8B			14.49	62° 05.60’	17° 48.97’	1944	38 cm
	RAPiD-12-1K			16.41	62° 05.43’	17° 49.18’	1936	641 cm
CD 159 - 13	13WS	189	7Tth	21.50	62° 12.70’	17° 59.30’		
	RAPiD-13-9B			22.58	62° 12.71’	17° 59.37’	1755	33 cm
	RAPiD-13-2P+PG	190	8th	01.12	62° 12.93’	17° 59.58’	1751	856 cm/ 60 cm PG

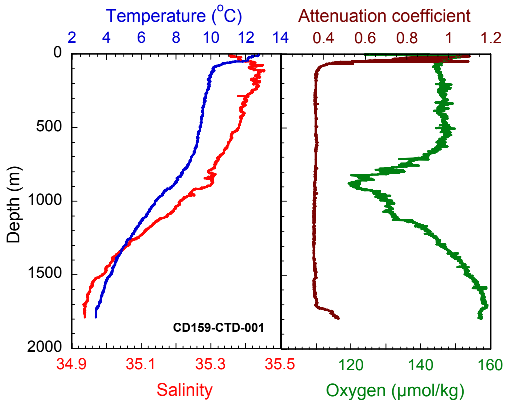
Station No.	Activity No.	day	Date July	Time (Z)	Latitude (N)	Longitude (W)	Depth	Remarks
CD 159 - 14	14WS	190	8th	07.57	62º 27.20'	18º 04.86'		
	RAPiD-14-10B			0845	62º 27.18'	18º 05.04'	1488	Crooked, 17 cm in one corner, gravelly.
	RAPiD-14-11B			10.57	62º 27.24'	18º 04.99'	1487	Similar (worse); bagged sample
	RAPiD-14-3P+PG			13.55	62º 27.26'	18º 05.49'	1475	850 cm; PG empty; 12 m barrel
CD159 - 15	15WS	190	8 th	19.15	62º 17.52'	17º 07.90'		1121cm/20 cm PG. 15 m barrel. Near Johnson-
	RAPiD-15-4P+PG			19.35	62º 17.58'	17º 08.04'	2133	Shor pos^{n}, but best 3.5 kHz.
CD159 – 16	CTD 10	191	9 th	07.46	61º 34.05'	19º 57.85'	2133	van Aken North.. minicorer failed
	RAPiD-16-2G			11.58	61º 34.34'	19º 58.24'	2129	13 cm
	16WS			13.35	61º 34.04'	19º 57.75'		
CD159 – 17	RAPiD-17-5P+PG	191	9 th	18.12	61º 28.90'	19º 32.16'	2303	1441 cm/ 75 cm PG – overpen^{d}. 18 m barrel.
CD159 – 18	17WS	191	9 th	23.45	60º 59.20'	19º 59.30'		van Aken South
	CTD 11			23.53	60º 59.20'	19º 59.30'	2407	
	RAPiD-18-3C	192	10 th	00.45	60º 59.26'	19º 59.32'	2407	8.5 cm in minicore.
	Net 04			02.45				
CD159 – 19	18WS	193	11 th	18 00	57º 11.93'	27º 50.97'		
	CTD 12			18.00	57º 12.01'	27º 50.95'	2780	
	RAPiD-19-4C			19.05	57º 11.95'	27º 50.97'	2780	Salvaged , washed sample
CD159 – 20	19WS	194	12 th	00.32	57º 16.42'	27º 56.23'		
	RAPiD-20-6P+PG			02.00	57º 16.25'	27º 56.25'	2695	1471 cm/47 cm PG. Section 6 imploded. 18m
CD159 – 21	20WS	194	12 th	08.40	57º 26.88'	27º 54.44'		
	RAPiD-21-2K			10.30	57º 26.99'	27º 54.24'	2622	690 cm, very overpenetrated
	RAPiD-21-12B			13.14	57º 27.09'	27º 54.53'	2630	58 cm, overfull but top is v.near top
	RAPiD-21-3K			18.54	57º 27.09'	27º 54.70'	2630	~360 cm (4 m barrel, 200 kg lead)

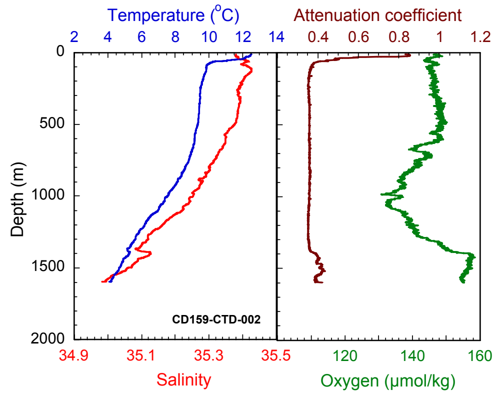
Station No.	Activity No.	day	Date July	Time (Z)	Latitude (N)	Longitude (W)	Depth	Remarks
CD159 - 22	21WS	197	15th	01.35	59 00.06’	32 47.88’		
	CTD 13			01.35	59 00.14’	32 47.74’	2106	Mini-core washed out
	RAPiD-22-3G			05.40	59 00.06’	32 47.88’	2099	30 cm
CD159 – 23	22WS	197	15 th	12.35	59° 08.08’	34° 04.39’	2612	
	CTD 14			12.55	59° 08.06’	34° 04.44’	2599	Few small pebbles in miniC, gravity failed; mount^{n}
CD159 - 24	23WS	198	16 th	16.45	60° 10.50’	39° 07.50’	2744	
	RAPiD-24-7P+PG			18.14	60° 10.43’	39° 07.39’	2744	1425 cm/ 61 cm PG, overpen. 18 m barrel
	RAPiD-24-13B			21.31	60° 10.36’	39° 07.49’	2748	48 cm
	CTD 15			23.29	60° 10.53’	39° 07.55’	2753	
CD159 – 25	CTD 16	199	17 th	12.35	59° 25.15’	40° 36.30’	2682	
	RAPiD-25-4G			16.50	59° 25.09’	40° 36.48’	2683	2 cm from above flap; core fell out
CD159 - 26	24WS	199	17 th	20.57	59° 35.06’	41° 09.66’		
	RAPiD-26-14B			21.56	59° 34.98’	41° 10.01’	2302	39 cm
	CTD 17			23.40	59° 34.98’	41° 10.00’	2305	no mini-C
CD159 - 27	25WS	200	18 th	09.44	59° 36.00’	42° 42.15’		
	CTD 18			10.40	59° 36.02’	42° 42.27’	776	
	RAPiD-27-15B			12.45	59° 36.18’	42° 42.47’	768	34 cm. Sponge mat at surface & below, IRD rocks.
	RAPiD-27-8P+PG			15.36	59° 35.92	42 41.82	742	548 cm/PG empty
CD159 - 28	26WS	201	19th	09.30	58° 39.15’	44° 12.50’		
	RAPiD-28-16B			10.25	58° 39.17’	44° 12.98’	1627	11 cm. Thin slice, rocky.
	RAPiD-28-17B			12.07	58° 39.35’	44° 12.48’	1628	..ditto, thinner.
	RAPiD-28-9P+PG			15.53	58° 39.03’	44° 12.75’	1625	686 cm/ PG overpen^{d}; sample only in CC, bagged.
CD159-29	RAPiD-29-18B	202	20th	06.15	58° 48.01’	44° 51.82’	2145	23 cm, but crooked hit (23-0 on one side)
	RAPiD-29-10P+PG			10.44	58° 48.00’	44° 51.92’	2145	1362 cm, PG empty

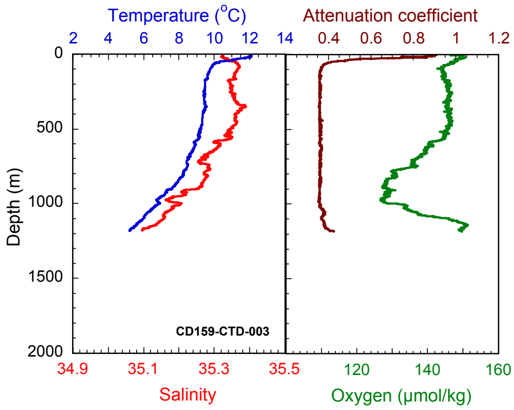
Station No.	Activity No.	day	Date July	Time (Z)	Latitude (N)	Longitude (W)	Depth	Remarks
CD159-30	RAPiD-30-**20B**	202	20th	21.40	58° 26.04’	45° 44.99’	2439	33 cm. **Note numbering error; No #19**
	RAPiD-30-11P+PG	203	21st	00.23	58° 35.93’	45° 45.00’	2440	1466 cm/ 25 cm PG
CD159-31	RAPiD-31-21B	203	21st	08.40	58° 36.65’	46° 11.41’	2570	32 cm.
	RAPiD-31-4K			11.47	58° 36.61’	46° 11.48’	2570	678 cm, overpenetrated by ~25 cm. 7 m barrel.
CD159-32	CTD 19	203	21st	19.49	58° 14.96’	47° 00.17’	3073	
	RAPiD-32-22B	204	22nd	00.20	58° 14.92’	47° 00.74’	3096	33 cm
	RAPiD-32-12P+PG			04.30	58° 15.00’	46° 59.86’	3072	1463 cm/45 cm PG
CD159-33	RAPiD-33-23B	204	22nd	13.56	57° 56.10’	46° 30.66’	3016	34 cm
	RAPiD-33-5K			16.32	57° 56.18’	46° 29.65’	3008	stopped @ 2 m, fell over, bent barrel, 42 cm recovd
CD159-34	RAPiD-34-13P+PG	205	23rd	04.08	57° 35.19’	48° 29.91’	3494	1740 cm/45 cm PG. **21 m barrel**
	RAPiD-34-24B			13.19	57° 35.14’	48° 30.62’	3496	28 cm.
CD159-35	RAPiD-35-25B	205	23rd	19.17	57° 30.47’	48° 43.40’	3486	43 cm.
	RAPiD-35-14P+PG			22.40	57° 30.25’	48° 43.34’	3484	1561 cm/bag top PG. 9.3 t shock tension @trigger
CD159-36	27WS	206	24th	18.25	56° 45.14’	52° 27.47’		
	CTD 20			1831	56° 45.14’	52° 27.47’	3520	ACM29 #1
	RAPiD-36-5C			1946	56° 45.16’	52° 27.41’	3520	Minicore, 12 cm
CD159-37	RAPiD-37-26B	207	25th	1621	54° 30.84’	52° 57.12’	1380	38 cm
	RAPiD-37-15P+PG			1820	54° 31.51’	52° 57.65’	1409	1006 cm/ 74 cm PG.
CD159-38	28WS	208	26th	00.10	54° 32.02’	52° 25.98’		
	RAPiD-38-27B			01.06	54° 31.97’	52° 25.94’	2152	35 cm.
	RAPiD-38-16P+PG			03.51	54° 31.95’	52° 25.55’	2159	1181 cm/18 cm PG. **90 mm dia. liner**.

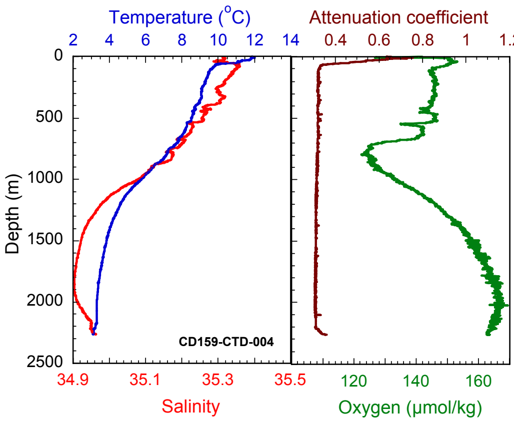
Station No.	Activity No.	day	Date July	Time (Z)	Latitude (N)	Longitude (W)	Depth	Remarks
CD 159-39	RAPiD-39-28B	208	26th	13.15	54° 54.76'	51° 28.89'	2863	35 cm
	RAPiD-39-17P+PG			16.10	54° 54.79'	51° 28.99'	2864	1343 cm/ 71 cm PG (overpen^d, top bagged)
	RAPiD-39-6K			19.37	54° 54.71'	51° 28.77'	2863	568 cm, overpenetrated by ~20 cm
CD 159-40	RAPiD-40-29B	210	28th	11.58	50 57.48'	49 57.54'	1044	33 cm
	RAPiD-40-18P+PG			16.45	50 57.14'	49 57.80'	1051	1096 cm/ PG bagged
CD 159-41	RAPiD-41-30B	210	28th	23.45	50 42.65'	49 42.82'	1271	39 cm
	RAPiD-41-19P+PG	211	29th	01.22	50 42.86'	49 43.12'	1266	1195 cm/ 52cm PG

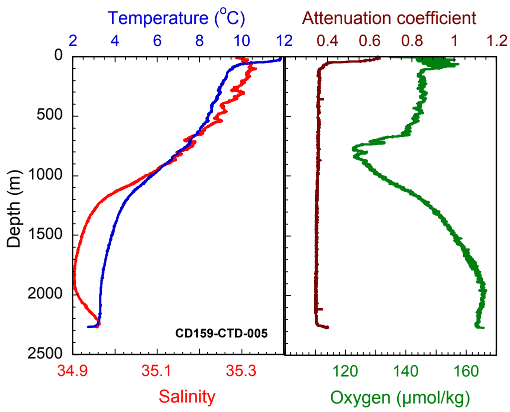
Appendix: Depth plots of Temperature, Salinity, Dissolved Oxygen and Attenuation coefficient for all CD 159 stations.

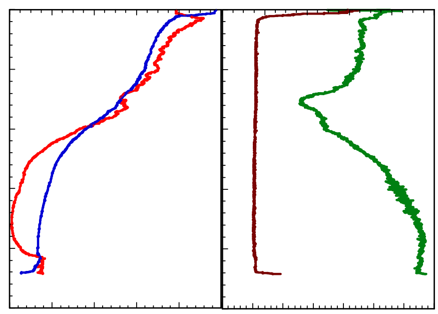


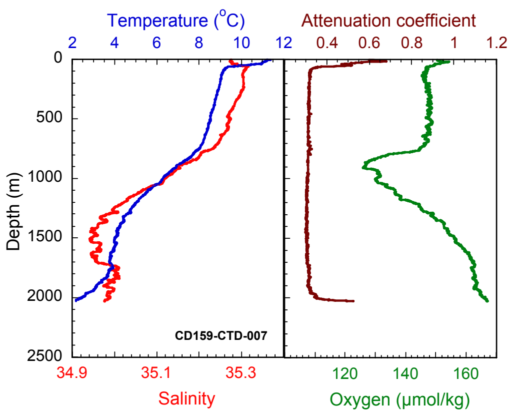


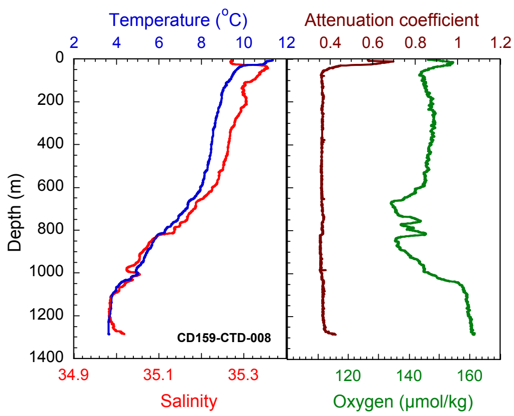


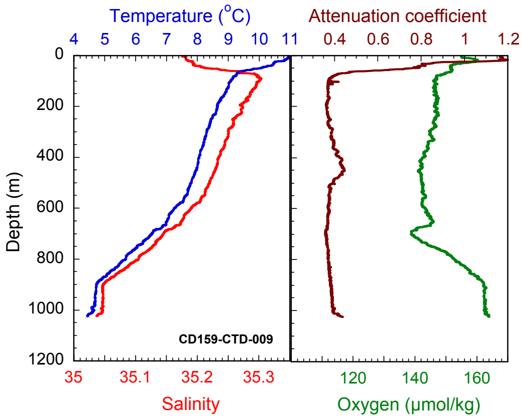


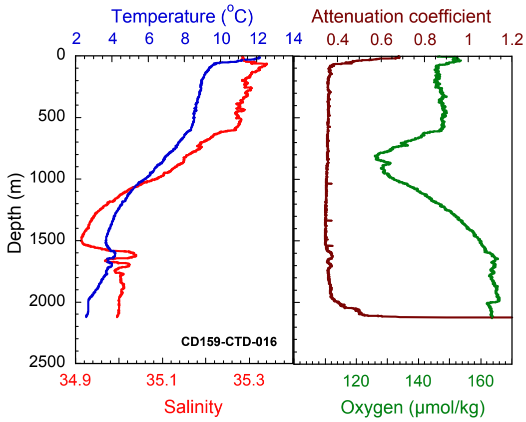


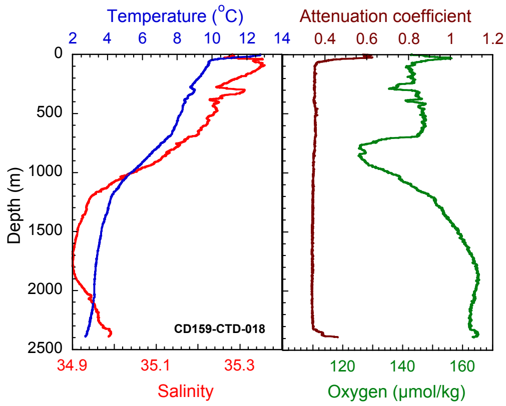


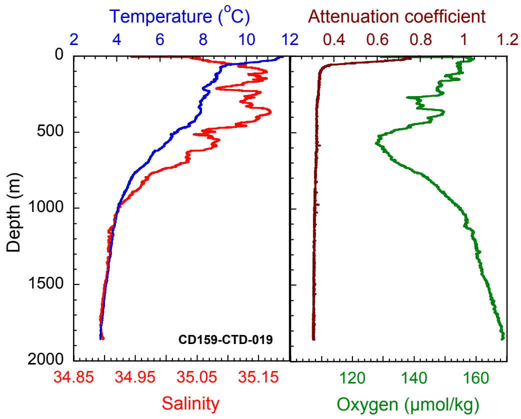


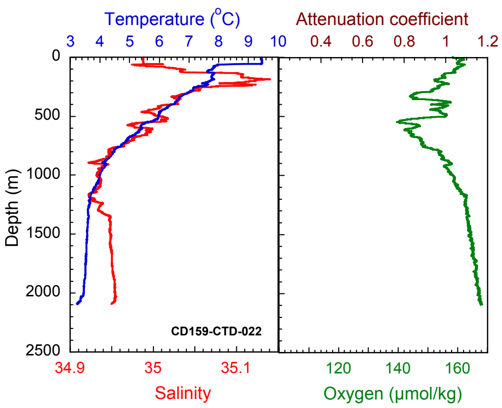


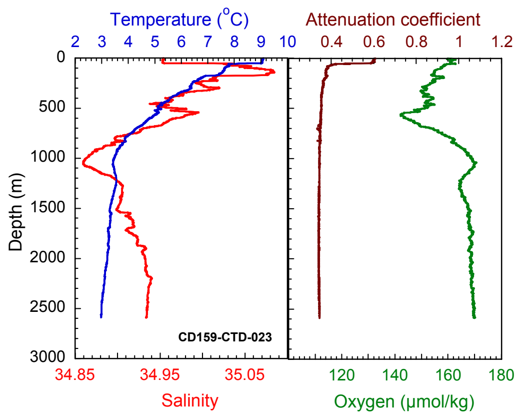

Temperature (°C)
Attenuation coefficient
Depth (m)
Salinity
Oxygen (µmol/kg)
CD159-CTD-009

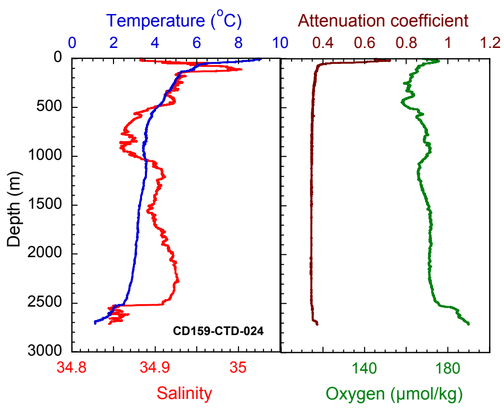

Temperature (°C)
Attenuation coefficient
Depth (m)
Salinity
Oxygen (µmol/kg)
CD159-CTD-016

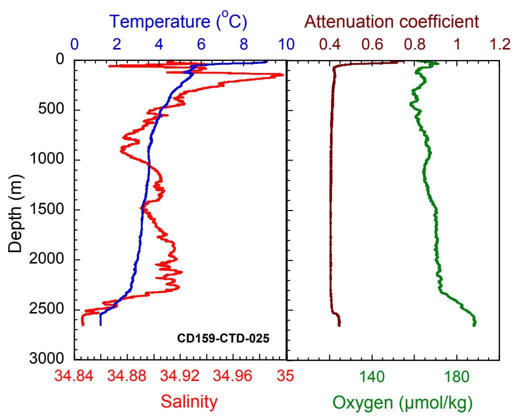

Temperature (°C)
Attenuation coefficient
Depth (m)
Salinity
Oxygen (µmol/kg)
CD159-CTD-018

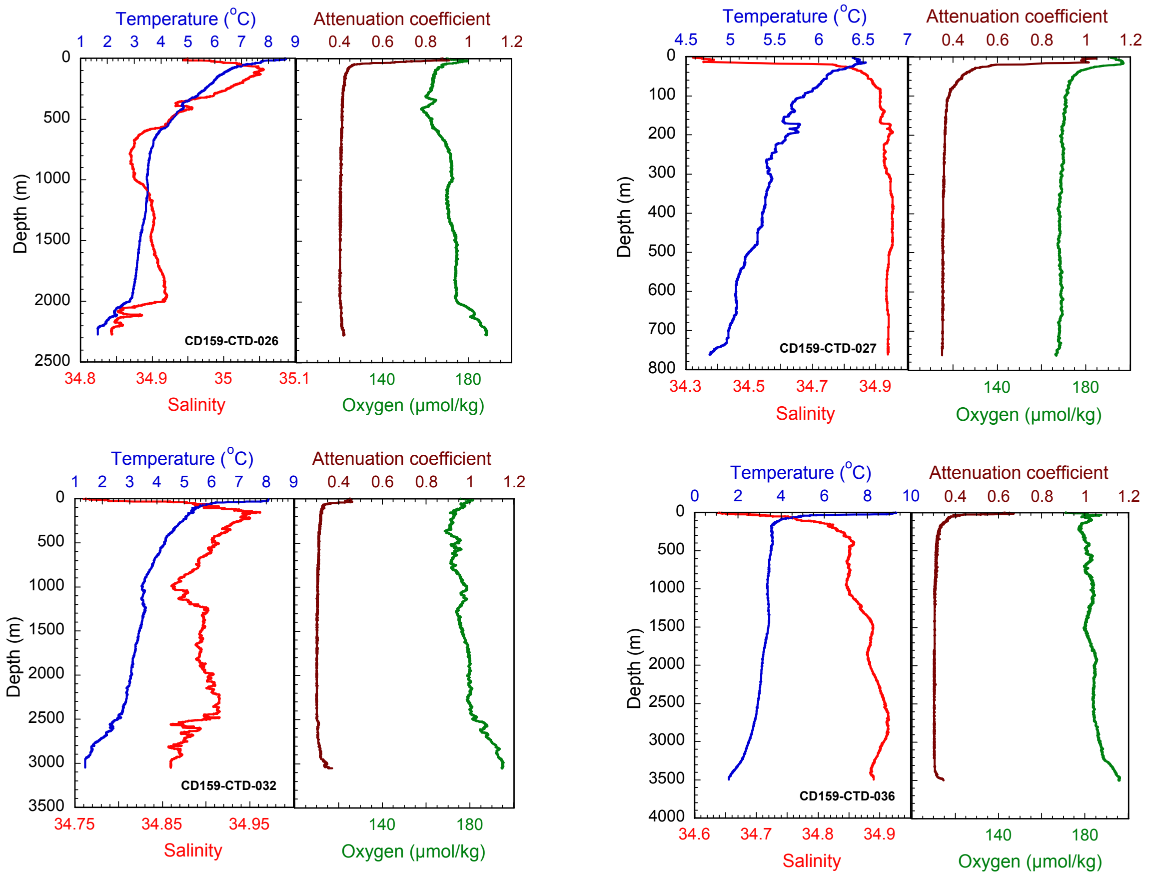

Temperature (°C)
Attenuation coefficient
Depth (m)
Salinity
Oxygen (µmol/kg)
CD159-CTD-019


Temperature (°C)
Attenuation coefficient
Depth (m)
Salinity
Oxygen (µmol/kg)
CD159-CTD-022


Temperature (°C)
Attenuation coefficient
Depth (m)
Salinity
Oxygen (µmol/kg)
CD159-CTD-023


Temperature (°C)
Attenuation coefficient
Depth (m)
Salinity
Oxygen (µmol/kg)
CD159-CTD-024


Temperature (°C)
Attenuation coefficient
Depth (m)
Salinity
Oxygen (µmol/kg)
CD159-CTD-025


Temperature (°C)
Attenuation coefficient
Depth (m)
Salinity
Oxygen (µmol/kg)
CD159-CTD-026
CD159-CTD-027
CD159-CTD-032
CD159-CTD-036