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Cruise Report – Oceanus 250 Leg 4
High Resolution Profiler Survey for the North Atlantic Tracer Release Experiment: (NATRE)
March 25 - April 24, 1992

by

Ellyn T. Montgomery and Raymond W. Schmitt, Jr.

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Technical Report

Funding was provided by the Office of Naval Research through
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Approved for Distribution:

James Luyten, Chair
Department of Physical Oceanography

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Abstract

This report describes fine- and microstructure profile data taken on R/V *Oceanus* cruise 250 leg 4, between March 25 and April 24, 1992. During this cruise, an area of the Canary Basin near the Subduction Experiment's central mooring was surveyed with the High Resolution Profiler (HRP). The goals of the survey were to describe the hydrographic properties of the water adequately to recommend a location for the North Atlantic Tracer Release Experiment (NATRE) tracer injection, and to characterize the microstructure for comparison with the NATRE results.

The cruise started in Madeira, and on the way to the experimental area, two HRP dives were conducted to test the instrument's functions. The HRP was then deployed 100 times in a 10 by 10 grid with 400 kilometer sides centered on the central subduction mooring. The first 90 profiles were to 2000 meters, and the last 10, comprising the easternmost line of the main survey, were to 3000 meters. Finally, another 55 HRP profiles were completed in smaller spatial surveys, time series, and additional deep stations. On this cruise the existing record for deep microstructure measurements was broken by the four profiles to 4000 meters taken off the African shelf on the way back to port in the Canary Islands.

The work performed at sea, instrumentation, data return and processing procedures will be summarized in this report.

Overview

The High Resolution Profiler (HRP) was used to perform the pre-cruise survey for North Atlantic Tracer Release Experiment (NATRE) because of its unique ability to make both fine- (10 Hz) and micro- (200 Hz) structure measurements. The HRP collects and stores data as it falls freely through the ocean during a dive. HRP profiles can be completed at almost the same rate as CTDs to equivalent depth, and the HRP provides additional velocity and microstructure data useful for quantifying the properties of the area surveyed.

The objective of the cruise was to survey the area of the Canary Basin targeted as the potential site for the NATRE tracer injection, and based on the data collected, recommend a specific location for the injection. The chart in Figure 1 shows the area surveyed with relation to North Africa. Because the tracer must be found at six month intervals to make the ensuing experiment a success, an area with relatively little large-scale eddy stirring was desired. The HRP survey data found an area of gently sloping dynamic height contours isolated from large eddy fields and water property fronts that seemed suitable for the injection.

The HRP surveys were the only work conducted during OCEANUS 250, leg 4. During the 30 day cruise, 6 days were spent in transit, and 155 HRP profiles were completed. Most (111) of the dives were done to 2000 meters, 25 were done to 1200 meters, 10 dives were done to 3000 meters, and four were done to between 3800 and 4000 meters. The remaining 5 dives were to various depths shallower than 2000 meters. The chronological log of the activities of the cruise is presented in the next section, Cruise Log.

Two modifications were made to the HRP for this cruise. First, the necessary changes were made to enable use of the shadowgraph, an optical microstructure instrument, with the HRP. Second, in order to avoid spikes in the microstructure data caused by the acoustic transducer used to track the HRP, a second transducer was installed at the upper end of the profiler. More information about the HRP and modifications is presented in the section entitled High Resolution Profiler Description.

The data processing methods used at sea are described in the next section, and finally the results are summarized.

The science party for this cruise on the R/V *Oceanus* consisted of employees and students of the Woods Hole Oceanographic Institution. The participants are listed below.

Scientist	Affiliation
Ray Schmitt	WHOI, Chief Scientist
John Toole	WHOI

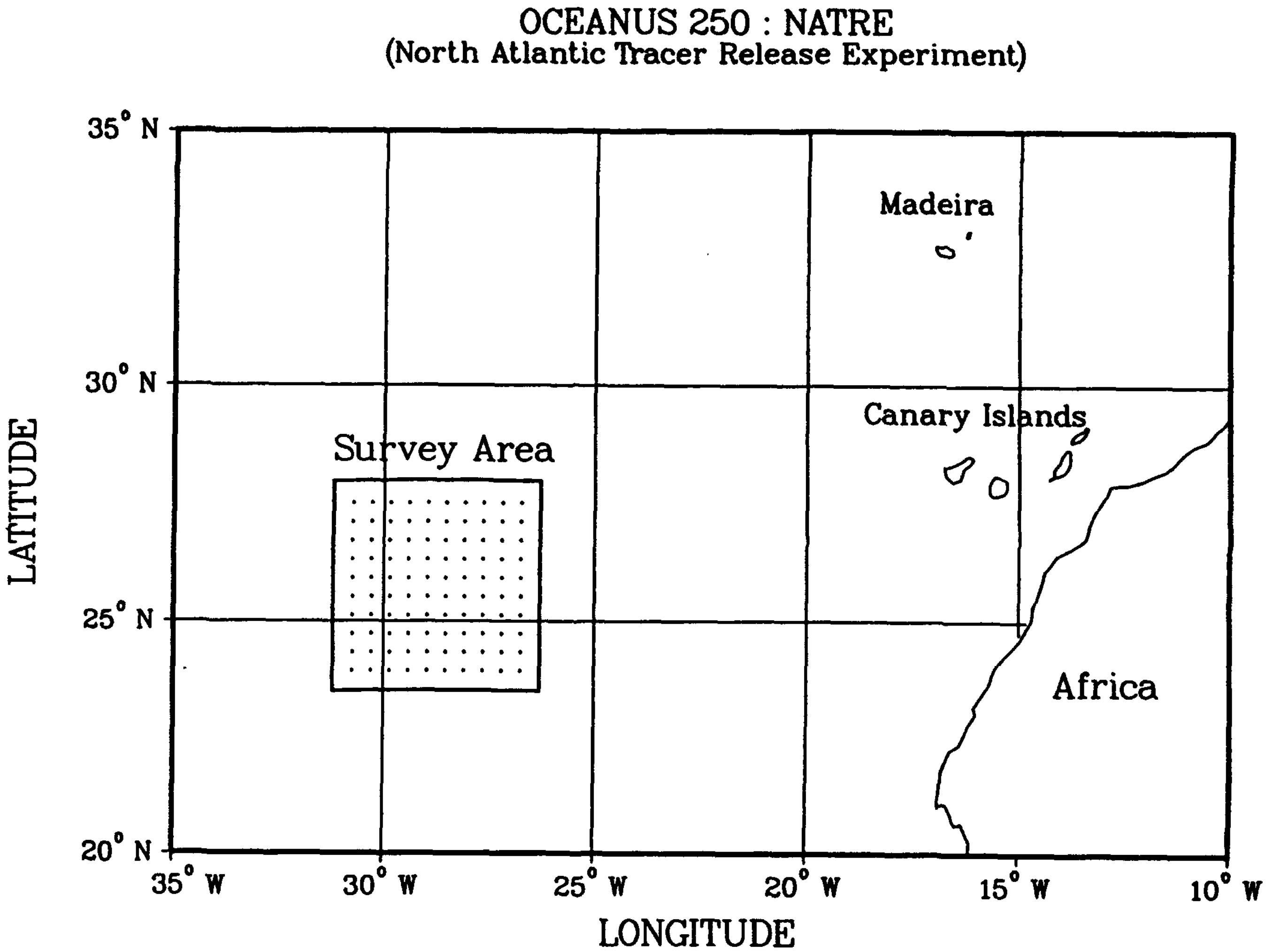

Figure 1: Chart of the eastern North Atlantic showing the survey area.

Scientist	Affiliation
Dick Koehler	WHOI
Ellyn Montgomery	WHOI
Tom Bolmer	WHOI
Dave Wellwood	WHOI
Kurt Polzin	MIT/WHOI Joint Program
Dave Gloss	MIT/WHOI Joint Program
Pascal LeGrand	MIT/WHOI Joint Program

Cruise Log

OCEANUS departed Funchal, Madeira, at 1300 on Wednesday, March 25 and began the three day transit to the initial point of the survey grid, 27°32′ N, 30°43.8′ W. This was the northwest corner of the 10 by 10 grid; the planned station spacing was 24 nautical miles (44.5 kilometers). In route, two test dives of the High Resolution Profiler (HRP) were performed, in order to adjust the ballast and examine sensor performance. The first was to 500 meters, the second to over 1750 meters. No major problems were discovered on these dives and all newly implemented features functioned well.

The grid of stations was commenced with HRP dive 3 at 1400 on March 28. This was the first station of a southward leg at the western edge of the survey area. By working eastward in alternating north and south legs, we minimized the time between adjacent stations and progressed upstream into the expected southwestward mean flow of the region. The grid of stations for the large survey and their numbers are shown in Figure 2.

The goal was to complete six dives per day, with a roughly even split between station and steaming time. In practice this worked well. The HRP took about an hour to reach 2000 db, and 22 minutes to return to the surface. Recoveries took about 15 minutes, leaving over two hours for the 24 mile steam between stations. The OCEANUS typically steamed at 11–11.5 knots, so it was possible to achieve six stations per day so long as the watches maintained efficiency. Three person science watches were established to work three eight hour shifts. Moderate weather, with 15–20 knot winds and commensurate seas, provided a challenging environment for starting HRP operations. After the fourth day, winds dropped to 10 knots or less and profiler handling became relatively routine.

Data quality was high and no major problems were experienced until the evening of April 3, when the HRP computer failed at the beginning of dive 39, immediately following a battery change. The weights dropped on command of the backup timing system but the lack of an acoustic signal from the profiler made for an anxious wait during its return to the surface. The problem arose during the battery change when a loose connection on one computer card required a substitution of cards and transfer of EPROM (erasable

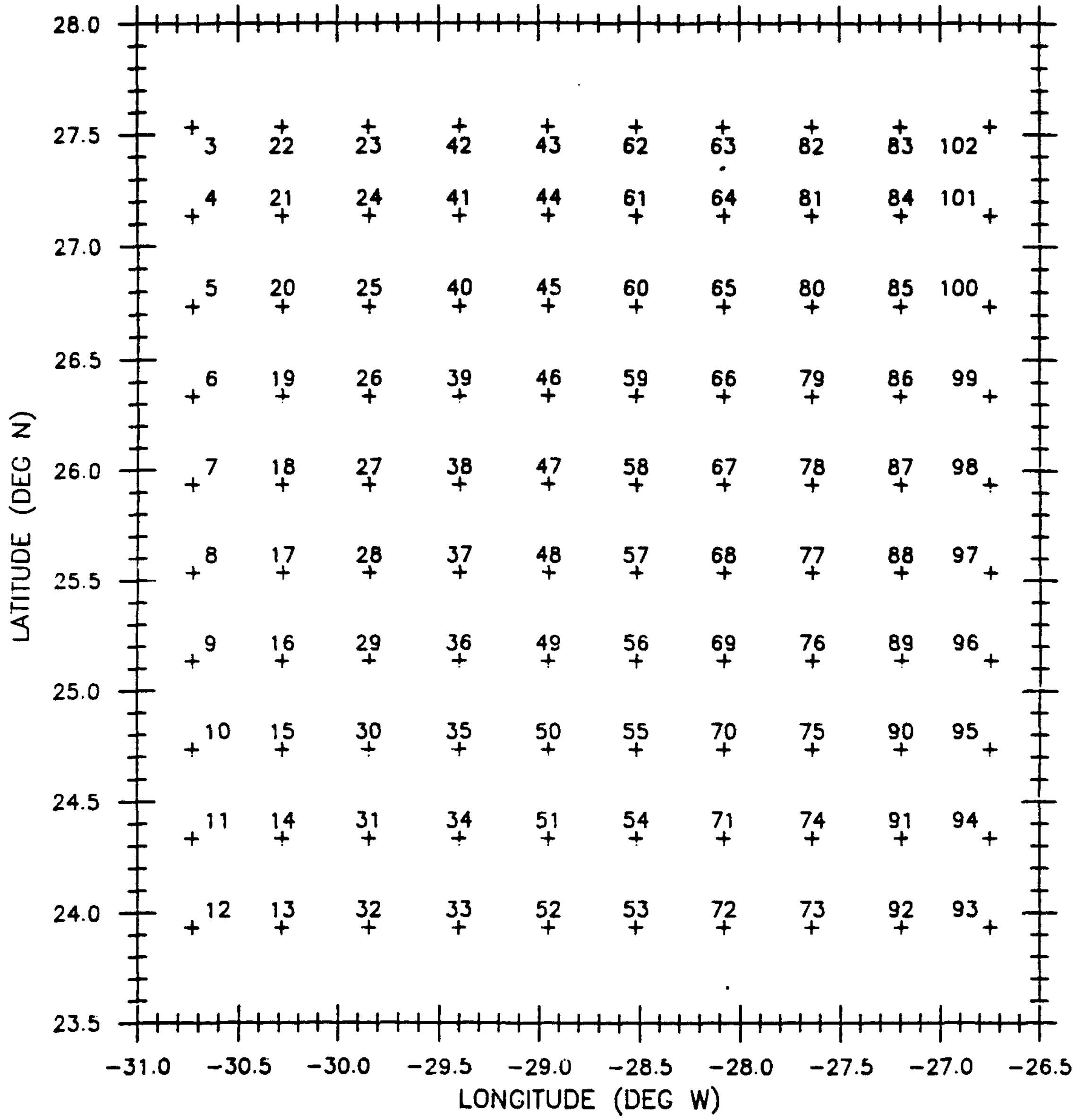

Figure 2: Chart showing the dive numbers and positions of the profiles comprising the large scale survey.

programmable memory) chips. The transfer apparently caused a failure in one of the EPROMs; reprogramming a new set of EPROMs cured the problem.

The survey then progressed without major incident. The weather worsened a bit, with heavy swell from the north, 15–25 knot winds, and overcast skies, for most of the rest of the survey. Even with the heavy weather, the efficiency of HRP operations improved with practice. A second battery replacement was effected without incident on April 11, after dive 83. The HRP requires a new battery every 35–45 dives (depending on dive duration).

For the sake of more than doubling the world total of deep microstructure profiles, the last 10 stations of the large survey (the easternmost line) were performed to a depth of 3000 meters. This line was completed with dive 102 on the afternoon of April 14.

Following the hundred dive large survey, a small scale survey was started in the northeast quadrant of the original survey box. Dives 103 to 107 comprised an east-west line south of station 66 and north of station 67 of the large grid; these confirmed the dynamic height field suggested by the large survey. To detail this field, a grid of stations, 4 dives and 25 kilometers on a side, was completed with 16 stations, numbers 108 to 123. This box was centered on 26°8′ N, 28°2.5′ W and executed between April 15 and 17. The positions of profiles 103 to 123 are shown in Figure 3. A third battery change was made without problems after station 122.

The weather had finally become calm, so on April 17 a profile with the shadowgraph mounted on the HRP was attempted. The connection of the two instruments is delicate and complicated, but was accomplished with little difficulty. The first shadowgraph/HRP dive to 500 meters was then commenced. Recovery of the shadowgraph/HRP was more difficult than anticipated. The calm weather and experienced watchstanders made the damage-free recoveries possible. The video did not record as expected on this dive, so a modification was made to the shadowgraph, and another profile attempted. This time the profile was to 1200 meters, and the images of the microstructure were recorded successfully. The HRP and shadowgraph were then uncoupled in preparation for more profiling.

A time series of repeated HRP dives to 1200 meters, over two inertial periods in an L shaped pattern (to obtain some measure of horizontal gradients and coherence), was done from April 18 to 20. This time series consisted of dives 126 to 150, and was performed at 26°N, 28°W, overlaying station 121 in the southeast sector of the small survey. On completion of the time series, a neutrally buoyant pop-up float to mark the parcel of water thought to be optimal for the tracer injection was deployed in a region of relatively weak horizontal gradients at 300 m. The float was deployed at 26°10′ N, 28°3′ W on April 20 at 1137 hours (GMT). Since the weather remained calm, another shadowgraph/HRP dive was performed before commencing the steam to port.

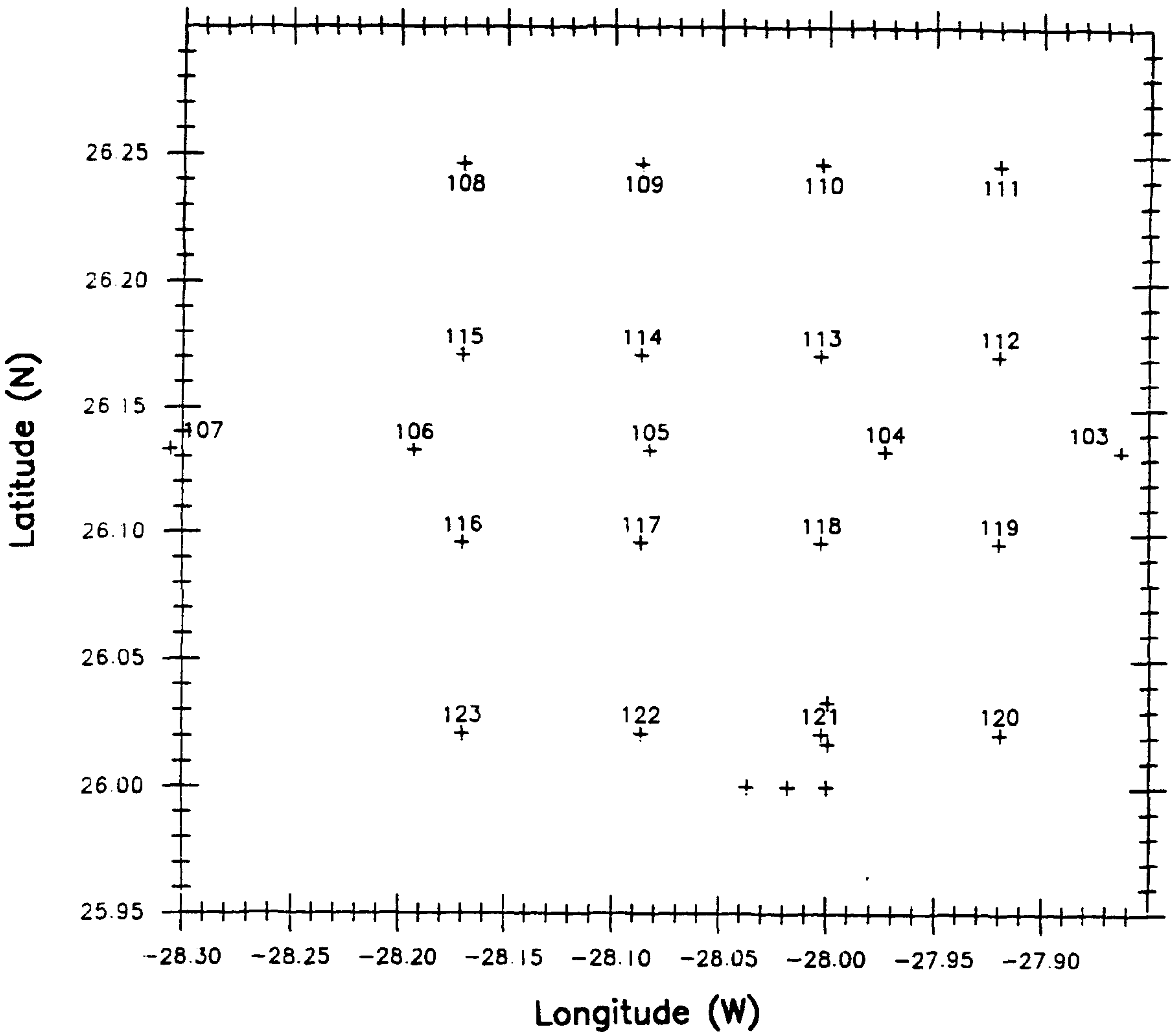

Figure 3: Chart showing the dive numbers and positions of the profiles comprising the small scale and inertial surveys.

Finally, four very deep HRP dives were performed on the transit to the Canaries, reaching unprecedented depths (for microstructure profiling) of 4000 meters. The last three were near the continental rise, but outside Africa's 200 mile limit. The profiles descended to within 150 meters of the bottom allowing the possibility of inertial wave reflection off weakly sloping topography to be explored. Dive 155 was completed the evening of April 22, expending the last available profiler weights and ship time. A list of station locations, deployment time and depth for all the HRP dives is given in Table 1.

The OCEANUS arrived in Las Palmas, Canary Islands on April 24, after two days of steaming. In port, discussions with Jim Ledwell and the other scientists on the next cruise were held to pass on the information gained from the surveys.

Table 1: HRP Survey for NATRE: Profile and Operations List

March 24 – April 25 1992

Cast #	Date Mo. Day 1992	Deployment Time (GMT)	Latitude Deg. N	Longitude Deg. W	Max. Pres. (db)	Comments
001	03 26	1051	31 11.68	20 59.39	500	test cast – all sensors
002	03 27	1016	29 36.76	25 22.91	1769	test to survey depth
003	03 28	1529	27 31.99	30 43.80	1898	start survey: NW corner
004	03 28	1930	27 08.06	30.43.79	2000	**started South on line 1
005	03 28	2345	26 43.73	30 43.65	2000	continued S on line 1
006	03 29	0352	26 20.11	30 43.39	2000	"
007	03 29	0757	25 55.99	30 42.71	2000	"
008	03 29	1204	25 32.20	30 43.78	2000	"
009	03 29	1610	25 08.20	30 43.56	2000	"
010	03 29	2018	24 44.07	30 43.76	2000	"
011	03 30	0026	24 20.02	30 43.60	2000	"
012	03 30	0438	23 56.22	30 43.62	2000	last cast on line 1
013	03 30	0848	23 55.96	30 17.05	2000	**begin line 2 northbound
014	03 30	1247	24 20.06	30 17.02	2000	continue N on line 2
015	03 30	1657	24 44.13	30 17.03	2000	"
016	03 30	2115	25 08.02	30 17.06	2000	"
017	03 31	0123	25 32.14	30 16.94	2000	"
018	03 31	0605	25 56.01	30 17.90	2000	"
019	03 31	1017	26 20.03	30 17.06	2000	"
020	03 31	1416	26 44.26	30 16.91	2000	"
021	03 31	1818	27 08.25	30 17.14	2000	"
022	03 31	2240	27 31.88	30 17.10	2000	last cast on line 2
023	04 01	0252	27 32.44	29 49.43	2000	**begin line 3 southbound
024	04 01	0652	27 08.01	29 50.69	2000	continue S on line 3
025	04 01	1110	26 44.02	29 50.75	2000	"
026	04 01	1505	26 20.10	29 50.69	2000	"
027	04 01	1909	25 56.01	29 50.70	2000	"
028	04 01	2304	25 32.01	29 50.72	2000	"
029	04 02	0314	25 08.11	29 50.68	2000	"
030	04 02	0708	24 43.97	29 50.71	2000	"
031	04 02	1111	24 20.08	29 50.75	2000	"
032	04 02	1502	23 56.11	29 50.76	2000	last cast on line 3
033	04 02	1900	23 56.06	29 24.13	2000	**begin line 4 northbound
034	04 02	2251	24 20.10	29 24.08	2000	continue N on line 4
035	04 03	0246	24 44.17	29 23.86	2000	"
036	04 03	0645	25 08.01	29 24.05	2000	"
037	04 03	1031	25 31.99	29 24.11	2000	"

Table 1: (Continued)

Cast #	Date Mo. Day 1992	Deployment Time (GMT)	Latitude Deg. N	Longitude Deg. W	Max. Pres. (db)	Comments
038	04 03	1431	25 56.10	29 24.20	2000	"
	04 03	1752				CHANGE HRP BATTERY
039	04 04	0257	26 20.01	29 24.14	2000	continue N on line 4
040	04 04	0650	26 44.02	29 24.08	2000	"
041	04 04	1037	27 07.58	29 24.01	2000	"
042	04 04	1425	27 32.19	29 23.91	2000	last cast on line 4
043	04 04	1815	27 32.10	28 57.24	2000	**begin line 5 southbound
044	04 04	2203	27 08.05	28 57.28	2000	continue S on line 5
045	04 05	0154	26 44.09	28 57.10	2000	"
046	04 05	0602	26 19.87	28 57.32	2000	"
047	04 05	0952	25 55.99	28 57.34	2000	"
048	04 05	1358	25 32.07	28 58.04	2000	at Subduction Surface Mooring
049	04 05	1751	25 07.89	28 57.36	2000	continue S on line 5
050	04 05	2138	24 44.14	28 57.29	2000	"
051	04 06	0144	24 20.17	28 57.21	2000	"
052	04 06	0541	23 56.05	28 57.24	2000	last cast on line 5
053	04 06	0953	23 55.94	28 31.43	2000	**begin line 6 Northbound
054	04 06	1344	24 20.14	28 30.98	2000	continue N on line 6
055	04 06	1733	24 44.08	28 31.11	2000	"
056	04 06	2147	25 08.01	28 31.24	2000	"
057	04 07	0137	25 32.09	28 31.03	2000	"
058	04 07	0535	25 56.05	28 31.19	2000	"
059	04 07	0930	26 20.03	28 31.17	2000	"
060	04 07	1317	26 44.05	28 30.98	2000	"
061	04 07	1659	27 08.16	28 30.93	2000	"
062	04 07	2043	27 31.96	28 31.10	2000	last cast on line 6
063	04 08	0030	27 31.94	28 05.03	2000	**begin line 7 Southbound
064	04 08	0415	27 08.01	28 04.78	2000	continue S on line 7
065	04 08	0801	26 43.86	28 04.80	2000	"
066	04 08	1145	26 19.99	28 05.18	2000	"
067	04 08	1530	25 56.03	28 04.87	2000	"
068	04 08	1914	25 31.99	28 05.10	2000	"
069	04 08	2258	25 08.09	28 05.29	2000	"
070	04 09	0253	24 44.01	28 04.76	2000	"
071	04 09	0636	24 19.95	28 04.94	2000	"
072	04 09	1024	23 55.95	28 05.03	2000	end line 7 — new antenna
073	04 09	1419	23 56.20	27 38.29	2000	**begin line 8 Northbound
074	04 09	1805	24 19.98	27 38.48	2000	continue N on line 8
075	04 09	2153	24 40.00	27 38.00	2000	"
076	04 10	0138	25 08.08	27 38.37	2000	"
077	04 10	0524	25 32.10	27 38.46	2000	Micro temperature sensor TN died 675 db

Table 1: (Continued)

Cast #	Date Mo. Day 1992	Deployment Time (GMT)	Latitude Deg. N	Longitude Deg. W	Max. Pres. (db)	Comments
078	04 10	0917	25 55.94	27 38.46	2000	replaced TN sensor
079	04 10	1312	26 20.16	27 38.55	2000	continue N on line 8
080	04 10	1700	26 44.05	27 38.36	2000	"
081	04 10	2048	27 08.13	27 38.45	2000	"
082	04 11	0033	27 32.06	27 38.52	2000	end line 8 Northbound
083	04 11	0422	27 32.03	27 11.75	2000	**begin line 9 Southbound
	04 11	0800				CHANGE HRP BATTERY
084	04 11	0858	27 08.10	27 11.69	2000	continue S on line 9
085	04 11	1254	26 43.95	27 11.98	2000	"
086	04 11	1644	26 20.11	27 12.13	2000	"
087	04 11	2038	25 56.03	27 11.93	2000	"
088	04 11	0030	25 31.98	27 12.05	2000	"
089	04 12	0438	25 08.13	27 11.89	2000	"
090	04 12	0830	24 43.98	27 11.94	2000	"
091	04 12	1218	24 19.91	27 11.98	2000	"
092	04 12	1621	23 56.06	27 11.79	2000	end of line 9 southbound
093	04 12	2028	23 56.06	26 45.07	3000	**begin line 10 Northbound
094	04 13	0223	24 20.00	26 45.10	3000	continue N on line 10
095	04 13	0632	24 44.08	26 45.12	3000	"
096	04 13	1111	25 08.00	26 45.17	3000	"
097	04 13	1554	25 32.06	26 44.90	3000	"
098	04 13	2035	25 55.99	26 44.99	3000	"
099	04 14	0117	26 20.09	26 45.10	3000	"
100	04 14	0605	26 43.94	26 45.12	3000	"
101	04 14	1044	27 08.04	26 45.07	3000	"
102	04 14	1517	27 32.10	26 44.95	3000	end of line 10 Northbound
						** END LARGE SURVEY **
	04 14	1745				Transit to E-W line site
103	04 15	0317	26 08.28	27 51.65	2000	**begin small E-W survey
104	04 15	0545	26 08.07	27 58.39	2000	continue W
105	04 15	1031	26 08.09	28 04.96	2000	"
106	04 15	1031	26 08.13	28 11.80	2000	"
107	04 15	1257	26 08.02	28 18.34	2000	end E-W survey
108	04 15	1605	26 14.82	28 10.13	2000	** begin 4 x 4 survey **

Table 1: (Continued)

Cast #	Date Mo. Day 1992	Deployment Time (GMT)	Latitude Deg. N	Longitude Deg. W	Max. Pres. (db)	Comments
109	04 15	1838	26 14.52	28 04.99	2000	continue top line east
110	04 15	2116	26 14.78	28 00.22	2000	"
111	04 15	2345	26 14.71	27 55.24	2000	easternmost on line
112	04 16	0204	26 10.19	27 55.07	2000	*start W on line 2
113	04 16	0453	26 10.42	28 00.00	2000	continue westward
114	04 16	0715	26 10.22	28 05.24	2000	"
115	04 16	0944	26 10.38	28 10.22	2000	westernmost on line
116	04 16	1224	26 05.78	28 10.26	2000	* start east on line 3
117	04 16	1500	26 05.82	28 05.16	2000	continue eastward
118	04 16	1724	26 05.75	28 00.18	2000	"
119	04 16	2052	26 05.74	27 55.31	2000	easternmost on line
120	04 16	2222	26 01.27	27 55.20	2000	* start west on last line
121	04 17	0158	26 01.28	28 00.26	2000	continue westward
122	04 17	0315	26 01.32	28 05.07	2000	"
	04 17	0500				CHANGE HRP BATTERY
123	04 17	0658	26 01.26	28 10.20	2000	** end small 4x4 survey
	04 17	0900				mount & test SHADOWGRAPH
124	04 17	1654	26 05.68	28 05.32	500	* shadowgraph *
125	04 17	1907	26 05.17	28 05.17	1200	* shadowgraph *
	04 17	2100				remove SHADOWGRAPH
126	04 18	0100	25 59.97	28 00.00	1200	** BEGIN inertial survey
127	04 18	0315	26 02.01	28 00.02	1200	continue inertial survey
128	04 18	0530	26 00.97	28 00.03	1200	"
129	04 18	0745	26 00.02	27 59.98	1200	"
130	04 18	1000	26 59.96	28 02.21	1200	"
131	04 18	1215	26 00.01	28 01.08	1200	"
132	04 18	1430	25 59.96	28 01.04	1200	"
133	04 18	1649	26 02.02	27 59.93	1200	"
134	04 18	1901	26 00.99	27 59.98	1200	"
135	04 18	2115	25 59.97	28 00.02	1200	"
136	04 18	2330	25 59.92	28 02.00	1200	"
137	04 19	0146	26 00.00	28 01.10	1200	"
138	04 19	0431	26 00.00	27 59.93	1200	"
139	04 19	0645	26 01.96	27 59.96	1200	"

Table 1: (Continued)

Cast #	Date Mo. Day 1992	Deployment Time (GMT)	Latitude Deg. N	Longitude Deg. W	Max. Pres. (db)	Comments
140	04 19	0900	26 00.98	27 59.99	1200	"
141	04 19	1115	25 59.97	28 00.03	1200	"
142	04 19	1330	25 59.98	28 02.22	1200	"
143	04 19	1548	26 00.05	28 01.07	1200	"
144	04 19	1802	26 00.06	28 00.01	1200	"
145	04 19	2017	26 02.05	27 59.94	1200	"
146	04 19	2231	26 01.02	27 59.98	1200	"
147	04 20	0045	26 00.00	28 00.00	1200	"
148	04 20	0300	26 00.01	28 02.22	1200	"
149	04 20	0515	26 00.01	28 01.09	1200	"
150	04 20	0723	26 00.03	27 59.99	4000	* END inertial survey
	04 20	1137	26 09.99	28 02.97		deploy ARGOS beacon
151	04 20	1547	26 03.80	27 22.03	950	HRP with SHADOWGRAPH
152	04 21	1342	25 14.08	23 13.44	4000	* start deep drops
153	04 22	0748	24 32.09	20 14.97	3819	at base of African
154	04 22	1148	24 31.97	20 14.99	3900	continental slope *
155	04 22	1613	24 31.96	20 14.96	3816	** last HRP cast **

Description of the High Resolution Profiler

The High Resolution Profiler (HRP) is a vertically profiling free vehicle. Being a free vehicle, the measurements taken by the HRP are not subject to cable-induced noise. Each deployment of the HRP, and the data collected during that deployment, is referred to as a station, profile, or dive.

The HRP was designed and developed at WHOI to make high quality fine- and microstructure measurements using the interface bus computer (IBC). The IBC is the HRP's controller, handling everything from software setup to data acquisition and storage. A suite of sensors interfaced to the IBC provides data on the physical properties of the water sampled as the HRP descends. All the data collected are stored internally in a 16 Mb RAM (random access memory) mass storage area. A schematic of the HRP and its components is shown in Figure 4. For additional information on the development of the HRP and IBC, see the papers by Schmitt *et al.* (1988) and Mellinger *et al.* (1986).

The HRP has two data streams: "fine" and "micro". The beginning and end of each deployment is triggered by the measured pressure reaching user-defined threshold values. The fine-scale data consists of inputs from the on-board CTD (conductivity, temperature, depth sensor), and a suite of analog devices is interfaced with the analog to digital (A/D) converter channels. During a profile, micro-structure measurements of turbulent velocity, as well as temperature and conductivity fluctuations, are acquired simultaneously with the fine-scale data. The sampling in both modes is driven by the 200 Hz interrupt, with micro-scale data acquired every cycle, and fine-scale data acquired every twentieth cycle, for a rate of 10 Hz.

The sensor configuration used for the NATRE cruise on the R/V *Oceanus* is shown below. (Pressure, temperature and conductivity do not have A/D channels assigned to them because they are acquired by the onboard CTD, which has its own A/D converter.)

fine sensors (10 Hz sampling)	**A/D channel**
pressure	
temperature	
conductivity	
accelerometer top X	0
accelerometer top Y	1
accelerometer bottom X	2

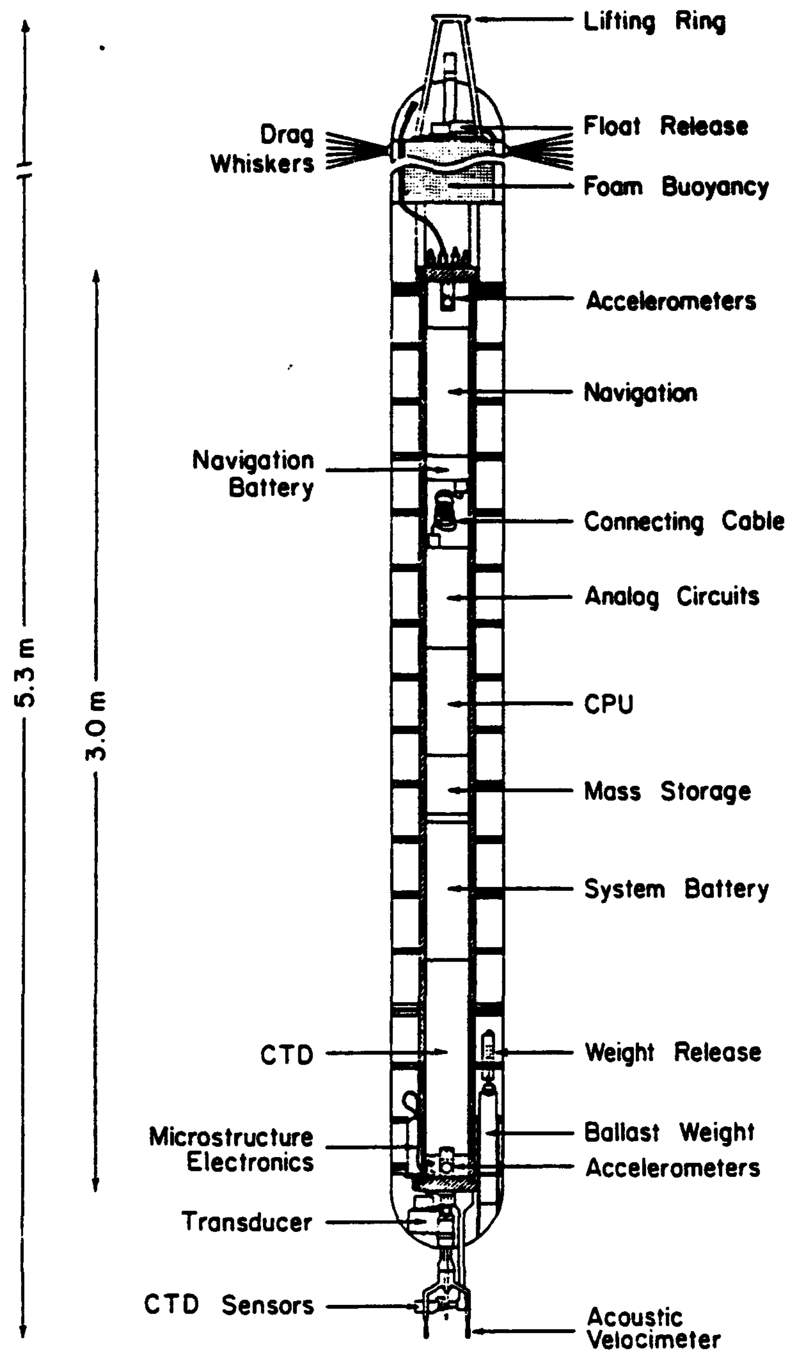

Figure 4: Schematic of the High Resolution Profiler (HRP)

accelerometer bottom Y	3
acoustic current meter — X velocity	4
acoustic current meter — Y velocity	5
X compass	6
Y compass	7
ground	14

micro sensors (200 Hz sampling)	**A/D channel**
micro conductivity	10
micro temperature	11
shear X	12
shear Y	13

Modifications to the HRP for this cruise included the following: adding a second transducer and modifying the software to support output of pressure data to the shadowgraph to be logged with the video images.

On previous cruises, the pulse generated by the transducer mounted in the nose of the HRP caused spikes in the microstructure data because of its proximity to the turbulence sensors. To solve the problem, a second transducer was mounted at the top of the instrument (5 meters above the sensors) to ping on the descent, while data is being collected. The original transducer was used during the ascent, so the transducer in use would be submerged, even at the surface. The HRP control program was modified to control two transducers.

This cruise was the first time the shadowgraph was used simultaneously with the HRP. The initial (and only other) deployments, in 1985 during the C-SALT (Carribean Sheets and Layers Transects) experiment, were done independently. Information on the development of the shadowgraph is available in the paper by Converse *et al.* (1988). In order to use the shadowgraph in this experiment, numerous issues had to be resolved. Dave Wellwood worked out the details of the mechanical connection to the HRP and made plans for instrument coupling and handling on deck. The mechanical connection to the HRP was designed with a shear pin release, so that if the shadowgraph and HRP were to descend beyond a preset pressure, the shear pin would break, releasing the shadowgraph so the HRP could be recovered. Paul Fucile revamped the electronics and control program running the shadowgraph, and added a pressure display to the video record. He also designed a serial connection to the HRP employing an optical link where a beam of light transmits the data signal between cable terminations. This allowed the cable to separate cleanly at the optical link and not cause the HRP to be dragged to the bottom by the data cable if the shadowgraph was released. Fortunately, the fail-safe mechanisms were unnecessary, and both the HRP and shadowgraph returned after each deployment. Ellyn Montgomery implemented software to control the serial output of HRP pressure data to the shadowgraph. During the cruise three profiles were completed with the shadowgraph connected to the HRP.

Very deep casts were also completed on this cruise. Some of the dive control variables were stored as integers, meaning the largest number possible was 32768 (3276.8 meters). This was not large enough to allow 4000 meter dives, so the parameters storing the dive termination pressures were changed to unsigned integers allowing values of up to 65535 (6553.5 meters) and data acquisition for deep profiles proceeded smoothly.

With the above improvements to the HRP, no transducer-induced spikes occurred in the microstructure data, the shadowgraph worked as we hoped, and dives to 4000 meters were made successfully.

Data Processing

The HRP collects and stores finestructure, microstructure, and navigation data. Each of the three types is treated separately after it is transferred from the HRP. The following section describes the data processing carried out routinely onboard the ship during a cruise.

The HRP is programmed to store only one profile at a time in its memory. Consequently, after each deployment, the data must be offloaded to another computer for permanent storage. Serial data transfer at 34 kilobaud is used to move the data from HRP memory to the hard disk of a 80386 type PC for intermediate storage. The transfer is first enabled at the HRP, then software on the PC controls the transfer. The data transfer rate allows the microstructure data for a 1000 meter profile to be sent to the PC in about 20 minutes. Once the data is transferred to the PC, the HRP can be programmed to start another dive. After several profiles of raw data have accumulated on the hard disk they are archived to an optical disk. Additional information on the data transfer is provided in the report by Montgomery (1991).

Once the data is on the PC, it can be transferred to the post processing computer via ethernet, using File Transfer Protocol (FTP). The bulk of the data processing is accomplished on Digital Equipment Corporation VAX VMS computers using Fortran programs developed at WHOI. The first step is to convert the data into engineering units, and then store it in a binary format to conserve storage space (Millard and Galbraith 1982). Quality control time series plots are then generated for each finestructure and microstructure data channel. Sample quality control plots from profile 78 are shown in Figures 5a through 5d.

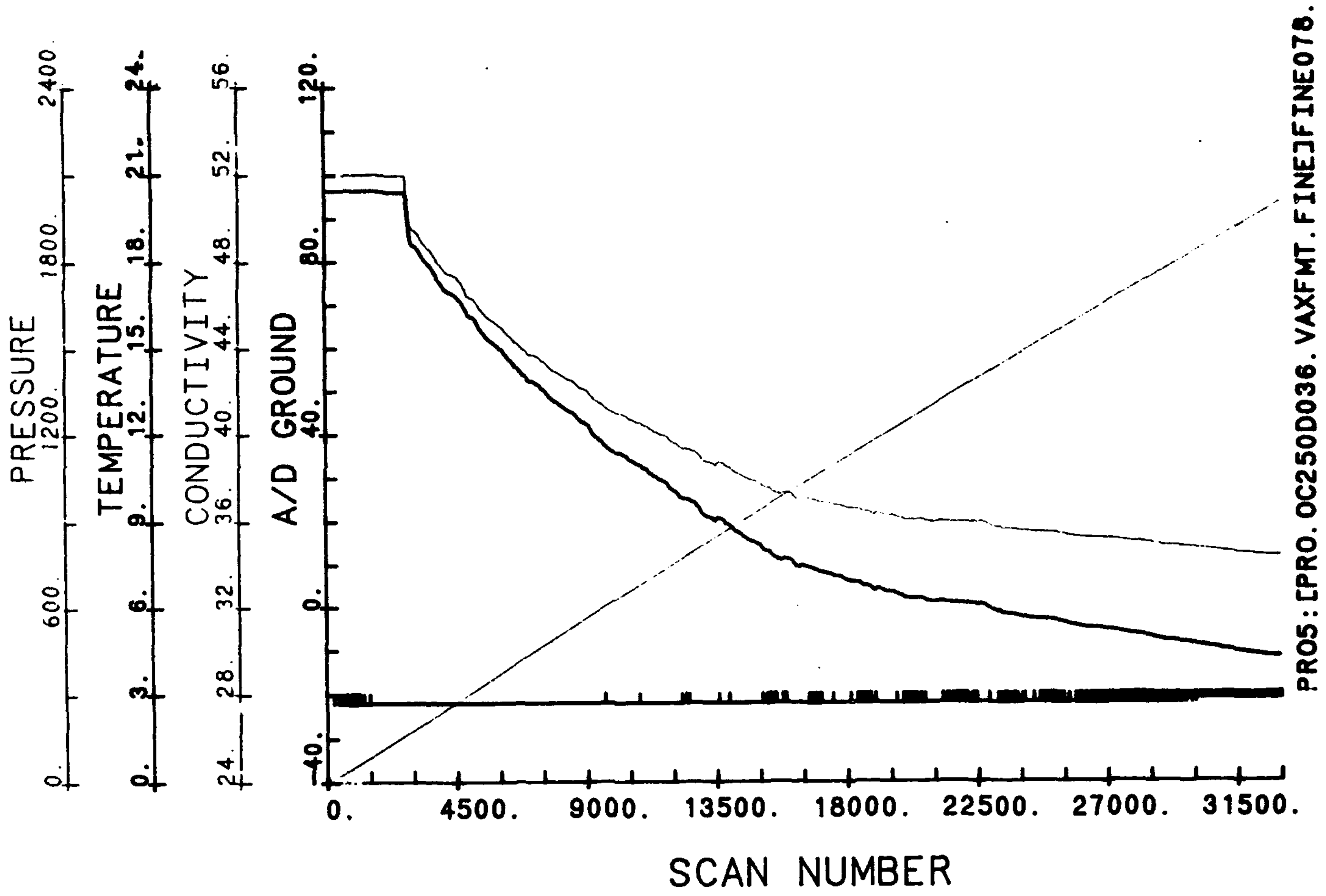

Figure 5a: Plot of Pressure, Temperature, Conductivity, and A/D ground versus scan number for dive 78.

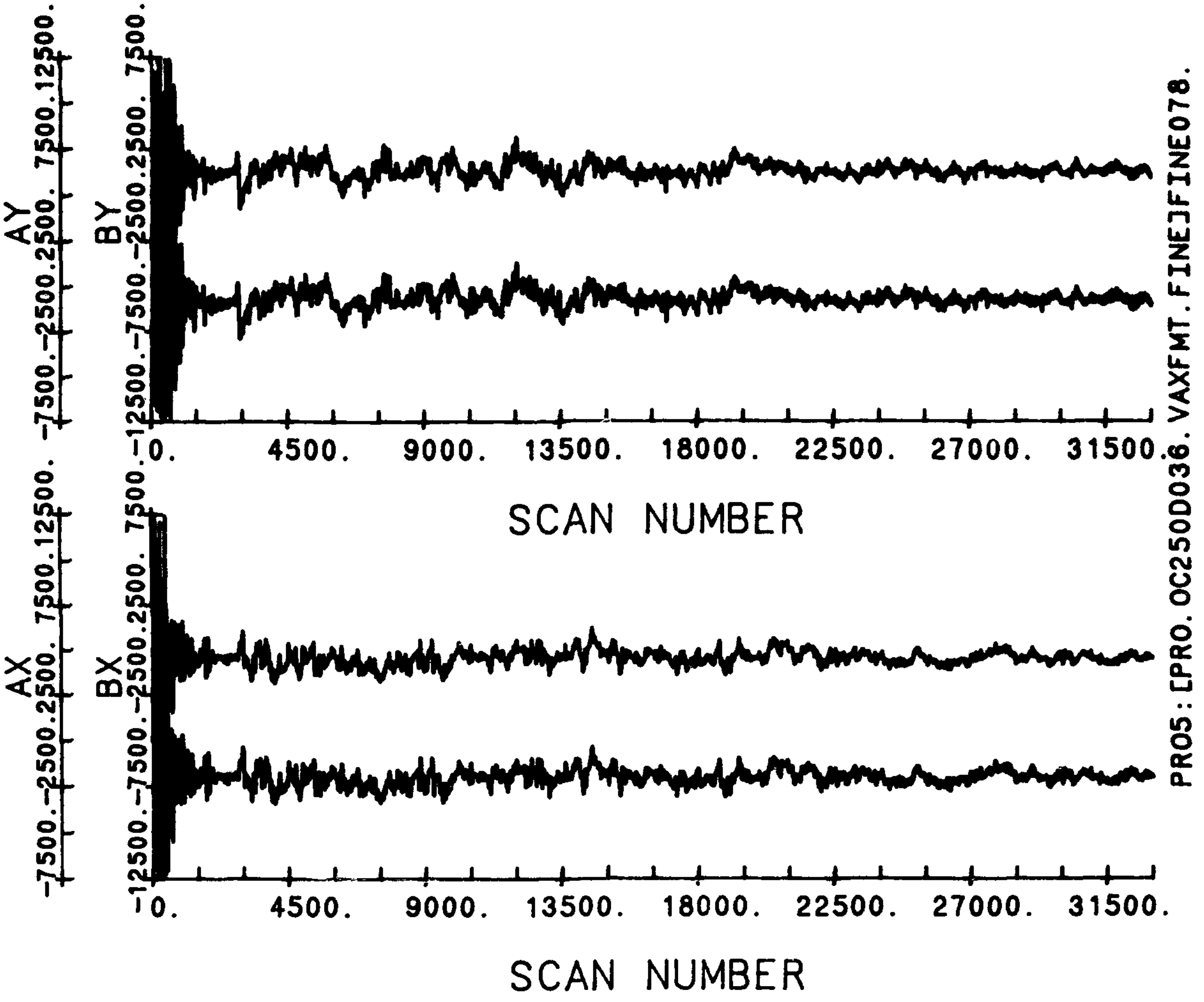

Figure 5b: Plots of accelerometer data for dive 78. The upper plot shows the y component of the two accelerometers and the lower plot shows the x components of the two accelerometers.

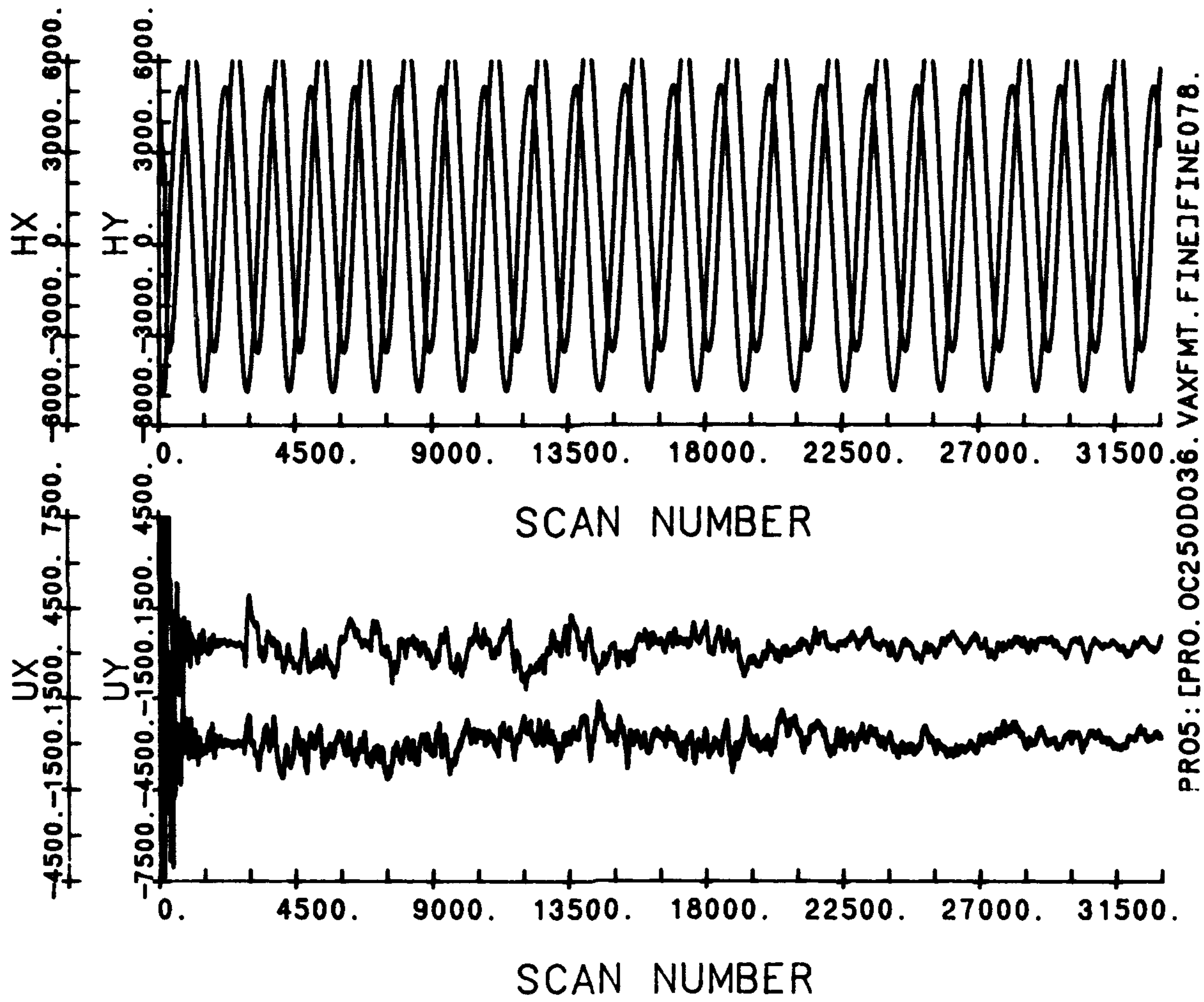

Figure 5c: Plot of x and y components of the magnetometer (top) and x and y components of the velocimeter (bottom) data for dive 78.

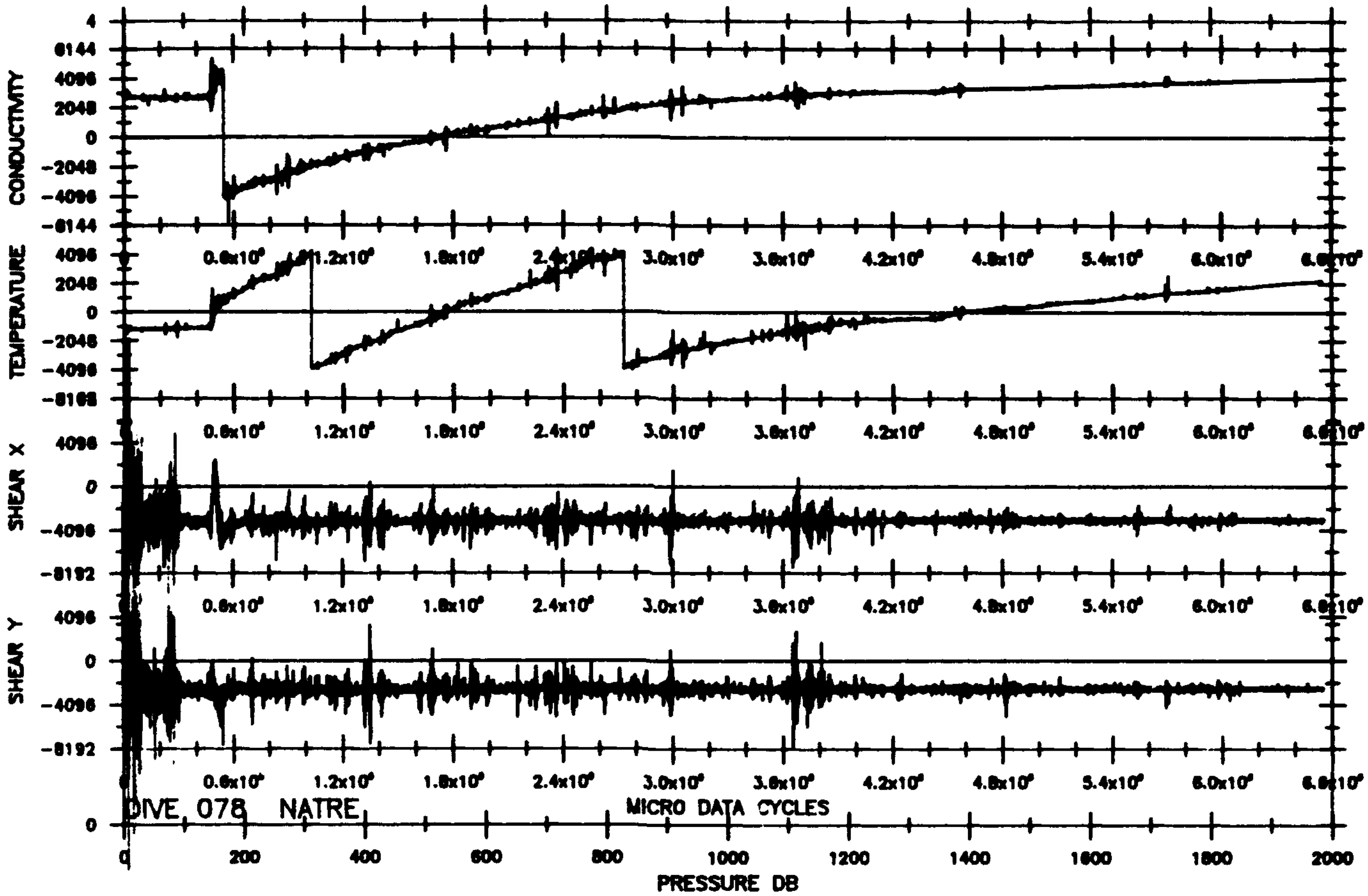

Figure 5d: Example of a microstructure data quality control plot using dive 78. Micro-temperature, micro-conductivity, shear x and shear y are plotted against scan number.

As the above plots are generated, a routine is run that computes the finescale velocity, potential temperature-salinity profiles and bins the data in a uniformly incremented pressure series (typically 0.5 db). The velocity computation employed is described by Schmitt *et al.* (1988) and uses the acceleration and magnetometer data to correct the raw acoustic current meter data for instrument motion. Laboratory-derived calibration data are used to convert raw pressure and temperature data to scientific units. A laboratory-derived relationship is also utilized for the initial estimate of the conductivity cell calibration. Adjustments of this scale are subsequently derived to obtain consistent deep water potential temperature-salinity relationships. The output is stored in another binary file from which a plot of temperature, salinity, east and north velocities versus pressure is created. An example of this type of plot, using profile 78, is shown in Figure 6.

Microstructure data processing is started concurrently with the fine, but takes much longer to complete due to more densely sampled data and more computations performed. The scheme used follows procedures developed by Neil Oakey (Bedford Institute of Oceanography). A report by Polzin and Montgomery (in prep.) describes the microstructure data processing, so only a brief summary is included here.

The processing utilizes laboratory-derived calibration coefficients for the shear probes (micro-scale velocity sensors), while *in-situ* calibration data for the microscale temperature and conductivity sensors are obtained by reference to the finescale temperature and conductivity from the HRP. The microstructure data are binned in time blocks aligned with the uniformly incrementing pressure series of the reduced finescale data. Gradient variances are estimated in the frequency domain after fast Fourier transforming by integrating spectra out to a local minimum in energy density. Spectral corrections are then applied for the finite responses of the sensors. After automated edit and consistency checking, scaling to scientific units yields estimates of the kinetic energy dissipation rate (ϵ , epsilon), and two measures of the dissipation rate of thermal variance (from the microscale temperature and conductivity sensors: Chi-T and Chi-C respectively). Profile plots (in "stick diagram" form) of the dissipation rates are then produced, examples of which (again using profile 78) are shown in Figures 7a-c.

Navigation data is acquired only when a net of acoustic transponders is deployed on the seafloor. It is used to determine the absolute velocity profile. There were no profiles on this cruise for which a transponder net was deployed, so all velocity profiles are relative to a depth average of zero in each component.

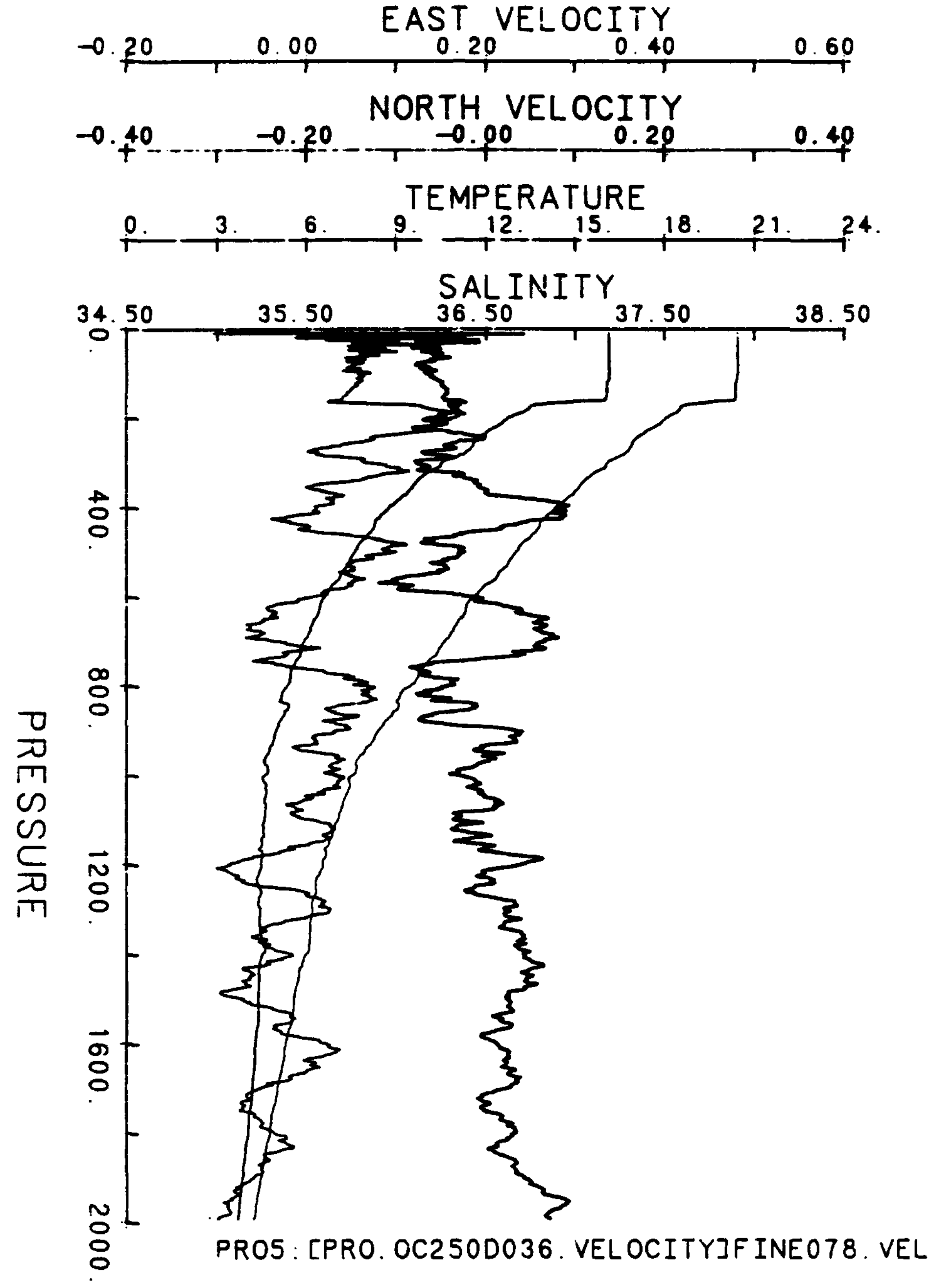

Figure 6: Plot of computed velocity (east and north components), temperature and salinity versus pressure for dive 78.

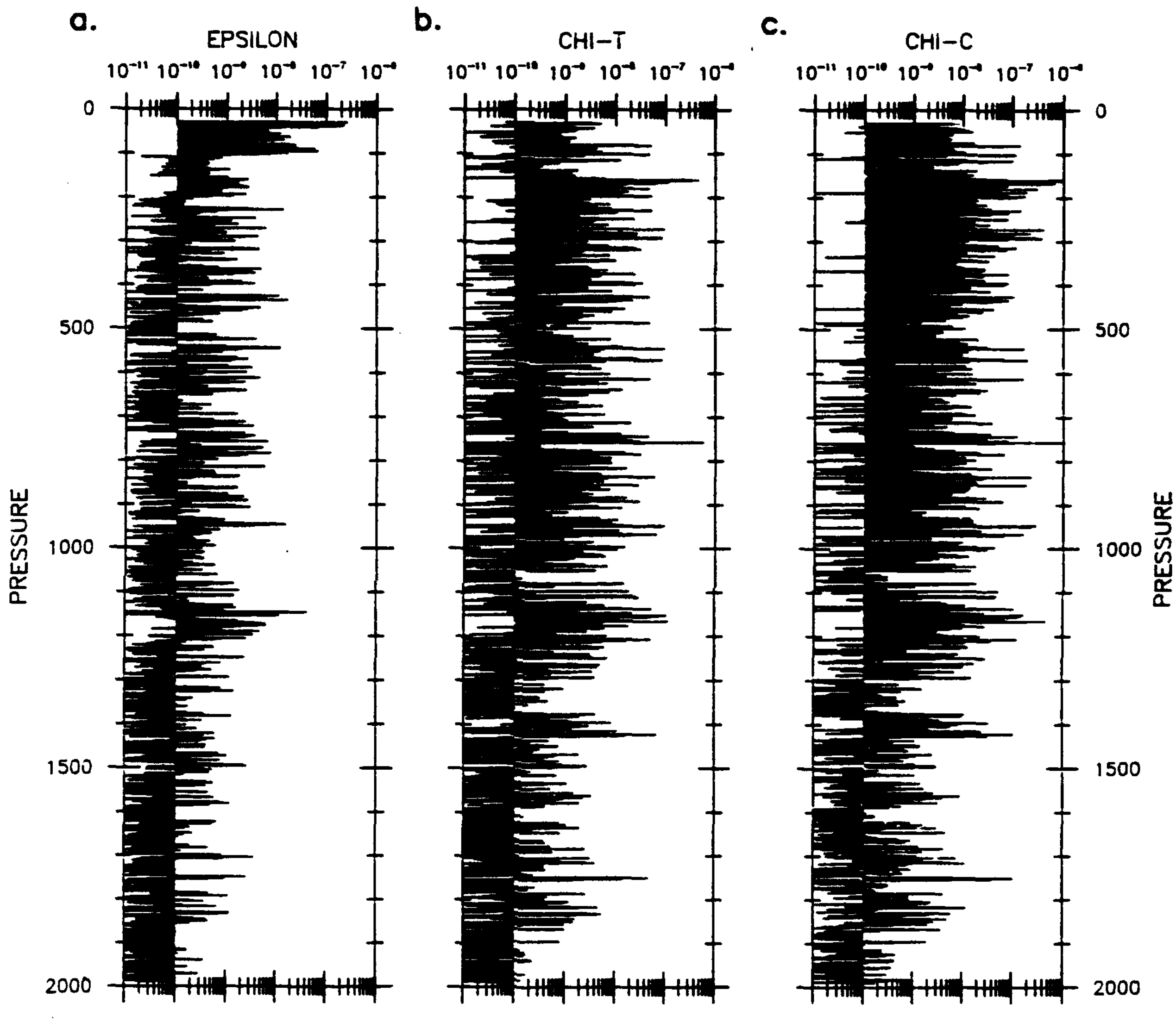

Figure 7: Plots of energy dissipation rate, epsilon (a), dissipation rate of thermal variance from micro-temperature (b), micro-conductivity (c) sensors for dive 78.

Summary

The large scale survey is the first of such magnitude to be done with a free profiler; typically only 10 to 20 dives per cruise have been made with free microstructure vehicles in the past. Indeed, it is relatively unusual to perform as many as 150 CTD casts in a cruise. A total of 300 km of vertical profile data was obtained on this cruise (over a gigabyte of raw data). The surveys and time series provide an accurate description of mesoscale variability for the subsequent tracer release experiment and a firm basis for characterizing mixing in the region.

The region surveyed met most of the expectations for NATRE; there was a main thermocline stratification favorable for salt fingers and little intrusive activity. Figure 8 shows vertical profiles of potential temperature, salinity, potential density and density ratio from station 78 of the survey. The mixed layer is deep, often 125 m or more. Temperature and salinity decrease monotonically through the thermocline from maxima in the mixed layer and display an "irregular steppiness," possibly related to salt fingering. Density ratios are low and near two for most of the thermocline; the lowest values tend to be in the upper thermocline. The shadowgraph dives revealed weak horizontal laminae, like those in C-SALT, in the main thermocline and in intrusions at depth. Intrusions are found below 700 m, where the lateral mixing of warm, salty Mediterranean water and cold, fresh Labrador Sea water begins to appear.

The temperature-salinity structure has a classic central water structure, a tight, smooth arc from the mixed layer downward, reflecting the relatively constant density ratio of the thermocline (Figure 9).

Intrusions are found at lower temperatures, as the large scale salinity minima and maxima are encountered. Some small T/S inversions are found in the upper waters in some casts.

Mesoscale eddy variability is a primary concern for NATRE. Accordingly, the dynamic height at 300 db relative to 1500 db is mapped for the large scale survey (Figure 10). Three hundred db is the target depth for the tracer deployment. The map reveals two high pressure regions in the west and east central areas, separated by a low which is particularly strong in the south central area. The low is centered on station 48, which is at the site of the central subduction mooring. Typical relief of these features is 2–4 dynamic centimeters; characteristic geostrophic velocities would be order 5–15 cm/s. A strong easterly flow is indicated in the northeast corner; the velocity profiles from HRP also showed this flow. Some reservations must be expressed with regard to the influence of the internal tide on such maps, an issue discussed later, but we generally see good coherence of features from section to section. (The north-south sections took typically a day and a half each.)

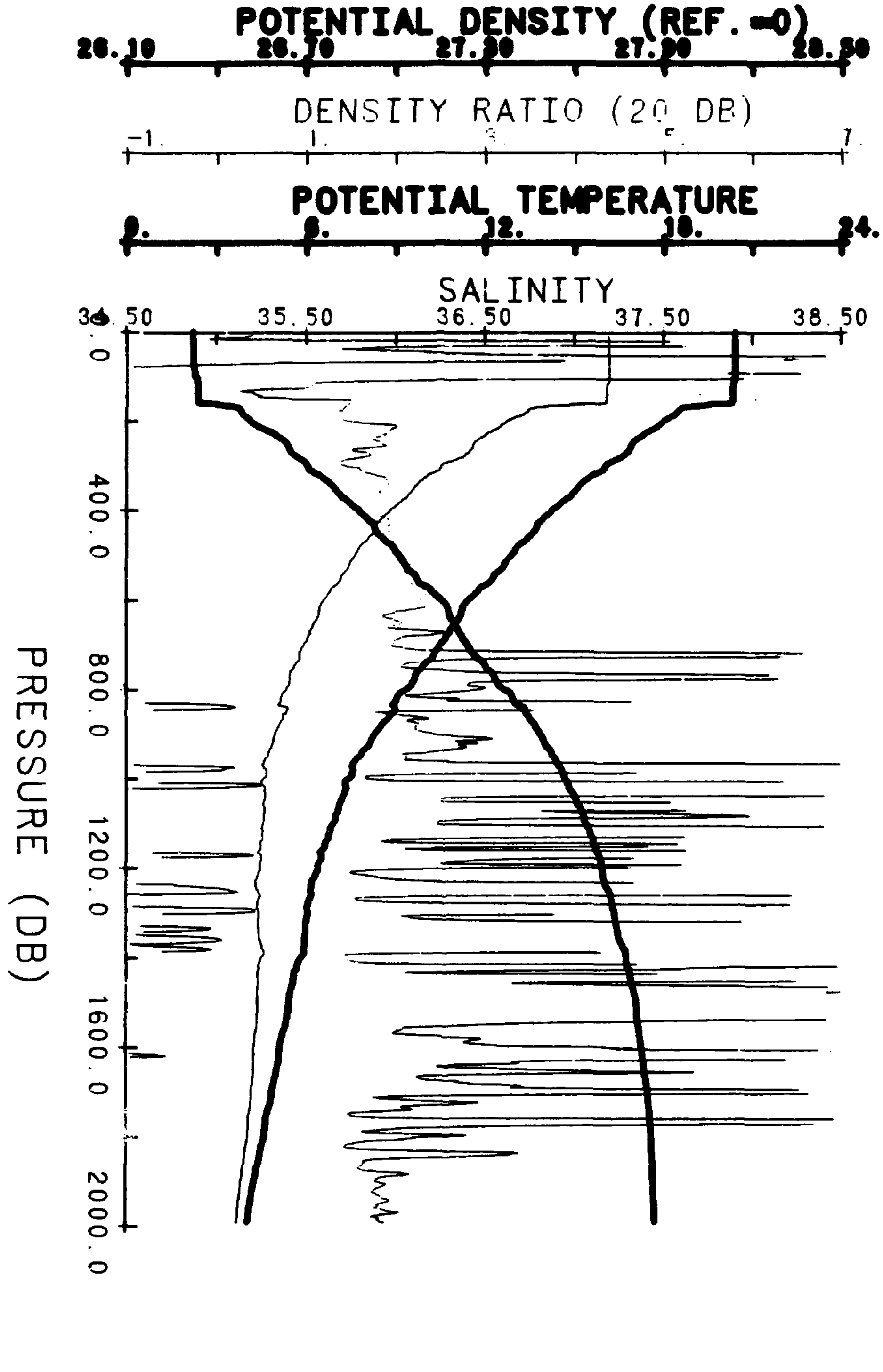

Figure 8: Profiles of potential temperature, salinity, potential density and density ratio versus pressure (computed from finescale data variables) are shown for dive 78.

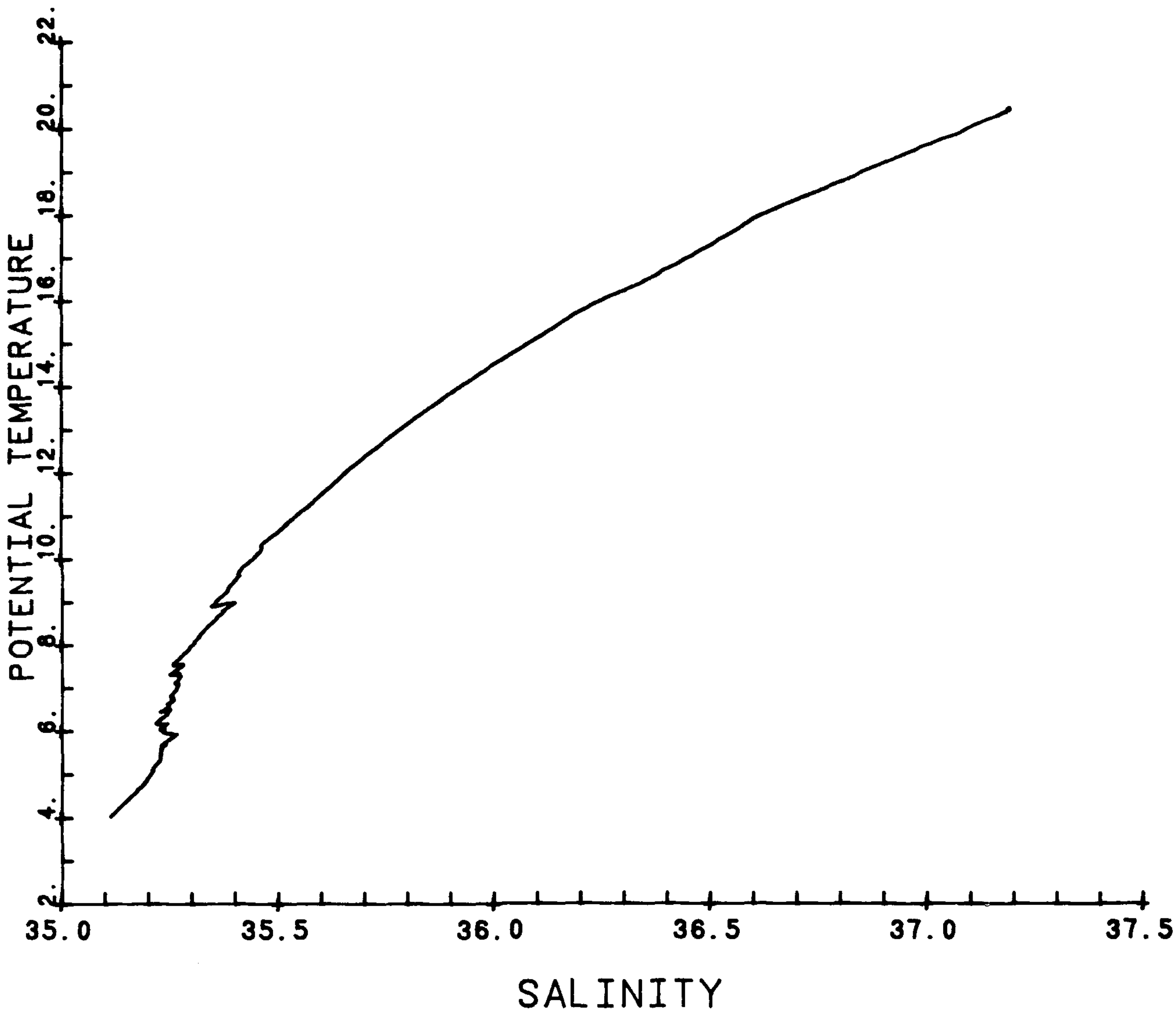

Figure 9: The theta-salinity relationship is shown for dive 78.

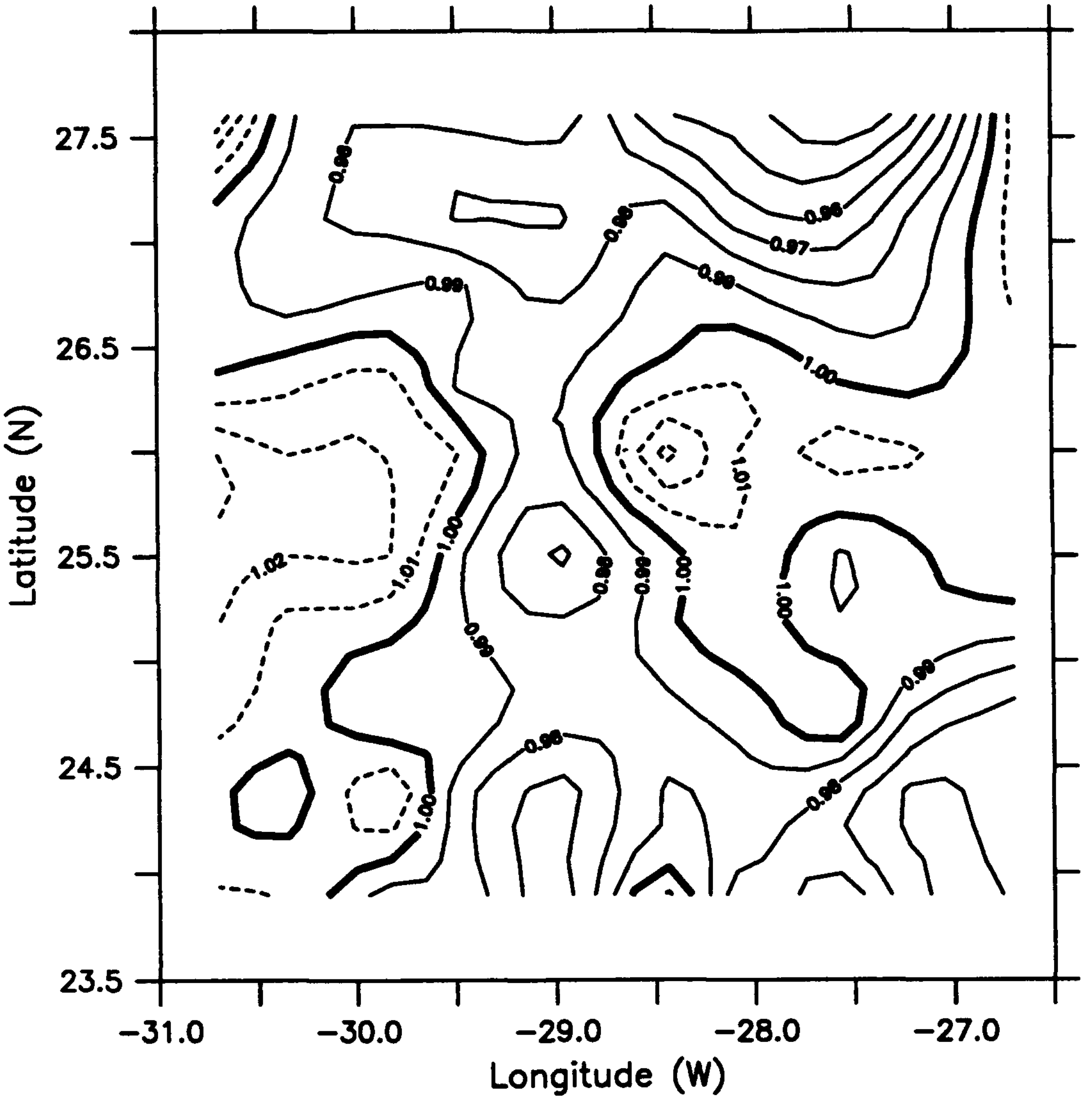

Figure 10: Contour plot showing the dynamic height field at 300 db referenced to 1500 db for the large scale survey.

If we accept the dynamic topography as a reasonable snap-shot of the structure, we can examine the higher order dynamics to infer evolution of the eddies. Figure 11 is a map of the relative vorticity, scaled with f, calculated from the Laplacian of the dynamic height field (by John Toole). It suggests that the strongest eddy feature is a dipole pair in the center of the box. One would infer northwestward propagation of such a pair from their mutual interaction. The planned NATRE deployment site is in the center of the northeast sector of the box, so it might not be adversely affected by this dipole pair, though it does lie within the northeast sector of the anticyclonic eddy.

The value of the density ratio is of particular interest, in order to determine the potential for salt fingering. This is mapped at 300 db using a 20 db least square fit to the vertical temperature and salinity gradients in Figure 12. At 300 db, there is a striking band of low density ratio trending from the southwest to the northeast across the southern portion of the box. The intended TRE deployment site near 26°N, 28°W, falls within this band.

We have selected the $\sigma_{300} = 28.00$ surface to represent the lateral thermohaline structure. In this area $\sigma_{300} = 28.07$ corresponds to sigma-theta = 26.75. This surface lies close to 300 db in the region of the small scale survey. Theta-300, salinity, pressure and density ratio on this surface are shown in Figures 13a-d. For the most part, the topography of these surfaces mirrors that of the dynamic height field. Horizontal T/S gradients are generally modest, with mesoscale variability dominating any large scale mean structure. Gradients in the tracer release area appear to be small.

Further detail on structure in the release area is revealed by the small scale survey (stations shown in Figure 3). Figures 14a-d show the potential temperature, salinity, pressure and density ratio for the small survey. Gradients of temperature and salinity of order 0.01°C/km and 0.0025°/$_{oo}$/km are seen. However, of more concern is the strong relief in the depth of this surface. Stations 114 and 118 have more than 24 db difference in the depth of $\sigma_{300} = 28.0$. However, only about 10 hours separate these two profiles, so we suspect aliasing by the internal tide.

The times series of stations taken in the vicinity of 26°N, 28°W is valuable for examining this question. Figure 15a shows the pressure of the sigma-theta =26.75 surface as a function of time, vertical excursions up to 40 db can be seen, with a 24 hour period. The effect of the internal tide on the dynamic height for these stations is shown in Figure 15b, the amplitude is of order 2 dynamic centimeters for the 300 db referenced to 1000 db surface. This variation raises some uncertainty about the representativeness of the large scale maps; some of the features there may be due to tidal aliasing. Also, such large vertical excursions of density surfaces will be of concern during the TRE injection and sampling programs, though the winch systems should certainly handle such variations. The exis-

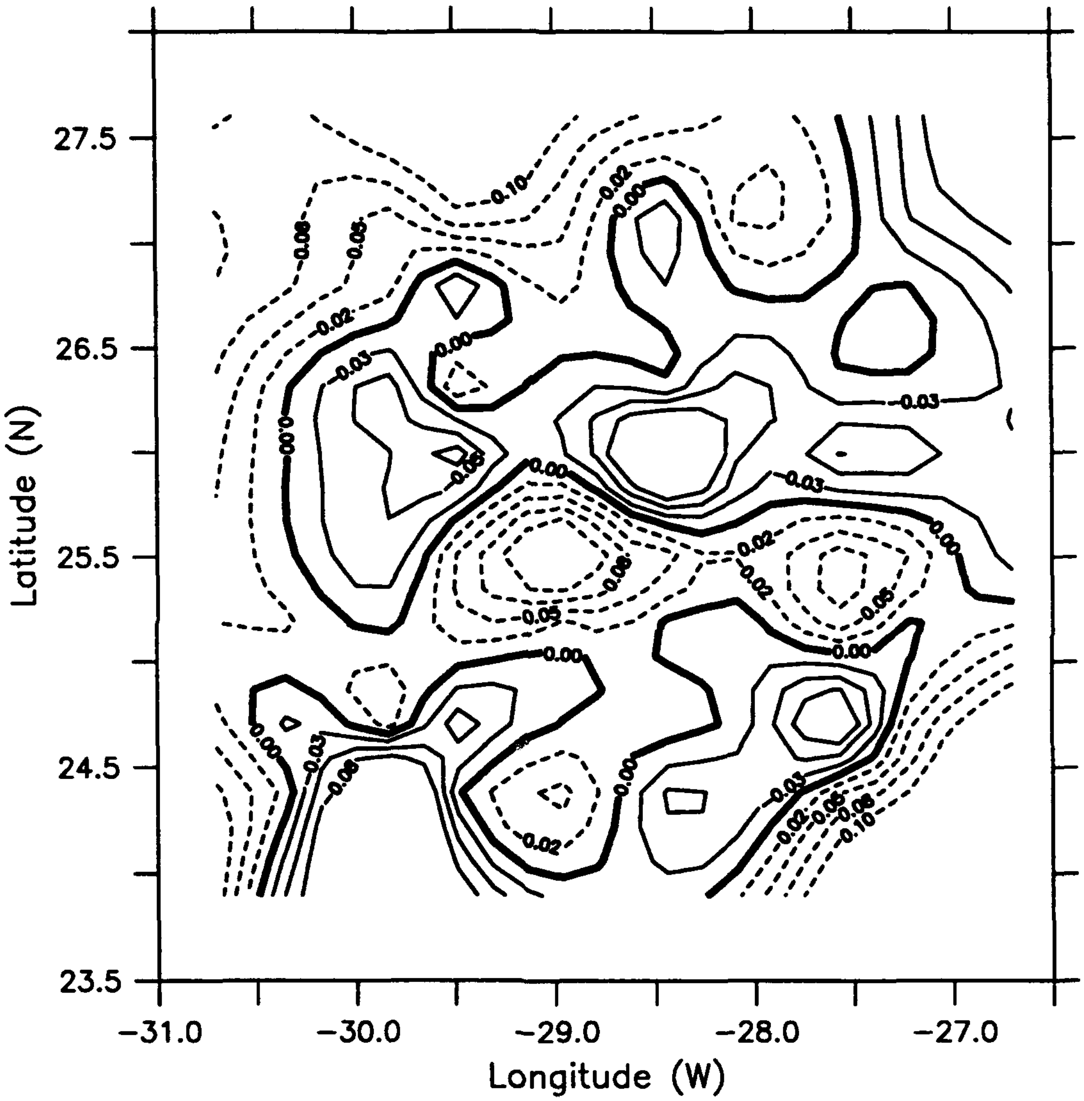

Figure 11: Contour plot showing the relative vorticity field at 300 db referenced to 1500 db for a subset of the stations in the large scale survey.

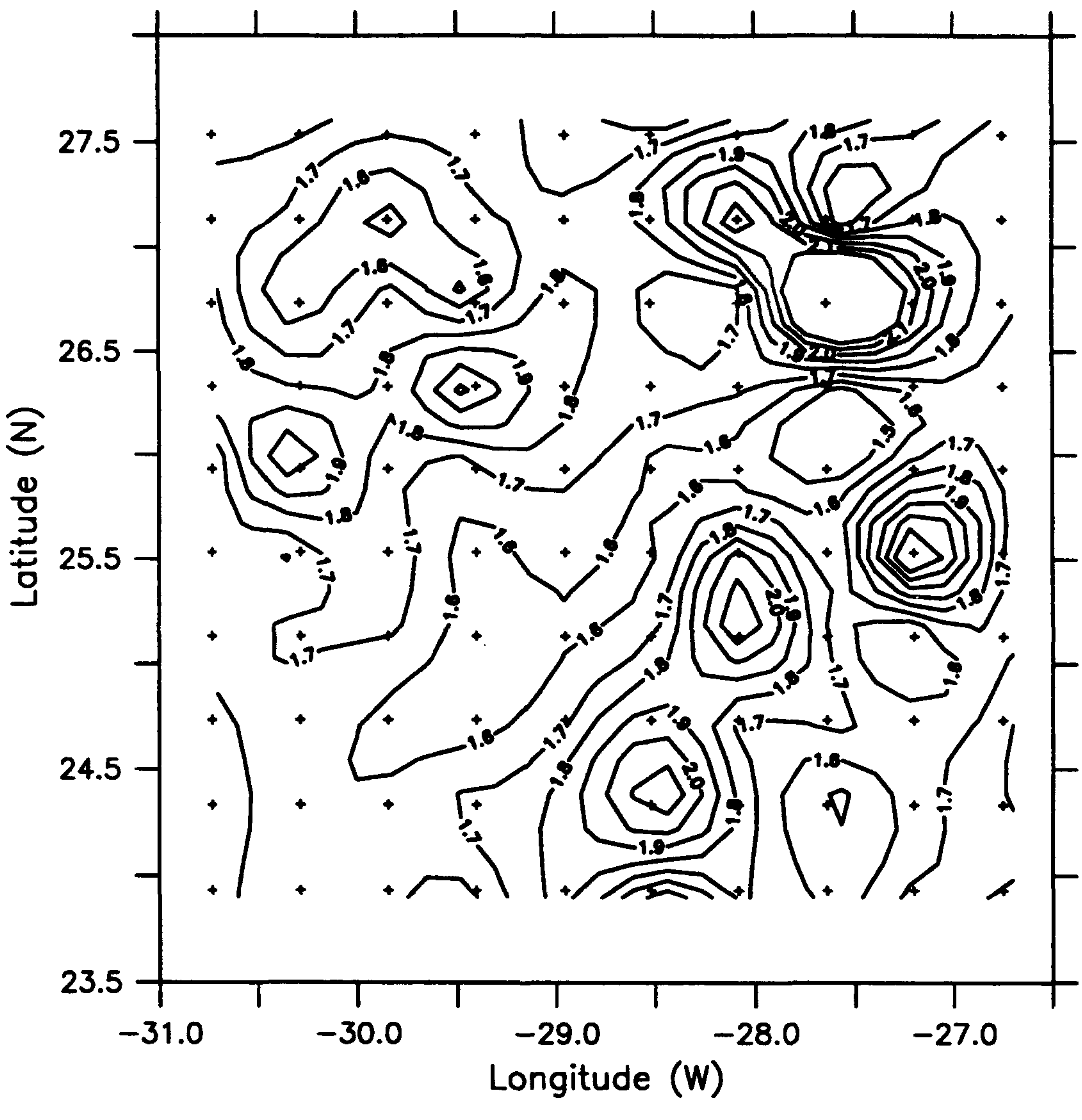

Figure 12: Contour plot showing the density ratio field at 300 db for the large scale survey.

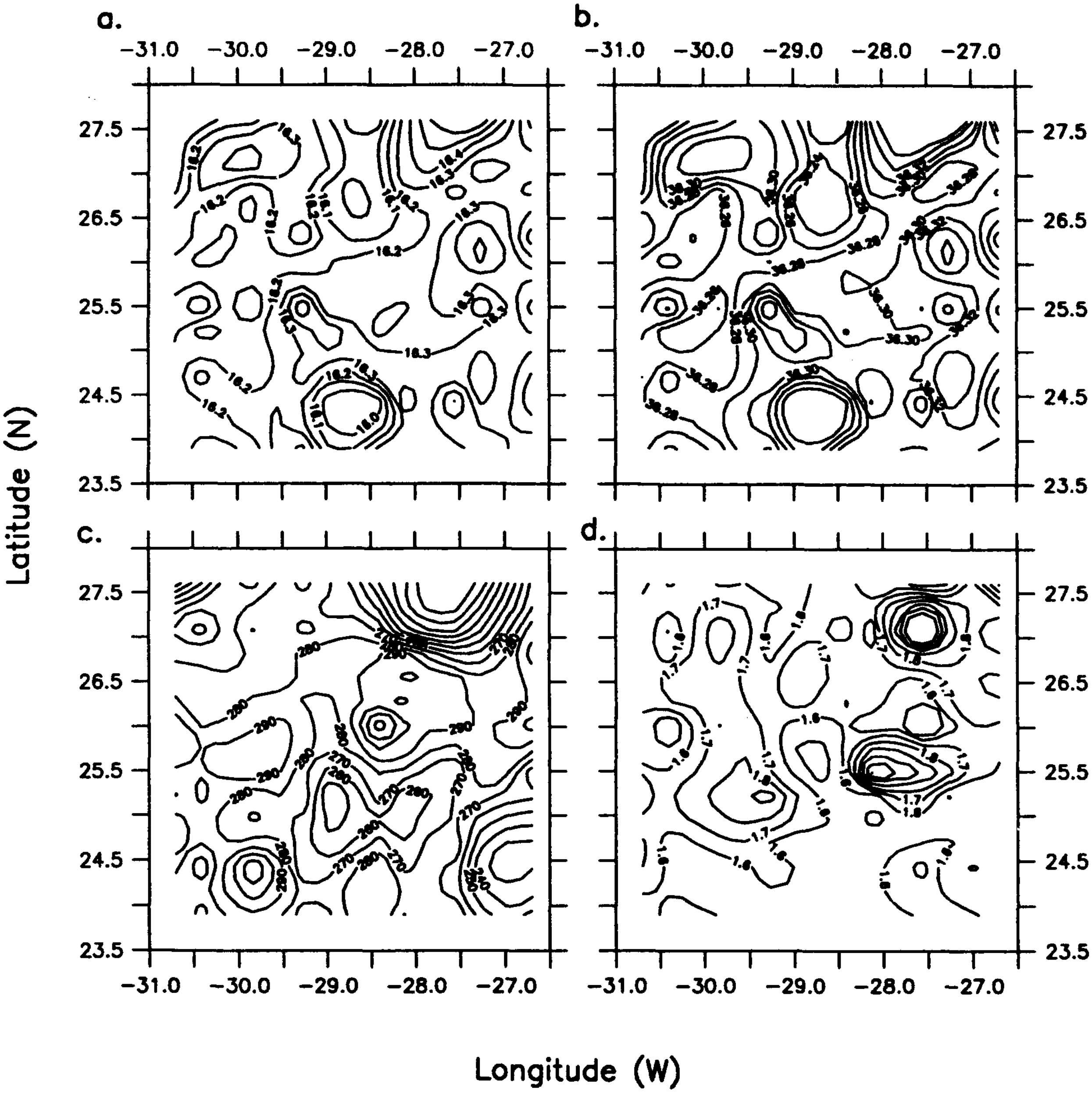

Figure 13: Contour plots of potential temperature (a), salinity (b), pressure (c), and density ratio (d) on the $\sigma_{300} = 28.00$ surface for the large scale survey.

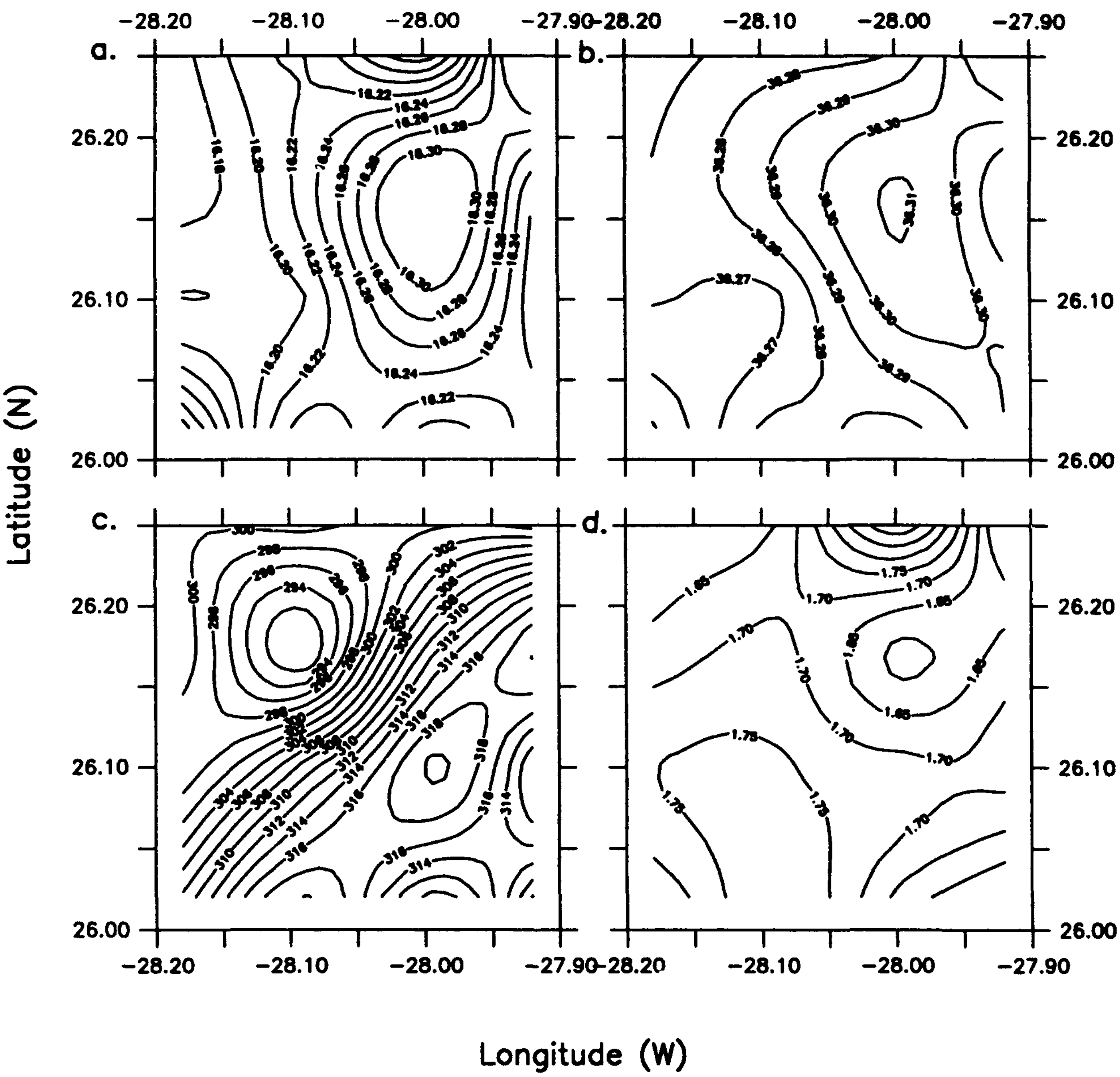

Figure 14: Contour plots of potential temperature (a) salinity (b) pressure (c) and density ratio (d) on the $\sigma_{300} = 28.00$ surface for the small scale survey

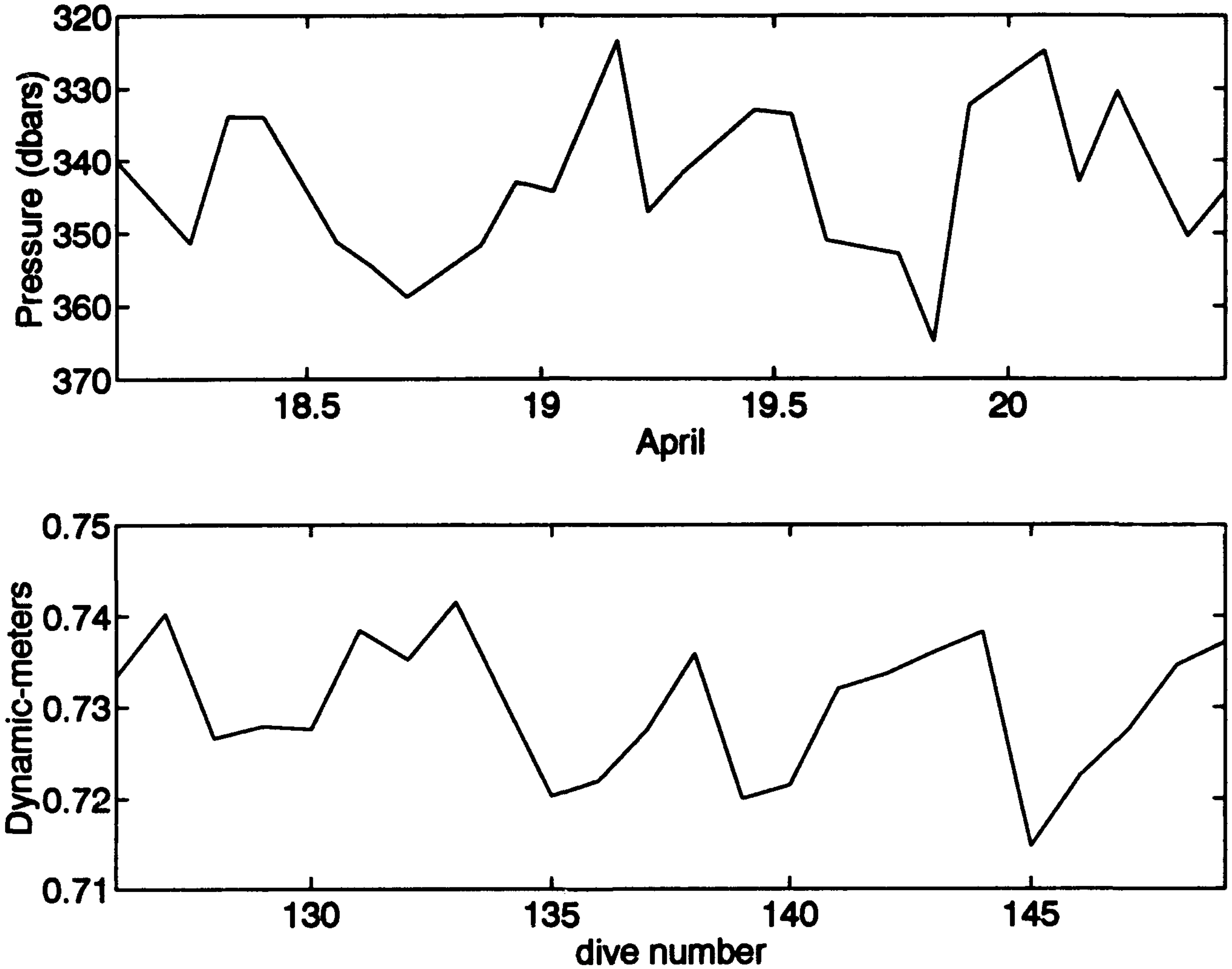

Figure 15: Plot of pressure on the sigma-theta = 26.75 surface as a function of time (a). Plot of dynamic height at 300 db referenced to 1000 db as a function of station number (b).

tence of such a large internal tide at an open ocean site with relatively flat topography is unexpected.

Also of concern for NATRE is the potential for additional complexity to the vertical and horizontal mixing due to the presence of lateral intrusions. At the depth of interest (300 m), intrusions are relatively infrequent and weak. For the density range of sigma-theta = 26.5 to 26.85, the number of temperature inversions in our 1/2 db pressure-sorted data set is displayed for the large survey in Figure 16a. There are relatively few inversions in the central part of the survey. The average thickness of the inversions is posted in Figure 16b. As they are generally a meter or less and some may represent overturns due to vertical mixing, intrusions should not be major problem for NATRE.

Finally, we offer a preliminary estimate of the vertical diffusivity. We saw no dramatic variations in internal wave energy levels during the survey, and believe that a stable estimate of diffusivity can be expected. We were able to borrow a faster computer for this cruise (a DEC workstation) which enabled us to keep up with the massive amounts of data obtained on each dive. Kurt Polzin has calculated average vertical profiles of diffusivity from the turbulent and thermal dissipations for the 100 HRP dives of the large survey. These are shown in Figures 17a and 17b. The first is derived from the standard Osborn formula, the second from the Cox number. These diffusivities were estimated with background gradients calculated from pressure averaged profiles of temperature and salinity. The turbulent diffusivity (17a) shows little variation with depth, and has a value of about 0.1 cm^2/s. The thermal diffusivity has comparable values in the upper ocean and gets larger in the intrusion region at mid-depth. The increase at depth is primarily associated with the average-based gradients being unrepresentative of the actual background against which the turbulence is straining. If salt fingers contribute to the turbulent dissipation, then the salt diffusivity may be enhanced above 0.1 by a possibly large factor (Hamilton *et al.*, 1989). However, careful analysis will be required to discriminate properly between the salt finger and turbulent contributions to the measured dissipations.

To conclude, a very successful cruise was executed utilizing a free profiler in survey mode for the first time. Much credit goes to the members of the scientific party and ships crew, who all persevered with operations through a fair bit of adverse weather. The cruise was long and tiring for all participants and we trust that the results were valuable to the execution of the tracer injection portion of NATRE.

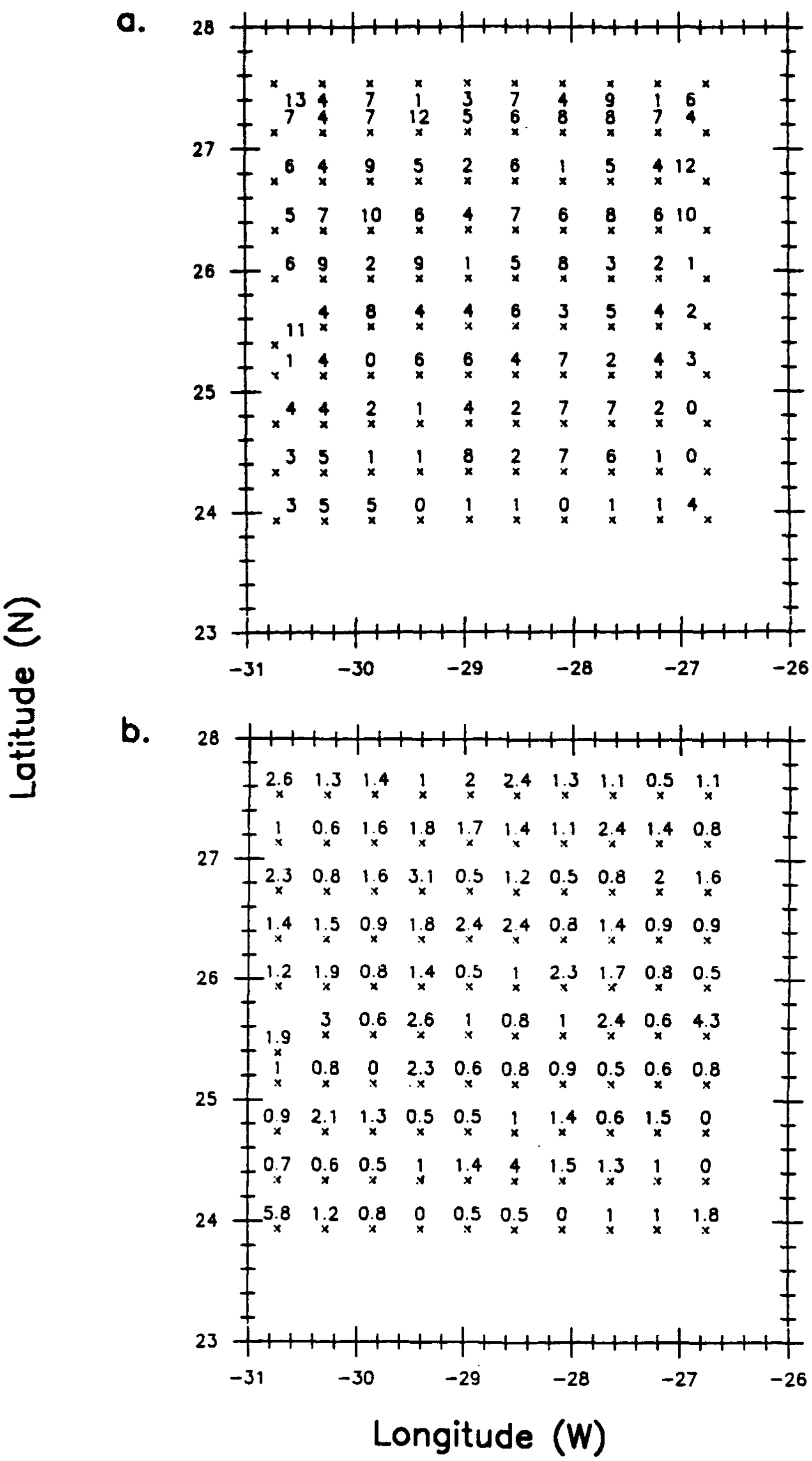

Figure 16: Contour plots showing the number of temperature inversions between 26.5 and 16.85° (a) and the average thickness of these inversions (b) for each station of the large scale survey.

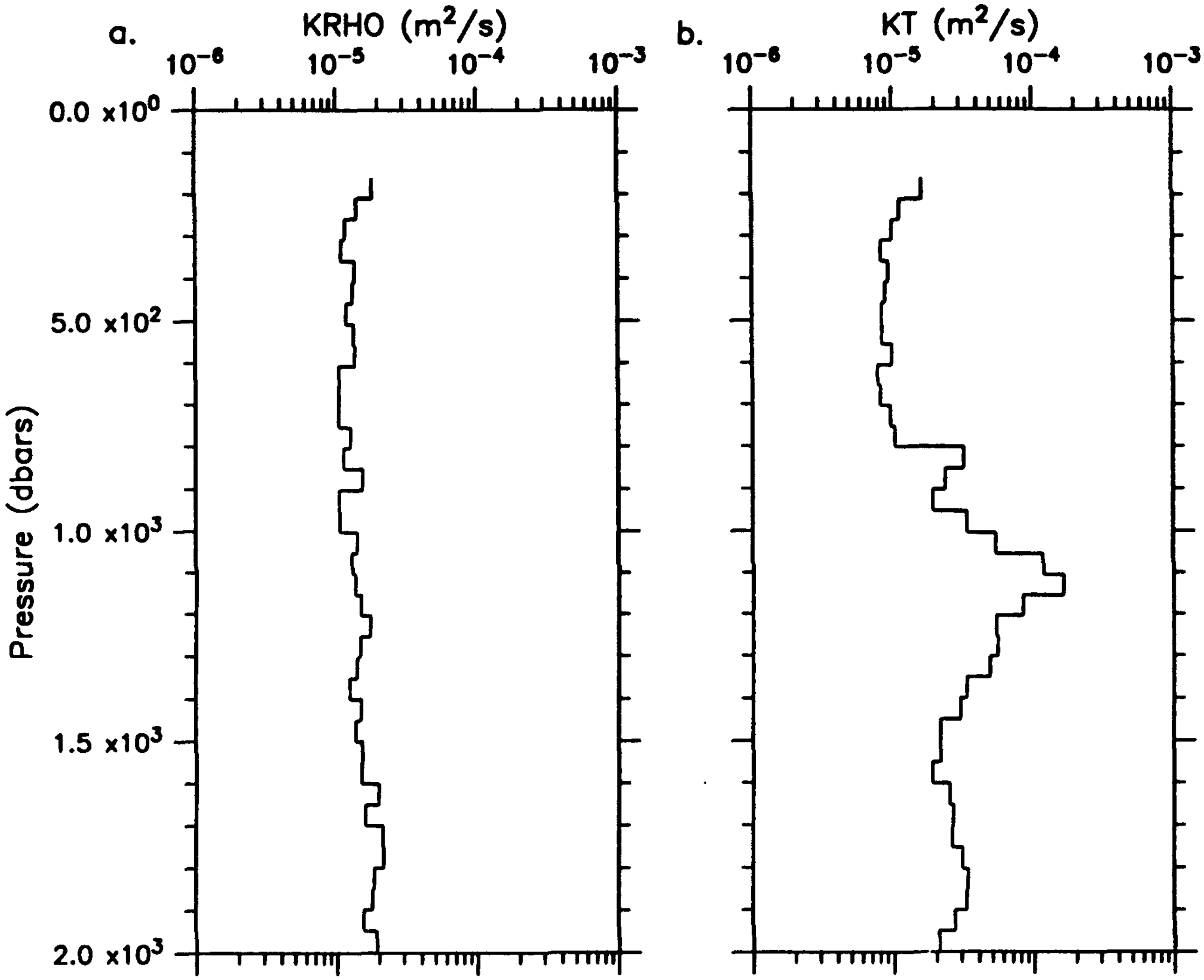

Figure 17: Plots showing the variation of energy dissipation rate (a) and thermal diffusivity (b) with pressure for the 100 stations of the large scale survey.

Acknowledgements

We would like to thank V. Green for preparing this document, and B. Gaffron for editing it. The crew and officers of the R/V *Oceanus* did their usual exemplary job in handling the ship during HRP operations. Even in adverse weather, they were able to place the ship for safe, dry and quick deployments and recoveries. We appreciate all their assistance in port and at sea. Finally, we wish to acknowledge the support of the Office of Naval Research and the National Science Foundation, who jointly sponsored this project through ONR grant number N00014-92-1323.

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16. Abstract (Limit: 200 words)

This report describes fine- and microstructure profile data taken on R/V *Oceanus* cruise 250 leg 4, between March 25 and April 24, 1992. During this cruise, an area of the Canary Basin near the Subduction Experiment's central mooring was surveyed with the High Resolution Profiler (HRP). The goals of the survey were to describe the hydrographic properties of the water adequately to recommend a location for the North Atlantic Tracer Release Experiment (NATRE) tracer injection, and to characterize the microstructure for comparison with the NATRE results.

The work performed at sea, instrumentation, data return and processing procedures will be summarized in this report.

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Canary Basin
internal tide

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

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