

RRS CHARLES DARWIN CRUISE CD78
22/4/93 - 24/5/93

THE NORTH ATLANTIC TRACER
RELEASE EXPERIMENT:
FINAL SAMPLING LEG.

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REPORT: RRS CHARLES DARWIN CRUISE 78, 22/4/93 - 24/5/93

The North Atlantic Tracer Release Experiment: final sampling leg.

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Introduction and cruise objectives

This cruise was the third and last scheduled "tracer documentation" cruise associated with the North Atlantic Tracer Release Experiment" (NATRE). The experiment is a major international exercise under the auspices of the World Ocean Circulation Experiment, "Core 3" programme, in which UK, US and Canadian scientists and ships are participating. Its object is to study the rates of both vertical and horizontal mixing in the main pycnocline of the Northeast Atlantic subtropical gyre, using a release of sulphur hexafluoride (SF_6) tracer, marked by neutrally buoyant floats, and accompanied by an extensive suite of measurements of micro- and fine-structure of the kind more conventionally used to infer rates of vertical mixing. By these means the existing techniques will be validated against a direct and accurate measurement of mixing processes associated with the tracer experiment. The experiment was initiated in April/May 1992 in a two-ship exercise in which the Woods Hole vessel R/V Oceanus released 139 Kg of tracer and the neutrally buoyant floats, while the Charles Darwin documented the distribution of the tracer in the first month after release (Cruise CD68). Subsequently, at six months after release, the Oceanus returned to the area and documented the distribution of about 25-33% of the tracer during October and November 1992, finding two lengthy streaks extending to about 600 Km in length and typically about 3 Km wide by 18 metres thick. An accurate measure of the vertical mixing rate during the April-October period was obtained by comparison of the CD 68 data with these Oceanus observations.

The task of the present cruise was to document the distribution of the tracer one year after release. In this we were assisted by the Canadian research vessel CSS Hudson, currently in the area conducting microstructure measurements as part of the overall experiment. Dr James Ledwell, the Principal Scientist on the US component of the experiments, was aboard the Hudson and made some tracer measurements in advance of our cruise, so that we had information on the location of at least some of the tracer before we left port.

Narrative

Fig 1 shows the overall cruise track, from Ponta Delgada in the Azores to Lisbon. We sailed from Ponta Delgada at 0810 on 22nd April 1993, and made course 204°T for a previously agreed rendezvous with the CSS Hudson, at 26°50' N, 31° 20' W. Hudson had to make an unscheduled journey to Las Palmas, due to a medical emergency, which set back their programme considerably. The original reason for the early rendezvous was to transfer analytical equipment to speed sample analysis. Dr James Ledwell, at this time aboard the Hudson, was scheduled to transfer to Darwin but not before about 10 May when the Hudson would leave the NATRE site.

We kept a regular radio schedule with the Hudson throughout the period that the two ships were working. We were told that they had succeeded in locating some of the neutrally buoyant SOFAR floats originally released with the tracer, i.e Float 55 at 23°50'N, 30°20'W, and float 58 at 21°20'N, 30°30'W, in what might be the SE corner of the tracer patch. One float, to which was attached a "Richardson Number" (RiNo) neutrally buoyant float, appeared at that time to be at about 30°N, 37°W, in what might demarcate a NW corner. This position later proved to be incorrect, but nevertheless the assumption that the tracer lay mostly east and south of there was verified.

We arrived at the rendezvous in the early hours of 25 April, but continued past the Hudson, having elected to postpone transfer of equipment for a time. After crossing 29°N, we began exploratory casts through the target surface, spacing these approximately 50 miles apart. No tracer was found on the first three casts, but we encountered it on the fourth, which was at the original rendezvous point.

It was soon apparent that the tracer had spread into an enormous area of ocean: the concentrations we observed averaged about 25 fM, with column integrals averaging around 2×10^{-9} moles per square metre, and given the initial amount released of approximately 1000 moles this indicates a patch ~ 700 km on a side. However the shape was not regular or simple, and the concentration varied widely even on the 10-20 Km scale. Given that we had very little information at the beginning of the cruise as to where this patch might be centred or what its shape might be, it was thought that it would not be possible to comprehensively document the entire patch. Instead we aimed to get a sufficient number of profiles, from many different areas of the patch, to be confident of a statistically valid description of properties such as the vertical thickness and streakiness. In the event however, we did end by accounting for more than 90% of the tracer.

Having approached the region on a course of 204° T we saw no reason to deviate after passing the Hudson, so continued on this heading for the better part of a week, finally running out of the patch at $21^\circ 20'$ N latitude. We then executed a series of east-west sections spaced approximately 1° apart in latitude, heading northwards, (see cruise track for the working area, fig 2). This pattern was designed to be complemented by the tracer measurements performed from the Hudson (see fig 29 for a map of Hudson stations). The pattern was broken at about the time of our RiNo hunt (see below), to make a number of tows using a high-resolution sampling system, and towards the end of the cruise when we "filled in" corners in the northwest and southeast. We finished science at 1200 on 19/5/93 and set course for Lisbon, docking there at 1700 on 24/5/93.

Sampling casts: These were to 500m: on the downcast, the depth of the target isopycnal (actually at $\sigma_{0.3} = 28.050$, though we used the previous year's calibration of the BBC microcomputer which gave $\sigma_{0.3} = 28.0395$), was noted -- it was generally between 300 and 400m depth. On the upcast, bottles were triggered at 10m intervals, starting 120m below the depth of the target surface and ending 120m above it. We found that the time taken for each cast was roughly an hour, which meant that at a spacing of 10 miles or more between casts, the limiting factor on the rate at which we could proceed was not the rate of processing samples in the laboratory, but the wire time and steam time. Stations were spaced initially at 10 mile intervals, but the "standard" spacing was increased to 15 miles after station 22 (Table 1). Stations were grouped into geographical working areas (fig 3). Tracer and salt samples only were taken from the Niskin bottles, and the work continued 24 hours a day. We found that we could progress about 130 miles per day in this mode, with the ship on station and wire out for about half the time, and steaming at 10 kts the other half of the time.

Rendezvous with CSS Hudson: On 6/5/93 we broke off sampling to rendezvous with the Hudson, chiefly for the purpose of transferring Dr Ledwell from the Hudson to the Darwin. Hudson at this time was continuing her programme of CTD and "Epsonde" microstructure casts for the overall experiment under the direction of Chief Scientist Neil Oakey of Bedford Institute of Oceanography. The rendezvous was at 1000 hr, at $24^\circ 58'N$, $31^\circ 6'W$. The Master of the Hudson invited members of the Darwin's company over for lunch which was taken up by nine scientists and ships personnel including the PSO. We extended a reciprocal invitation, which was taken up by Dr Oakey and several members of the science party aboard Hudson. Gifts were exchanged between the two ships companies. Dr Ledwell transferred, and we took the opportunity to transfer a SF_6 gas standard from the Hudson to the Darwin to cross calibrate our measurements with theirs. We were finished with the transfer and pleasantries at about 1430 and departed to continue our programme.

Hunt for the RiNo: One of the aims of Hudson was to locate and recover the Richardson Number (RiNo) float deployed by Oceanus at the time of the tracer injection. RiNo is tracked by SOFAR signal, and at close range by means of a

10kHz beacon. We determined last year during cruise CD68 that the Simrad EA500 precision echo-sounder aboard the Darwin was an efficient instrument for sensing these beacons.

The task of recovering the RiNo was greatly hampered by what appears to have been a malfunction of the clock on the SOFAR beacon, which initially led the team aboard the Hudson to believe that the float was situated well to the west at about 36°W latitude. Latterly, the best-guess for the position of the float was thought to be near 26° 15'N, 29° 30'W. We offered to assist the Hudson in the search they were to undertake for this float after leaving our rendezvous, since the Simrad was thought to have a better range for the 10kHz beacon than the equipment aboard the Hudson. We agreed to search two lines out of a grid of 5 lines, covering a region about 8 - 16 miles NW of the most likely position of the float.

The search began at 1600 on 7/5 and lasted until about 1300 the following day. The actual lines originally agreed with Hudson took only 8 hours. These are shown in fig 4. However, as we were ending this pattern we saw a trace on the Simrad, lasting about 20 minutes, which looked characteristic of a beacon behind the ship. The trace was very faint, appearing and then disappearing without obvious cause. We therefore retraced and re-retraced our course, running over the section on which the signal had appeared a total of four times, but without seeing it again. We then began a box-search pattern (fig 5) centred on the location where we considered the source most likely to be, and continued this for 8 hours further, without at any time again seeing the signal. We remain unsure about the source of this signal, but we know of no phenomenon other than a regularly repeating beacon which could give rise to such a trace. Therefore we believe that we must have heard the float we were searching for, but perhaps due to freak acoustic conditions, at a distance very much greater than the normal range of the apparatus.

Sled tows using high-resolution carousel sampler: Casts 220 through 223 were tows in which the CTD was mounted on a sled with sequentially-filling syringe samplers. 50 samples were collected on each tow, but the distance covered varied from 8 to 65 Km (Table 2). The package was lowered on the CTD wire from the starboard A frame, and "flown" on the target surface by automated control of the winch, using the control system developed by R. Powell of RVS for cruise CD68. The longest tow entailed steaming at approximately 2 kts, at which speed the wire angle was considerable, (60-70° from the vertical). The tracks towed along are shown in fig 6 and the along-track concentrations are shown in fig 7: they reveal a pattern of "plates" of relatively constant concentrations of dimension ~ 10Km, separated by rather sharp boundaries.

CTD Data

Calibration: Hydrographic data were gathered with an EG&G Mark 3 CTD, equipped with a PRT thermometers and a single conductivity probe. A laboratory temperature calibration performed just prior to the cruise indicated that the primary PRT was within 0.0005°C of the bath standard. No adjustment was made for a temperature offset.

Salinity samples taken on each cast showed the salinity reading from the system to be low by 0.028 to 0.029 PSU throughout the cruise. The constants in the acquisition system had already been set to compensate for a raw salinity that was low by 0.018 PSU. Thus, another 0.011 PSU were added to the salinity calculated using these constants.

The pressure sensor read high by 4.7 dbar at the surface, and this amount was subtracted from all pressures throughout the cruise.

A sample profile and a θ/S plot are shown in figs 8 and 10, respectively.

Data Reduction: The descent for each cast was selected from the CTD data stream, and made into a separate file named "cd780xxx.dat", where "xxx"

represents the number of the cast, from 001 to 241. These raw data were then interpolated to a 1 dbar pressure grid and stored in files called "cd780xxxpi.dat". At the same time the potential temperature $\theta_{,3}$, and potential density $\sigma_{,3}$, both referenced to 300 dbar, were added to the files, in the 4th and 5th columns, respectively. A sixth column reports the number of scans skipped during the original file because the pressure was decreasing. Seldom was this number different from 0, since the weather was light, and the payout rate of the CTD wire was typically 60 m/min.

The target $\sigma_{,3}$ for the tracer release was 28.05 kg/m³. Hydrographic properties at this surface were estimated from the CTD data for each cast (Table 3), and vertical gradients in the properties were estimated for casts that went more than 50 m below the target surface, as follows.

First, the nearest pressure to the target density surface was found, and a window spanning ± 50 dbar about this pressure was selected. A quadratic fit of $\theta_{,3}$ versus $\sigma_{,3}$ in this window was performed, and the value of $\theta_{,3}$ at the target surface was determined from the resulting polynomial. This procedure reduces the uncertainty in finding the target surface created by noise in salinity which propagates to potential density. The salinity at the target density was then found from the potential temperature, using the equation of state. Also, an accurate pressure at the target surface was found by interpolation.

Gradients of in situ temperature, dT/dP , and salinity, dS/dP , at the target surface were then determined by making quadratic fits of $T(P)$ and $S(P)$ in the ± 50 dbar window about the target surface. The coefficient of thermal expansion, α , the change of density with salinity, β , and the adiabatic lapse rate, Γ , were determined at the target surface. Then, a density gradient, $d\sigma/dp$, the density ratio, R_p , and the buoyancy frequency, N , were calculated from the following equations:

$$\rho_0 = 1000 + \sigma_0 \quad \rho = 1000 + \sigma_3$$

$$d\sigma/dP = \rho_0 [\alpha \{-dT/dP + \Gamma\} + \beta dS/dP]$$

$$R_p = \alpha \{-dT/dP + \Gamma\} / \{-\beta dS/dP\}$$

$$N = \text{sqrt}\{g (d\sigma/dP)/\rho\}$$

The values for P , $\theta_{,3}$, S , $-dT/dP$, $-dS/dP$, $d\sigma/dP$, R_p , and N at the target density surface are given for each cast in Table 4.

The CTD casts were sorted into the same groups as the tracer data (Table 5). The data from each group were averaged, and the average data were treated the same way as above to give the properties and gradients for each group (Table 4).

The last entry in Table 4 gives the properties and gradients calculated from the average of the deep CTD profiles that went at least 50 dbar deeper than the target surface for the whole cruise. This average CTD profile is tabulated every 10 dbar in Table 3, and is plotted in fig 9. A typical θ/S relation is plotted in fig 10 and the mean θ/S relation is plotted in fig 11.

SF₆ Data

SF₆ Analysis

Water samples were analysed using two identical systems (A and B), each of which consisted of a vacuum-sparge front end in which the SF₆ was stripped from the water and trapped on Porapak Q at -70°C, followed by chromatographic separation and detection by an Electron Capture Detector (Shimadzu GC8-AIE). Both systems were fully automated requiring minimal input from the operator, and so reducing any errors arising from sample handling and manual valve-switching. Water from the Niskin bottles was sub-sampled into 500ml glass bottles which were flushed three times, and then transferred to the laboratory where they were stored underwater. The SF₆ concentration at the target density was obtained within 10 minutes of the CTD landing on deck, allowing alterations in the cruise track to be made relatively rapidly. A volume of 350ml was required for analysis of profile samples, although GC-B was adjusted to facilitate analysis of 50 ml samples obtained from the carousel sampler for a period of 4 days towards the end of the cruise. A typical profile cast consisted of 25 samples, which at a rate of 6.75 minutes per sample resulted in a cast analysis time of 90 minutes; in total, 5000 water samples and 500 standards were run by a pool of 10 analysts.

The sensitivity of GC-A and B were 0.05 and 0.03 fmol /l, respectively, although the background concentration was higher than these values. Samples from each profile were artificially divided, with the "tails" of the profile analysed on the more sensitive GC, and the middle of the profile on the less sensitive system. Duplicate samples from the target density were run on both instruments at the start of each cast analysis to determine an average reproducibility of 3.6% between the two instruments. This reproducibility is a reflection of the difference in calibration between the two instruments as opposed to variability in the efficiency of the analysis. The reproducibility within both GC's was 0.6% (A) and 0.88% (B) for duplicate samples (including background samples).

Calibration of each system took approximately 75 minutes every 36-48 hours, requiring certain casts to be run entirely on one system while the other was calibrated. The response of both instruments remained relatively constant (Table 6), except for the initial recovery of GC-A in the first 3 days from a previous contamination event on a recent cruise. Despite continuous analysis for 30 days, both instruments performed extremely well with virtually no down-time and minimal sample back-up. A valve driver board had to be replaced at the start of the cruise when a motor burnt out during start up on GC-A, and occasional maintenance was required to clean up salt crystal deposit in valves and solenoids on both systems. The gland in the 29.4 ppt standard cylinder failed, although the calibration fitting programme was able to compensate for the absence of standards in this range.

SF₆ Data reduction.

The SF₆ data were calibrated using a linear fit for samples less than 1.3×10^{-14} moles (300 ppt in 1 ml gas standard), smoothly joined to a cubic fit for higher values: previous work at PML has shown this to be the best polynomial type of fit to cover the range 0 to 5×10^{-13} moles. Calibrated data, identified by Niskin bottle number, were merged on the RVS computer with CTD data from the last frame before the bottle was closed. For each cast, a file was made tabulating pressure, temperature, salinity, $\sigma_{0.3}$ and SF₆ for each bottle. These files constitute a basic data output from the cruise.

For further analysis, the SF₆ profiles were interpolated onto a regular density grid (27.8 to 28.2 x 0.01) and averaged by regional group (fig 3) to give statistics on mean concentration, depth and RMS width. To obtain meaningful widths in depth (actually pressure) space, correctly referenced to the target surface, the mean pressure versus density profile of the initial sampling cruise CD68 was used to map SF₆ from density space into pressure. Individual profiles versus $\sigma_{0.3}$, these mean profiles versus "CD68" depth, and the statistics of mean depth and RMS width relative to the centre of mass are plotted in figs 12-24. The interpolation could profitably have been continued to 28.3 as data from the lower tail were sometimes missed out of the interpolation.

The entire cruise average of casts interpolated from 27.8 to 28.3 is plotted, in fig 26. The centre of mass is at 28.058, 0.008 units lower than the original injection, and the RMS width relative to the centre of mass is 31.14 m in "CD68" depth space. The width indicates a vertical mixing rate, K_z in the range 0.17 to 0.2 cm² s⁻¹ since the October-November period when the tracer was last sampled. This is significantly larger than the value of 0.11 cm² s⁻¹ for the first 6 months of the experiment, presumably due to larger forcing energy during the winter months. The actual value of K_z will be defined to better accuracy after post-cruise analysis. The average profile is almost a perfect gaussian (see fig 27).

The lateral dispersion of the tracer, expressed as column integral in nmol m⁻², is shown in fig 30 after gridding and contouring the data, using a 0.75 degree radius of integration. The tracer was spread over about 5-6 degrees of latitude and 9-10 degrees of longitude -- an area in excess of 150 000 square miles. Though still highly variable in space, there were few points within this region that had no tracer at all -- in other words, the tracer streaks had combined to "paint in" this area. Integrating under the contours gives a total amount of 937 moles, which is less than 2% different from the 950 moles which were released. An alternative way of integrating the tracer, by obtaining an average concentration along the cruise track and multiplying by the overall area covered, gave essentially the same value. However, the margin of error is undoubtedly larger than these figures suggest. Provisionally we estimate that we accounted for 99±10%.

TABLE I: STATION LIST:

Notes:

- 1) "Full" casts were 24 bottle casts with approx 10m spacing centred on the target surface.
- 2) "Short" casts: one or two bottles were fired at the target surface only.
- 3) "Background" casts (2-4) were used as representative background measurements, the average of which was subtracted from the remainder in all calculations.
- 4) "Sled" casts, (218 - 223) were tows along the target surface of the WHOI sled with carousel samplers.
- 5) The SF₆ column integral, background subtracted, is in nanomoles per square metre. "est" indicates it was estimated from the concentration at the target surface.
- 6) Casts 38-65 are numbered differently in the original cast sheets: original numbering is in brackets under "cast type".

Cast	Date	Time GMT	Latitude	Longitude	Cast type	SF6 Column Integral
1	22/04/93	19:23	35 55.76N	26 38.05W	background	0.00
2	24/04/93	13:36	29 0.32N	30 14.82W	background	0.00
3	24/04/93	19:14	28 17.12N	30 36.97W	background	0.00
4	25/04/93	0:44	27 33.24N	30 58.01W	background	0.00
5	25/04/93	6:26	26 49.86N	31 20.12W	full	2.69
6	25/04/93	9:27	26 32.01N	31 27.75W	full	3.92
7	25/04/93	11:49	26 22.21N	31 32.92W	full	2.04
8	25/04/93	14:00	26 13.14N	31 37.98W	full	1.28
9	25/04/93	16:00	26 4.20N	31 42.89W	full	0.86
10	25/04/93	18:16	25 54.99N	31 47.06W	full	1.72
11	25/04/93	20:42	25 45.90N	31 51.47W	full	2.01
12	25/04/93	23:00	25 35.82N	31 56.38W	full	2.75
13	26/04/93	1:02	25 26.93N	32 0.83W	full	1.19
14	26/04/93	3:07	25 18.23N	32 4.88W	full	1.50
15	26/04/93	5:31	25 8.85N	32 9.92W	full	0.52
16	26/04/93	8:02	24 59.63N	32 14.25W	full	2.59
17	26/04/93	10:48	24 50.34N	32 18.02W	full	6.03
18	26/04/93	13:04	24 41.23N	32 22.68W	full	4.42
19	26/04/93	15:25	24 32.11N	32 27.71W	full	6.23
20	26/04/93	17:39	24 23.11N	32 32.14W	full	2.86
21	26/04/93	19:52	24 13.65N	32 36.36W	full	0.59
22	26/04/93	22:22	24 4.95N	32 40.88W	full	0.87
23	27/04/93	1:03	23 50.89N	32 47.14W	full	1.06
24	27/04/93	3:41	23 37.28N	32 53.94W	full	0.39
25	27/04/93	6:24	23 23.11N	32 59.93W	full	2.74
26	27/04/93	9:08	23 9.27N	33 6.79W	full	3.12
27	27/04/93	11:55	22 55.06N	33 13.27W	full	0.76
28	27/04/93	14:32	22 41.09N	33 19.71W	full	1.22
29	27/04/93	17:05	22 28.21N	33 25.99W	full	1.89
30	27/04/93	19:50	22 14.43N	33 32.51W	full	2.76
31	27/04/93	22:30	22 0.48N	33 39.01W	full	0.82
32	28/04/93	1:08	21 46.66N	33 45.25W	full	0.40
33	28/04/93	4:15	21 32.12N	33 51.87W	full	0.05
34	28/04/93	6:53	21 19.02N	33 58.91W	short	0.00

Cast	Date	Time GMT	Latitude	Longitude	Cast type	SF6 Column Integral
35	28/04/93	10:43	21 19.29N	33 26.90W	short	0.00
36	28/04/93	14:09	21 18.94N	32 54.44W	short	0.00
37	28/04/93	17:40	21 19.02N	32 22.36W	short	?
38	28/04/93	18:18	21 19.47N	32 22.33W	full (37i)	0.39
39	28/04/93	22:04	21 18.96N	31 50.27W	short (38)	?
40	28/04/93	22:42	21 19.15N	31 50.21W	full (38i)	0.31
41	29/04/93	1:48	21 42.17N	31 49.96W	full (39)	0.42
42	29/04/93	5:04	22 6.08N	31 50.24W	full (40)	0.08
43	29/04/93	8:23	22 29.97N	31 50.41W	full (41)	0.49
44	29/04/93	10:46	22 29.94N	32 4.29W	full (42)	0.45
45	29/04/93	13:17	22 30.19N	32 20.10W	full (43)	0.82
46	29/04/93	15:53	22 29.95N	32 36.18W	full (44)	0.87
47	29/04/93	18:30	22 29.98N	32 52.04W	full (45)	0.36
48	29/04/93	21:24	22 30.00N	33 7.87W	full (46)	0.91
49	30/04/93	1:17	22 30.15N	33 40.17W	full (47)	1.58
50	30/04/93	4:17	22 29.55N	33 55.96W	full (48)	0.92
51	30/04/93	7:07	22 29.61N	34 11.94W	full (49)	0.32
52	30/04/93	9:47	22 29.77N	34 28.17W	full (50)	0.20
53	30/04/93	12:18	22 29.94N	34 43.96W	full (51)	0.26
54	30/04/93	14:36	22 29.53N	34 59.84W	full (52)	0.16
55	30/04/93	17:00	22 29.87N	35 16.20W	full (53)	0.00
56	30/04/93	19:50	22 44.97N	35 16.10W	full (54)	0.12
57	30/04/93	22:26	22 59.98N	35 16.04W	full (55)	0.02
58	1/5/93	1:01	23 15.37N	35 16.06W	full (56)	0.00
59	1/5/93	3:24	23 30.32N	35 16.25W	full (57)	0.84
60	1/5/93	6:02	23 29.87N	34 59.76W	full (58)	0.09
61	1/5/93	8:35	23 30.05N	34 44.04W	full (59)	0.00
62	1/5/93	12:37	23 30.23N	34 12.37W	full (60)	0.08
63	1/5/93	15:00	23 30.11N	33 55.54W	short (61)	0.00
64	1/5/93	16:58	23 30.12N	33 39.35W	short (62)	0.00
65	1/5/93	17:29	23 30.46N	33 39.37W	full (63)	0.45
100	1/5/93	19:49	23 30.13N	33 23.00W	full	0.02
101	1/5/93	22:21	23 29.87N	33 7.04W	full	2.75
102	2/5/93	0:57	23 30.15N	32 50.57W	full	0.46
103	2/5/93	3:16	23 37.53N	32 58.18W	full	3.58
104	2/5/93	5:27	23 45.03N	32 58.64W	full	1.35
105	2/5/93	7:29	23 44.93N	33 6.78W	full	2.77
106	2/5/93	9:56	23 37.29N	33 15.21W	full	0.79
107	2/5/93	11:42	23 37.57N	33 6.84W	full	3.34
108	2/5/93	15:09	23 37.60N	32 39.58W	full	0.65
109	2/5/93	18:07	23 30.14N	32 24.00W	full	3.15
110	2/5/93	20:48	23 29.98N	32 8.16W	full	2.53
111	3/5/93	1:32	23 30.48N	31 51.76W	full	2.35
112	3/5/93	4:38	23 30.15N	31 35.33W	full	0.93
113	3/5/93	7:15	23 29.91N	31 19.21W	full	3.67
114	3/5/93	9:51	23 30.13N	31 3.01W	full	1.27
115	3/5/93	12:25	23 30.28N	30 46.78W	full	1.33
116	3/5/93	16:37	23 30.02N	30 30.26W	full	4.14
117	3/5/93	19:21	23 30.13N	30 14.22W	full	1.05
118	3/5/93	22:12	23 29.90N	29 58.16W	full	3.39

Cast	Date	Time GMT	Latitude	Longitude	Cast type	SF6 Column Integral
119	4/5/93	0:47	23 30.31N	29 41.69W	full	0.48
120	4/5/93	3:46	23 30.26N	29 25.19W	full	0.18
121	4/5/93	6:32	23 29.94N	29 8.74W	full	0.23
122	4/5/93	9:08	23 30.13N	28 52.45W	full	0.00
123	4/5/93	11:53	23 30.22N	28 36.17W	full	0.14
124	4/5/93	14:28	23 30.18N	28 19.51W	full	0.45
125	4/5/93	16:59	23 30.15N	28 3.37W	full	0.28
126	4/5/93	19:36	23 45.04N	27 59.84W	full	0.35
127	4/5/93	22:28	23 59.94N	27 59.82W	full	0.27
128	5/5/93	2:52	24 29.94N	27 59.99W	full	0.32
129	5/5/93	6:03	24 29.92N	28 16.51W	full	0.41
130	5/5/93	8:31	24 30.23N	28 32.88W	full	1.85
131	5/5/93	10:40	24 30.12N	28 43.86W	full	3.30
132	5/5/93	12:50	24 30.12N	28 54.91W	full	3.55
133	5/5/93	15:22	24 30.35N	29 11.29W	full	1.79
134	5/5/93	18:16	24 30.02N	29 27.76W	full	2.02
135	5/5/93	20:44	24 29.89N	29 44.46W	full	8.70
136	5/5/93	23:10	24 29.87N	30 0.42W	full	0.49
137	6/5/93	1:37	24 29.82N	30 17.06W	full	4.34
138	6/5/93	4:05	24 30.18N	30 33.54W	full	3.87
139	6/5/93	6:15	24 29.87N	30 50.15W	full	2.01
140	6/5/93	16:19	24 44.97N	31 6.41W	full	1.22
141	6/5/93	18:47	24 30.04N	31 6.60W	full	3.59
142	6/5/93	21:44	24 45.02N	30 50.01W	full	1.28
143	7/5/93	0:14	24 58.27N	30 43.64W	full	1.00
144	7/5/93	2:40	25 12.62N	30 36.85W	full	0.72
145	7/5/93	4:54	25 26.47N	30 29.98W	full	0.39
146	7/5/93	7:12	25 39.96N	30 23.01W	full	3.46
147	7/5/93	9:30	25 53.79N	30 16.13W	full	0.09
148	7/5/93	11:52	26 7.81N	30 9.63W	full	0.00
149	7/5/93	14:11	26 7.89N	29 53.16W	full	0.18
150	7/5/93	17:44	26 21.70N	29 35.85W	short	
151	8/5/93	9:54	26 22.09N	29 35.00W	full	0.16
152	8/5/93	12:52	26 22.45N	29 52.44W	full	0.05
153	8/5/93	15:12	26 22.27N	30 9.20W	full	0.00
154	8/5/93	17:37	26 22.20N	30 26.05W	full	0.04
155	8/5/93	20:15	26 22.08N	30 46.86W	full	0.12
156	8/5/93	22:37	26 8.94N	30 53.88W	full	0.00
157	9/5/93	0:53	25 54.57N	31 0.29W	full	0.01
158	9/5/93	3:12	25 41.18N	31 7.24W	full	0.00
159	9/5/93	5:27	25 27.04N	31 14.19W	full	1.22
160	9/5/93	7:35	25 13.08N	31 20.52W	full	3.44
161	9/5/93	10:14	24 59.22N	31 27.05W	full	2.08
162	9/5/93	12:26	24 45.92N	31 34.06W	full	5.14
163	9/5/93	18:09	24 29.95N	31 41.57W	full	4.51
164	9/5/93	20:39	24 29.94N	31 57.76W	full	2.91
165	9/5/93	23:06	24 30.19N	32 14.39W	full	1.55
166	10/5/93	1:26	24 30.02N	32 30.90W	full	0.60
167	10/5/93	3:45	24 29.86N	32 47.17W	full	4.57
168	10/5/93	5:50	24 29.91N	32 58.05W	full	4.48

Cast	Date	Time GMT	Latitude	Longitude	Cast type	SF6 Column Integral	
169	10/5/93	7:48	24 29.88N	33 9.10W	full	4.57	
170	10/5/93	9:44	24 30.10N	33 19.79W	full	5.58	
171	10/5/93	11:40	24 30.07N	33 30.76W	full	5.02	
172	10/5/93	13:41	24 30.07N	33 41.89W	full	5.01	
173	10/5/93	15:37	24 30.22N	33 52.90W	full	5.13	
174	10/5/93	17:40	24 30.26N	34 4.20W	full	3.99	
175	10/5/93	19:32	24 30.18N	34 15.10W	full	5.86	
176	10/5/93	21:35	24 29.95N	34 26.12W	full	4.27	
177	10/5/93	23:23	24 29.97N	34 37.15W	full	5.80	
178	11/5/93	1:13	24 30.07N	34 47.81W	full	3.18	
179	11/5/93	3:04	24 30.22N	34 58.95W	full	0.81	
180	11/5/93	5:33	24 30.13N	35 15.35W	full	0.08	
181	11/5/93	7:51	24 30.15N	35 31.96W	full	0.82	
182	11/5/93	10:12	24 29.70N	35 48.40W	full	3.02	
183	11/5/93	12:25	24 29.81N	36 4.34W	full	0.65	
184	11/5/93	14:51	24 29.66N	36 20.84W	full	1.23	
185	11/5/93	17:01	24 29.79N	36 37.34W	full	0.79	
186	11/5/93	19:14	24 29.93N	36 53.64W	full	0.03	est.
187	11/5/93	21:29	24 29.84N	37 10.30W	full	0.15	
188	11/5/93	23:55	24 44.42N	37 10.58W	full	0.08	est.
189	12/5/93	2:41	24 59.21N	36 54.85W	full	0.21	
190	12/5/93	5:10	25 14.43N	36 53.99W	full	0.11	
191	12/5/93	8:15	25 29.73N	36 38.03W	full	0.34	
192	12/5/93	10:40	25 44.79N	36 37.70W	full	0.28	
193	12/5/93	13:33	25 59.73N	36 37.64W	full	1.93	
194	12/5/93	16:06	26 15.06N	36 37.91W	full	1.98	
195	12/5/93	18:33	26 29.69N	36 37.57W	full	1.35	
196	12/5/93	21:05	26 44.87N	36 37.67W	full	0.01	
197	12/5/93	23:33	27 0.01N	36 37.79W	full	0.00	
198	13/05/93	2:44	27 15.18N	36 20.85W	full	0.05	
199	13/05/93	5:46	27 29.86N	36 4.58W	full	5.34	
200	13/05/93	8:24	27 40.58N	35 51.54W	full	0.84	
201	13/05/93	10:59	27 40.90N	35 34.65W	full	1.27	
202	13/05/93	13:09	27 40.90N	35 17.97W	full	0.57	
203	13/05/93	15:28	27 40.87N	35 0.17W	full	0.64	
204	13/05/93	17:49	27 40.65N	34 42.33W	full	0.35	
205	13/05/93	20:10	27 25.86N	34 37.53W	full	1.70	
206	13/05/93	22:18	27 12.58N	34 33.90W	full	0.82	
207	14/05/93	0:23	27 0.10N	34 30.00W	full	1.59	
208	14/05/93	2:42	26 45.05N	34 29.84W	full	0.81	
209	14/05/93	4:56	26 30.18N	34 30.03W	full	0.61	
210	14/05/93	7:06	26 29.82N	34 46.78W	full	0.47	
211	14/05/93	9:16	26 30.18N	35 3.49W	full	1.42	
212	14/05/93	11:31	26 30.25N	35 20.35W	full	0.36	
213	14/05/93	13:45	26 30.00N	35 35.99W	full	1.72	
214	14/05/93	17:12	26 0.16N	35 36.96W	full	3.57	
215	14/05/93	19:28	25 45.11N	35 36.88W	full	5.07	
216	14/05/93	21:46	25 30.09N	35 36.97W	full	2.13	
217	15/05/93	1:22	25 7.46N	35 15.12W	full	1.29	
218	15/05/93	8:00	24 15.07N	34 24.98W	sled (test)		

Cast	Date	Time GMT	Latitude	Longitude	Cast type	SF6 Column Integral	
219	15/05/93	9:15	24 14.62N	34 24.78W	sled (aborted)		
220	15/05/93	10:50	24 15.89N	34 24.65W	sled tow		
221	15/05/93	16:00	24 19.73N	34 24.6W	sled tow		
222	16/05/93	2:51	24 53:49N	34 22.51W	sled tow		
223	16/05/93	21:10	23 37.08N	32 39.92W	sled tow		
224	17/05/93	22:28	22 31.87N	31 16.76W	full	1.38	
225	18/05/93	0:44	22 27.30N	31 2.35W	full	0.84	
226	18/05/93	3:00	22 21.79N	30 46.99W	full	1.07	
227	18/05/93	5:13	22 16.28N	30 31.72W	full	0.81	
228	18/05/93	7:21	22 1.42N	30 31.76W	full	0.88	
229	18/05/93	9:37	21 46.39N	30 31.61W	full	1.12	
230	18/05/93	11:49	21 31.90N	30 31.26W	full	0.37	
231	18/05/93	13:54	21 20.62N	30 31.87W	full	0.00	
232	18/05/93	16:08	21 31.29N	30 21.39W	full	0.00	
233	18/05/93	18:15	21 41.67N	30 9.95W	full	0.00	
234	18/05/93	20:39	21 52.09N	29 58.33W	full	0.00	
235	18/05/93	22:49	22 1.94N	29 46.81W	short	0.00	
236	19/05/93	0:46	22 12.61N	29 36.14W	short	0.00	
237	19/05/93	2:41	22 23.16N	29 24.42W	short	0.00	
238	19/05/93	4:40	22 34.12N	29 12.82W	short	0.05	est.
239	19/05/93	6:35	22 44.04N	29 1.53W	short	0.07	est.
240	19/05/93	9:03	22 58.36N	28 45.93W	short	0.63	est.
241	19/05/93	11:35	23 12.60N	28 30.50W	short	0.62	est.

TABLE II: Sled tow data

Cast	Day, Time Start	Position		Day, Time End	Position	
		Lat	Long		Lat	Long
220	5/15, 11:13	24° 15.8N	34° 25.2W	5/15, 14:23	24° 20.2N	34° 24.6W
221	5/15, 16:33	24° 20.4N	34° 24.1W	5/16, 00:33	24° 37.2N	34° 22.9W
222	5/16, 03:08	24° 53.3N	34° 22.1W	5/16, 11:08	24° 32.2N	34° 23.8W
223	5/16, 21:30	23° 36.7N	32° 39.9W	5/17, 11:16	23° 07.1N	32° 57.5W

TABLE III: Cruise-mean CTD profile, interpolated to 10m intervals.

P	T	S	Θ_3	σ_3
dbar	°C	PSU	°C	
10.00	22.238	37.382	22.297	27.239
20.00	22.182	37.384	22.239	27.257
30.00	22.138	37.387	22.192	27.274
40.00	22.082	37.391	22.134	27.293
50.00	22.013	37.391	22.063	27.313
60.00	21.901	37.382	21.949	27.339
70.00	21.753	37.365	21.799	27.369
80.00	21.590	37.346	21.634	27.401
90.00	21.442	37.326	21.484	27.429
100.00	21.327	37.313	21.366	27.452
110.00	21.209	37.295	21.246	27.472
120.00	21.050	37.263	21.086	27.493
130.00	20.867	37.225	20.900	27.515
140.00	20.651	37.177	20.681	27.540
150.00	20.345	37.106	20.373	27.570
160.00	19.994	37.028	20.020	27.606
170.00	19.580	36.933	19.604	27.645
180.00	19.144	36.838	19.166	27.689
190.00	18.718	36.745	18.738	27.731
200.00	18.377	36.675	18.395	27.766
210.00	18.085	36.617	18.101	27.797
220.00	17.825	36.567	17.839	27.825
230.00	17.578	36.520	17.590	27.852
240.00	17.339	36.476	17.349	27.878
250.00	17.112	36.434	17.120	27.902
260.00	16.892	36.394	16.899	27.925
270.00	16.671	36.352	16.676	27.947
280.00	16.462	36.314	16.465	27.969
290.00	16.255	36.276	16.257	27.989
300.00	16.048	36.238	16.048	28.010
310.00	15.854	36.203	15.853	28.029
320.00	15.668	36.171	15.665	28.048
330.00	15.471	36.136	15.466	28.067
340.00	15.284	36.104	15.278	28.086
350.00	15.094	36.072	15.086	28.105
360.00	14.908	36.041	14.899	28.123
370.00	14.721	36.010	14.710	28.142
380.00	14.535	35.980	14.522	28.160
390.00	14.357	35.952	14.343	28.179
400.00	14.181	35.925	14.166	28.196
410.00	14.017	35.901	14.000	28.213
420.00	13.853	35.876	13.835	28.230
430.00	13.693	35.852	13.674	28.246
440.00	13.536	35.829	13.515	28.262
450.00	13.377	35.806	13.355	28.278
460.00	13.218	35.783	13.196	28.295
470.00	13.062	35.762	13.038	28.311
480.00	12.913	35.742	12.888	28.326

TABLE IV Hydrographic properties at the target surface

Group	Count	P dbar	θ $^{\circ}\text{C}$	S PSU	$-\text{dT}/\text{dp}$ 10^{-3} $^{\circ}\text{C}/\text{dbar}$	$-\text{dS}/\text{dp}$ ppm/ dbar	$\text{d}\sigma/\text{dp}$ 10^{-3} dbar $^{-1}$	$R\rho$	N 10^{-3} s^{-1}
A	7	339.3	15.592	36.151	17.1	2.88	1.79	1.81	4.15
B	18	312.6	15.624	36.161	22.0	3.96	2.10	1.69	4.49
C	15	327.1	15.594	36.151	20.5	3.64	2.00	1.72	4.39
D	17	332.3	15.657	36.170	20.4	3.56	2.04	1.75	4.43
E	8	292.5	15.676	36.176	19.5	3.49	1.90	1.71	4.27
F	9	298.5	15.724	36.191	20.4	3.67	1.97	1.70	4.35
G	6	304.4	15.665	36.173	18.7	3.21	1.92	1.78	4.30
H	11	294.2	15.761	36.202	17.6	3.12	1.75	1.73	4.10
I	18	322.2	15.662	36.172	18.9	3.29	1.91	1.76	4.28
J	15	319.4	15.657	36.170	20.0	3.50	2.00	1.74	4.38
K	9	325.6	15.607	36.155	18.4	3.17	1.87	1.77	4.24
L	8	343.7	15.589	36.150	17.6	3.00	1.84	1.80	4.20
M	19	348.6	15.632	36.163	18.2	3.12	1.88	1.79	4.25
N	7	293.6	15.631	36.163	22.7	4.05	2.18	1.70	4.58
All	166	321.2	15.640	36.165	19.4	3.40	1.93	1.74	4.31

TABLE V: Regional Groups of Stations.

Group	Casts
A	5-10
B	27-33, 38, 41-49
C	50-62, 65, 100
D	21-26, 101-111
E	112-119
F	120-128
G	129-134
H	147-149, 151-158
I	12-20, 159-167
J	168-182
K	183-191
L	191-198
M	199-217
N	224-230

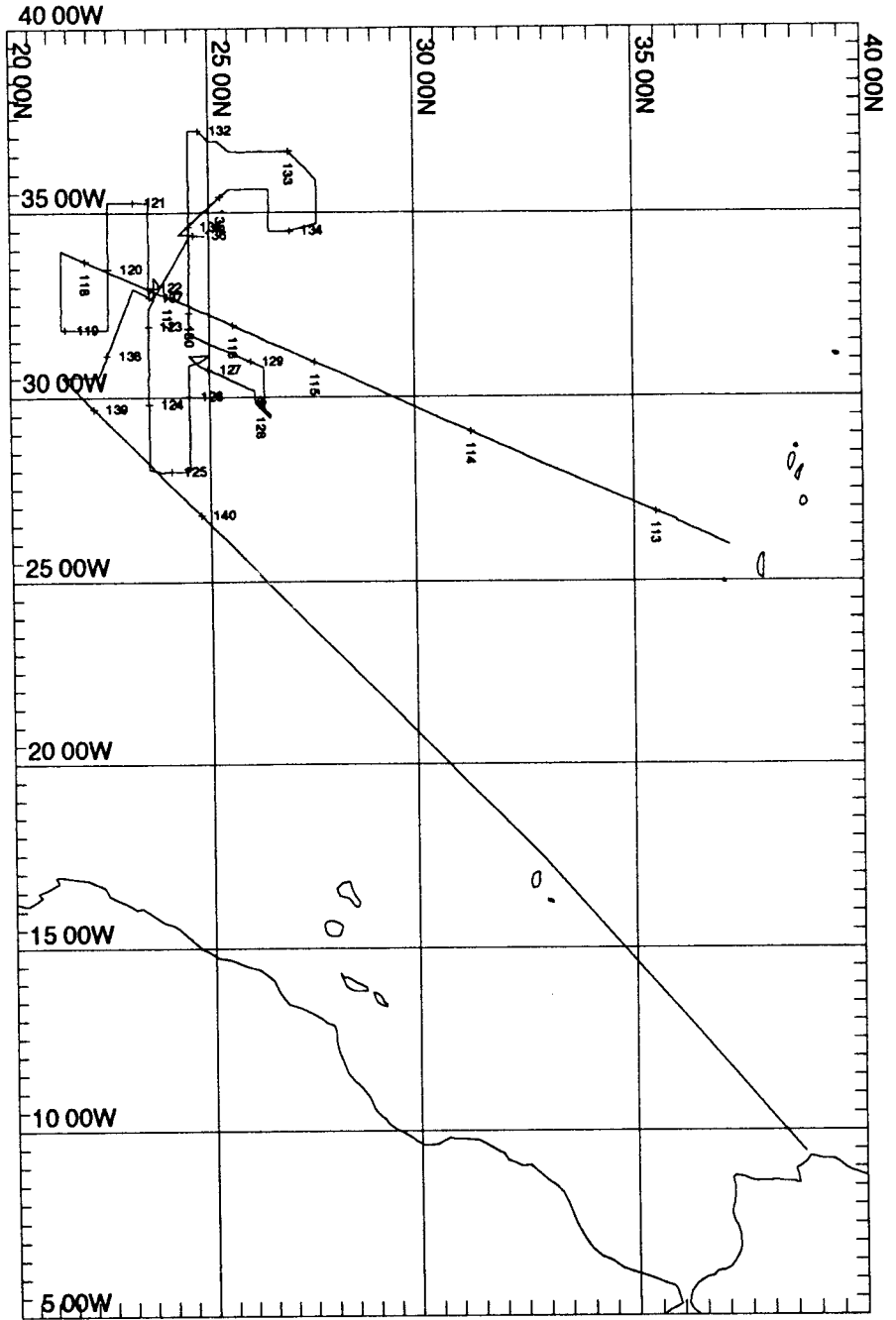
TABLE VI: GC calibration

File	Date	Time	Std Loop	Stds	Fit *	A	B	C	Max Error
GC A									
2SA	24/4	1015	1	1.6-1.1	L/C	-0.000	0.047	340.5	111.28
24SA	27/4	0400	1	1.6-1.2	L/C	0.00004	0.011	358.7	205.29
34SA	28/4	0940	1	1.6-1.2	L/C	0.00004	0.0088	361.8	96.72
47SA	30/4	0000	1	1.6-1.2	L/C	0.00003	0.0159	361.2	406.29
57SA	1/5	0400	1	1.6-1.2	L/C	0.00003	0.0165	372.1	417.46
111SA	3/5	0100	1	1.6-1.2	L/C	0.00003	0.0104	365.34	136.2
128SA	5/5	0400	1	1.6-1.2	L/C	0.00007	0.0103	348.3	345.37
140SA	6/5	1030	1	1.6-1.2	L/C	-0.000002	0.0517	358.67	466.5
140SAS	6/5	1300	1/3	1.4-1.1	C	0.000001	0.00009	121.41	186.6
151SA	7/5	2000	1/3	1.4-1.1	L/C	0.000003	-0.0091	126.88	216.45
					C	0.000003	-0.0083	129.07	
157SA	9/5	0100	1	1.6-1.2	C	0.000021	0.0065	352.45	313.88
163SA	9/5	1600	1	1.6-1.1	L/C	-0.000006	0.0733	363.87	446.69
180SA	11/5	0630	1	1.6-1.1	L/C	-0.000002	0.0541	372.40	1823.3
189SA	12/5	0250	1	1.6-1.1	L/C	0.0000003	0.0382	383.5	114.13
208SA	14/5	0300	1	1.6-1.2	L/C	0.00006	0.0137	376.47	281.97
224SA	16/5	2110	1	1.6-1.2	L/C	-0.000004	0.0635	380.79	255.04
228SA	18/5	1300	1	1.6-1.2	L/C	0.000063	0.0535	368.93	291.64
GC B									
3SB	24/4	1700	1	1.6-1.1	L/C	-0.0000	0.187	704.17	1337.9
19SB	26/4	1820	1	1.6-1.2	L/C	0.00018	0.0113	712.22	980.0
39SB	29/4	0200	1	1.6-1.2	L/C	0.002	0.0125	710.33	1066.4
59SB	1/5	0800	1	1.6-1.2	L/C	0.00015	0.0232	707.73	377.08
111SB	3/5	0000	1	1.6-1.2	L/C	0.00022	0.0026	695.4	1673.0
128SB	5/5	0125	1	1.6-1.2	L/C	0.00024	-0.0010	691.19	1960
140SB **	6/5	1000	1	1.4-1.1	C	-0.00003	0.1562	643.62	1717.7
140SBS	6/5	1300	1/3	1.4-1.1	C	0.000002	0.0050	222.48	176.54
150SBS	7/5	2100	1/3	1.4-1.1	C	0.000002	0.0047	234.83	244.38
163SB	9/5	1600	1	1.6-1.2	L/C	0.00181	0.093	699.95	673.62
179SB	11/5	0300	1	1.6-1.1	L/C	0.000034	0.159	703.04	742.65
199SB	13/5	0600	1	1.6-1.2	L/C	-0.000045	0.190	702.44	402.65
220SB	15/5	1255	1	1.6-1.2	L/C	0.00055	0.0089	701.11	874.16
223SB	17/5	0830	1	1.6-1.2	L/C	0.000249	0.0113	699.42	1527.56
230SB	18/5	0815	1	1.6-1.2	L/C	-0.00006	0.2403	688.63	1724.73

* L/C - linear cubic

C - cubic

** Calibrated across cubic range only



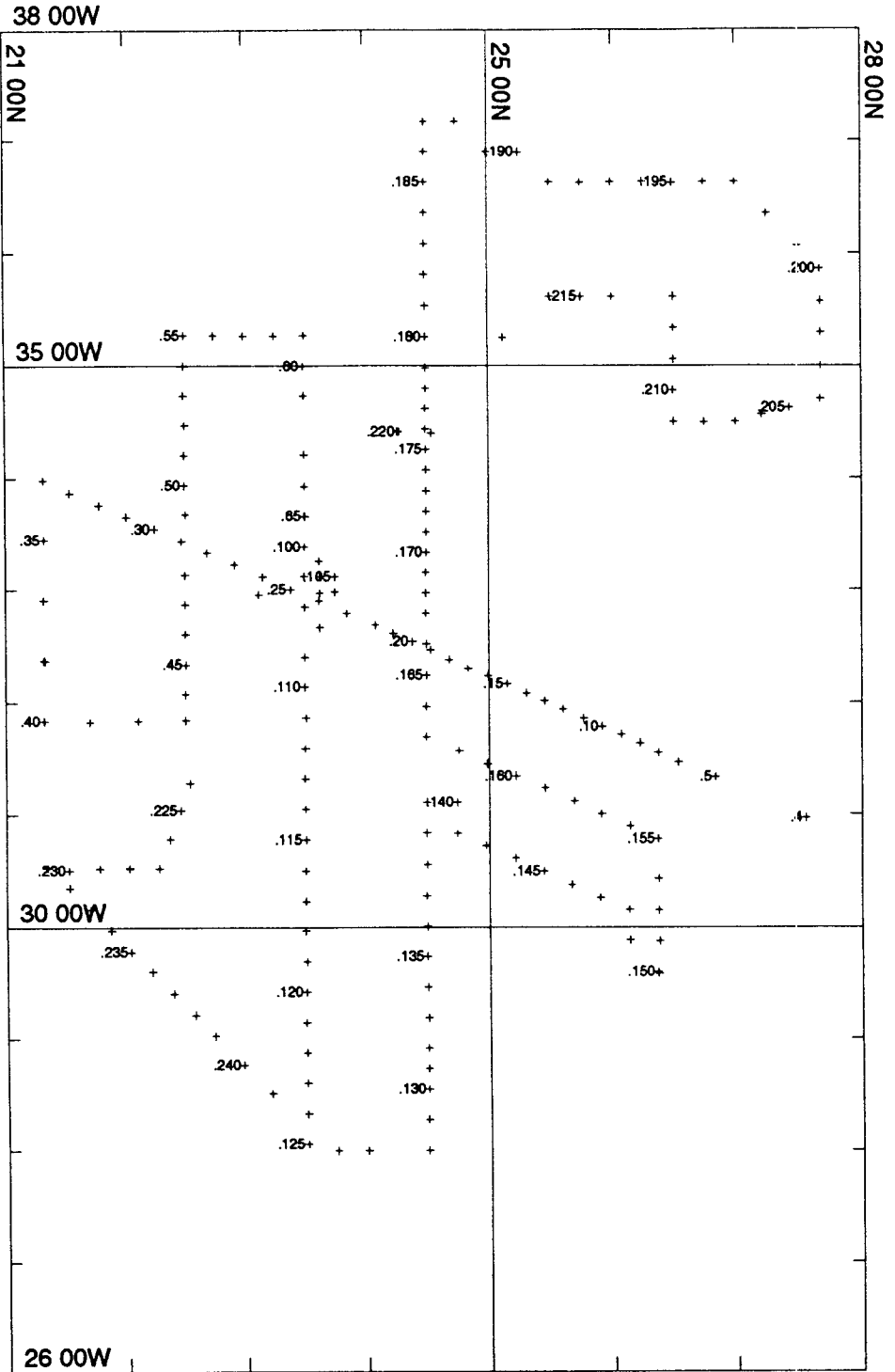
MERCATOR PROJECTION

SCALE 1 TO 15000000 (NATURAL SCALE AT LAT. 33)
INTERNATIONAL SPHEROID PROJECTED AT LATITUDE 0

GRID NO. 1

— Track plotted from bathymetry

RRS Charles Darwin 78 Cruise Track



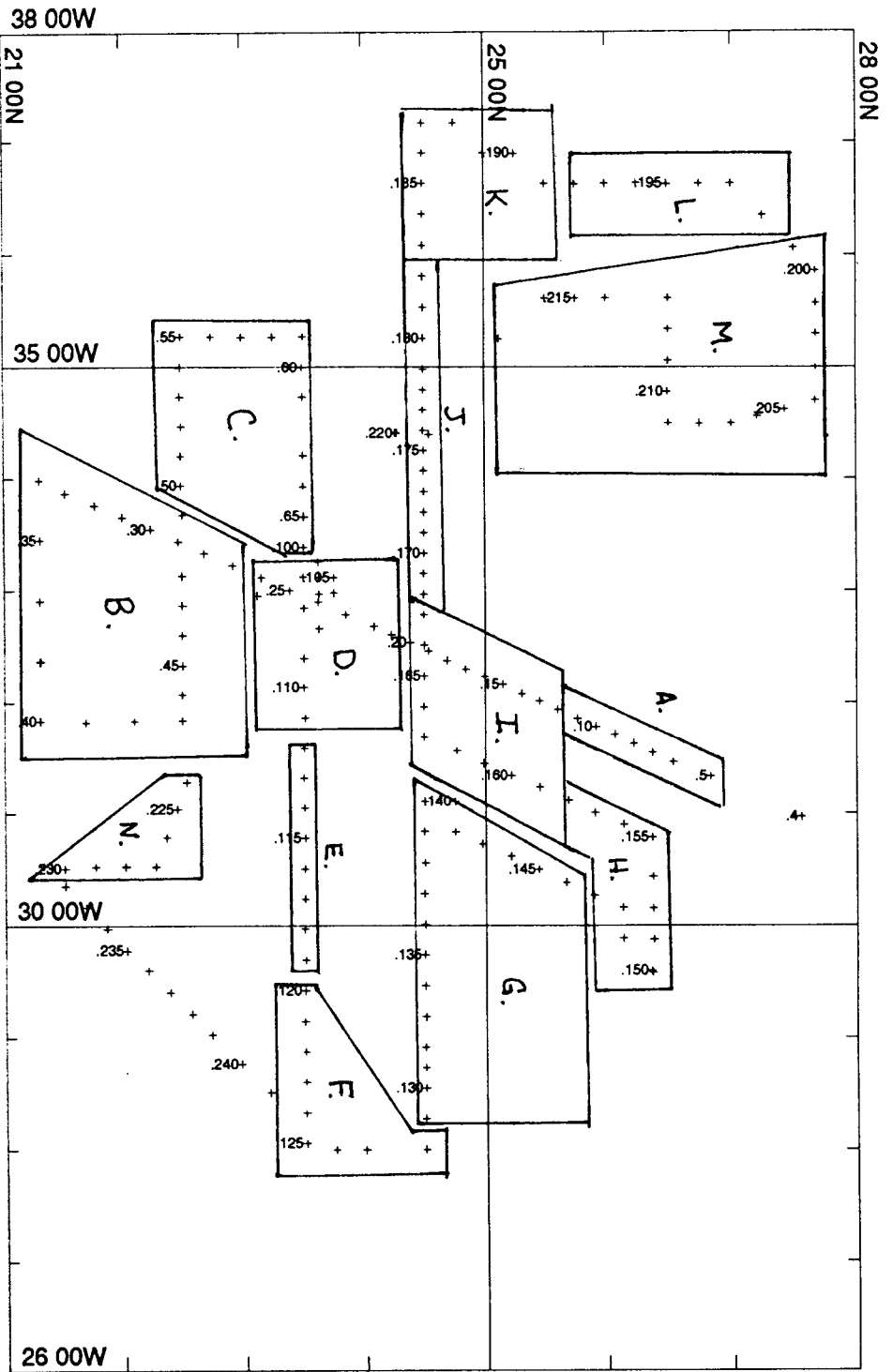
MERCATOR PROJECTION

SCALE 1 TO 5000000 (NATURAL SCALE AT LAT. 39)

INTERNATIONAL SPHEROID PROJECTED AT LATITUDE 0

GRID NO. 1

RRS Charles Darwin 78 CTD Stations in Work Area



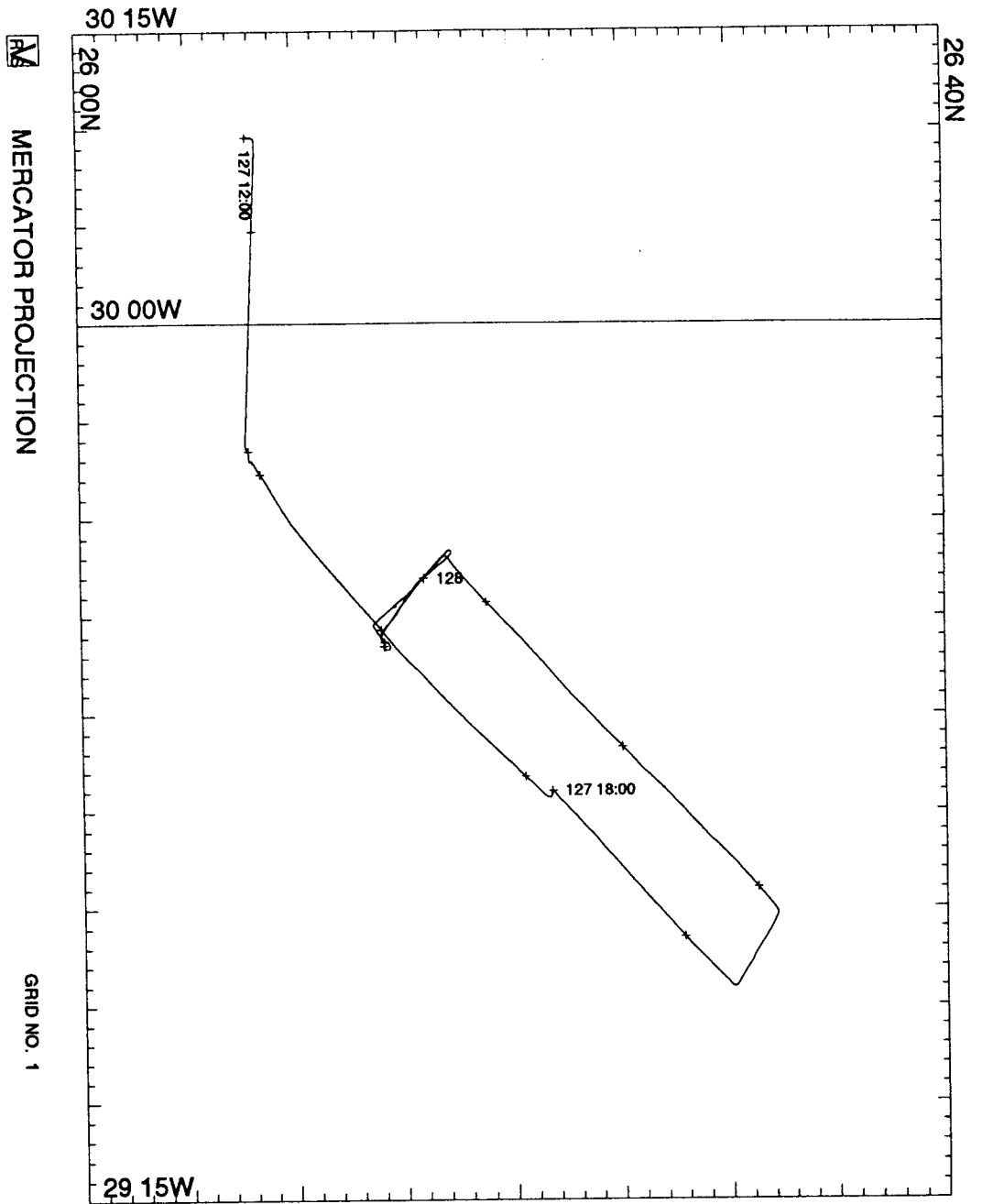
MERCATOR PROJECTION

SCALE 1 TO 5000000 (NATURAL SCALE AT LAT. 33)

INTERNATIONAL SPHEROID PROJECTED AT LATITUDE 0

GRID NO. 1

RRS Charles Darwin 78 CTD Stations in Work Area



MERCATOR PROJECTION

SCALE 1 TO 500000 (NATURAL SCALE AT LAT. 33)

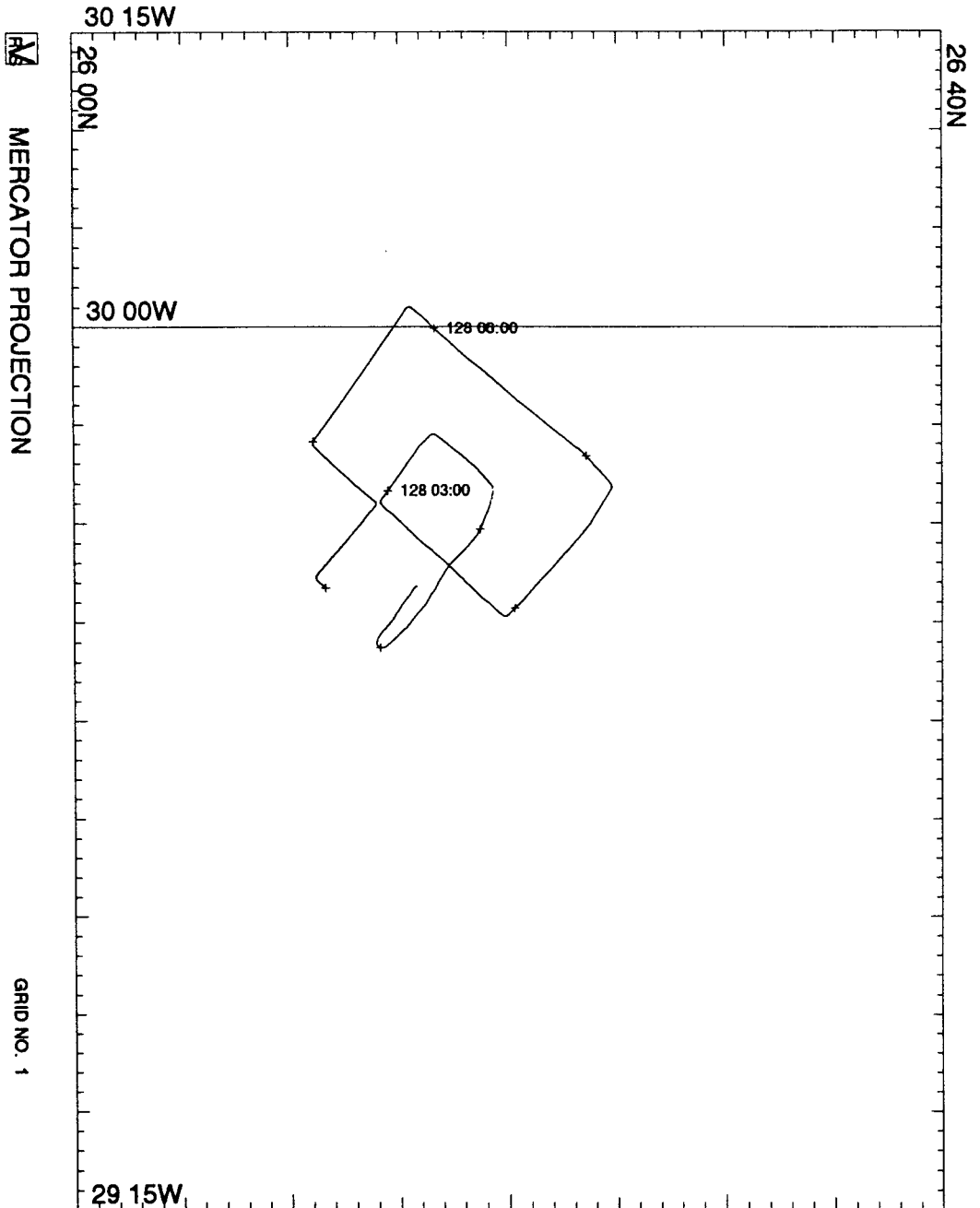
INTERNATIONAL SPHEROID PROJECTED AT LATITUDE 0

GRID NO. 1

— Track plotted from bearings

RRS Charles Darwin 78 Search Area 1

+



MERCATOR PROJECTION

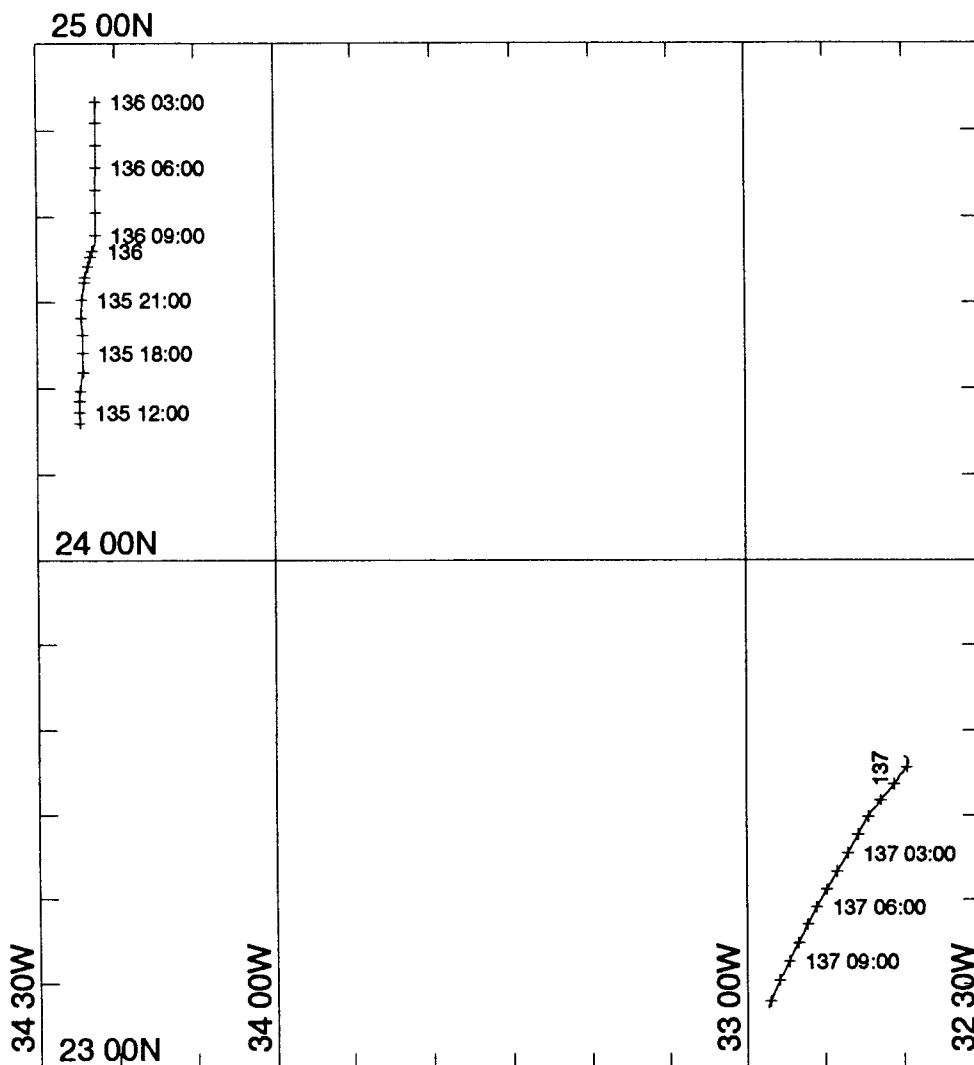
GRID NO. 1

— Track plotted from bearing

SCALE 1 TO 500000 (NATURAL SCALE AT LAT. 33)
INTERNATIONAL SPHEROID PROJECTED AT LATITUDE 0

RRS Charles Darwin 78 Search Area 1

+



MERCATOR PROJECTION

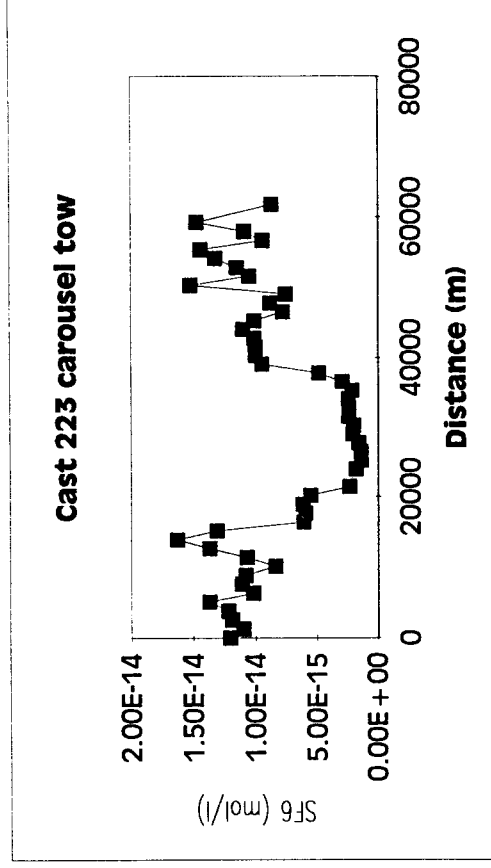
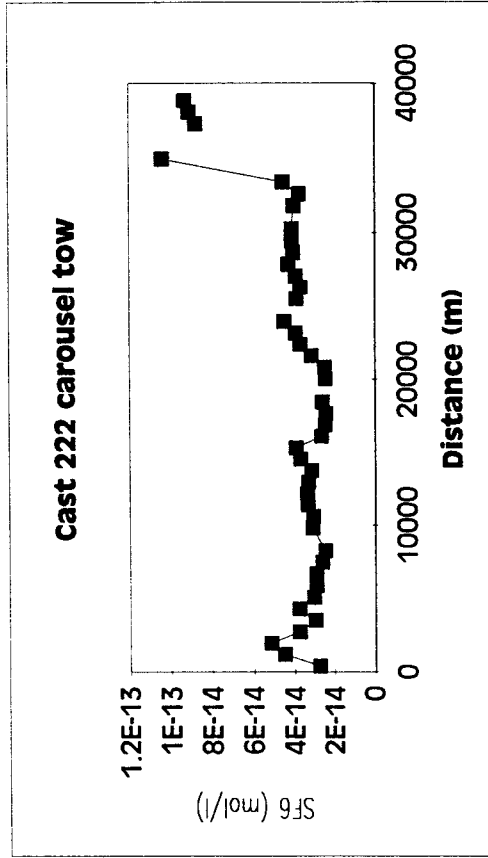
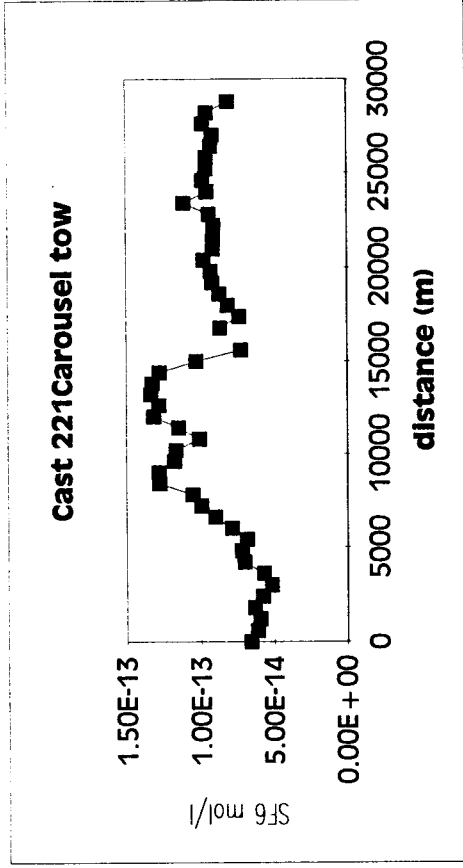
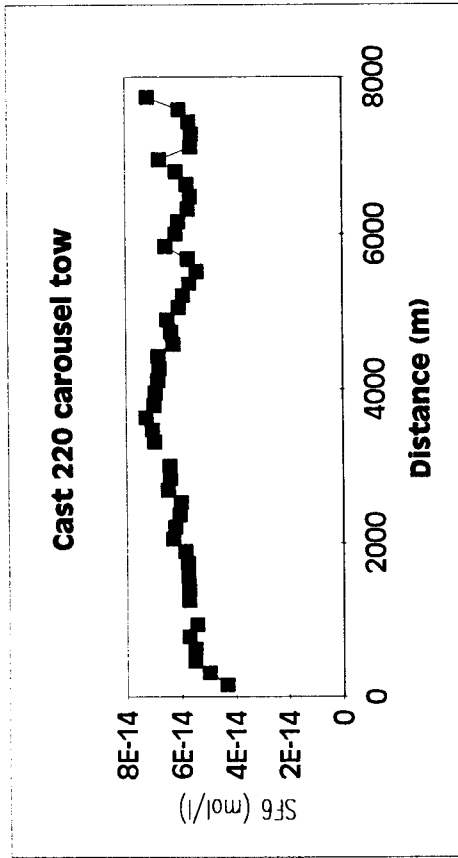
SCALE 1 TO 1500000 (NATURAL SCALE AT LAT. 33)

INTERNATIONAL SPHEROID PROJECTED AT LATITUDE 0

RRS Charles Darwin 78 Sled Tows in Work Area

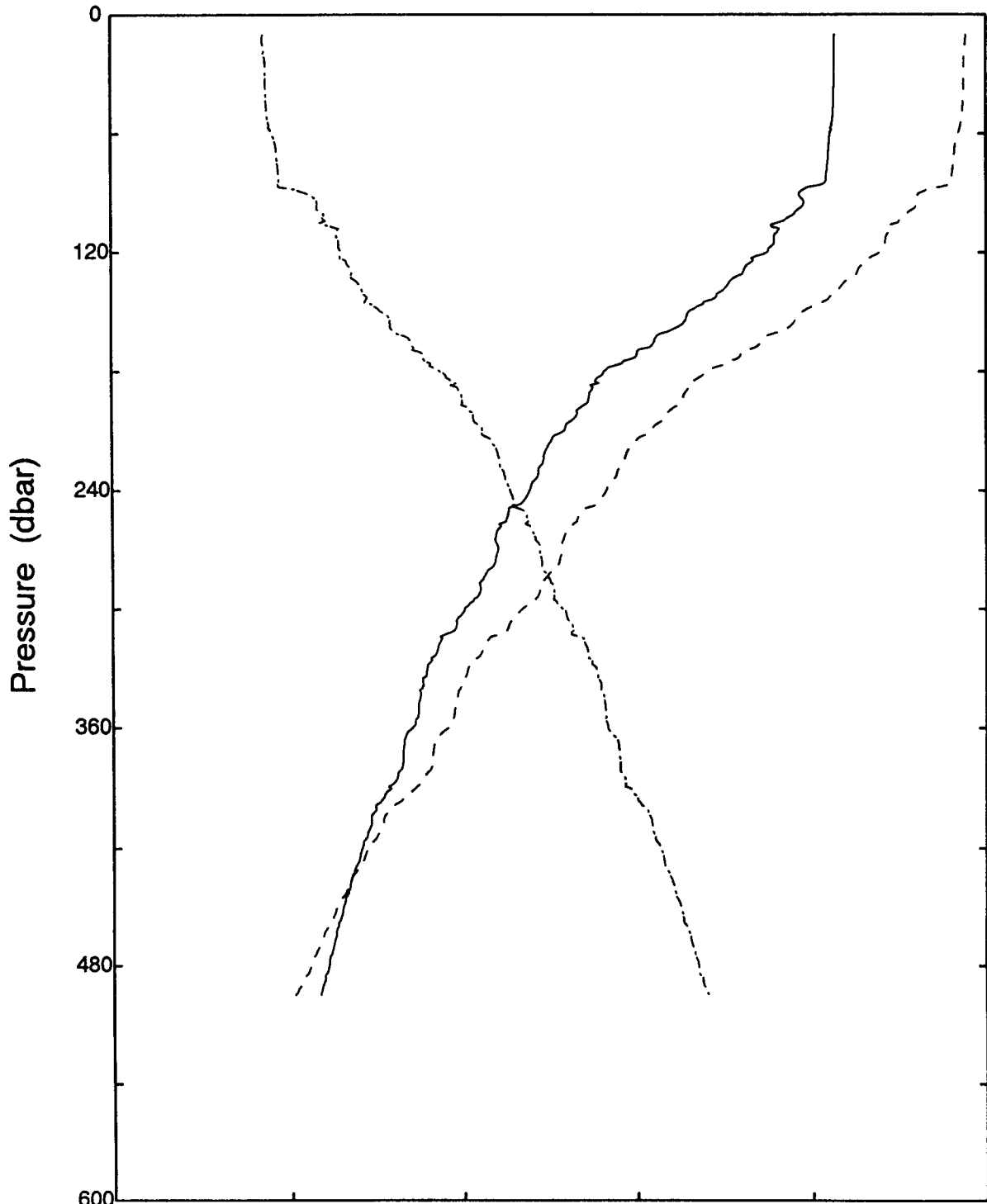
+

SLED TOWS -- CONCENTRATION VERSUS DISTANCE



Charles Darwin cd780018

Theta 10.0 12.5 15.0 17.5 20.0 22.5
Sal 35.0 38.0
Sigma 27.0 29.0

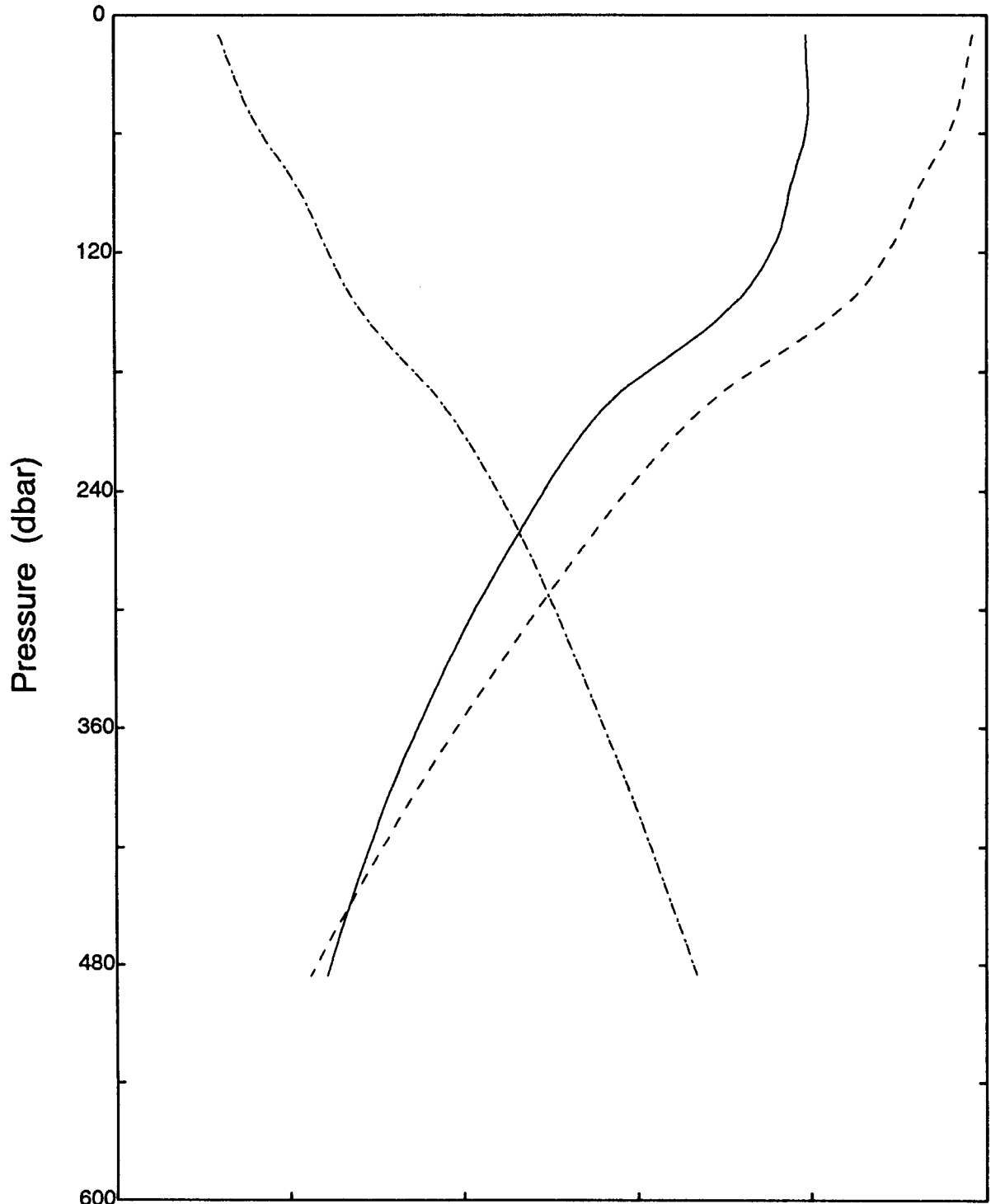


--- Theta
—— Salinity
-.-.- Sigma Theta

22 May 1993

Charles Darwin averages cd783100

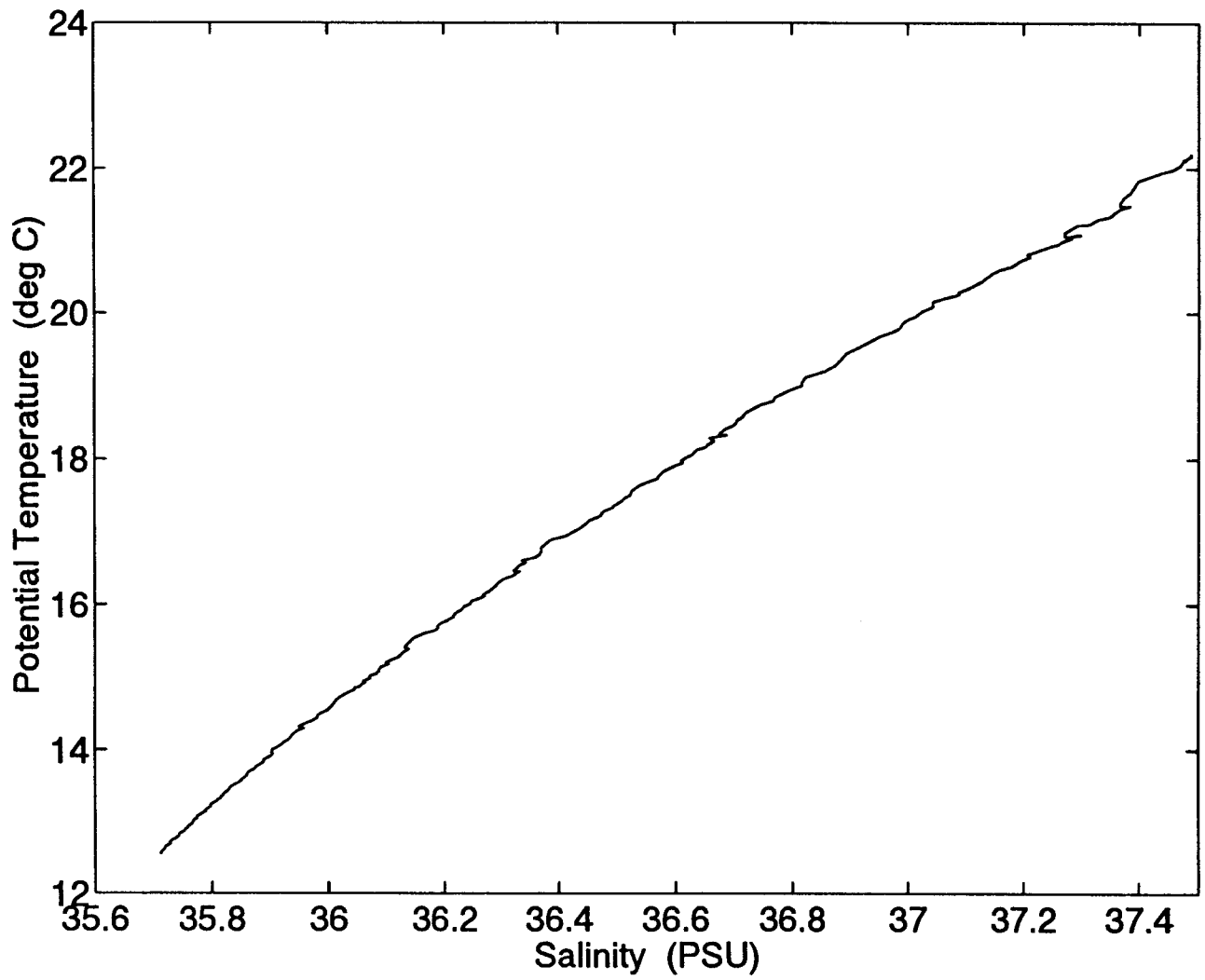
Theta 10.0 12.5 15.0 17.5 20.0 22.5
Sal 35.0 38.0
Sigma 27.0 29.0



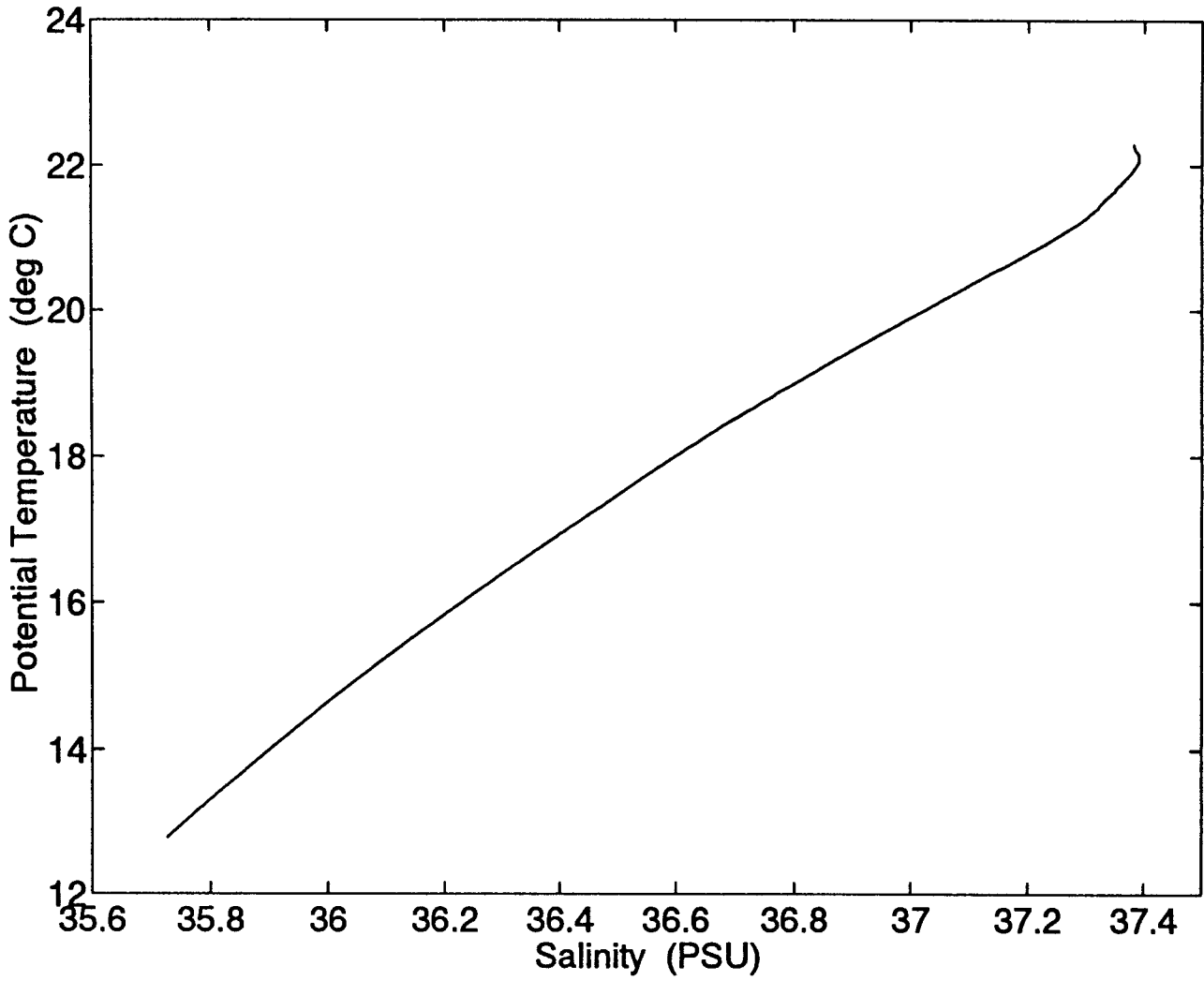
--- Theta
— Salinity
-.- Sigma Theta

21 May 1993

CD78 Cast 18



CD78 Mean Downcast



Area A

Column Integral in density space:

3.6E-15

Mean sigmap

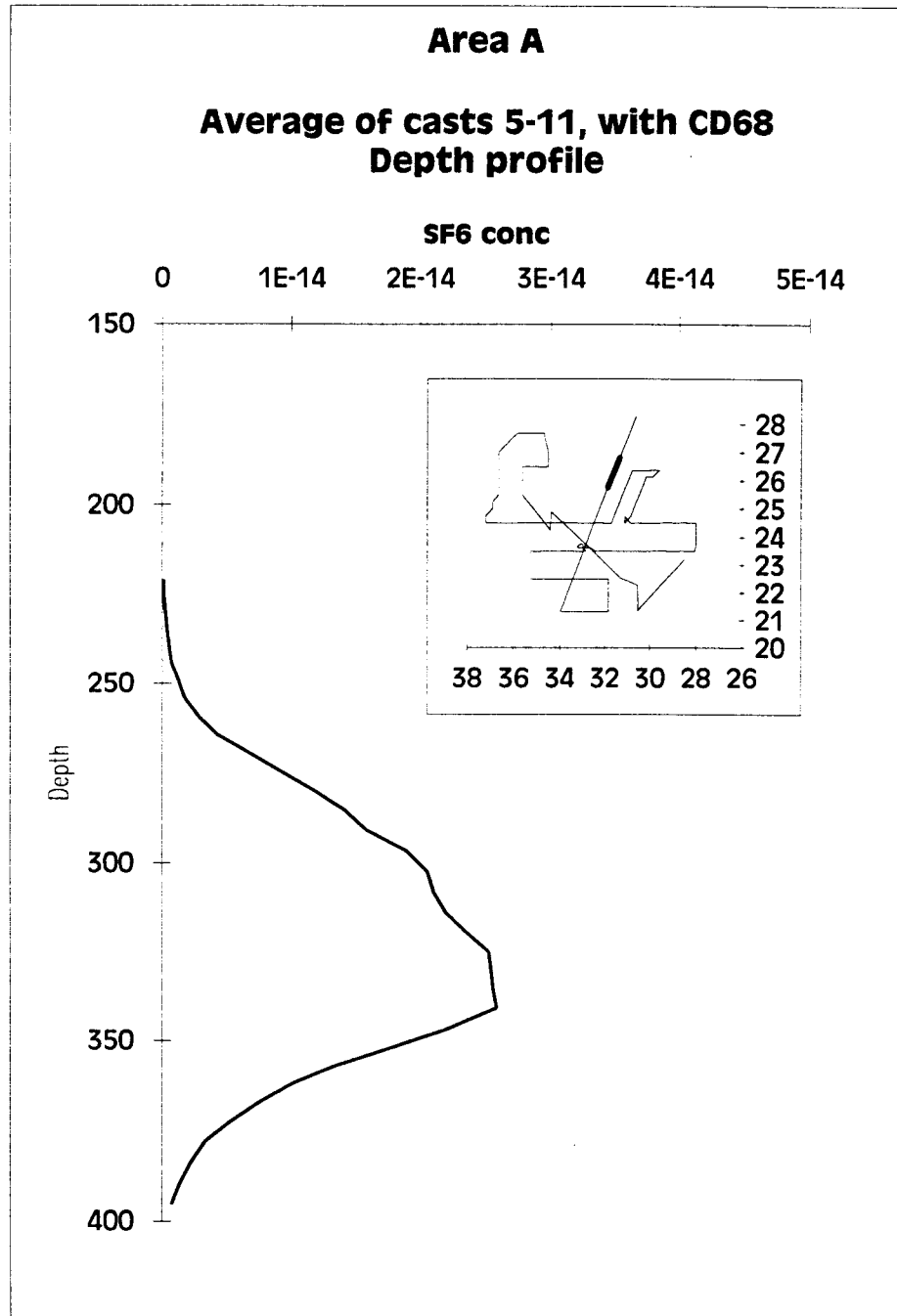
28.0637

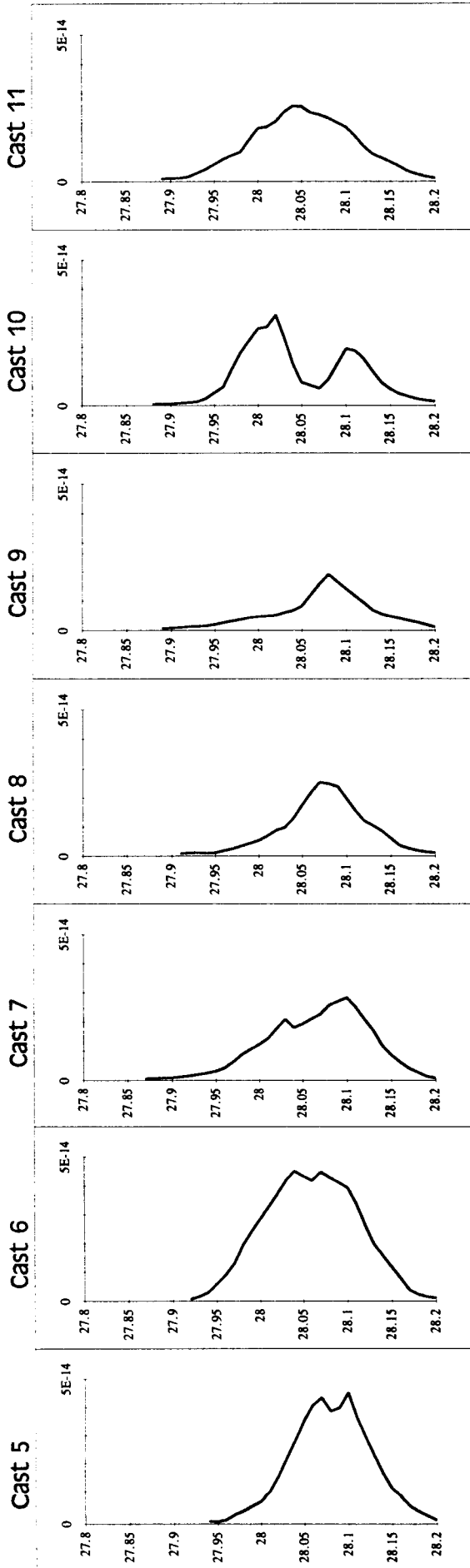
Mean cd68 pressure:

320.928

RMS CD 68 Width:

29.4257





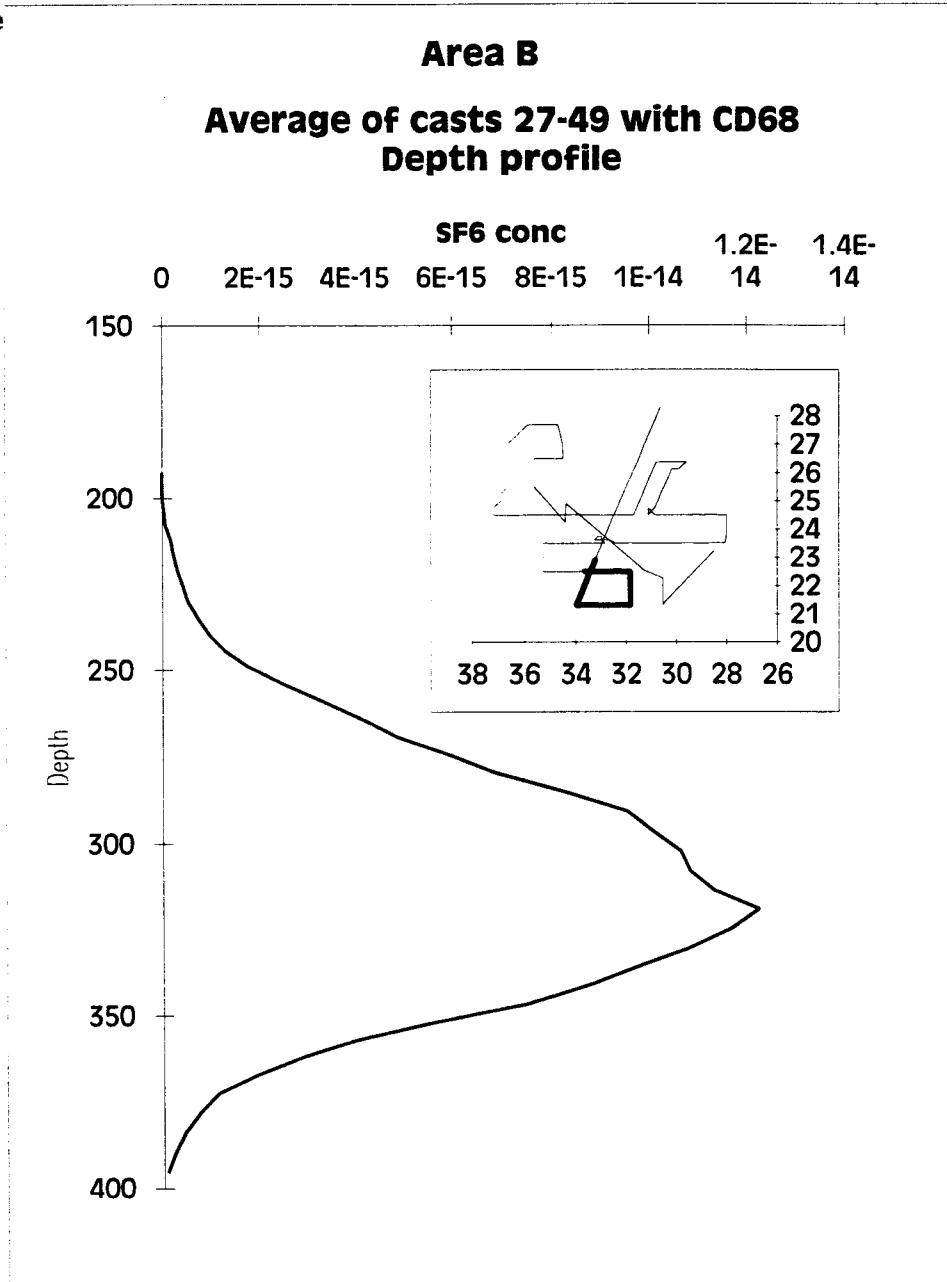
Area B

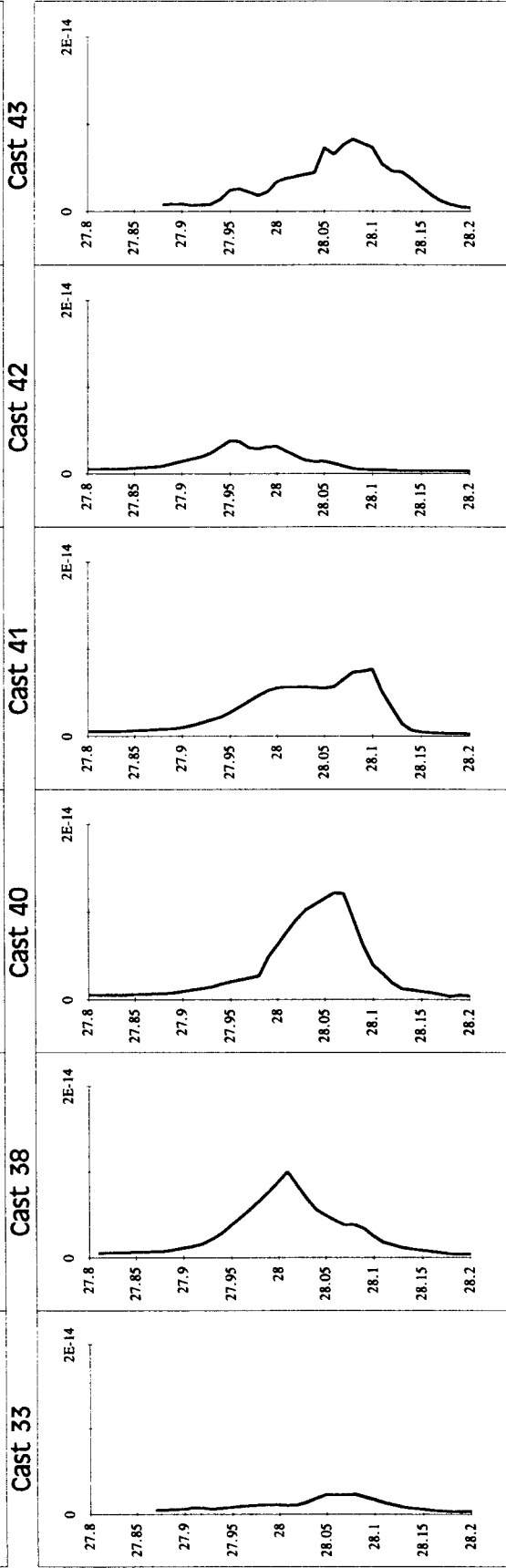
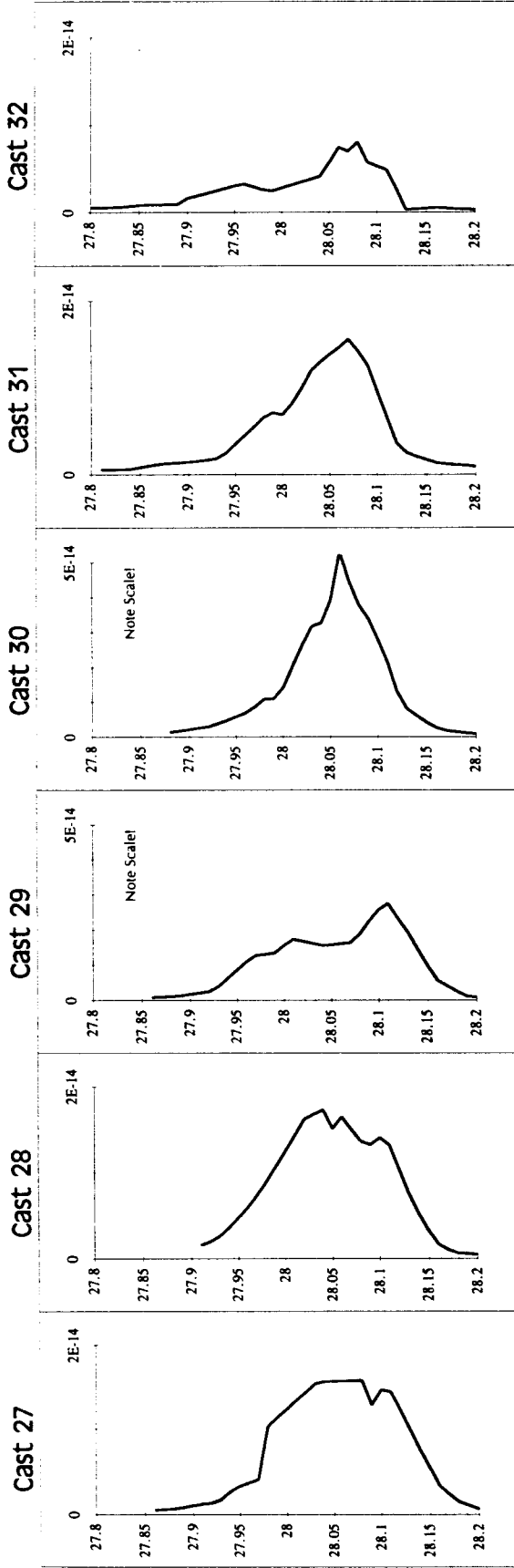
Column Integral in density space:

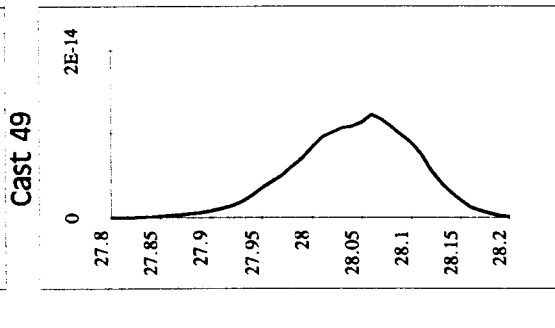
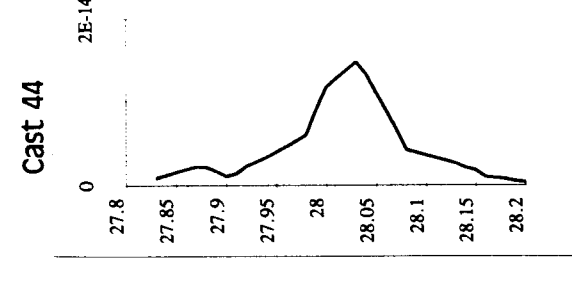
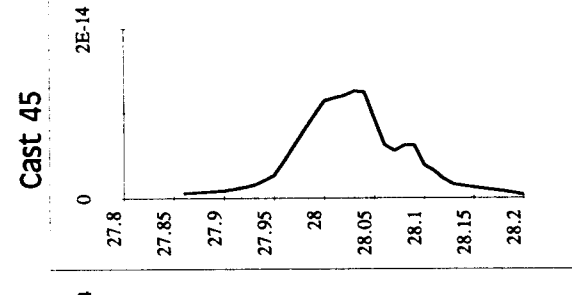
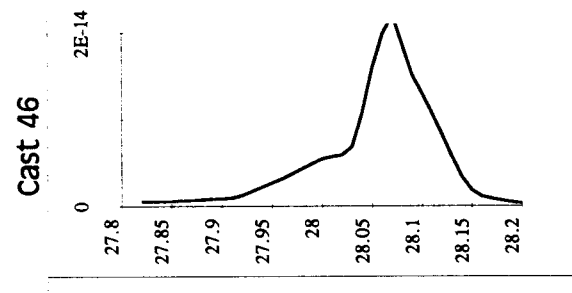
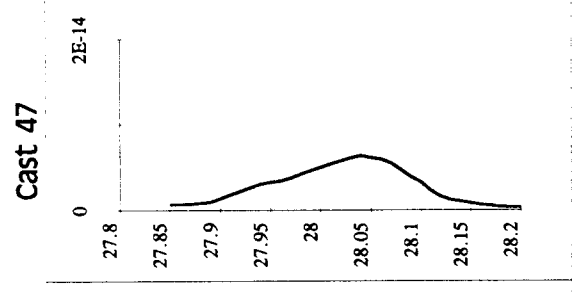
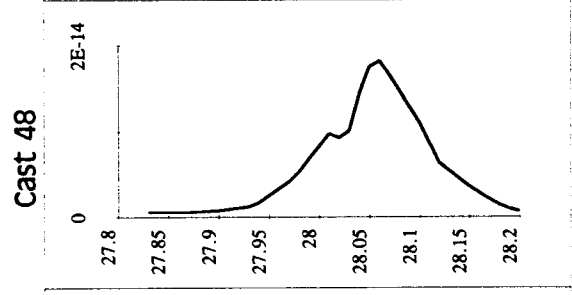
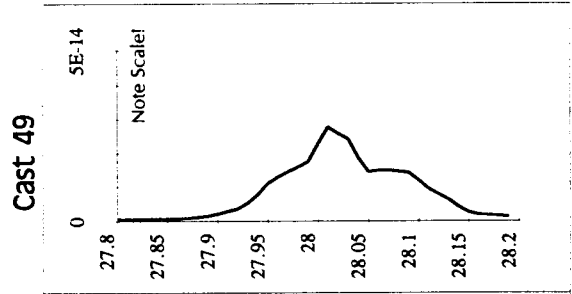
1.73E-15
Mean sigmap
28.0436

Mean cd68 pressure
310.007

RMS CD 68 Width:
31.43599







Area C

Column Integral in density space:

5.56E-16

Mean sigmap

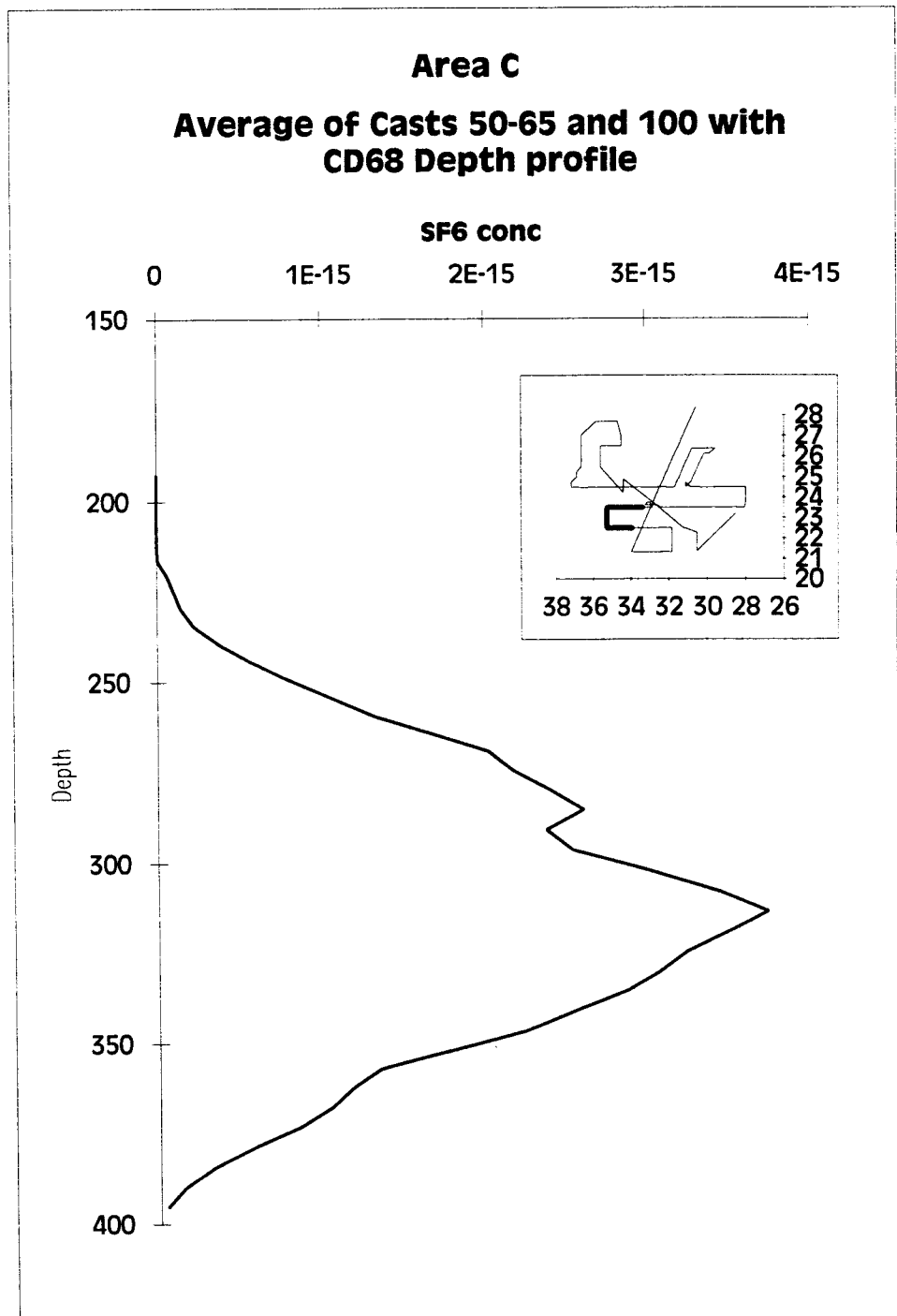
28.04443

Mean cd68 pressure:

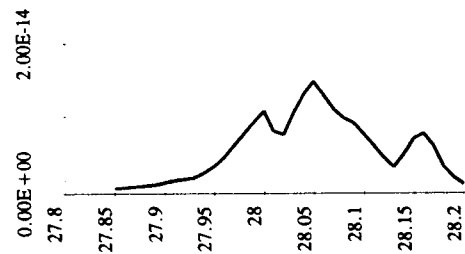
310.4178

RMS CD 68 Width:

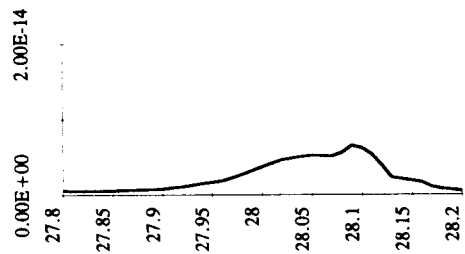
33.97823



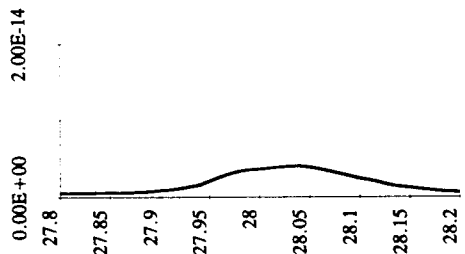
Cast 50



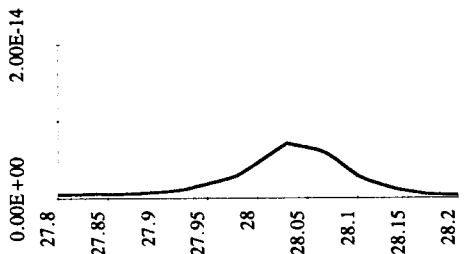
Cast 51



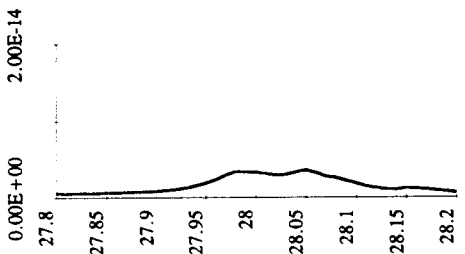
Cast 52



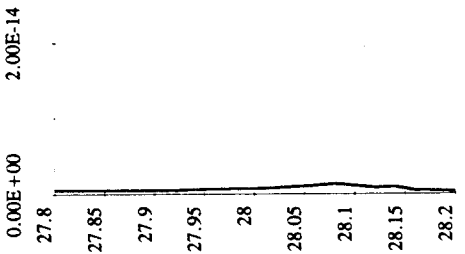
Cast 53



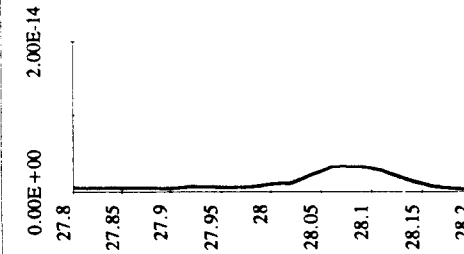
Cast 54



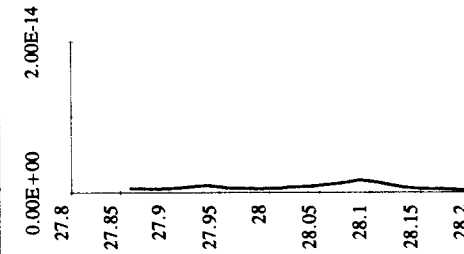
Cast 55



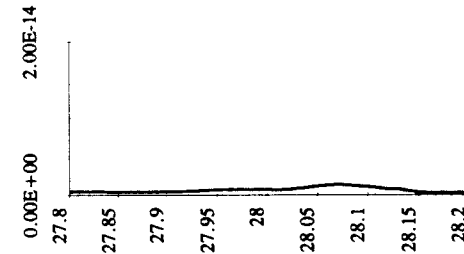
Cast 56



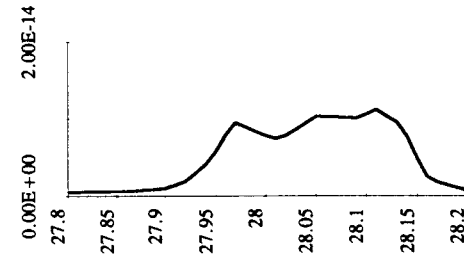
Cast 57



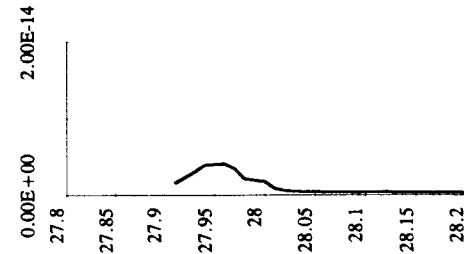
Cast 58



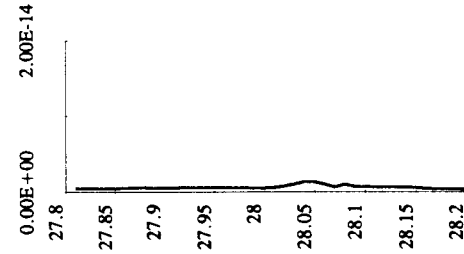
Cast 59

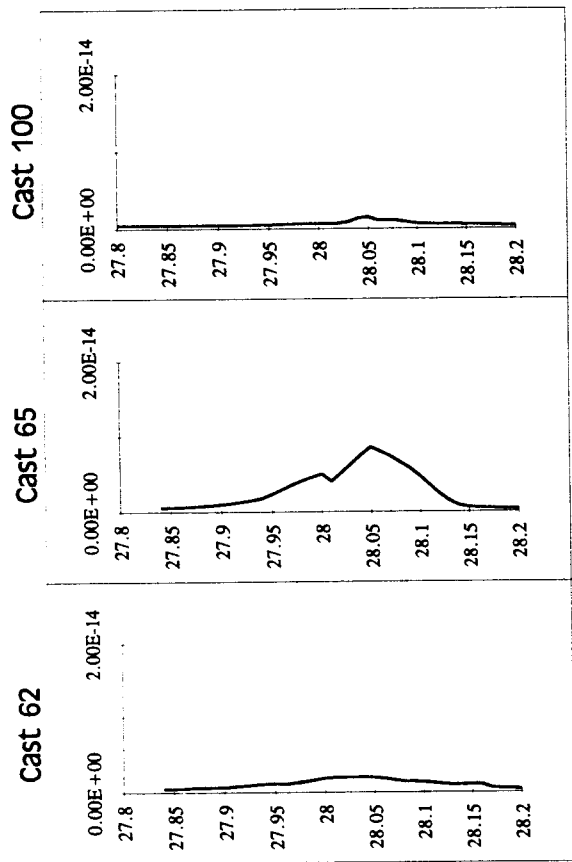


Cast 60



Cast 61

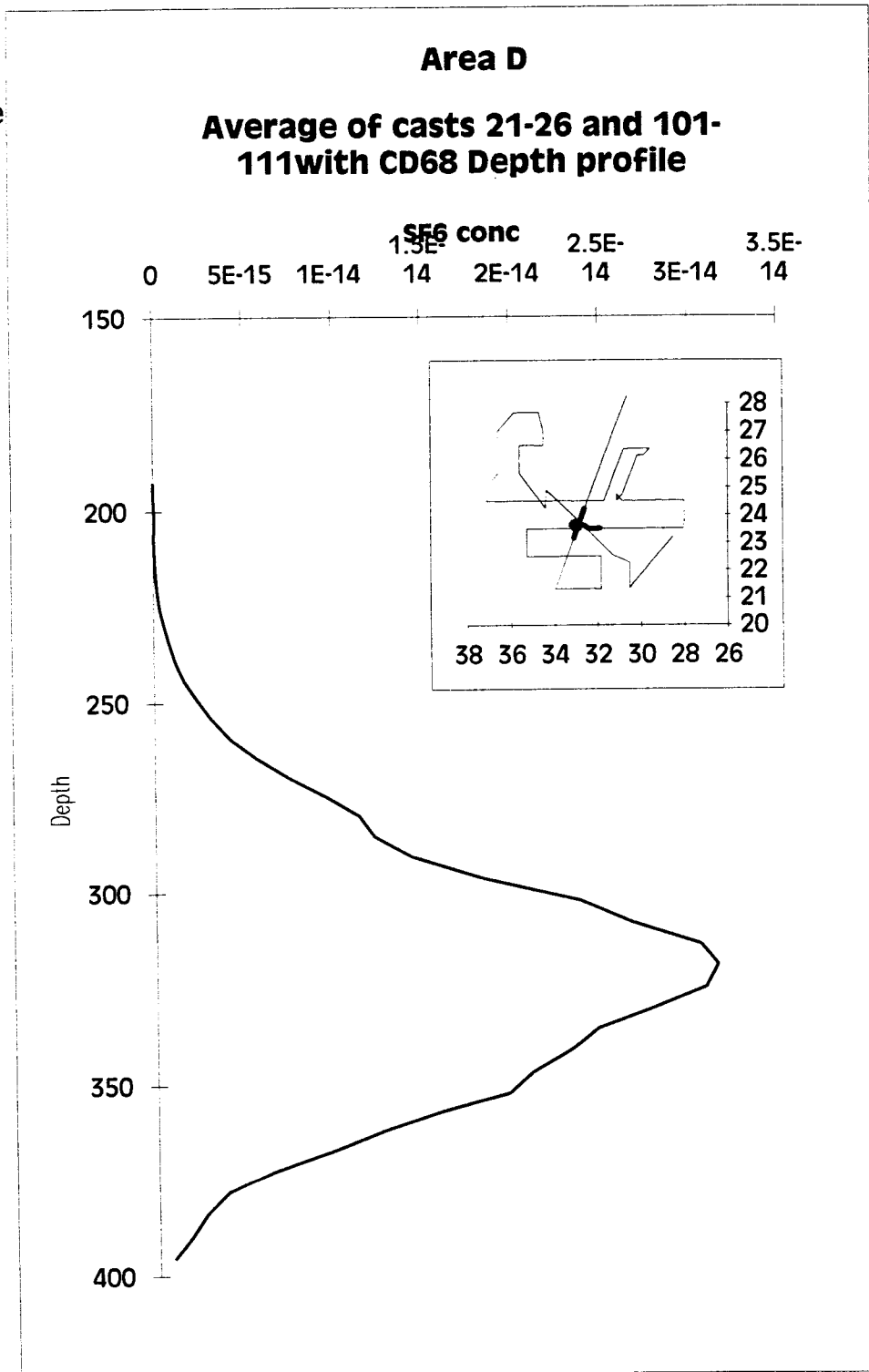


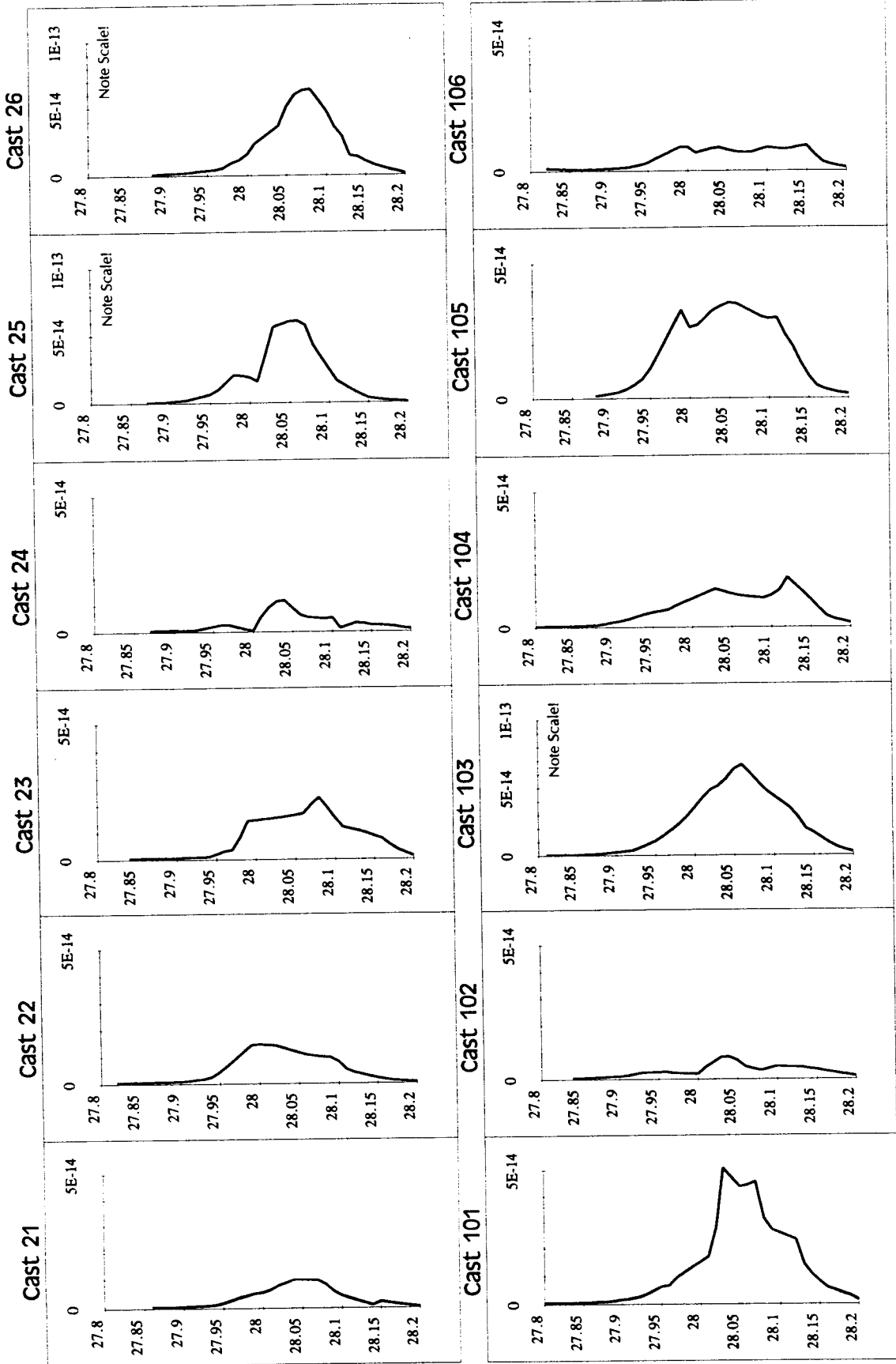


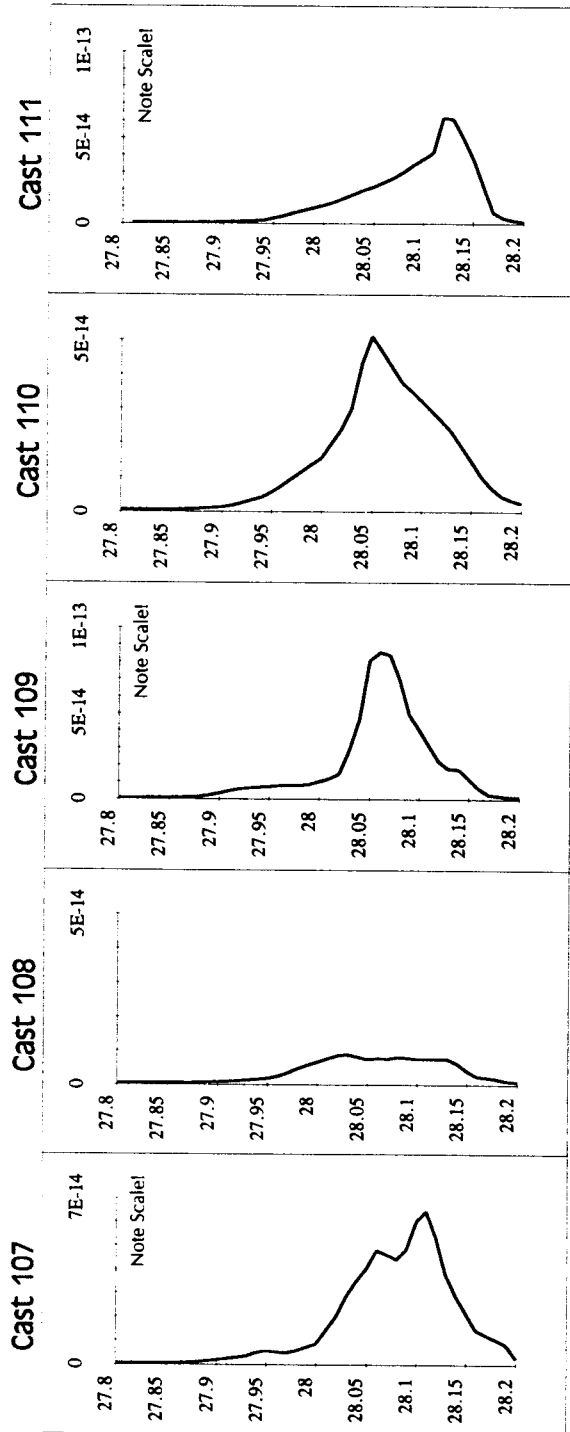
Area D

Column Integral in density space:

4.09E-15
Mean sigmap
28.06248
Mean cd68 pressure
320.3006
RMS CD 68 Width:
30.52039







Area E

Column Integral in density space:

4.16E-15

Mean sigmap

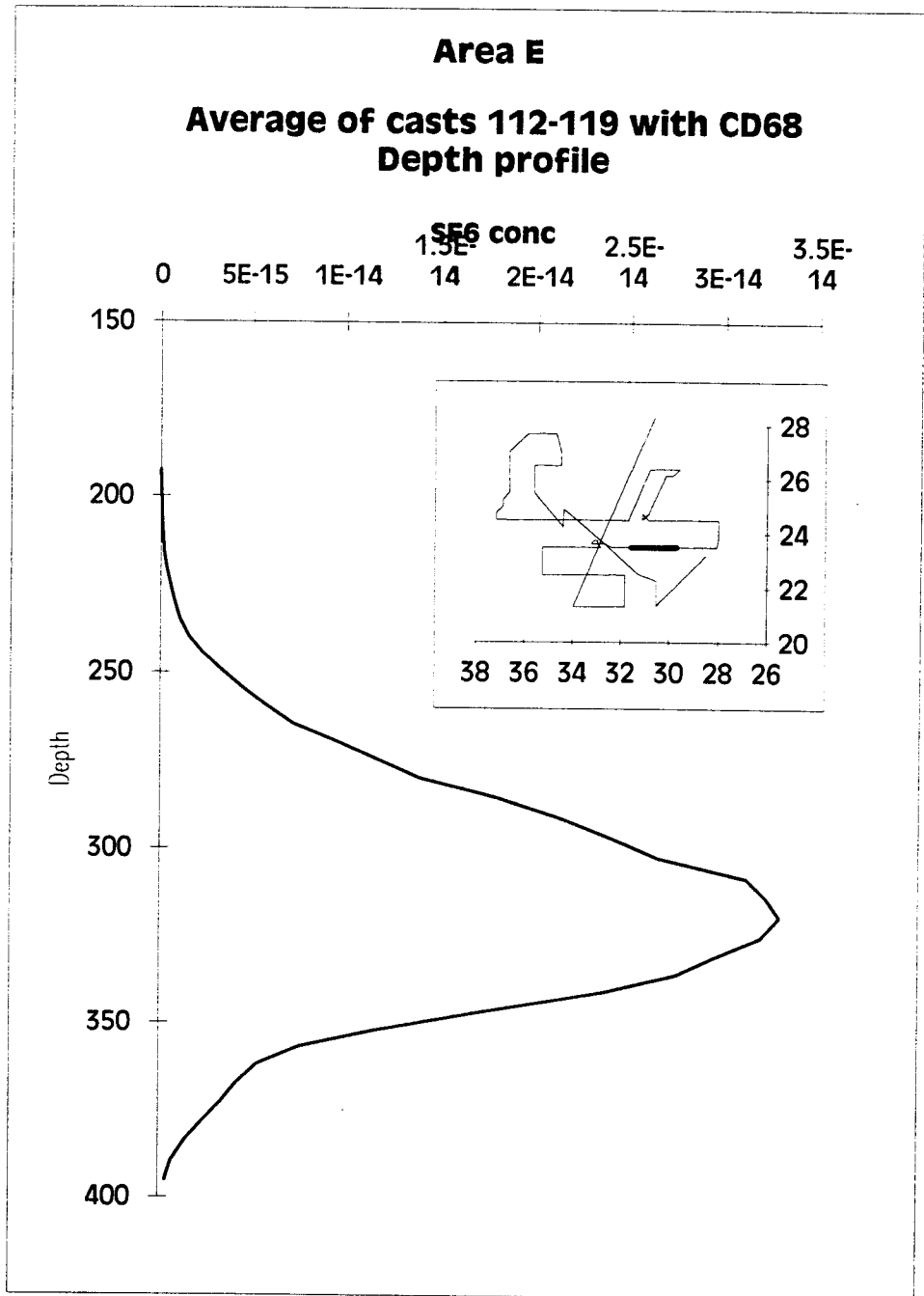
28.04906

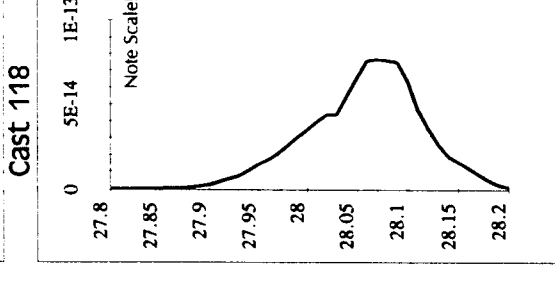
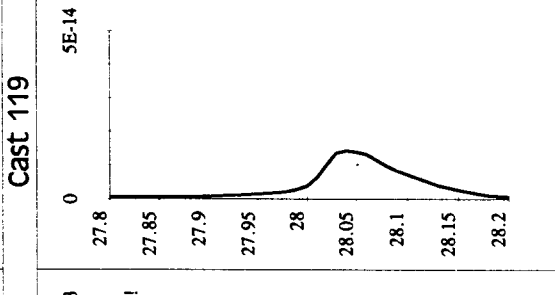
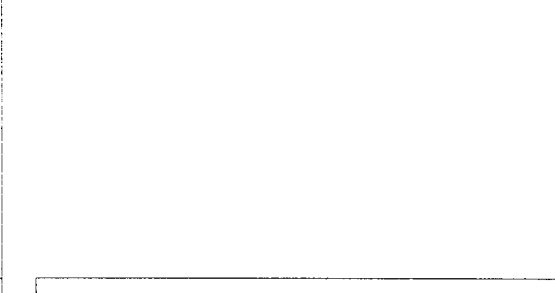
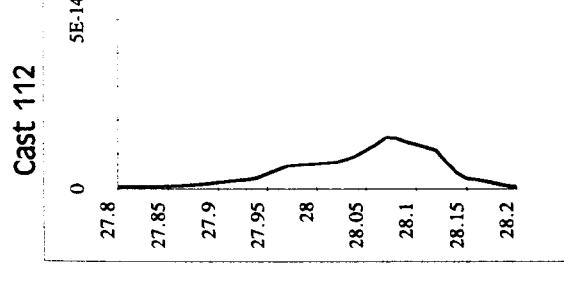
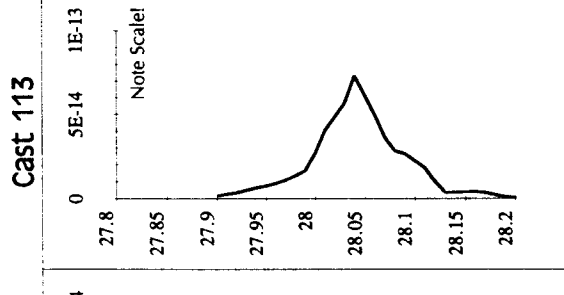
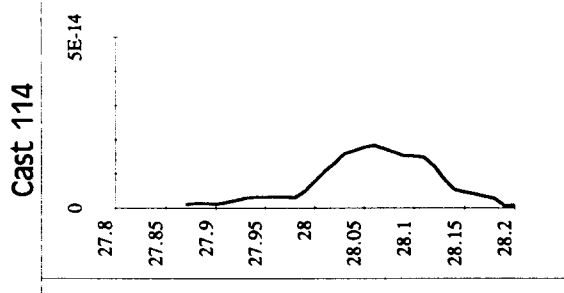
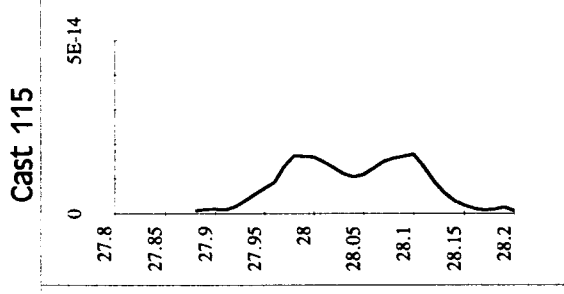
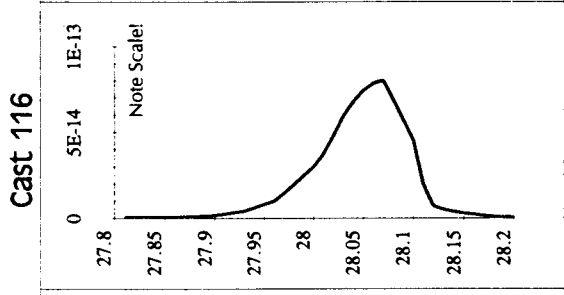
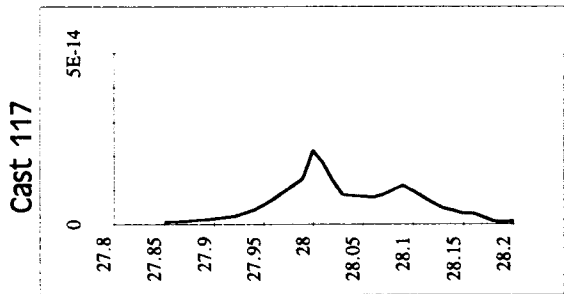
Mean cd68 pressure:

312.9763

RMS CD 68 Width:

29.11196

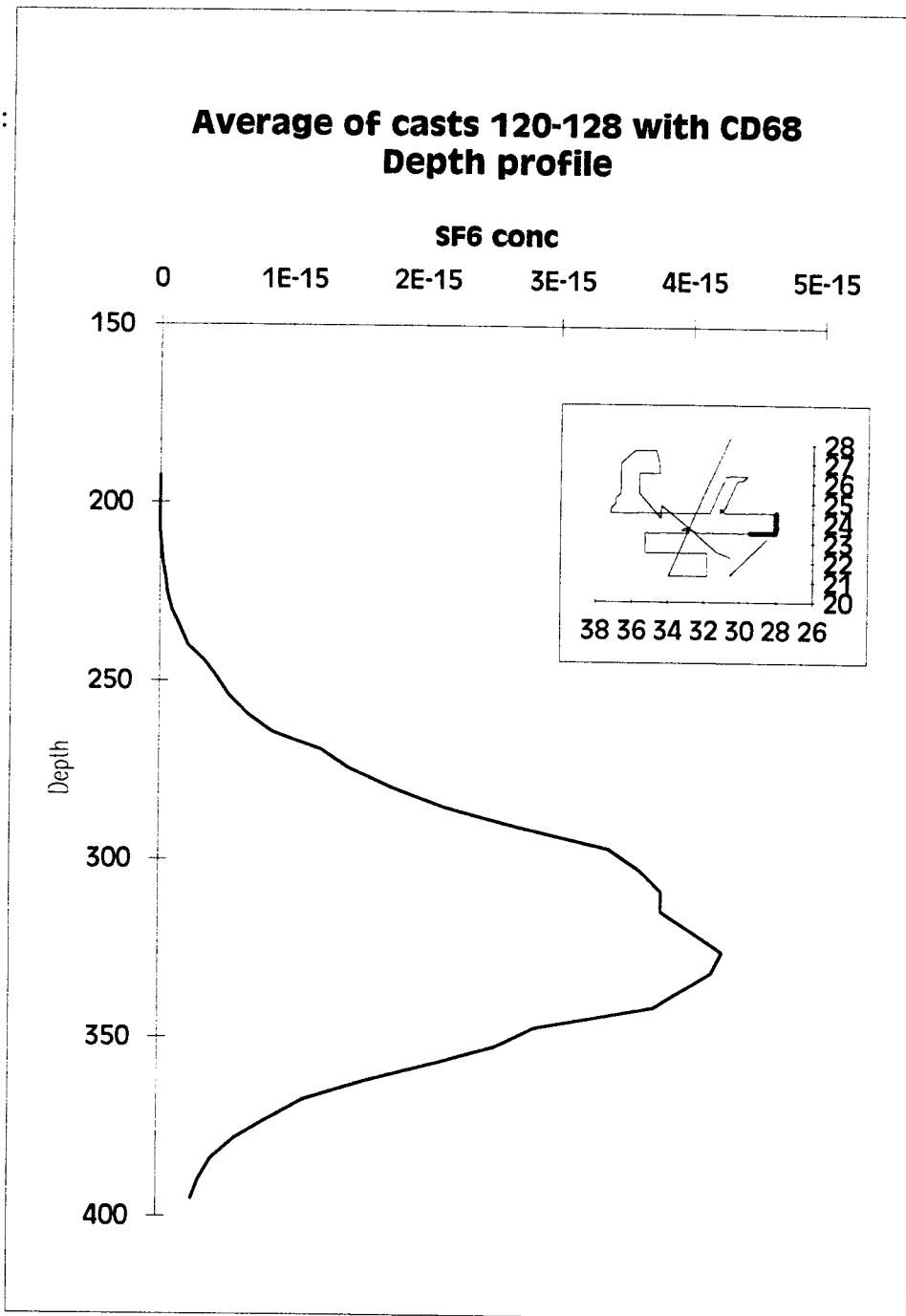


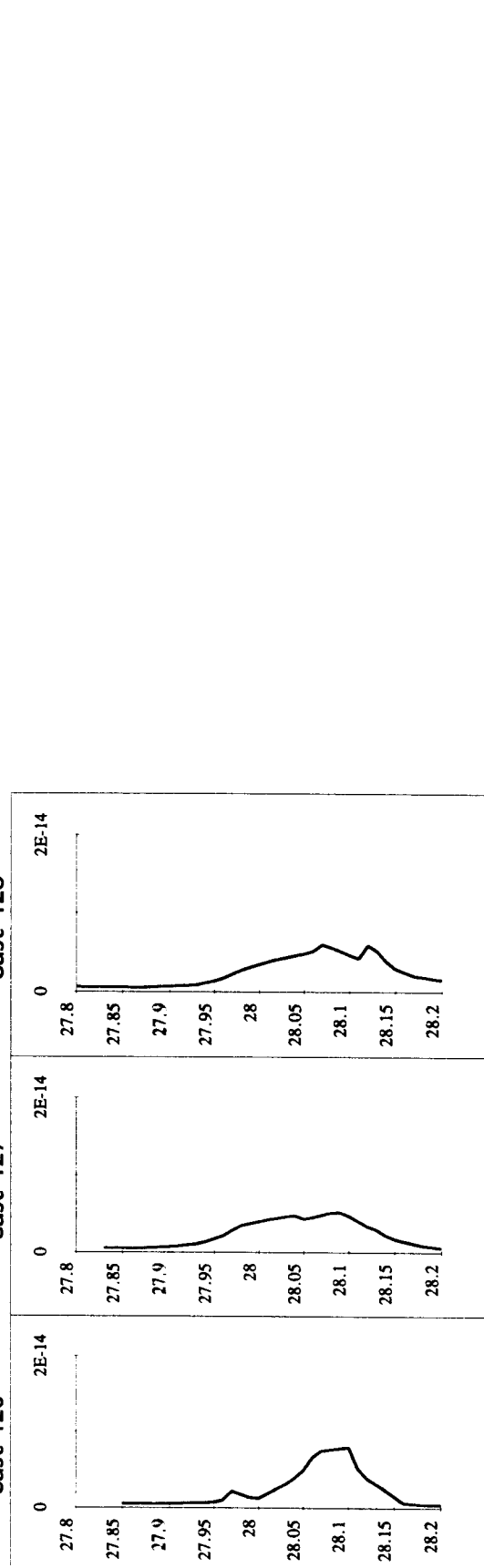
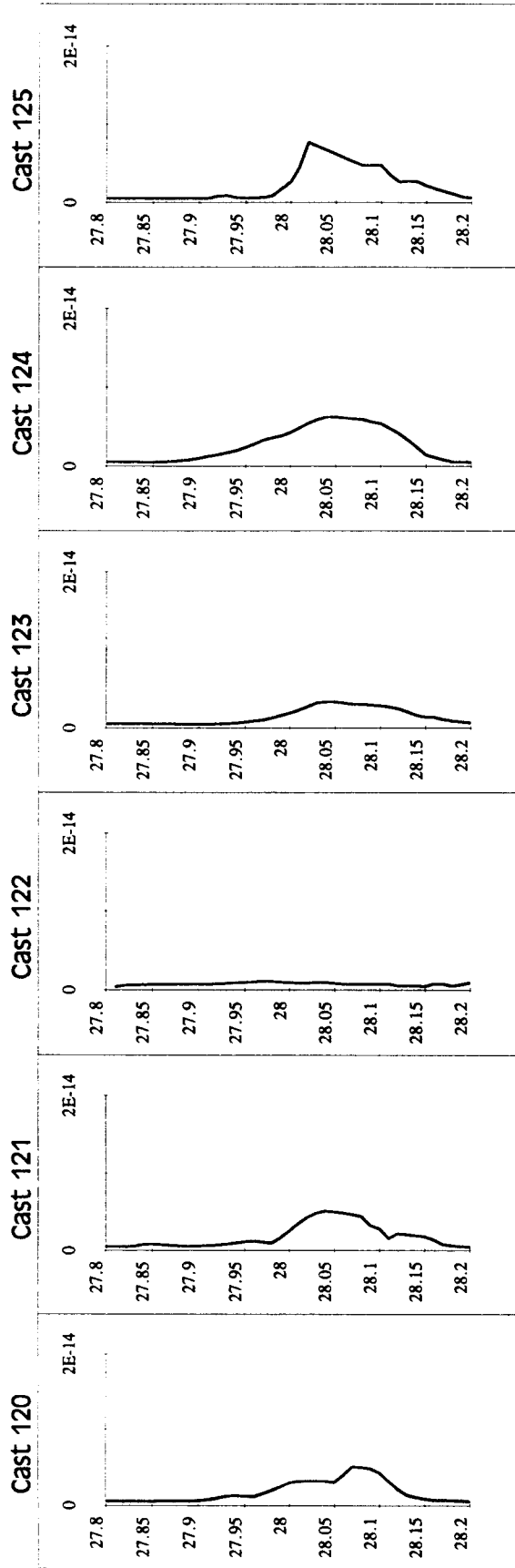


Area F

Column Integral in density space:

6.01E-16
Mean sigmap
28.05904
Mean cd68 pressure:
318.4042
RMS CD 68 Width:
31.2402

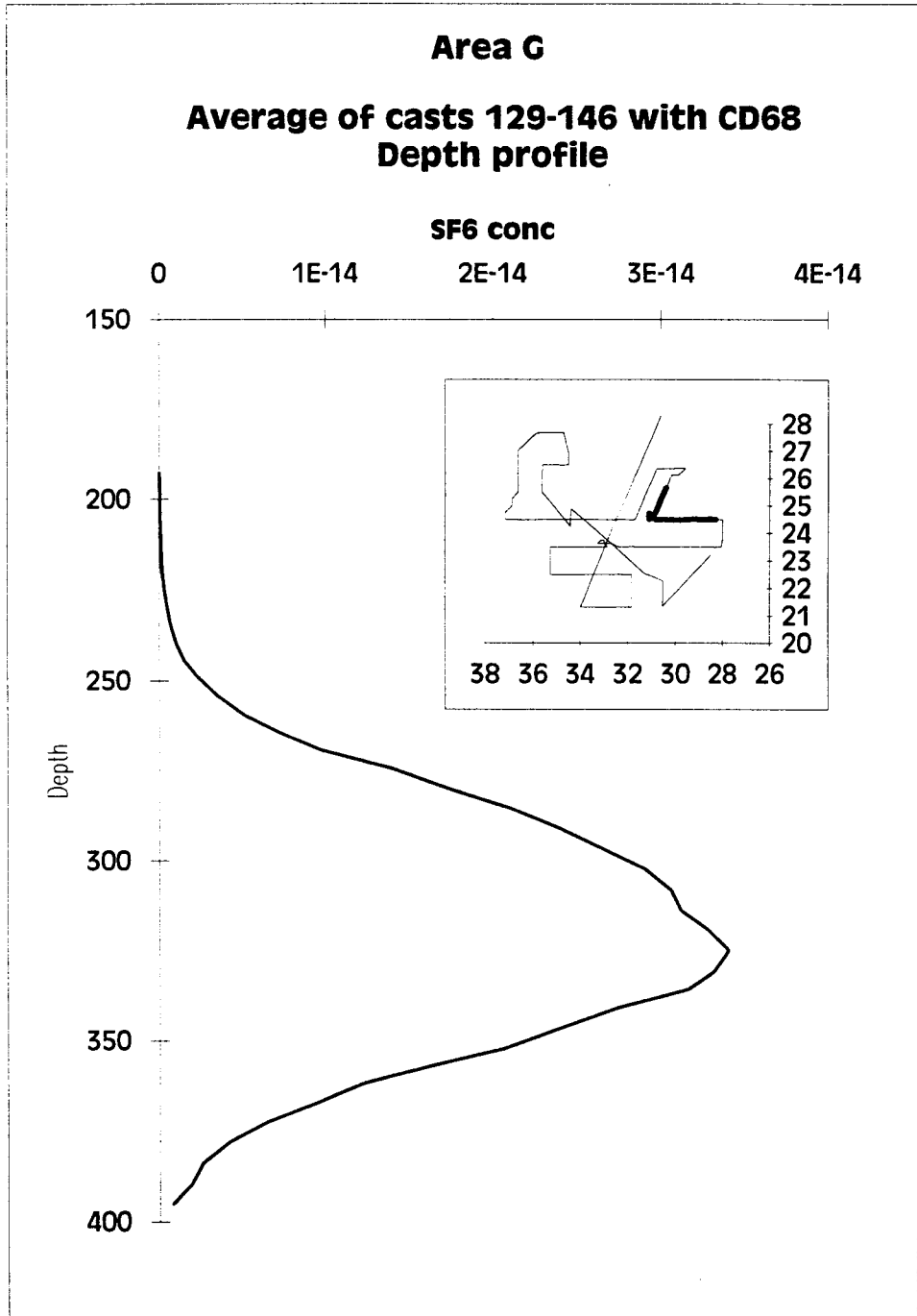


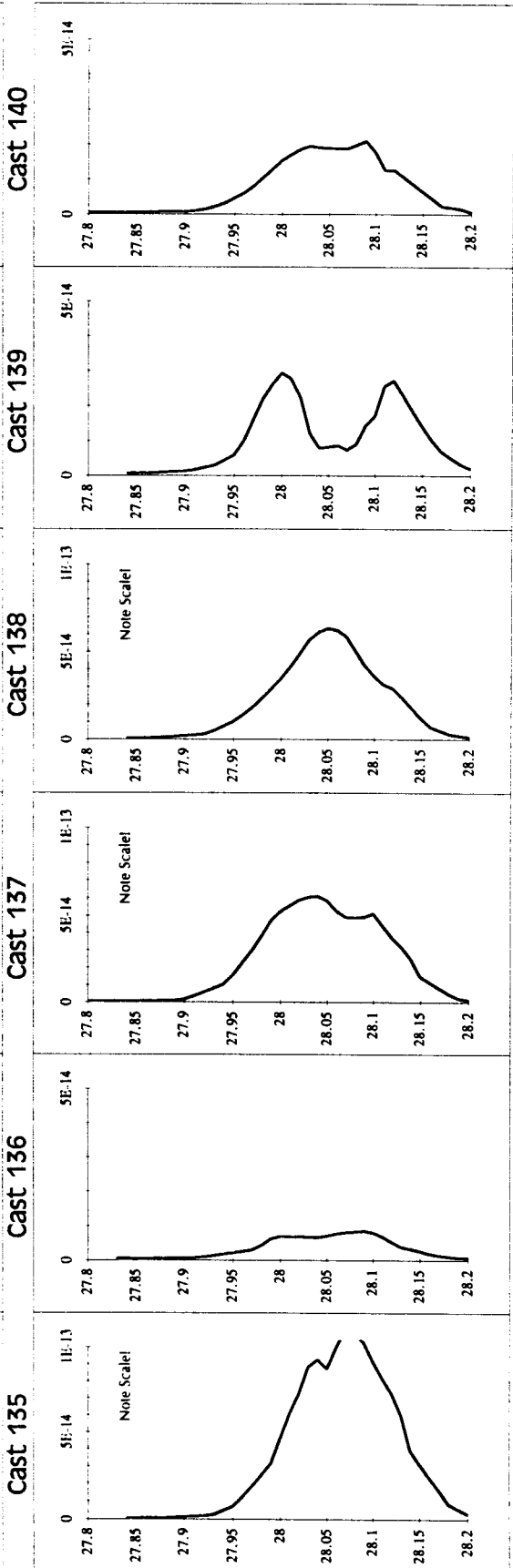
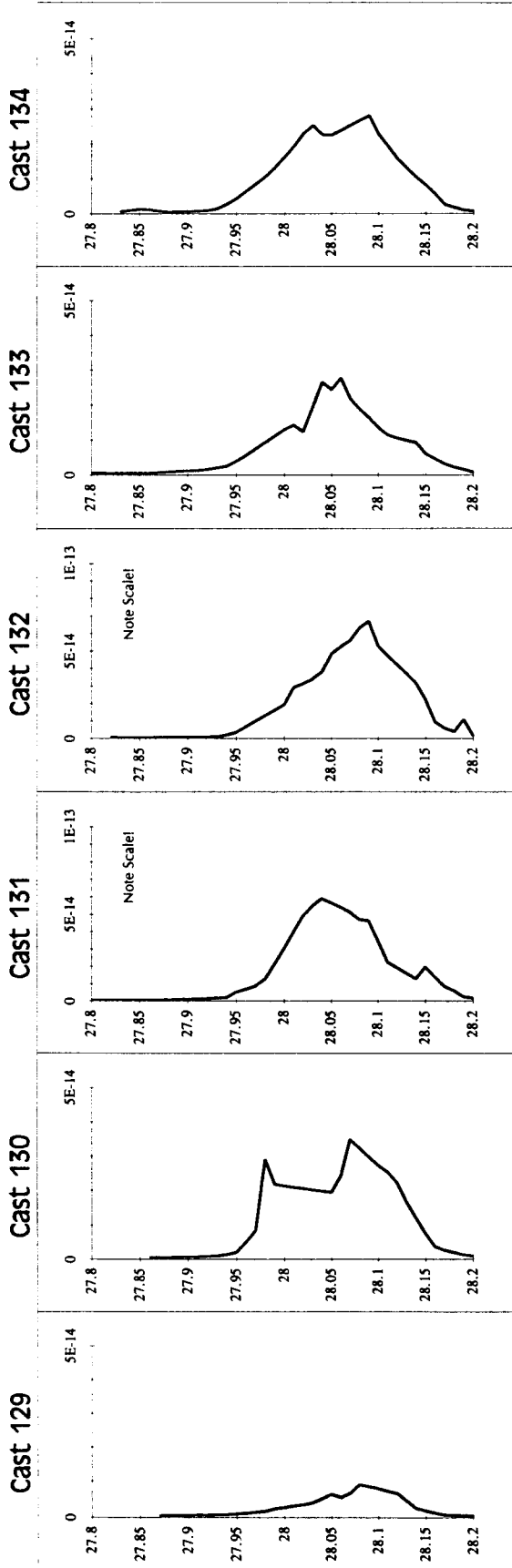


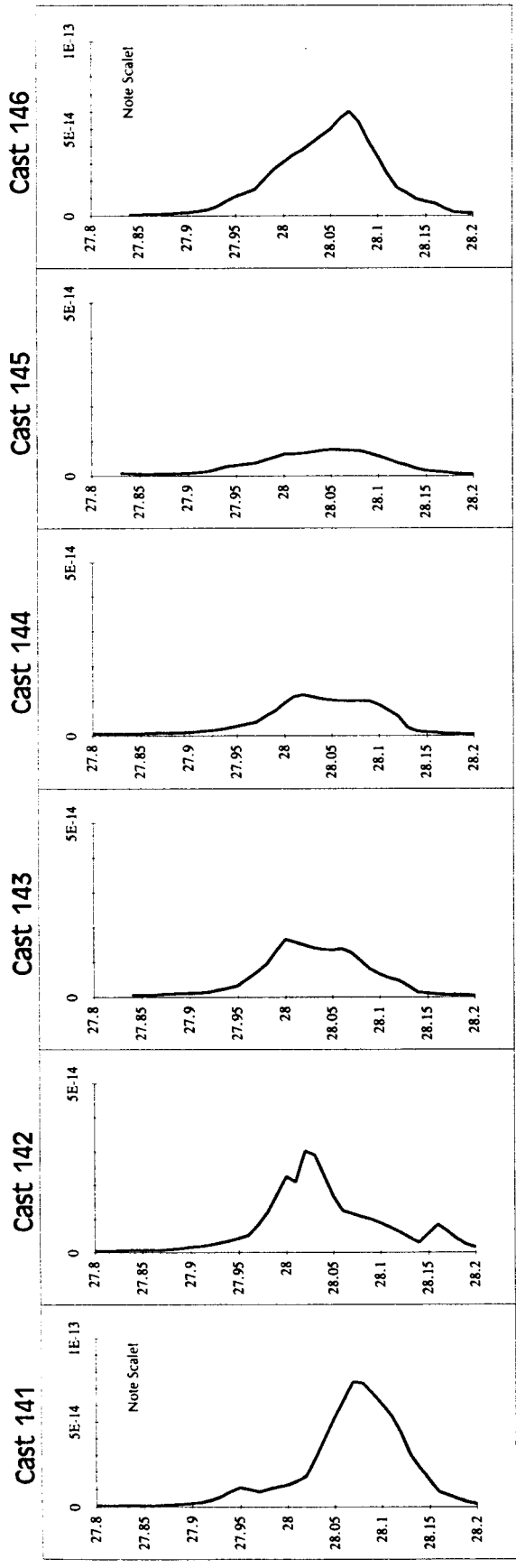
Area G

Column Integral in density space:

4.84E-15
Mean sigmap
28.05794
Mean cd68 pressure:
317.7726
RMS CD 68 Width:
30.16065



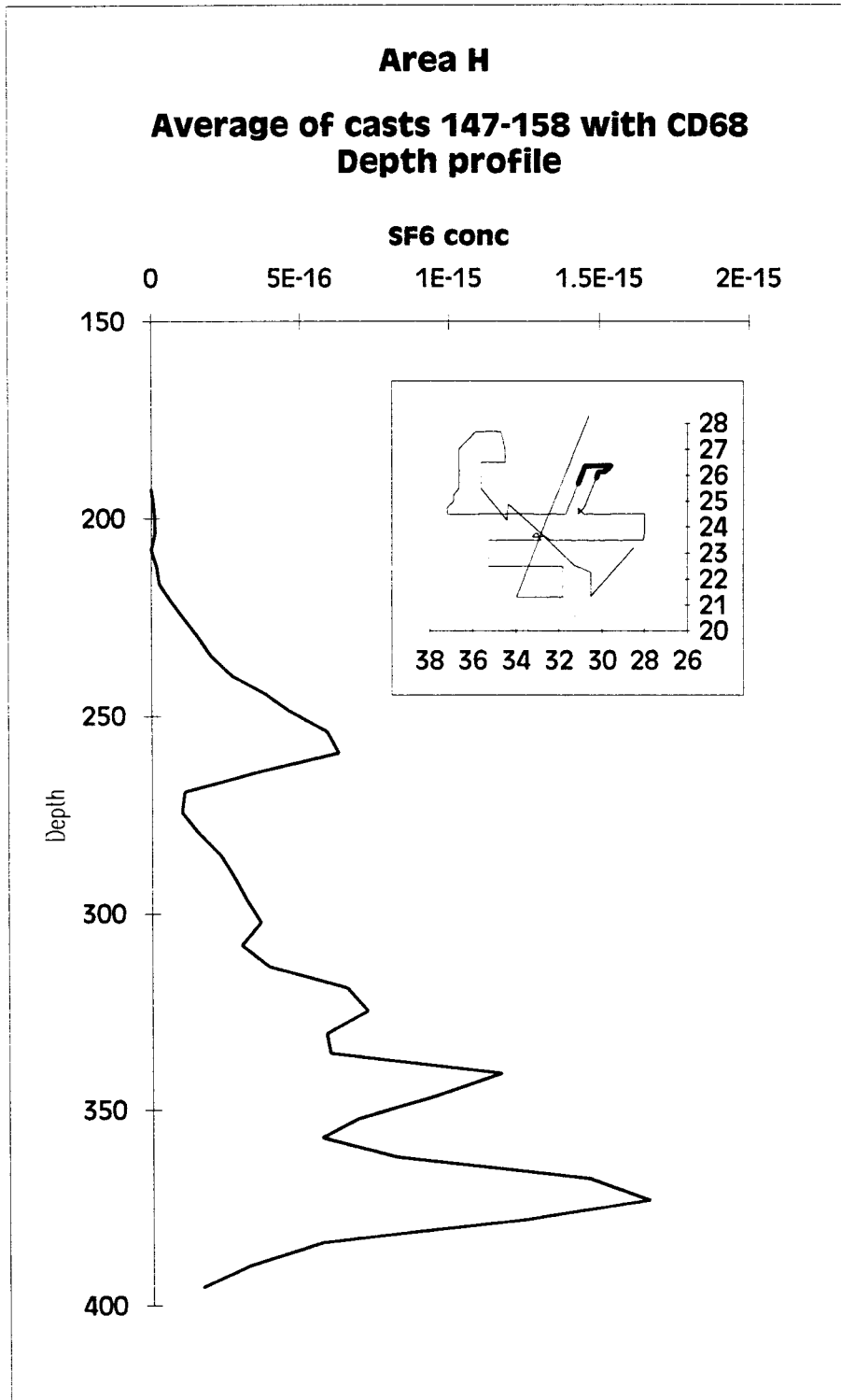


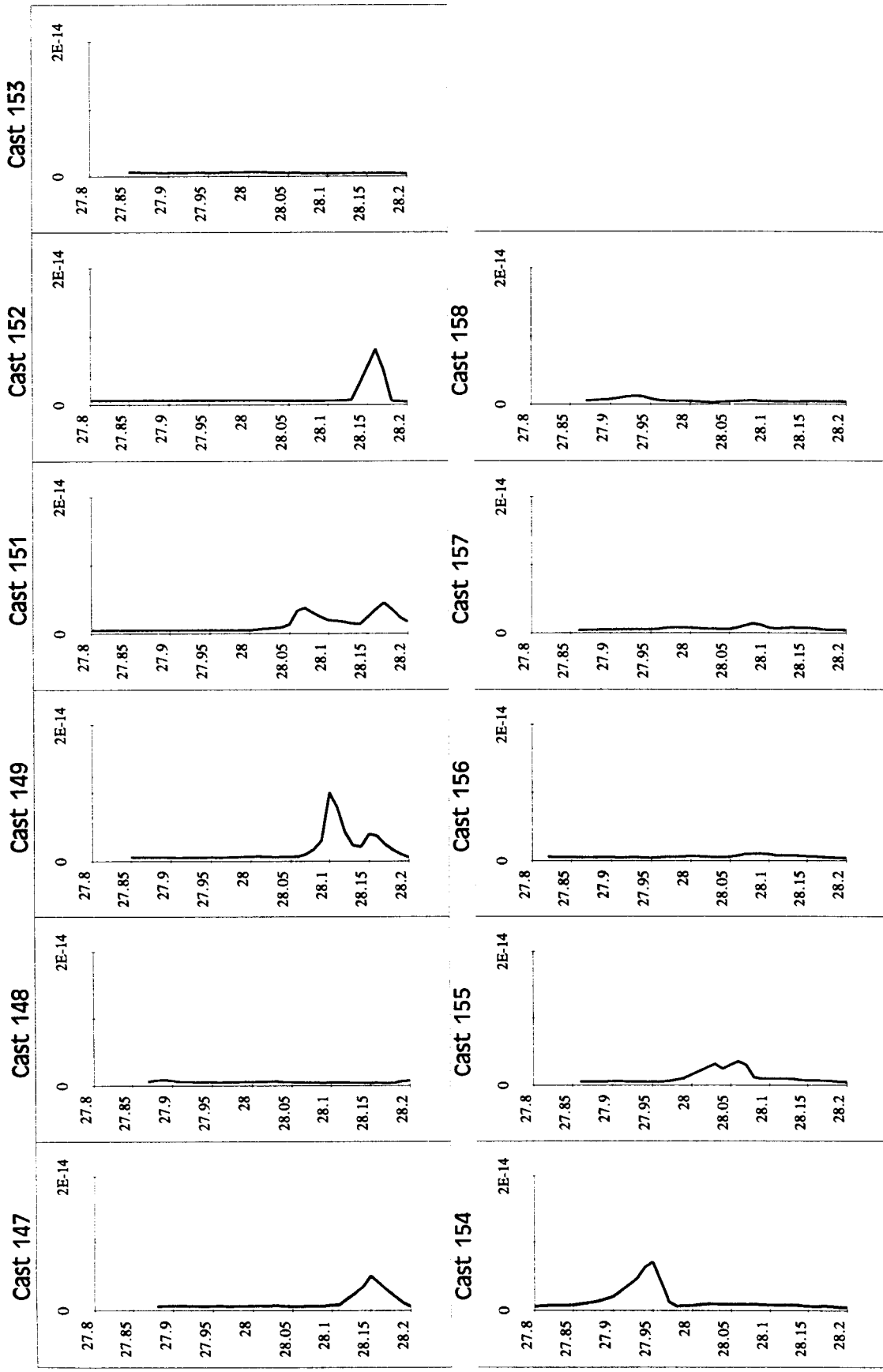


Area H

Column Integral in density space:

1.8E-16
Mean sigmap
28.0782
Mean cd68 pressure:
328.964
RMS CD 68 Width:
46.8257

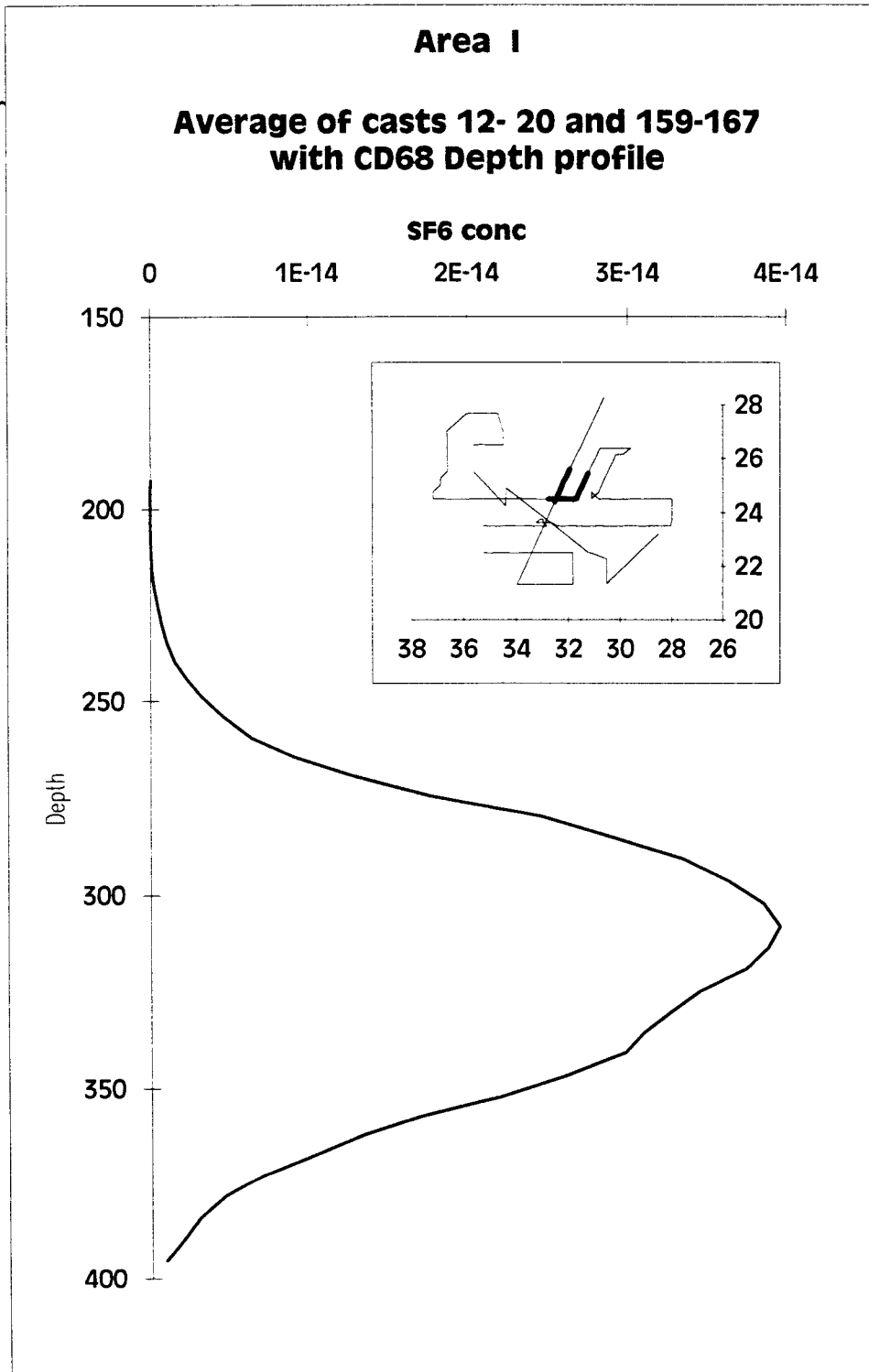




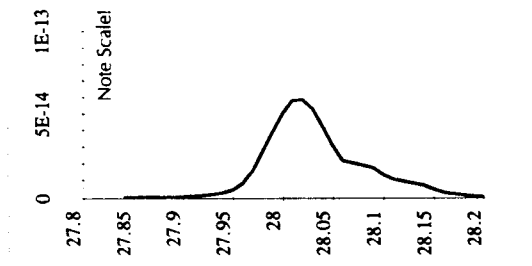
Area I

Column Integral in density space:

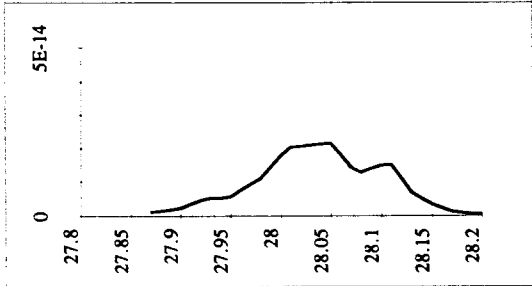
5.74E-15
Mean sigmap
28.05272
Mean cd68 pressur
314.8748
RMS CD 68 Width:
30.42777



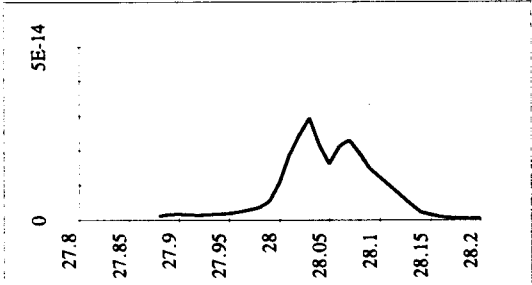
Cast 12



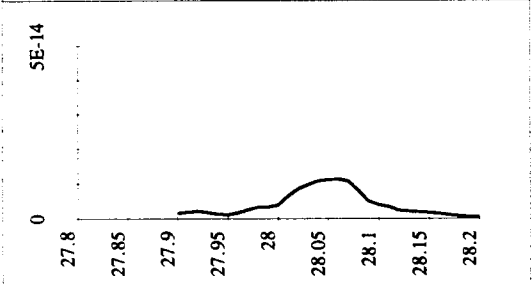
Cast 13



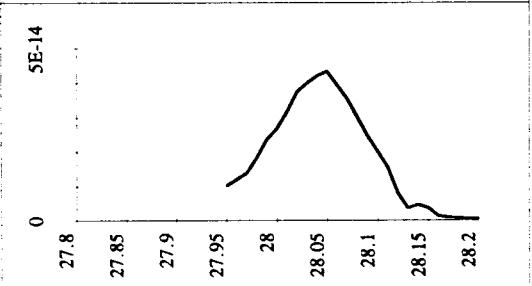
Cast 14



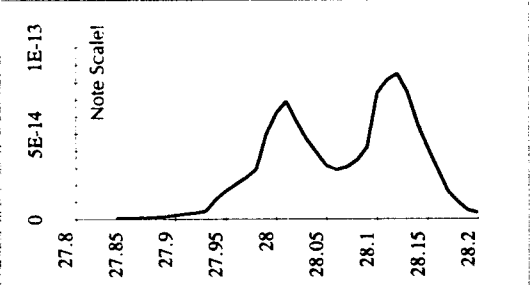
Cast 15



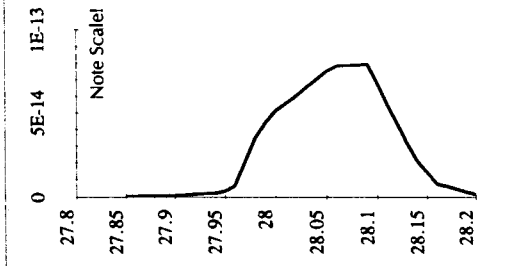
Cast 16



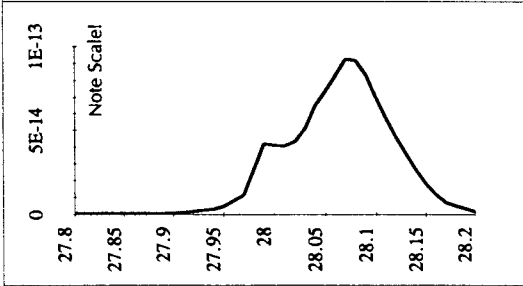
Cast 17



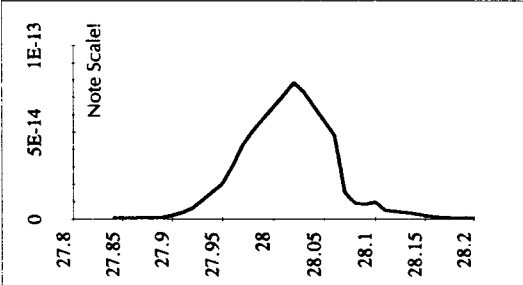
Cast 18



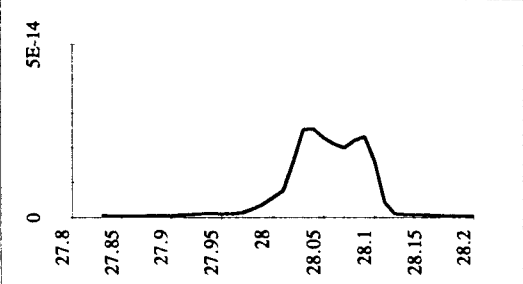
Cast 19



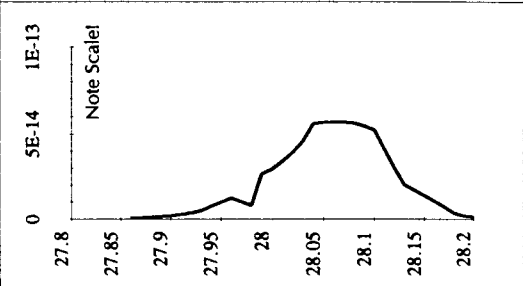
Cast 20



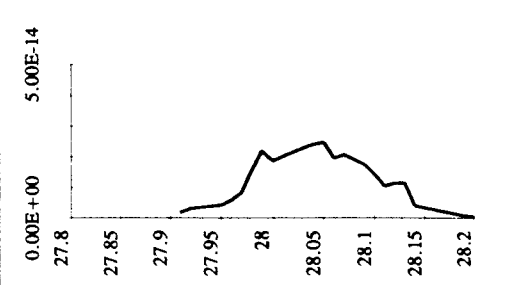
Cast 159

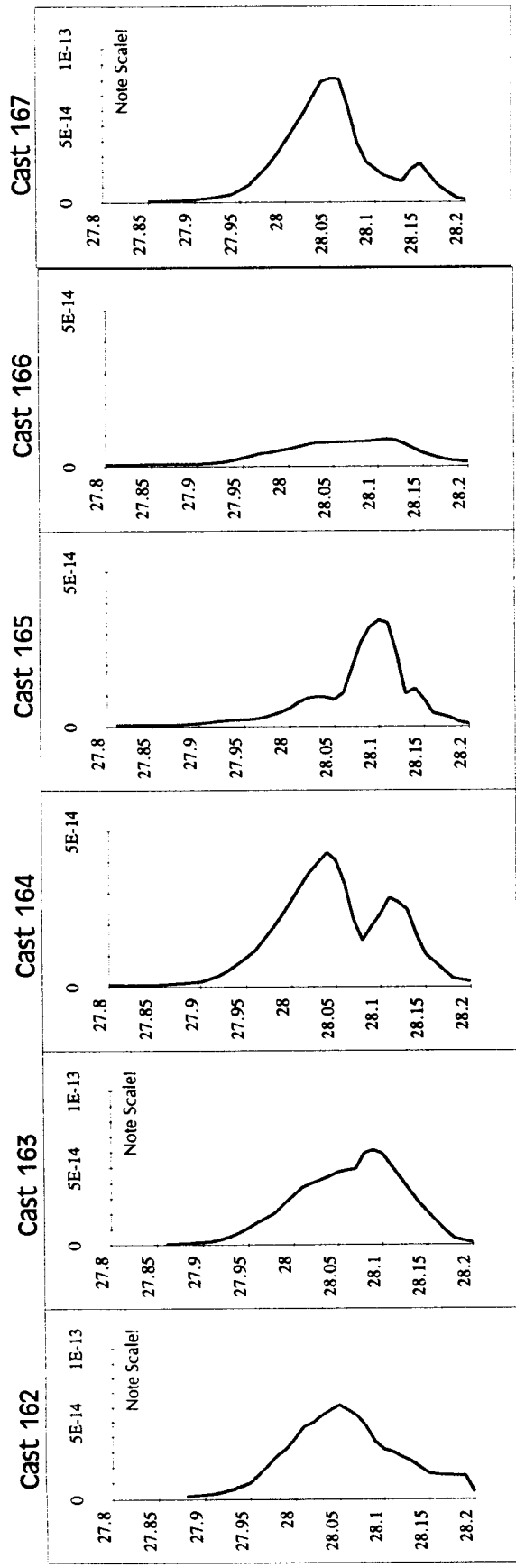


Cast 160



Cast 161

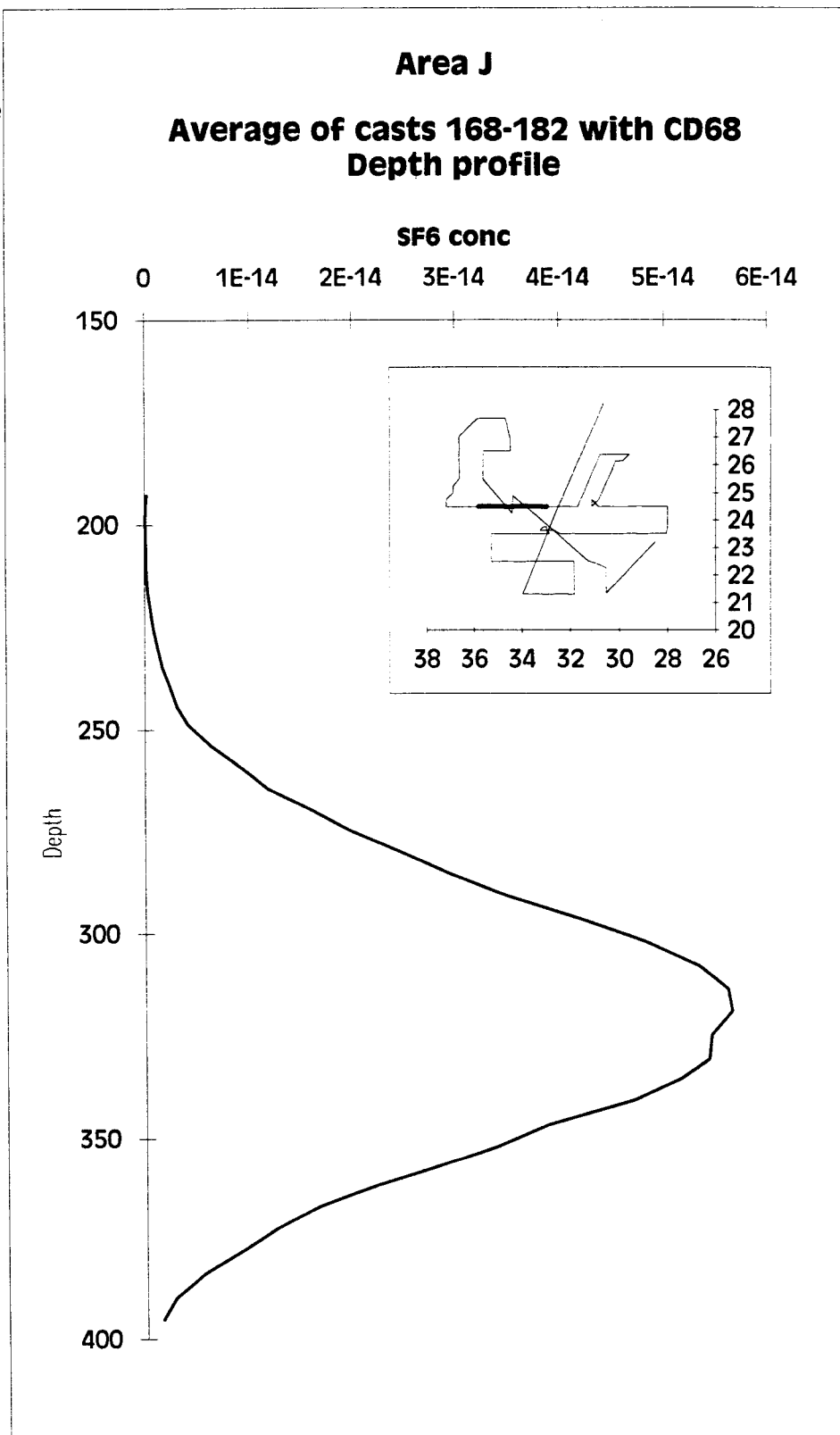


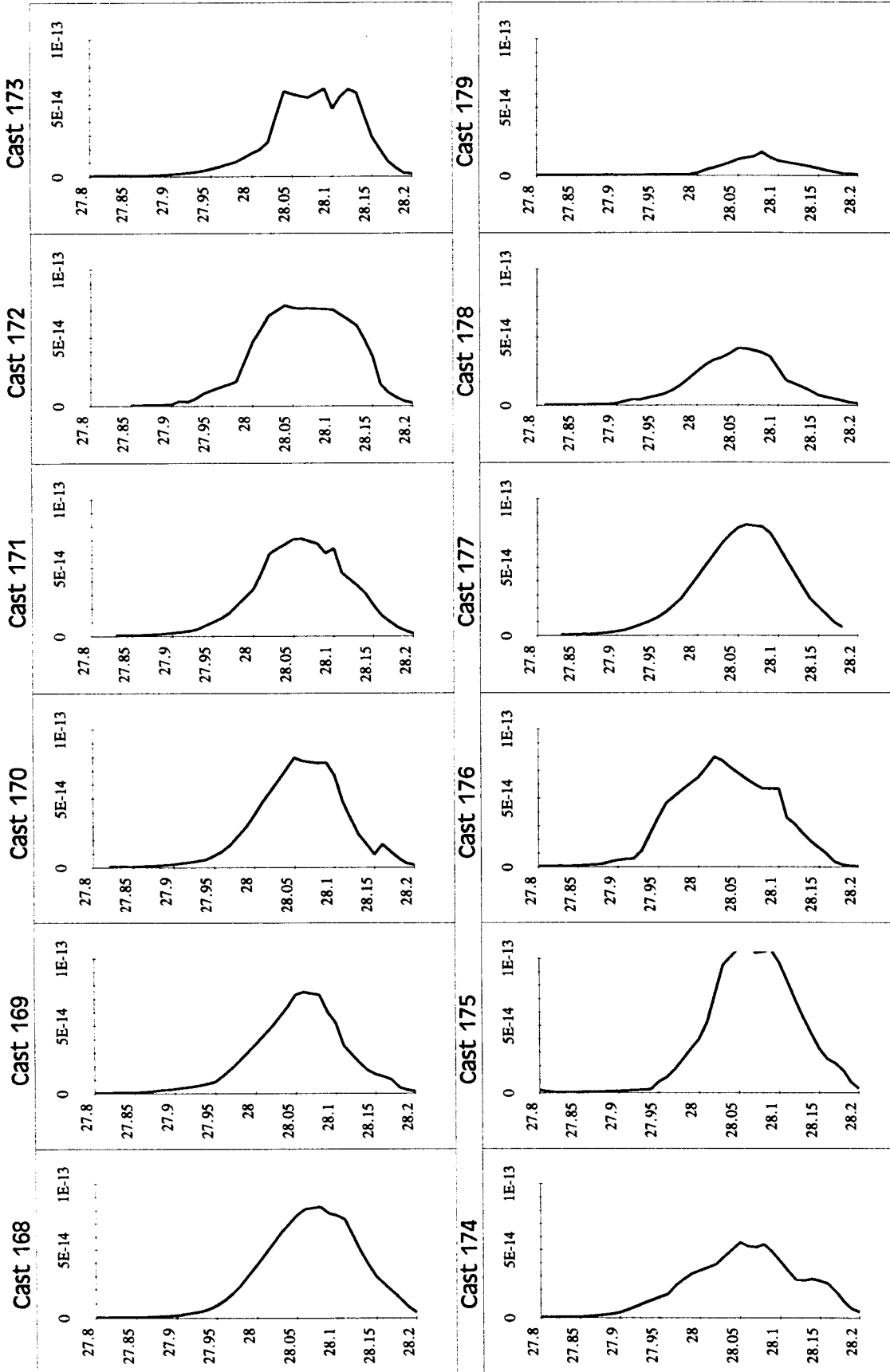


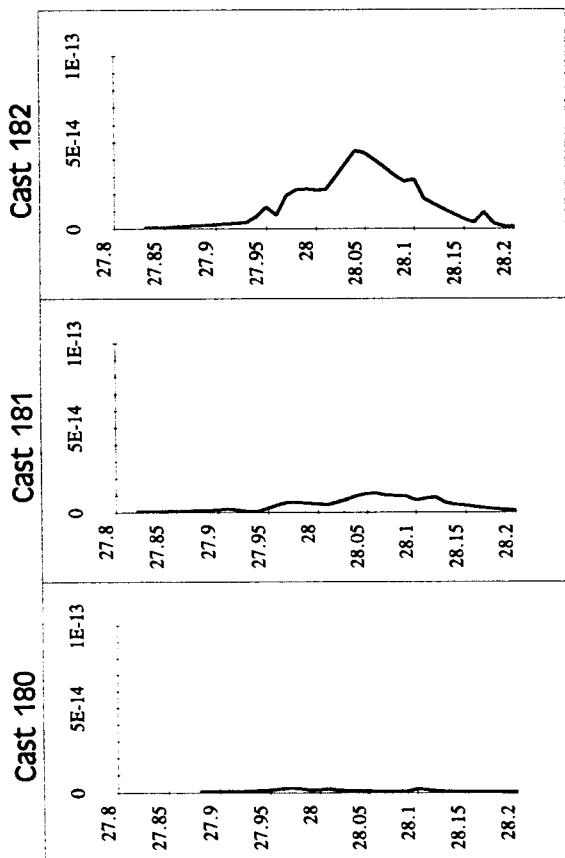
Area J

Column Integral in density space:

8.04E-15
Mean sigmap
28.05943
Mean cd68 pressure
318.6186
RMS CD 68 Width:
30.89238



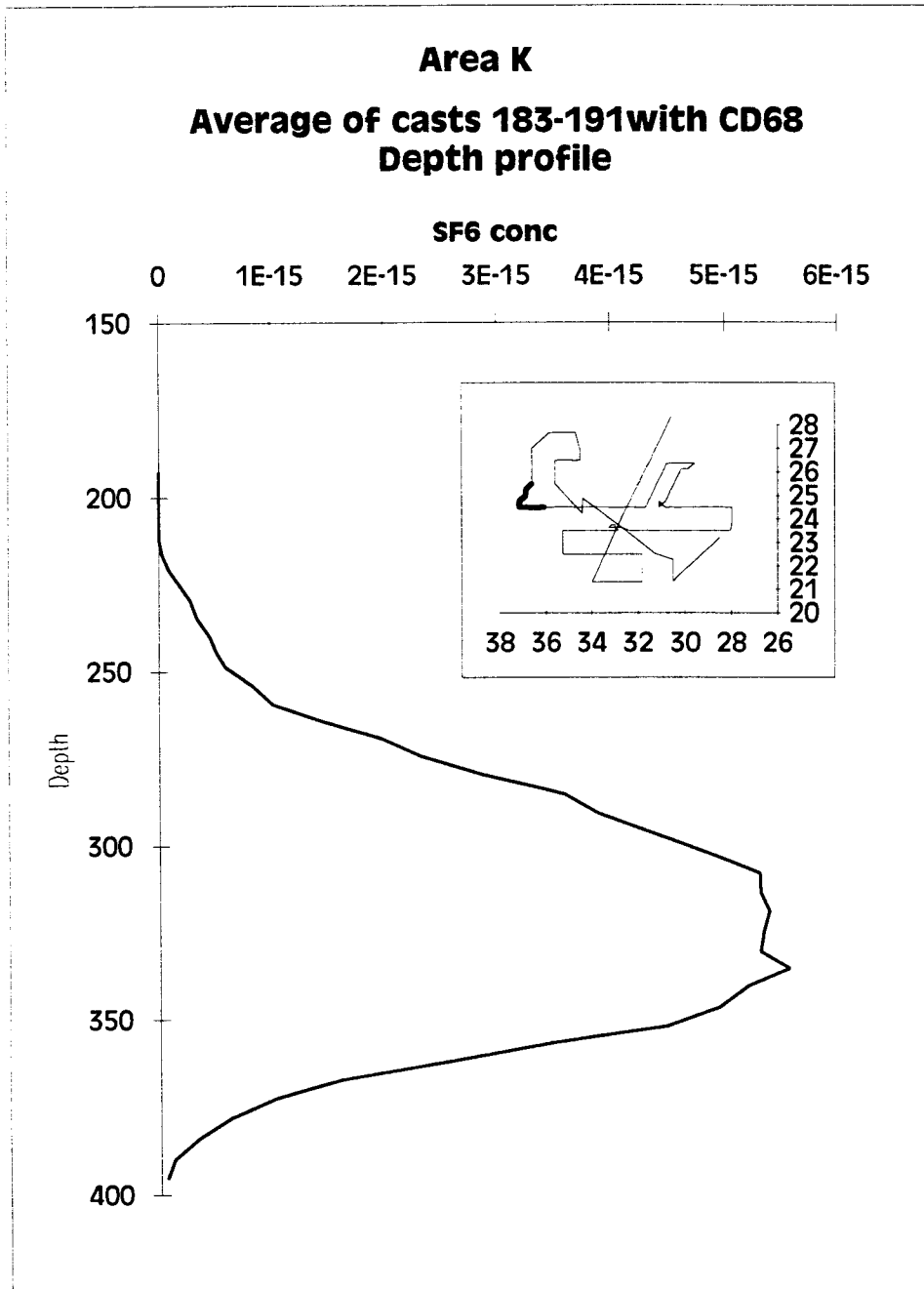


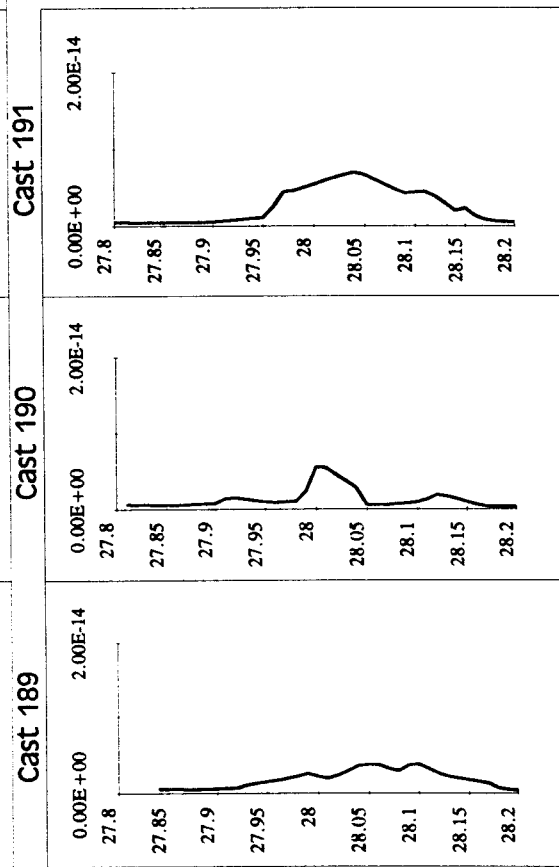
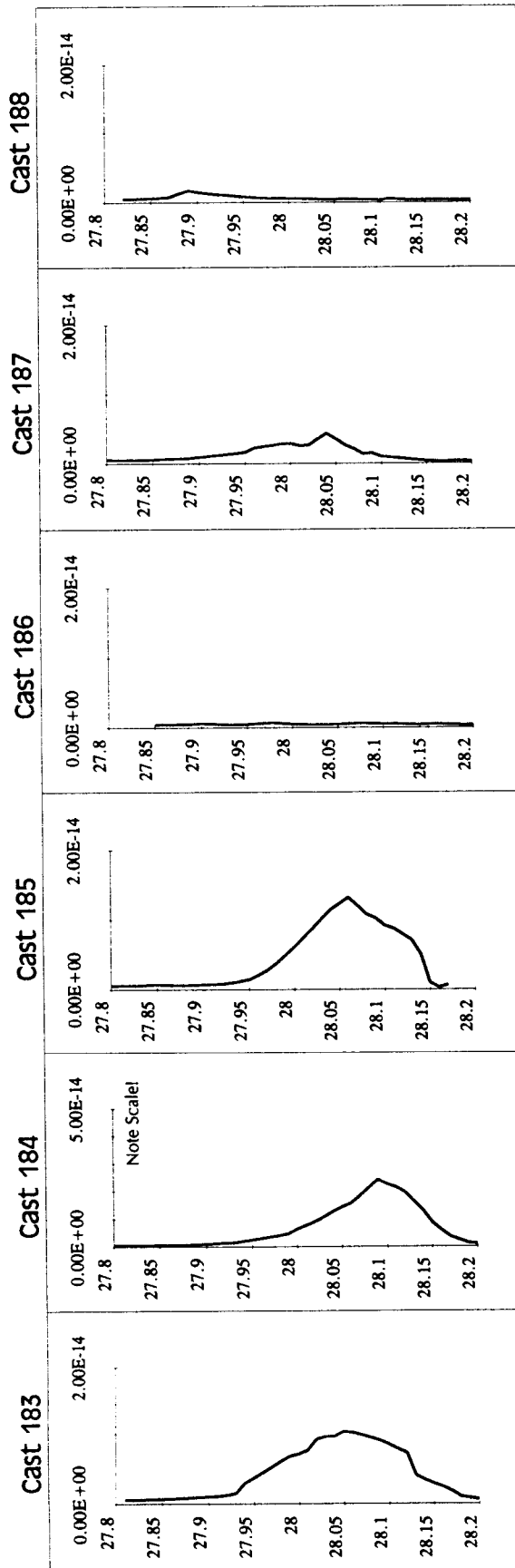


Area K

Column Integral in density space:

8.66E-16
Mean sigmap
28.05655
Mean cd68 pressure:
317.0606
RMS CD 68 Width:
31.81439





Area L

Column Integral in density space:

1.53E-15

Mean sigmap

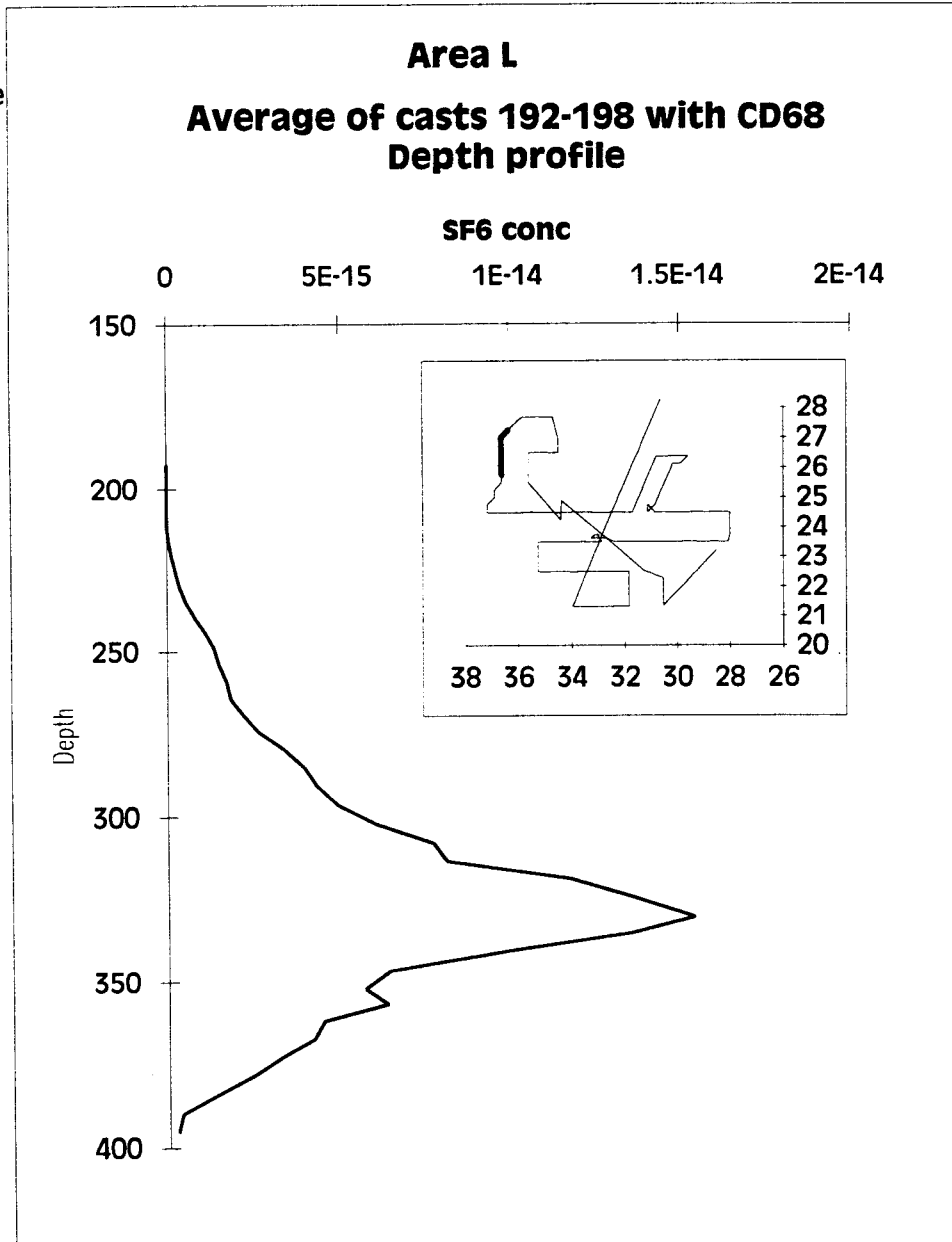
28.06673

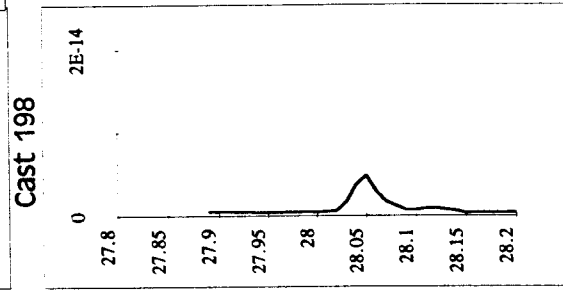
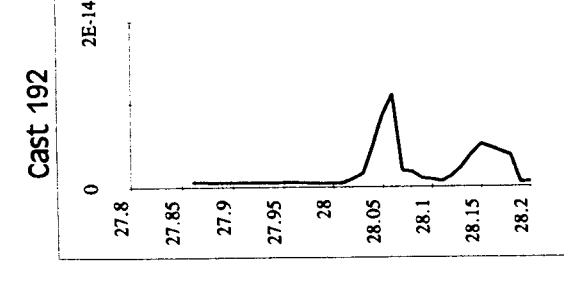
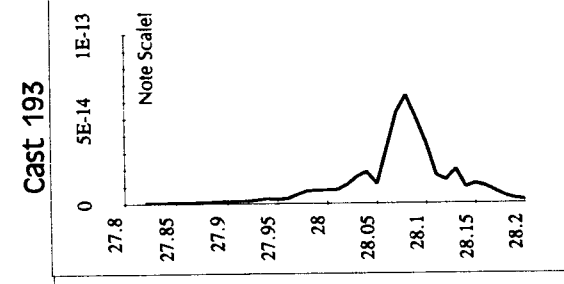
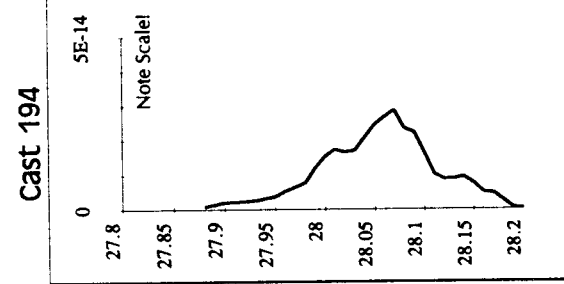
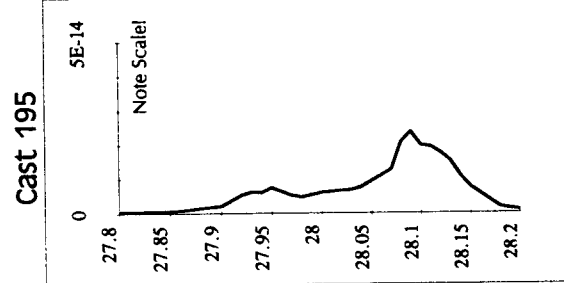
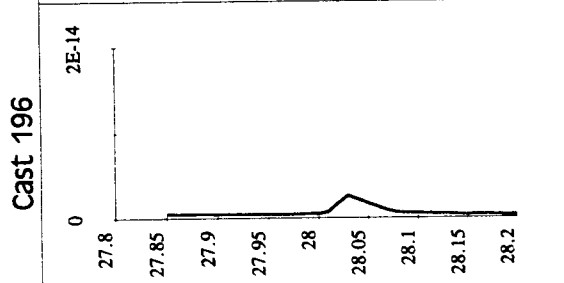
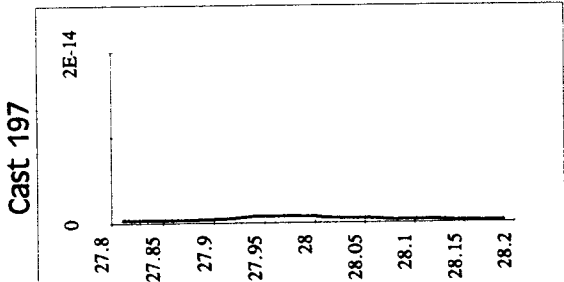
Mean cd68 pressure

322.6952

RMS CD 68 Width:

31.44292





Area M

Column Integral in density space:

3.07E-15

Mean sigmap

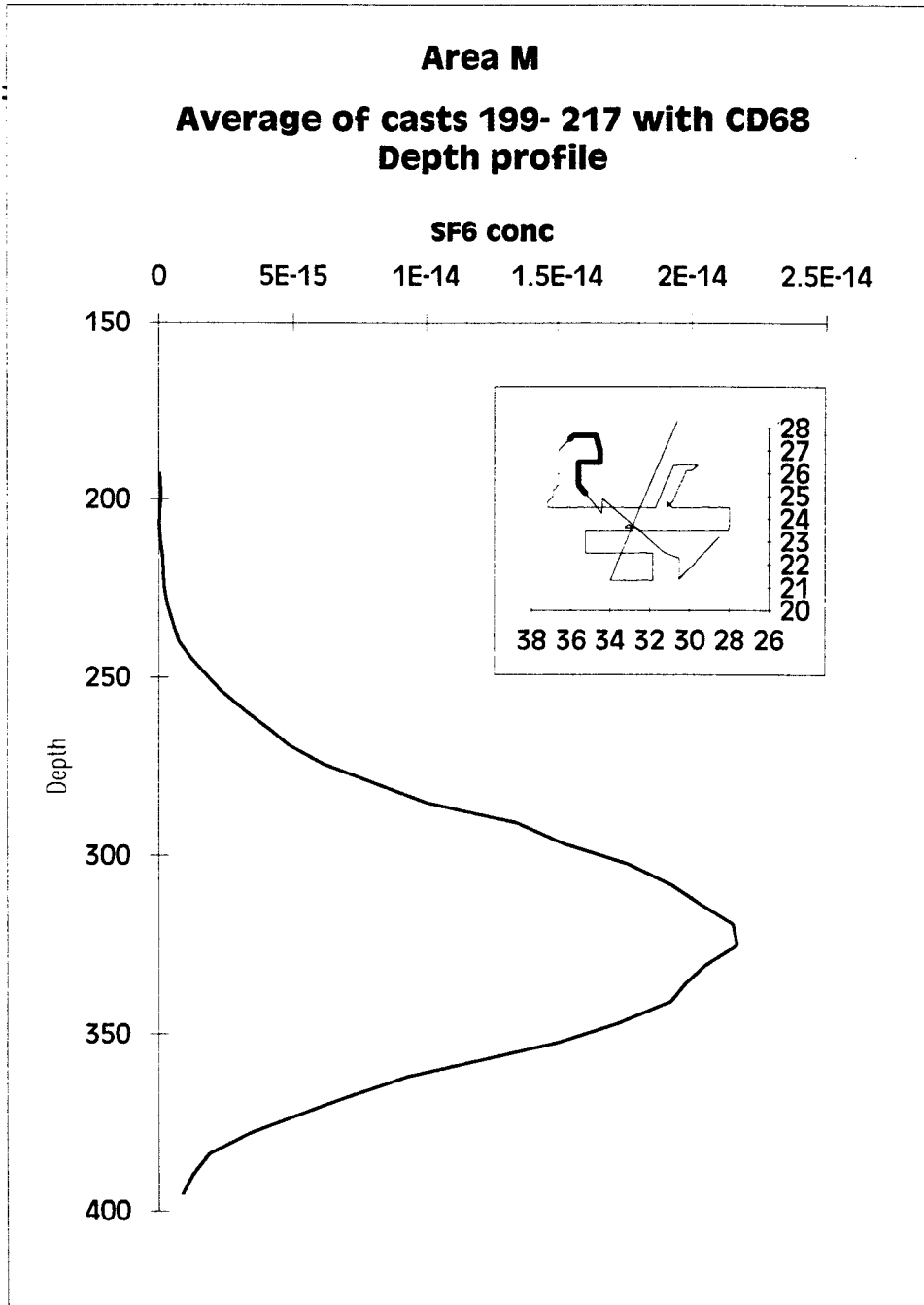
28.06356

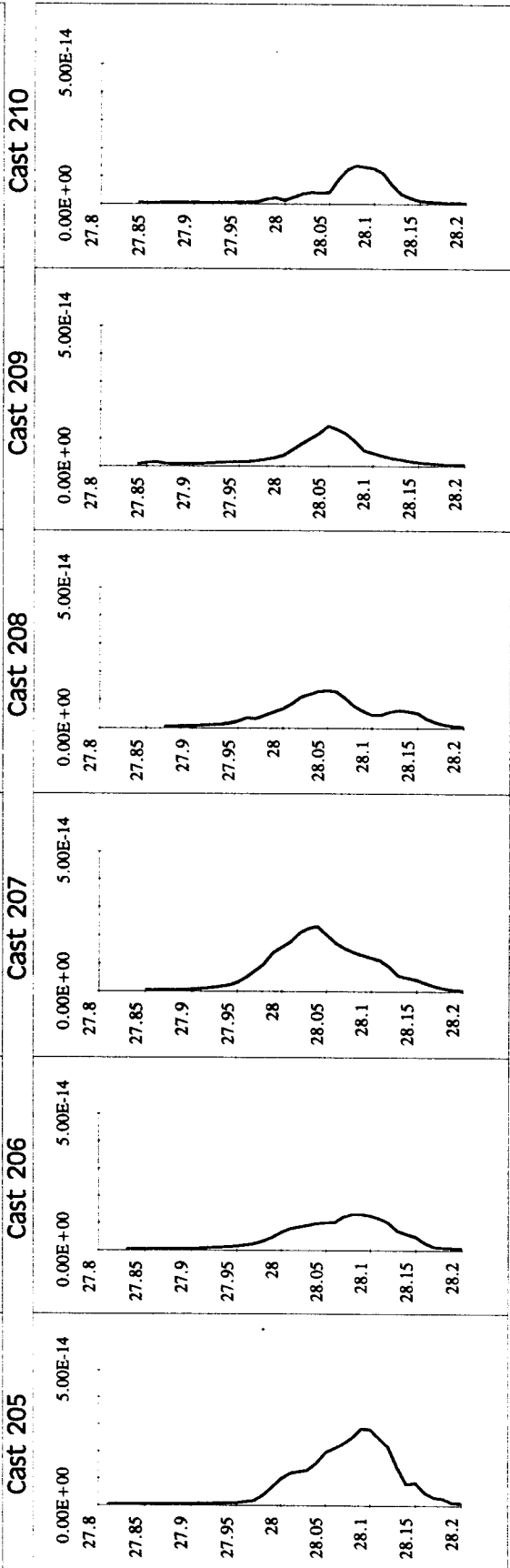
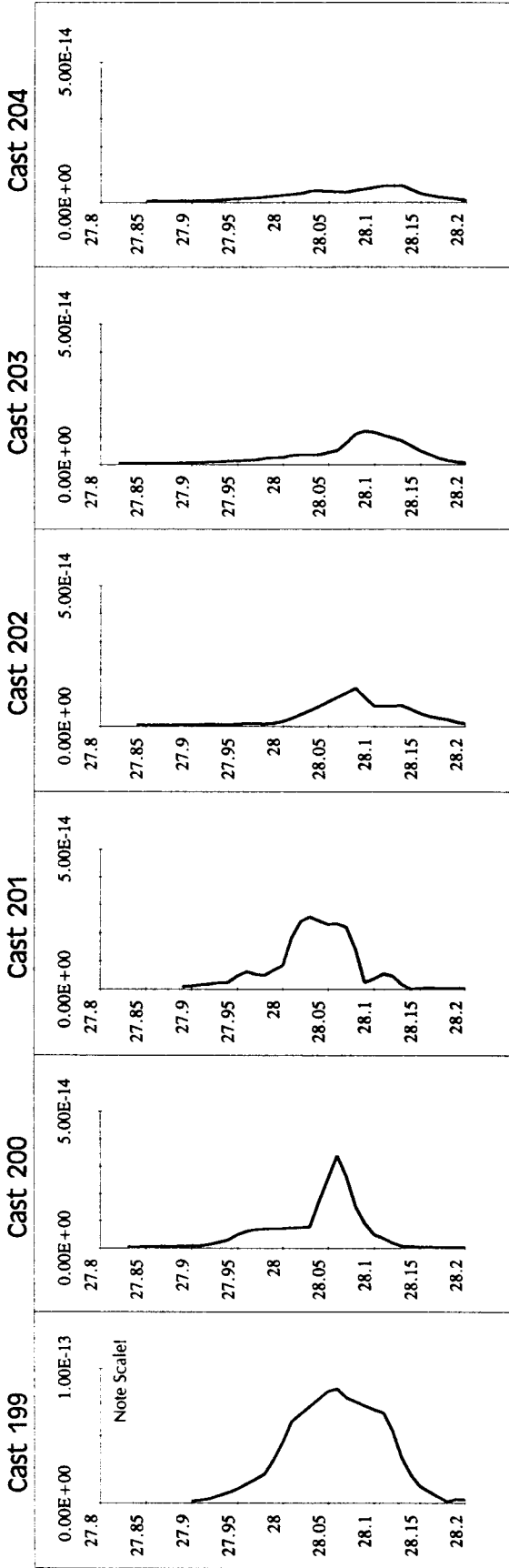
Mean cd68 pressure:

320.8799

RMS CD 68 Width:

30.6507





Area N

Column Integral in density space:

2.06E-15

Mean sigmap

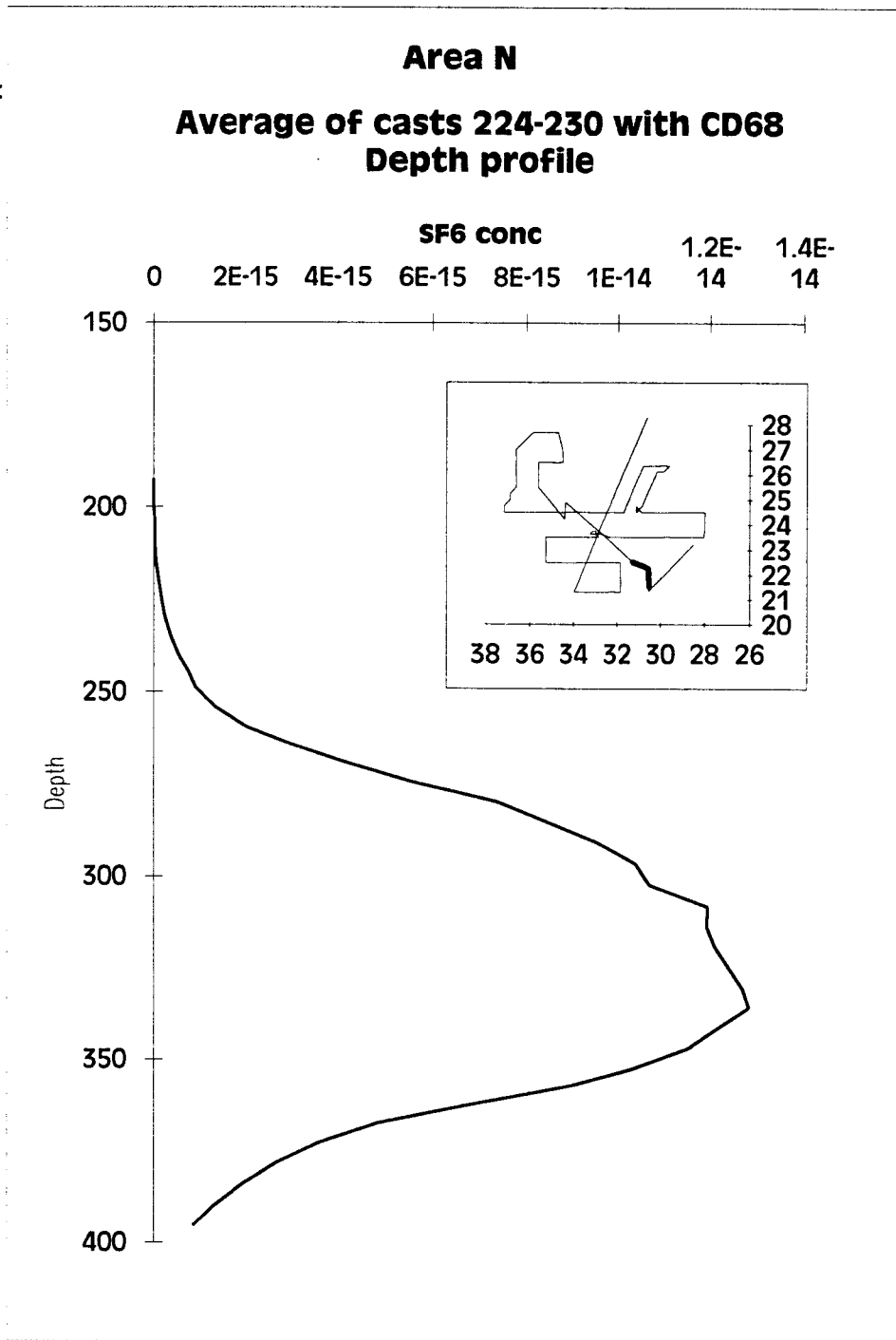
28.06319

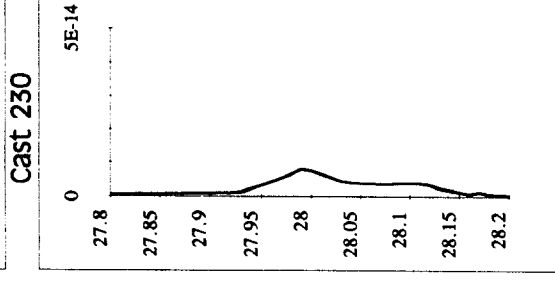
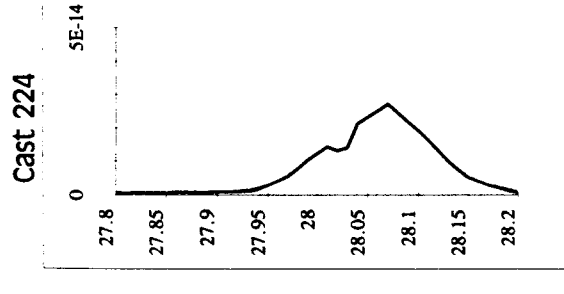
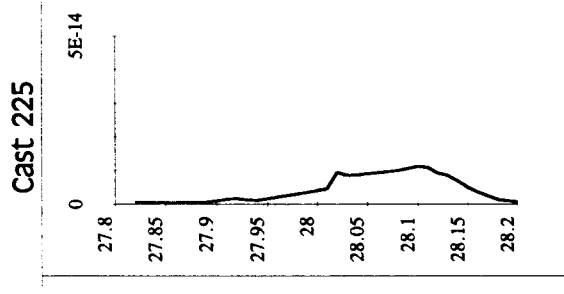
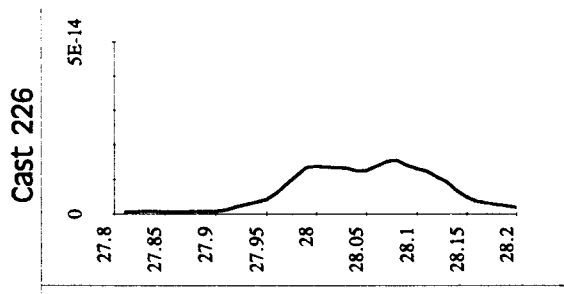
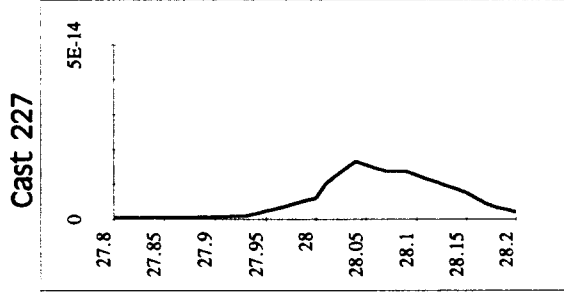
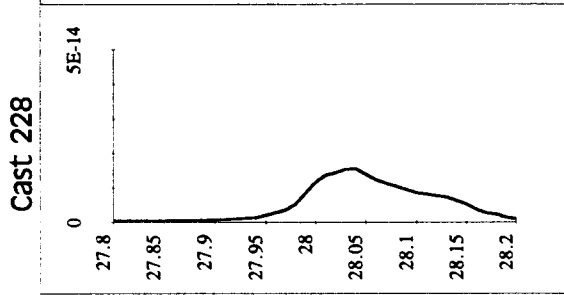
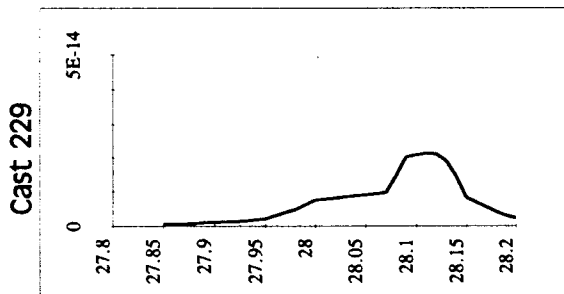
Mean cd68 pressure:

320.6238

RMS CD 68 Width:

32.03053





Column Integral in density space:

3.2E-15

Mean sigmap

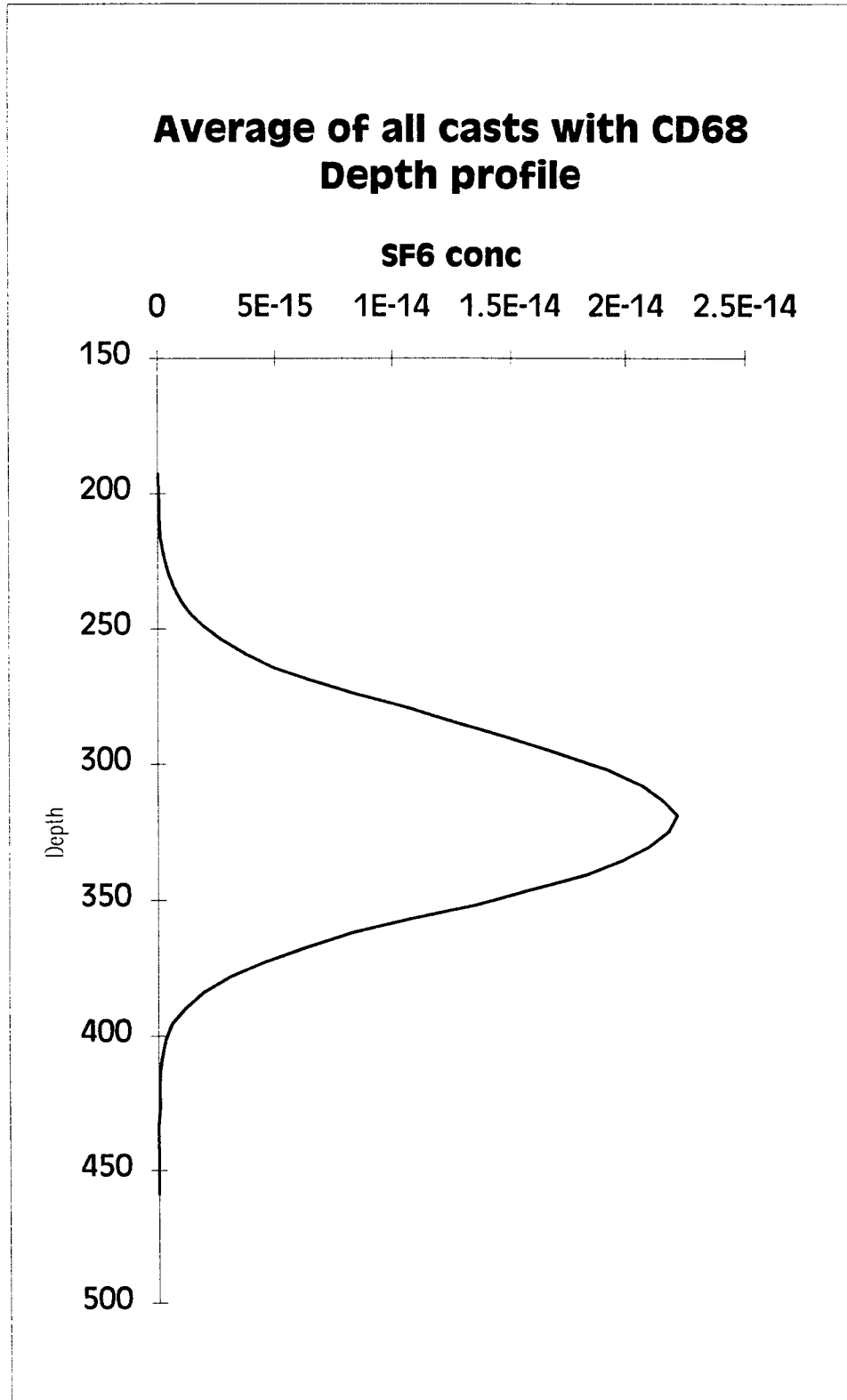
28.05779

Mean cd68 pressure:

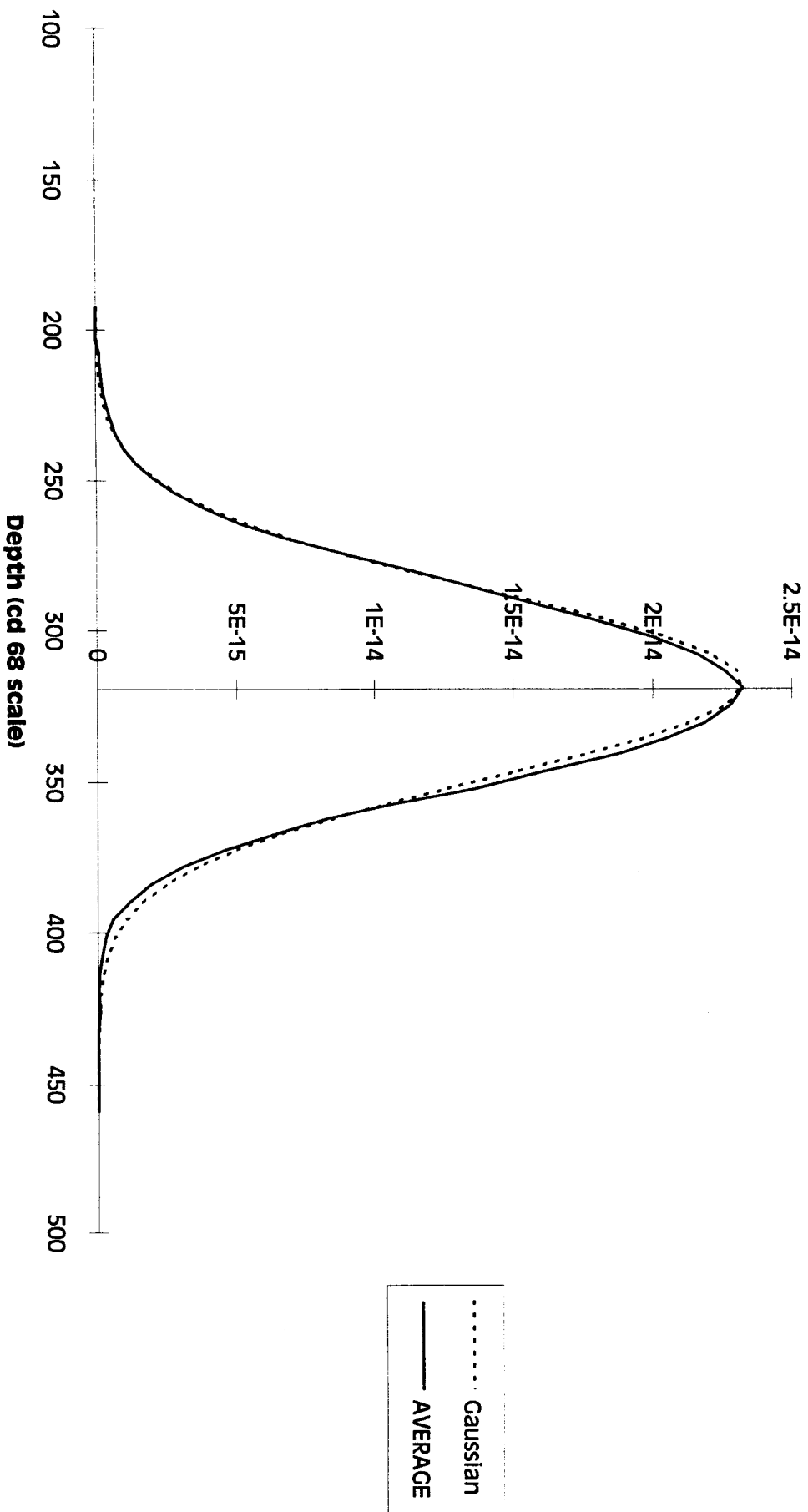
317.7156

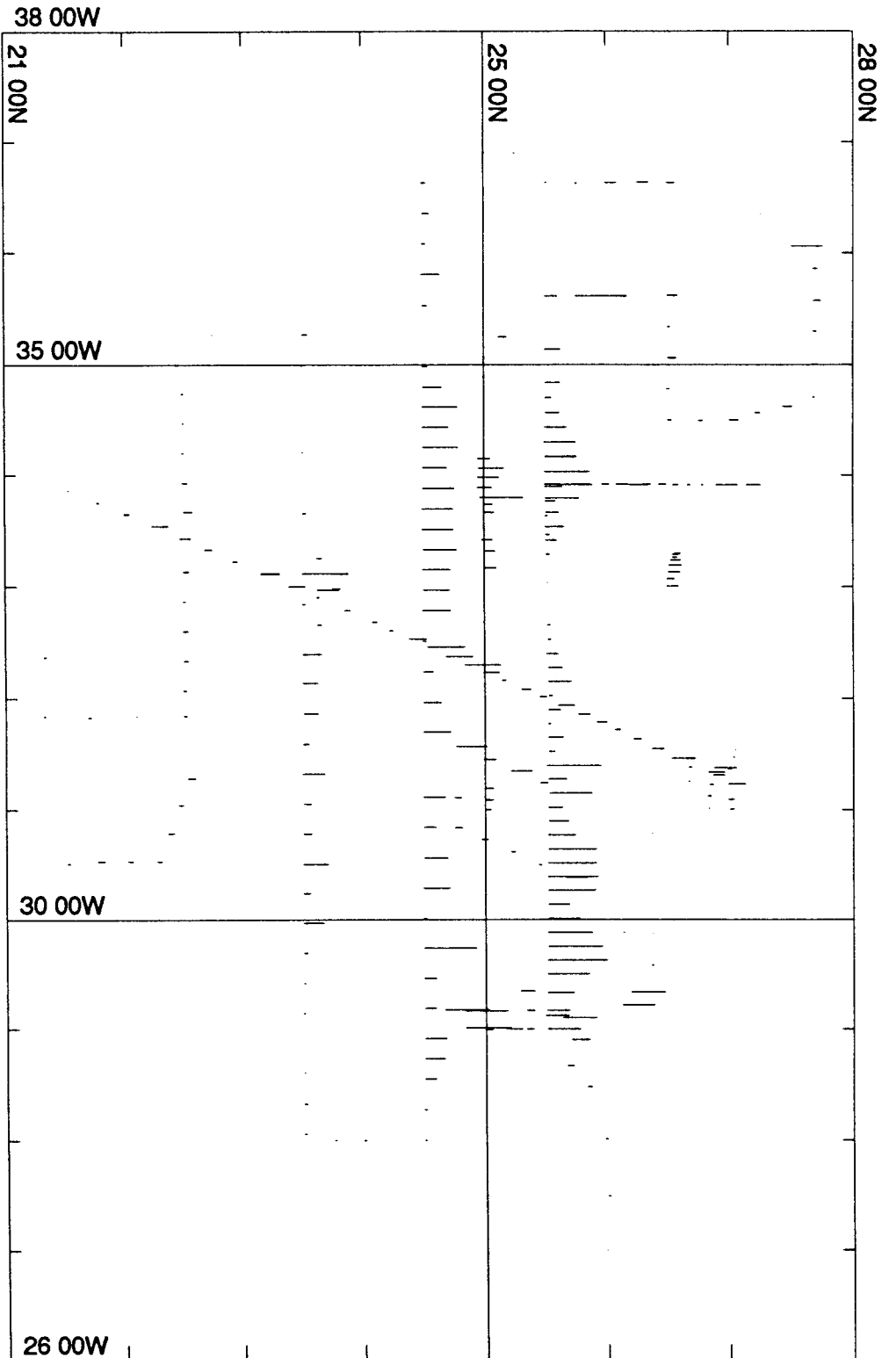
RMS CD 68 Width:

31.14419



Mean SF6 Profile -- compared to gaussian with same RMS width





MERCATOR PROJECTION

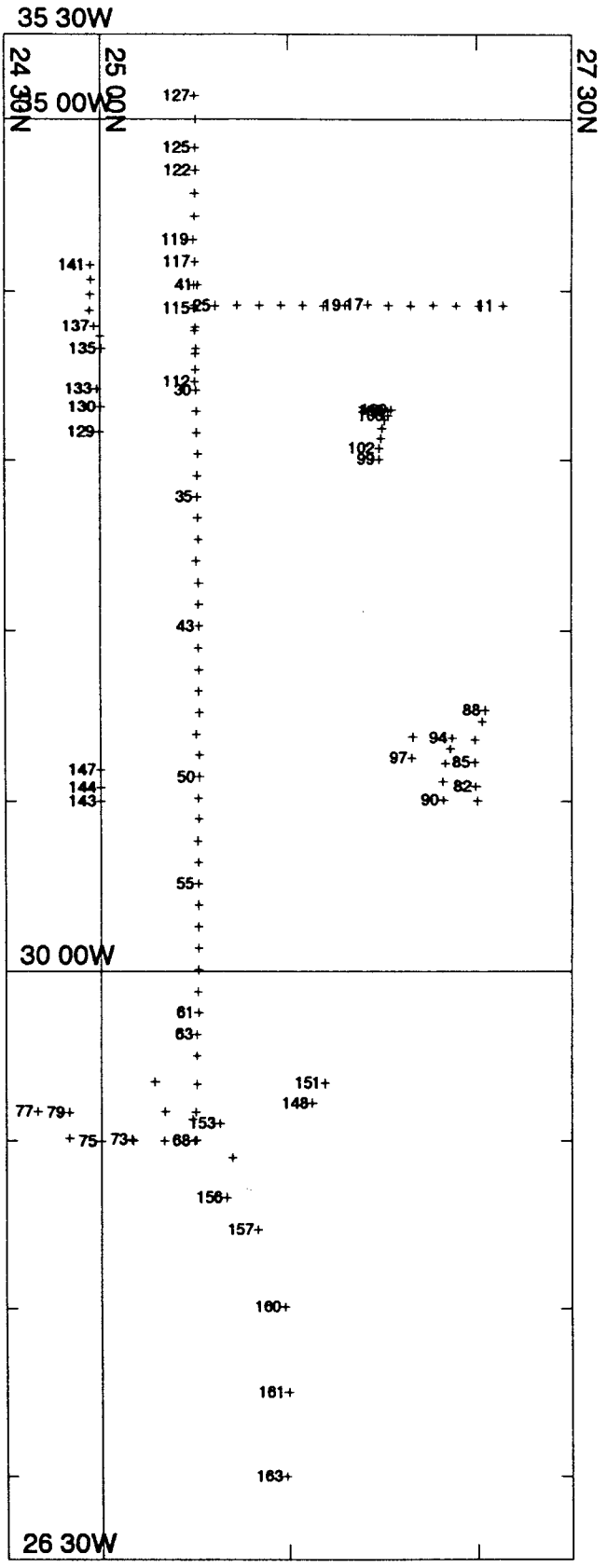
SCALE 1 TO 5000000 (NATURAL SCALE AT LAT. 39)


INTERNATIONAL SPHEROID PROJECTED AT LATITUDE 0

RRS Charles Darwin 78 & CSS Hudson SF6 Column Integrals

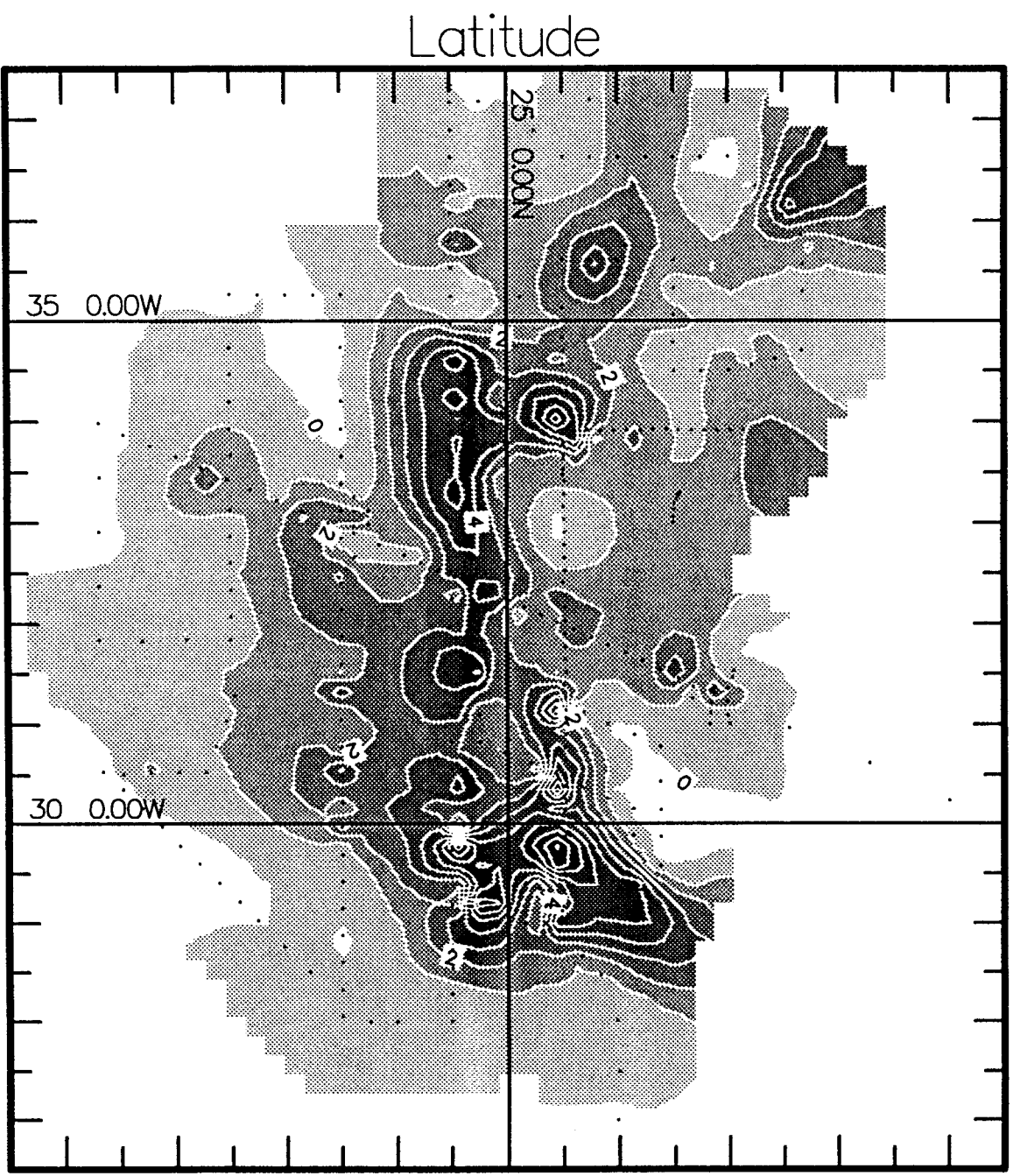
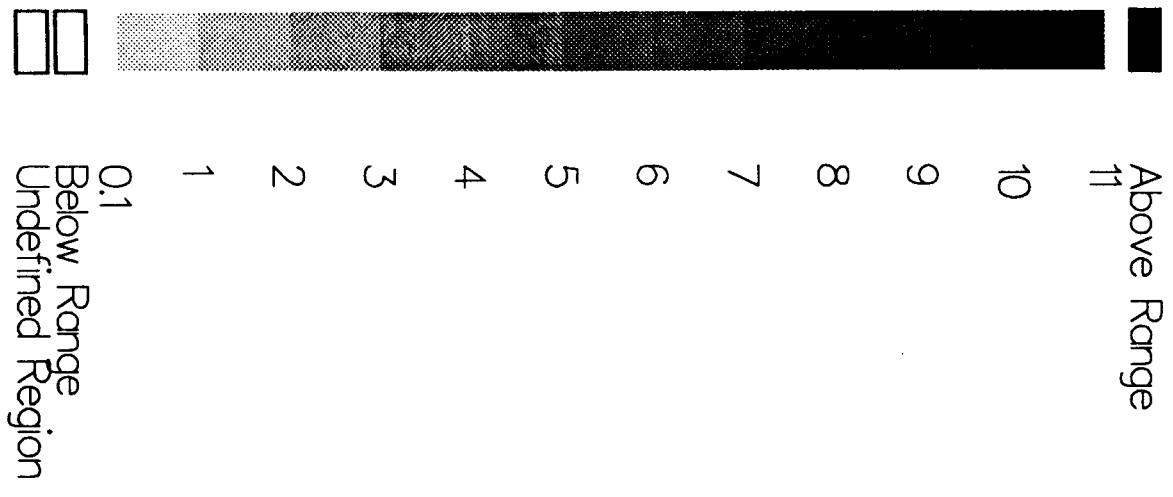
+

+




MERCATOR PROJECTION
 SCALE 1 TO 3600000 (NATURAL SCALE AT LAT. 39)
 INTERNATIONAL SPHEROID PROJECTED AT LATITUDE 0
 CSS Hudson CTD Stations in Work Area

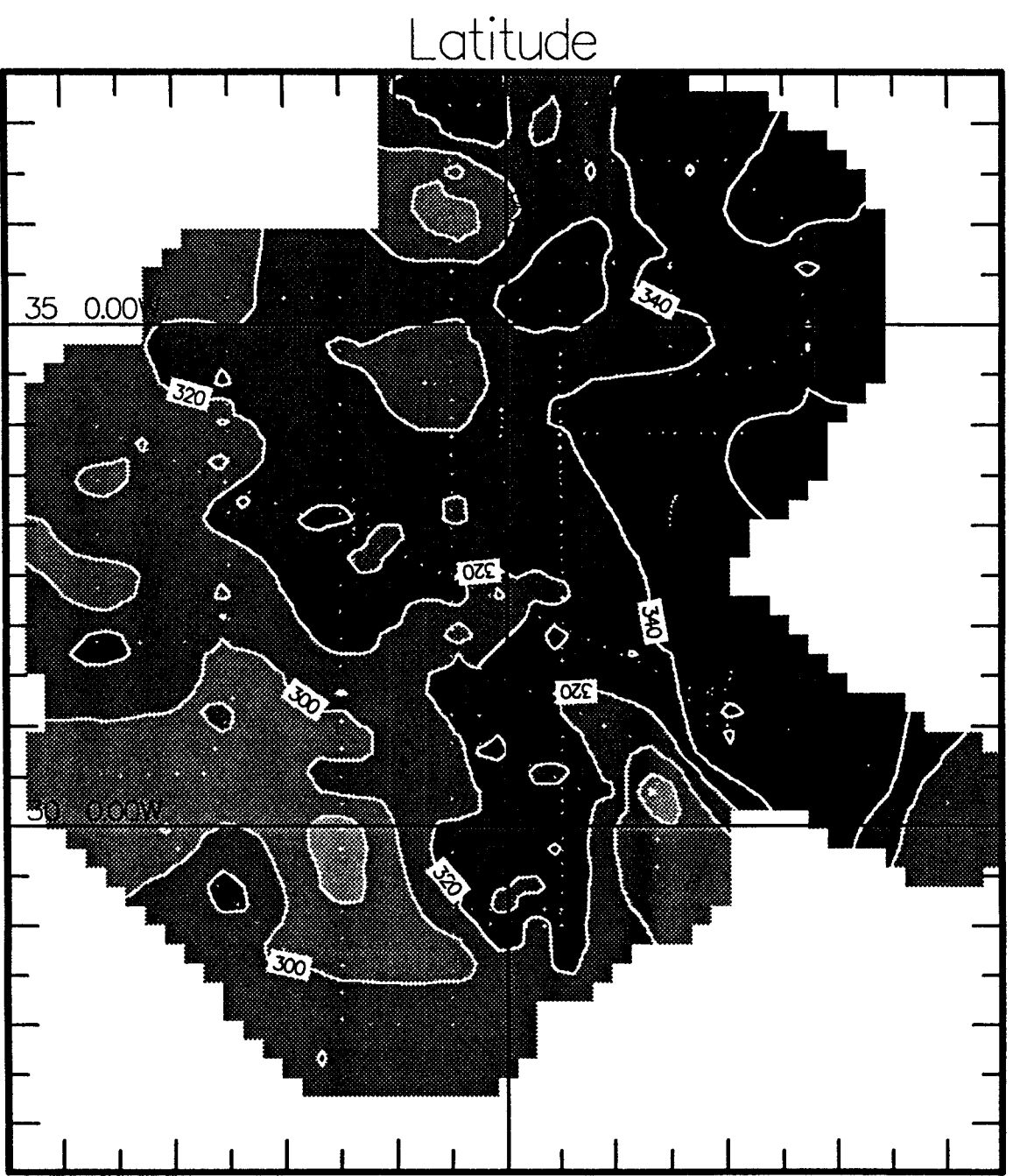
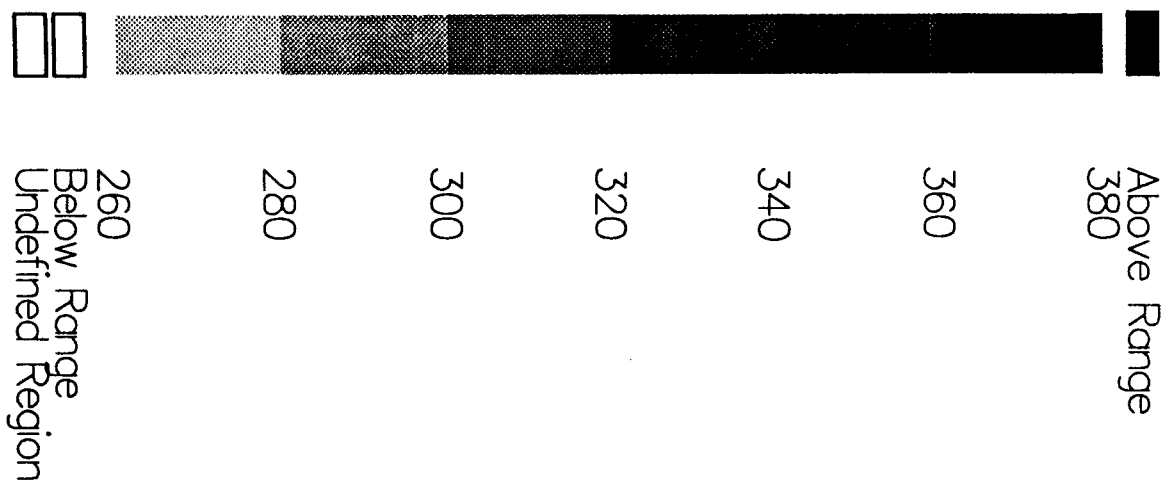
GRID NO. 1



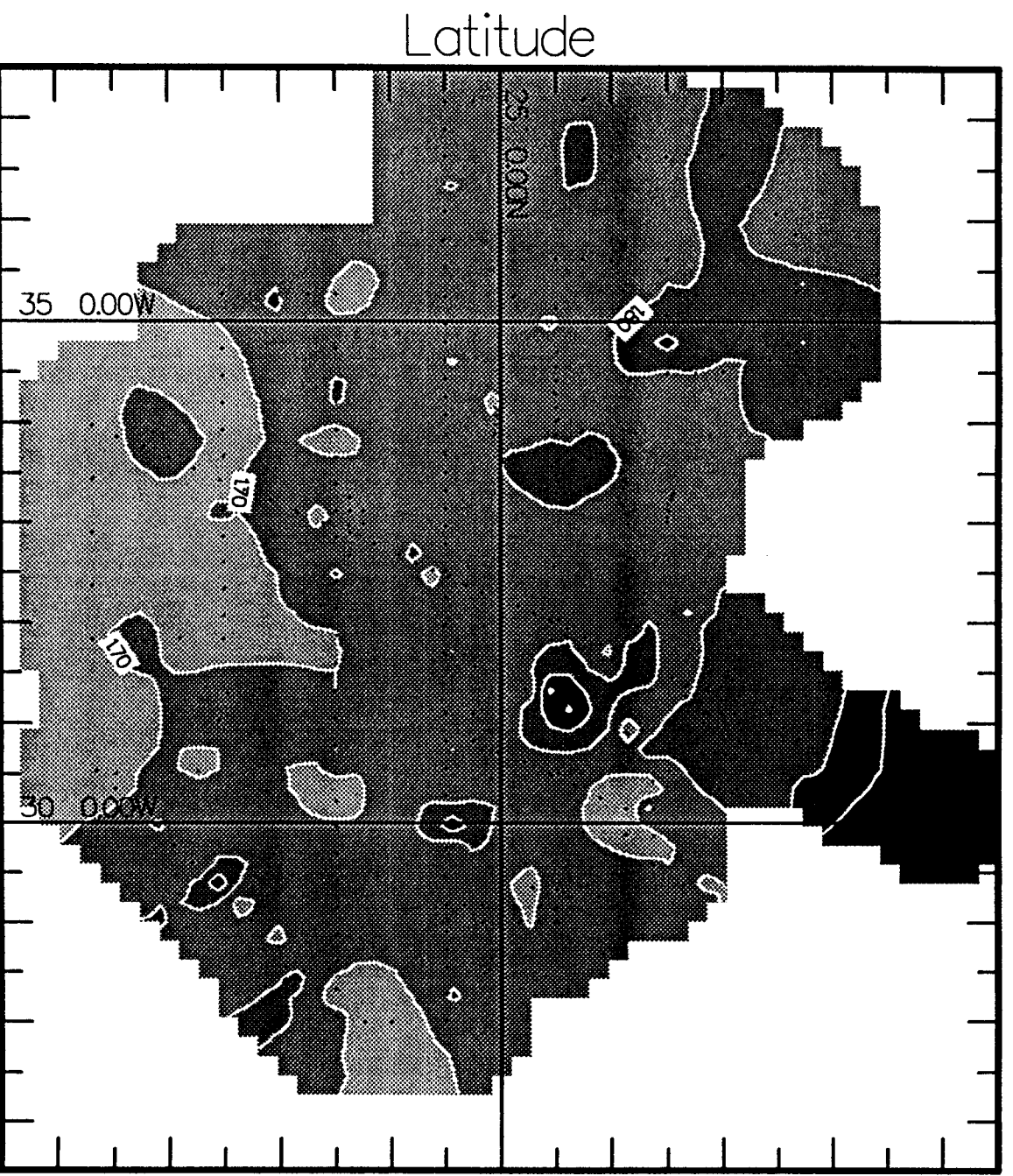
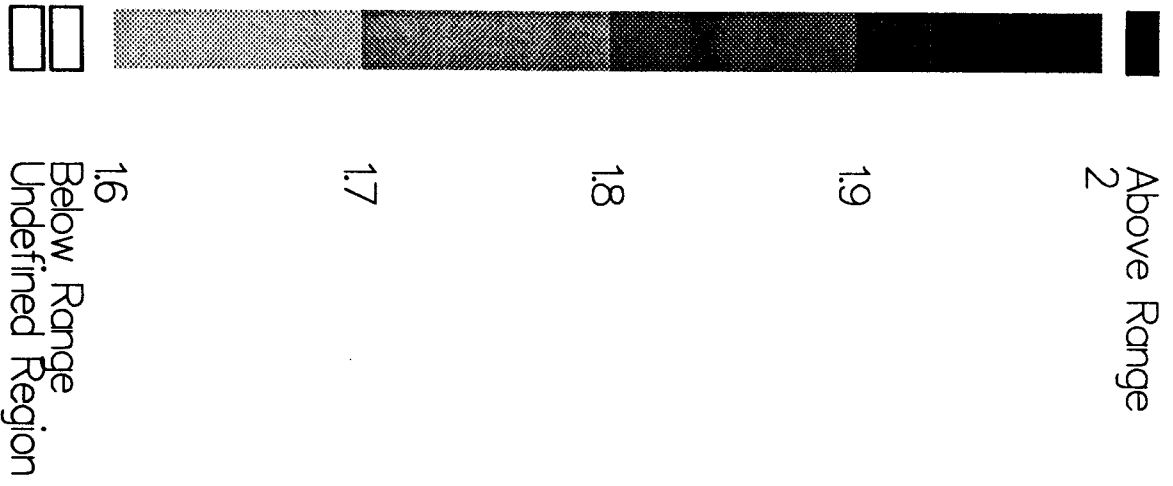
RV


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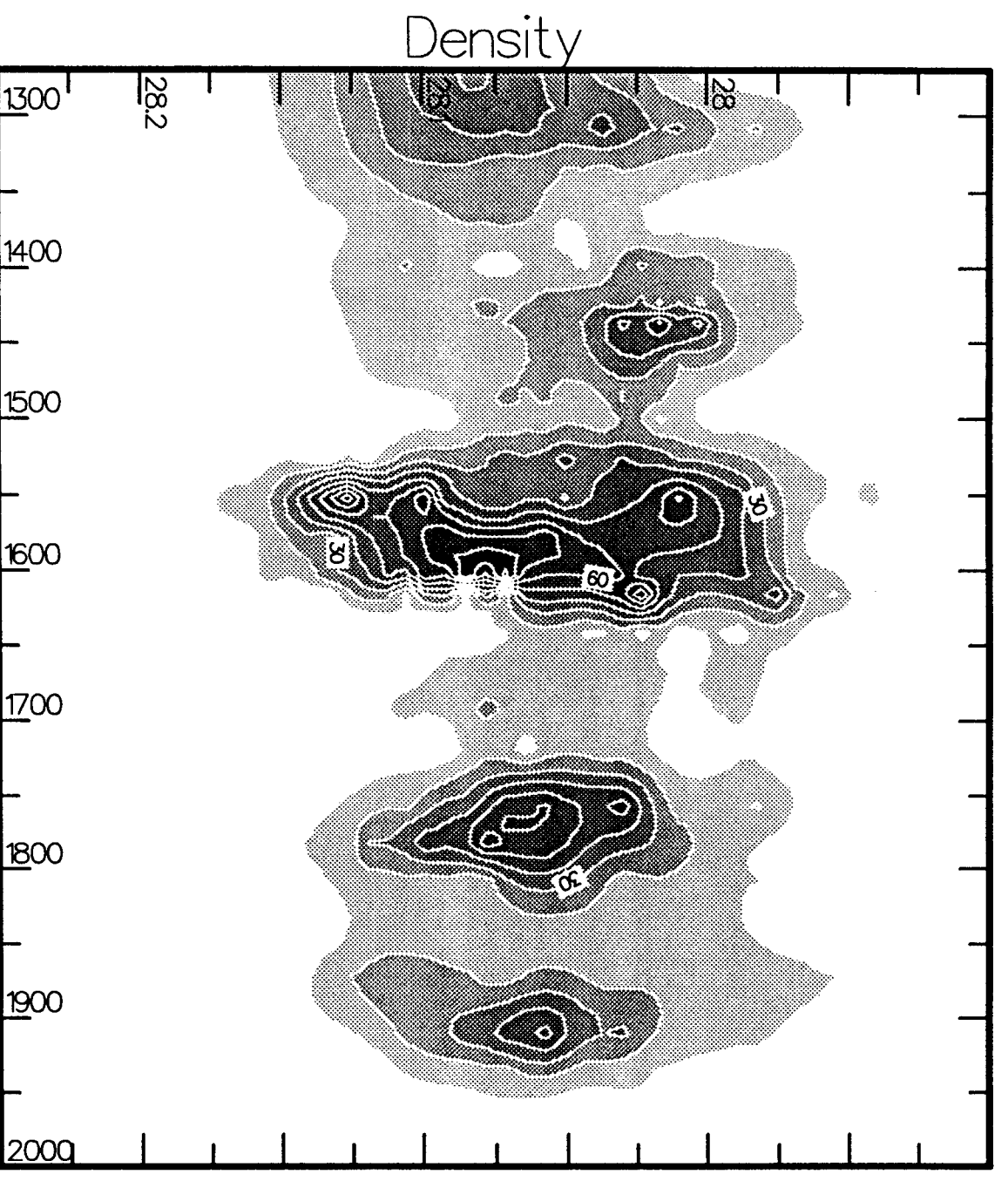
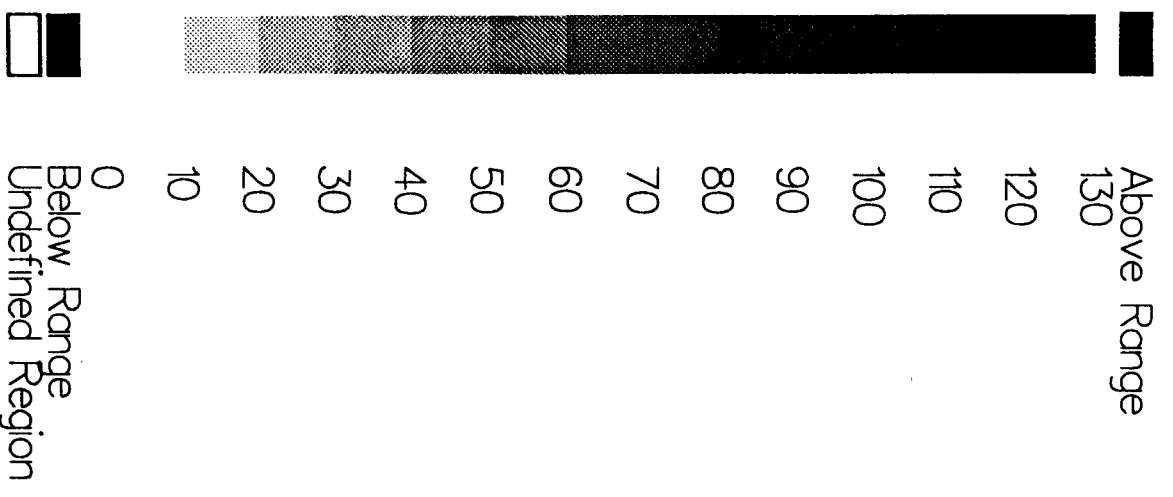
VARIARI F.--SFG C. Internal



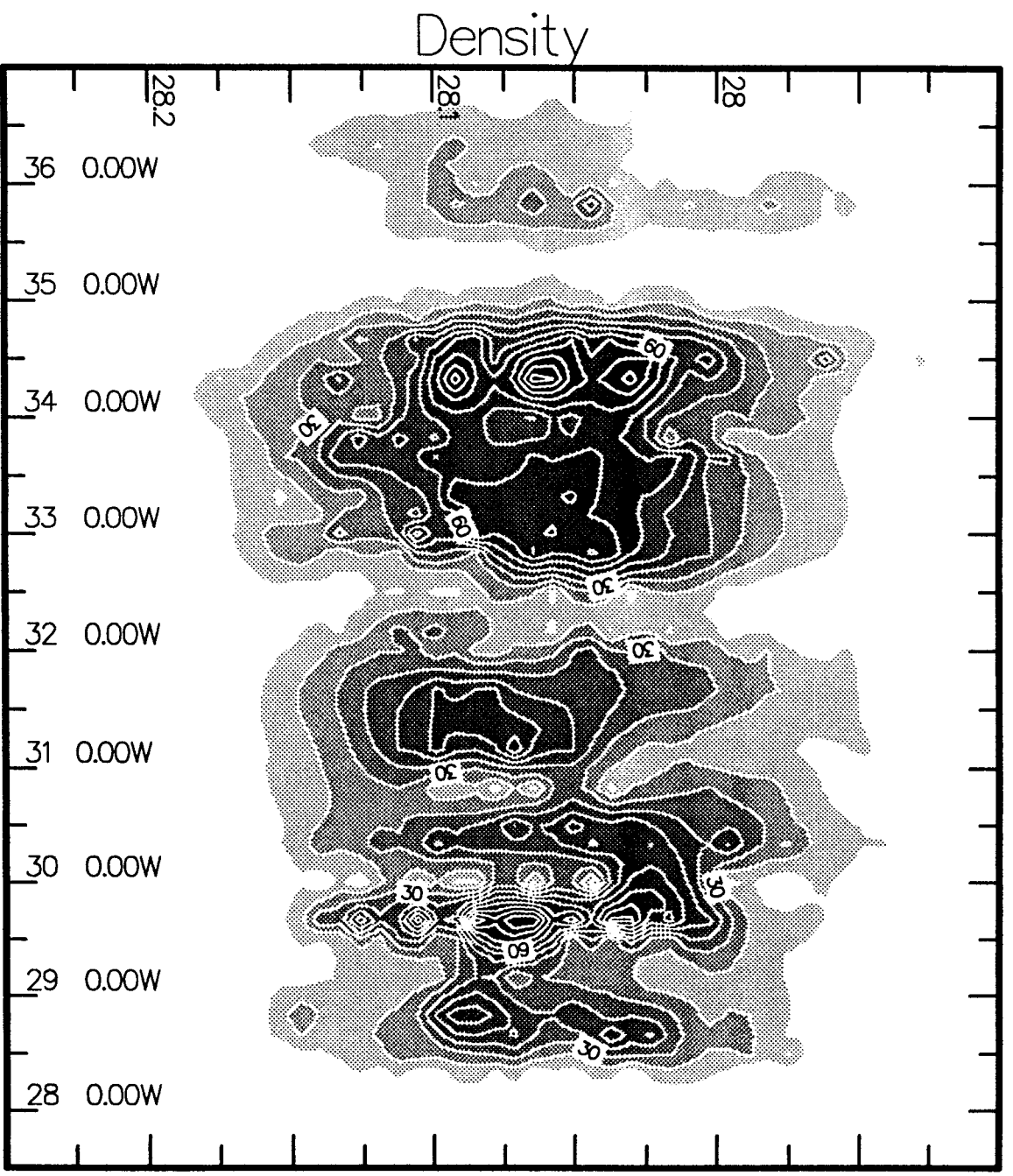
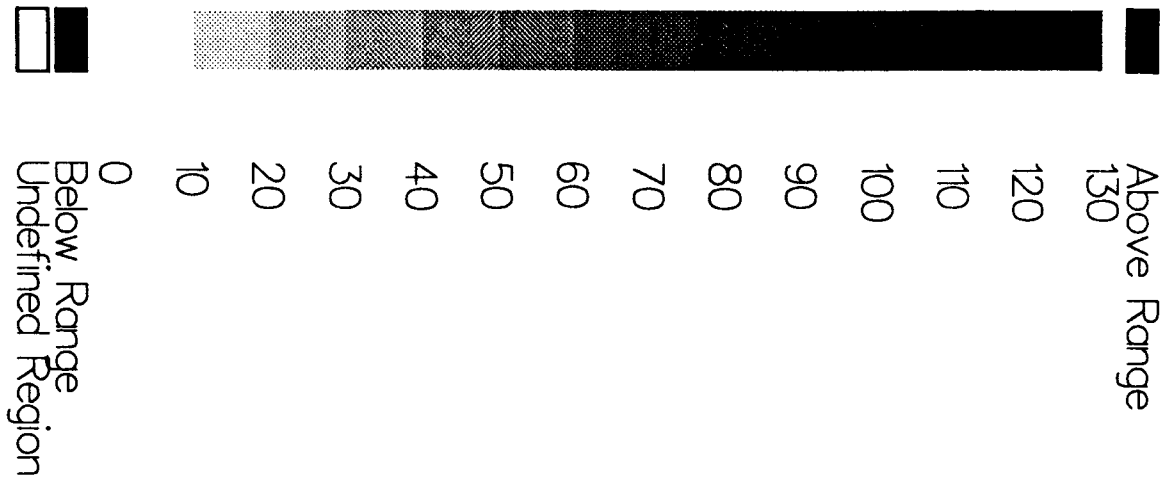
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VARIARI F.--Pressure




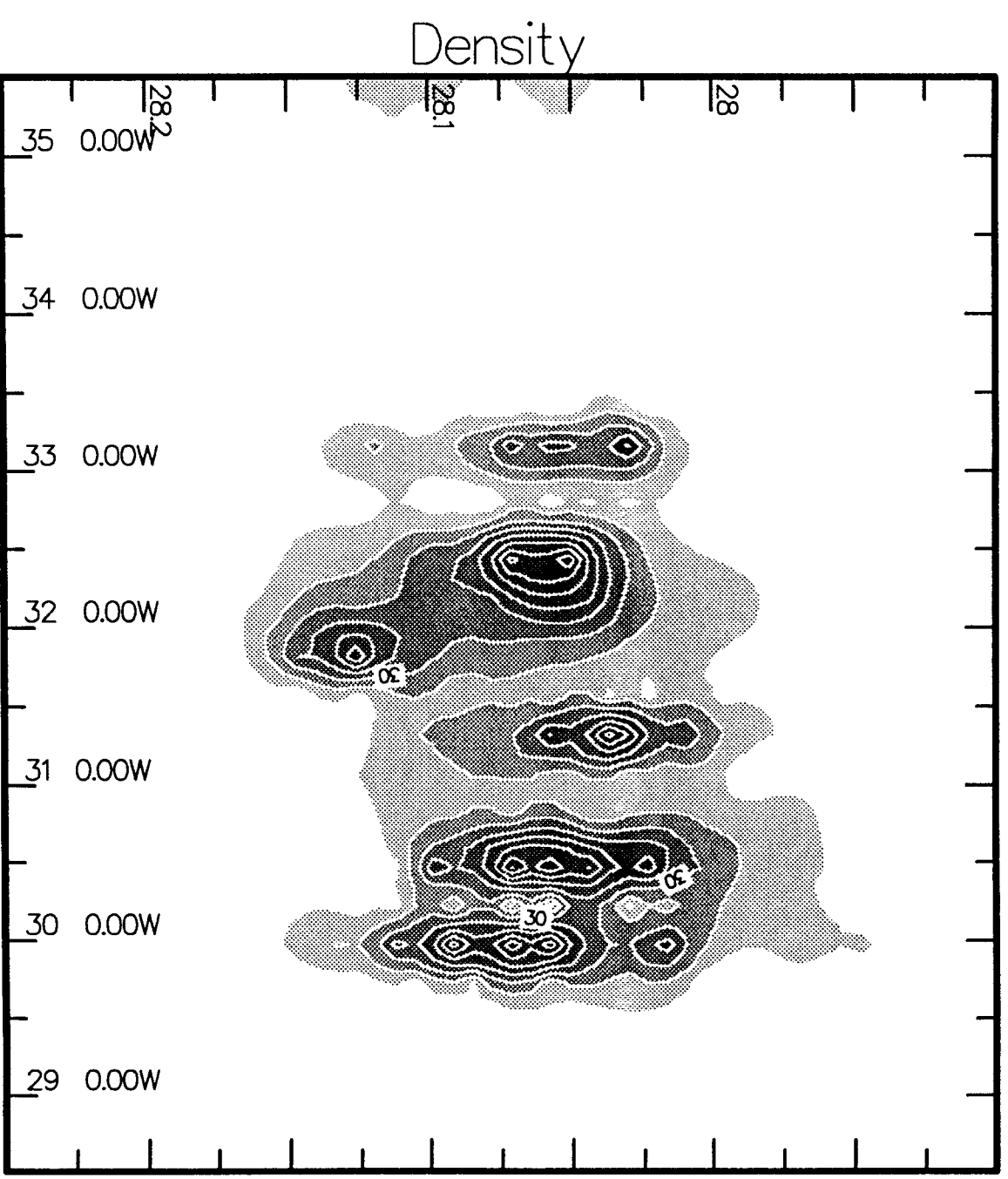
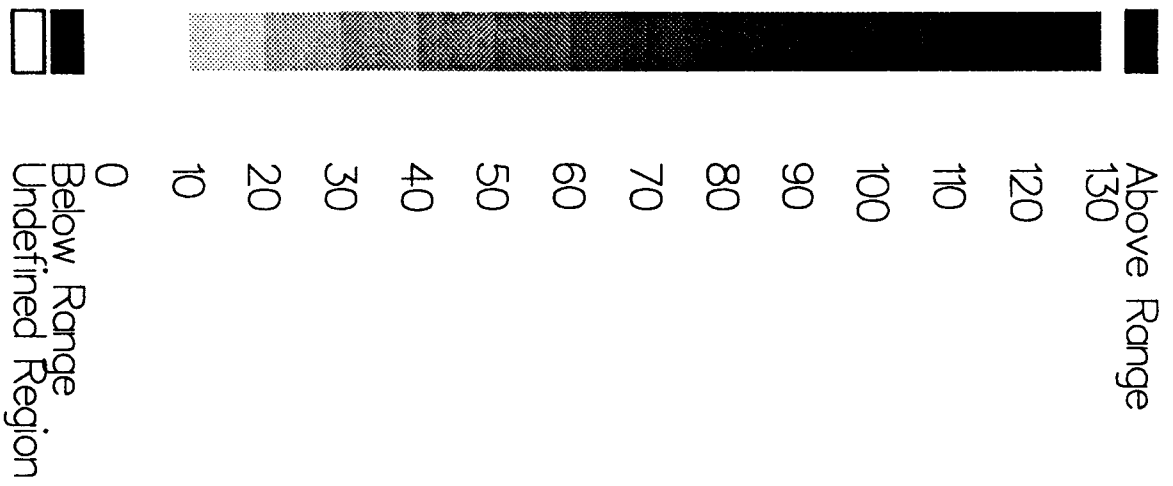

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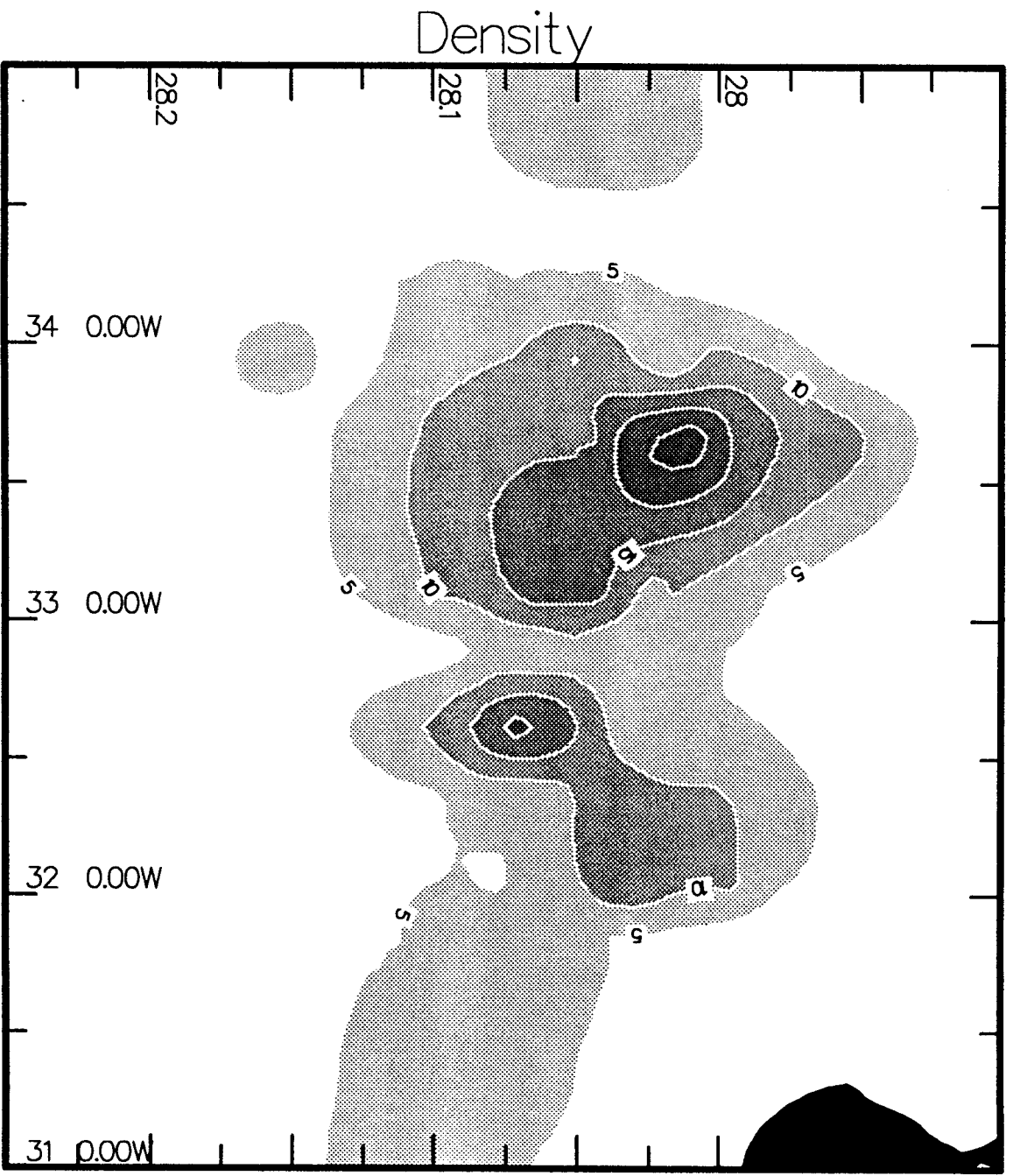
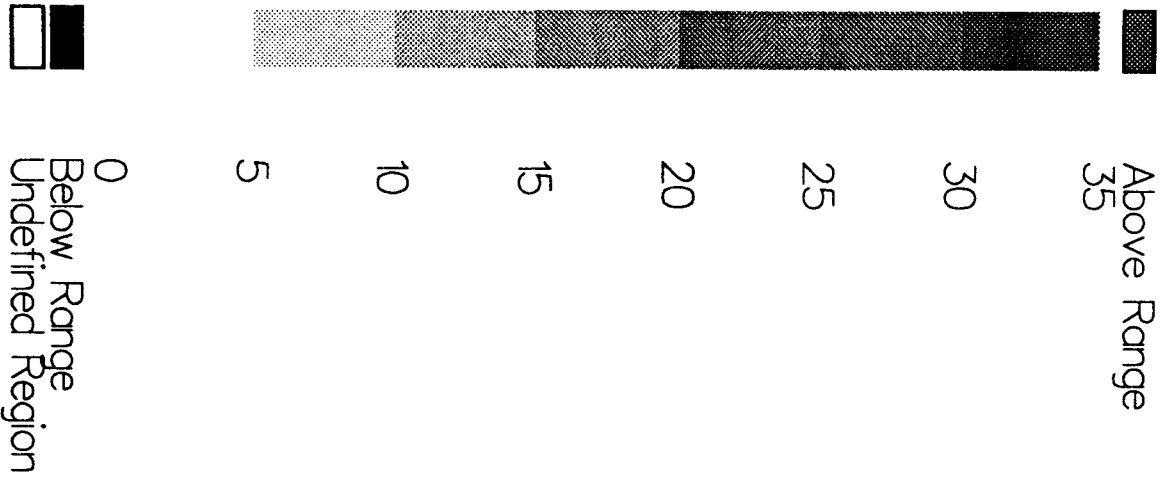
AV
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VARIARI F.--SF6




 TITLE:-- 'RRS Charles Darwin Cruise 78 SF6 casts (24.5 N)
 VARIARI F.--SF6



AV
TITLE:-- "RRS Charles Darwin Cruise 78 SF6 casts (23.5 N)
VARIARI F.--SF6



RM
TITLE:- 'RRS Charles Darwin Cruise 78 SF6 casts (22.5 N)
VARIARI F.-SF6

APPENDIX I: CTD CALIBRATIONS

CTD System

During the cruise 202 CTD casts were completed using an RVS Neil Brown MIII CTD (SN 01-1195) and WHOI 24 bottle rosette pylon and frame. Despite a few breakdowns at the start of the cruise the system worked very well and only three hours were lost when the CTD cable was reterminated. Also 5 casts were completed using the sled and winch control system.

CTD Calibration

Temperature: The CTD temperature calibration was found to drifted by less than one milli-degrees from last year's NATRE cruise and was therefore left unchanged.

Pressure: The pressure reading had increased by 4.7 decibars compared with last year and this was subtracted from the data.

Salinity: Salinity samples were taken from twenty four casts. (See Table) An average offset of 28 ppm was found from the first ten casts and this was added to the CTD data. The last ten casts showed that the CTD remained in calibration for the rest of the cruise.

TABLE I: Salinity calibrations using Autosal: note CTD was recalibrated after station 53: archived data for stations 1-53 were re-calculated using the new calibration.

Cast Number	Samples	Reading
1	23	0.0348
2	24	0.031
4	23	0.0289
10	24	0.0288
13	24	0.0277
22	24	0.0272
27	24	0.0282
31	24	0.0264
45	19	0.0262
48	23	0.0256
53	24	-0.001
60	16	-0.0011
100	22	-0.0011
115	18	-0.0005
147	24	-0.0002
151	24	-0.0013
156	24	-0.002
163	24	0.0004
176	24	0.0001
205	24	-0.0014

APPENDIX II: CONFIGURATION AND USE OF THE ROSETTE SYSTEM

Twenty four 5 liter Niskin bottles were needed to sample vertical distribution of SF6. A 43" rosette frame and a 60" cage were borrowed from the WHOI CTD group. There was an upper section to the cage that housed a General Oceanics pylon, rosette and Niskin bottles.

The lower section housed a Neil Brown CTD hung vertically from an "A" bracket below the pylon. The vertical distance from the T and C probes to the center of the Niskin bottles was 112 cm. Three sets of shock cords were wrapped around the lower section of the CTD and to three legs of the cage 120 degrees apart. A 31" shock cord was wrapped around the CTD and a 15" shock cord was wrapped around the cage leg. Hooks were taken out of the ends of one of the shock cords, and the hooks from the other were inserted into it. The cords were wrapped in vulcanizing tape and a tie wrap was put on the end of the cords near where they went around the CTD. This turned out not to be a good idea. All of the stretch of the shock cord was taken in the short length of cord that was not taped. One of the cords gave out near the end of the cruise and was replaced by a new cord and not wrapped with tape. This new one showed no signs of strain whereas the wrapped ones showed cracking and necking down after the first couple of casts.

About 525 pounds of weight, in the form of 28 pound slugs of lead from the WHOI Stockroom, were added to the bottom ring and vertical pipes of the lower cage. These were held in place by hose clamps. Adding this weight enabled the cage to be lowered at about 30 meters/minute to about 50 meters, and then the speed slowly increased to about 60 meters/minute while maintaining a tension on the CTD wire of between 500 and 1000 pounds.

Considerable corrosion appeared on the rosette rings and the aluminium stanchion on which the rosette was mounted after the first few casts. More and larger anodes were added to both rosette rings and the stanchion and this seemed to alleviate the problem.

APPENDIX III: CAROUSEL PUMP AND VALVE.

For the fall 1992 and spring 1993 sampling cruises, OC253 and CD78, a carousel with more syringes was needed due to the spreading of the SF6 patch. A 50-port valve was built by McLane for the greater number of samples required. Along with this, new software was written to run this valve and pump combination.

When the valve was first tested before OC253, the valve would not mechanically return to the home, valve position 1, although it indicated it was home in the software. There are two microswitches in the valve. One counts revolutions and the other counts valve position. It was thought that if the microswitch that indicated valve position was wired, fine adjustments could be made to align the valve mechanically. This did not work. On OC253 in order to "fool" the software into thinking the valve was home, the pump would first be programmed for deployment. The valve would then have to be mechanically turned with a screwdriver to align it to the home position. This was difficult to do due to the position and stiffness of the valve.

Before CD78, two things were done to make the valve more user-friendly. Firstly, the microswitch to indicate revolutions was hooked back up so that when the valve was commanded to go home, it obeyed. Second, new software was written for the 50-port valve called PUMP1_47.BAS. It had menu commands to enable small adjustments to the valve from the keyboard to align the valve in the home position. It was found that due to backlash of the stepping motor, trying to move the valve one step of the motor wouldn't work. The software was modified to make the stepper motor go twenty steps, which is a small movement compared to one valve position. This worked fine. The software version to do this is called PUMPADJ.BAS., and is installed into the tattletale in place of PUMP1_47.BAS.

The pump and 50-port valve system, on the sled, was used four times on CD78, with the sled towed at 2 to 2.5 knots. In addition to a depressor weight of 500 lbs, hung below the sled, about 300 lbs of lead weight, in the form of 28 pound slugs, were added to the sled frame. The resulting wire angle was around 45 degrees at 2.3 knots. The direction of tow was constrained by the need to have the wind on the starboard side. An effective sampling program with the carousel system will usually require towing from the stern.

With the exception of a couple of syringes which only partially filled, the pump and valve worked well. It was again started by a lanyard switch hooked to a General Oceanics pylon. When that position was tripped from the deck unit, two pins on the pump electronics housing were shorted to enable the pump. Mechanical alignment of the valve to the home position was not a problem on this cruise either. At the end of each the cast, the valve returned almost to its proper position; when the alignment pin was inserted, a small amount of force on the pin was all that was needed to put the valve in the proper place for deployment. Therefore, though we had the capability to align the valve using the computer keyboard, it was not needed.