The Acoustic Mid-Ocean Dynamics Experiment (AMODE): Recovery Cruise Report

February 28–March 23, 1992

R/V ENDEAVOR Voyage EN-233
U.S. Department of State Cruise 91-103

by

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Acknowledgments

B. Howe contributed greatly to preparation of this report. K. Bader, A. Ganse, D. Horwitt, and B. Ma assisted in the data analysis. B. Betts assisted in preparing the figures. Credit for the success of the AMODE recovery cruise belongs largely to the dedicated engineers and technicians participating in this project from the Scripps Institution of Oceanography and the Applied Physics Laboratory of the University of Washington, to the Captain, T. Tyler, and crew of the R/V ENDEAVOR, and to B. Fanning, the shipboard marine technician. This research is supported by the Office of Naval Research and the Office of Naval Technology.

The scientific party for the cruise consisted of:

Leg 1	Leg 2
Steve Abbott	Steve Abbott
Brian Dushaw	Brian Dushaw
Kevin Hardy	Kevin Hardy
David Horwitt	David Horwitt
Larry Nielson	Larry Nielson
Beau Paisley	
Douglas Peckham	Douglas Peckham
Peter Worcester	Peter Worcester

Leg 1: Quonset Point, Rhode Island, to San Juan, Puerto Rico
Leg 2: San Juan, Puerto Rico, to St. Georges, Bermuda

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AMODE Recovery Cruise Summary

The principal goal of the March 1992 Acoustics Mid-Ocean Dynamics Experiment (AMODE) Cruise was to recover the six 250 Hz tomography transceivers previously deployed in the region between Bermuda and Puerto Rico and the 250 Hz source deployed on the south side of Bermuda. The six tomography transceivers were deployed at about 1000 m depth on taut, sub-surface moorings. In all cases the bottom depth exceeded 5000 m. The Bermuda source was bottom-mounted in about 1000 m of water on the southern edge of Plantagenet Bank. All recoveries were successful.

Since all of the instruments would not fit on the R/V ENDEAVOR, the cruise consisted of two legs (Fig. 1). On the first leg, from Quonset Point, Rhode Island, to San Juan, Puerto Rico, four acoustic transceiver moorings were recovered (Moorings 1, 2, 5, and 3, in that order). On the second leg, from San Juan to St. Georges, Bermuda, the final two deep moorings were recovered (Moorings 4 and 6). We originally planned to recover the Bermuda source on the way into St. Georges, but were prevented from doing so by bad weather. We therefore unloaded most of our equipment in St. Georges prior to going back out for one day after the weather had moderated to recover the Bermuda source.

Secondary, but important, goals were (i) to measure the bathymetry along additional acoustic paths for which bathymetric data were not obtained during the March 1991 AMODE deployment cruise and (ii) to measure the sound speed field along as many of the acoustic paths as possible, using both CTD and XBT data. Figures 2 and 3 show the paths along which we obtained bathymetric and sound speed data, respectively. In addition, near surface temperature and salinity (3 m sea water intake depth) were routinely measured while underway, although those data are not included in this report.

Moored data. Table 1 summarizes the AMODE source positions and characteristics.

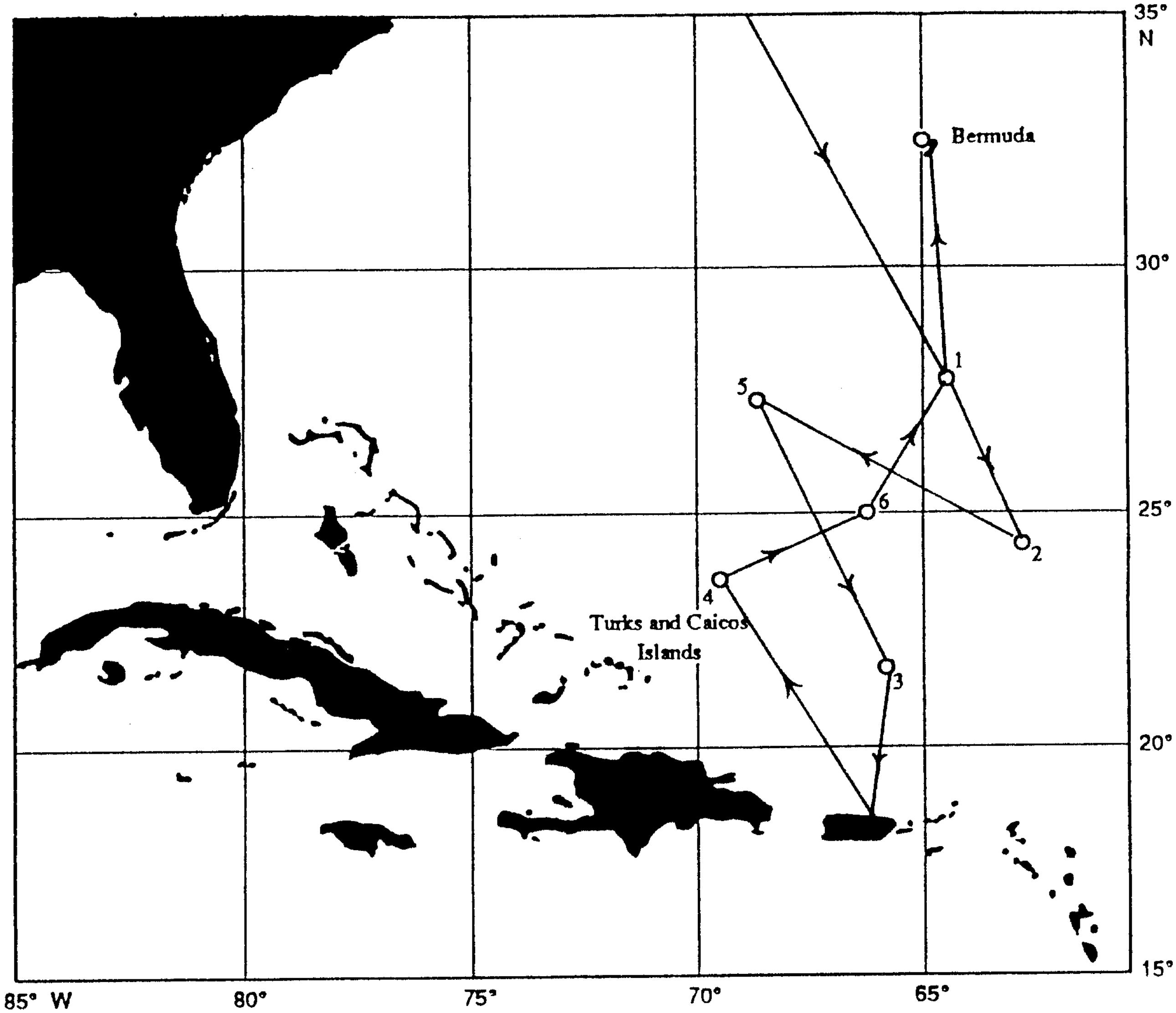

Figure 1. Cruise track for R/V ENDEAVOR cruise EN-233.

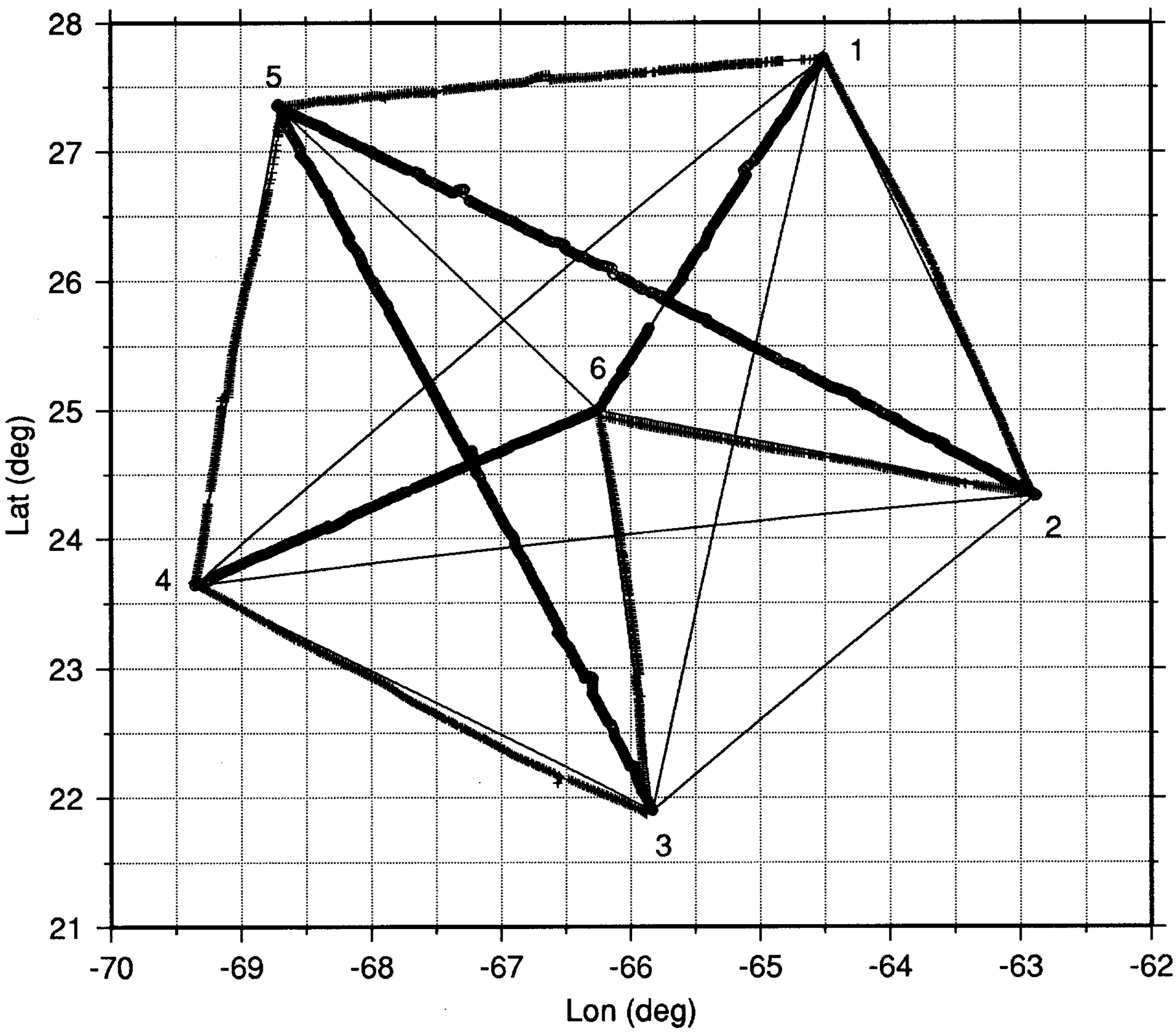

Figure 2. Bathymetric data was collected on a subset of the paths between the tomographic transceiver locations (1–6) on the deployment cruise (crosses) and on the recovery cruise (circles). The thin lines are geodesics.

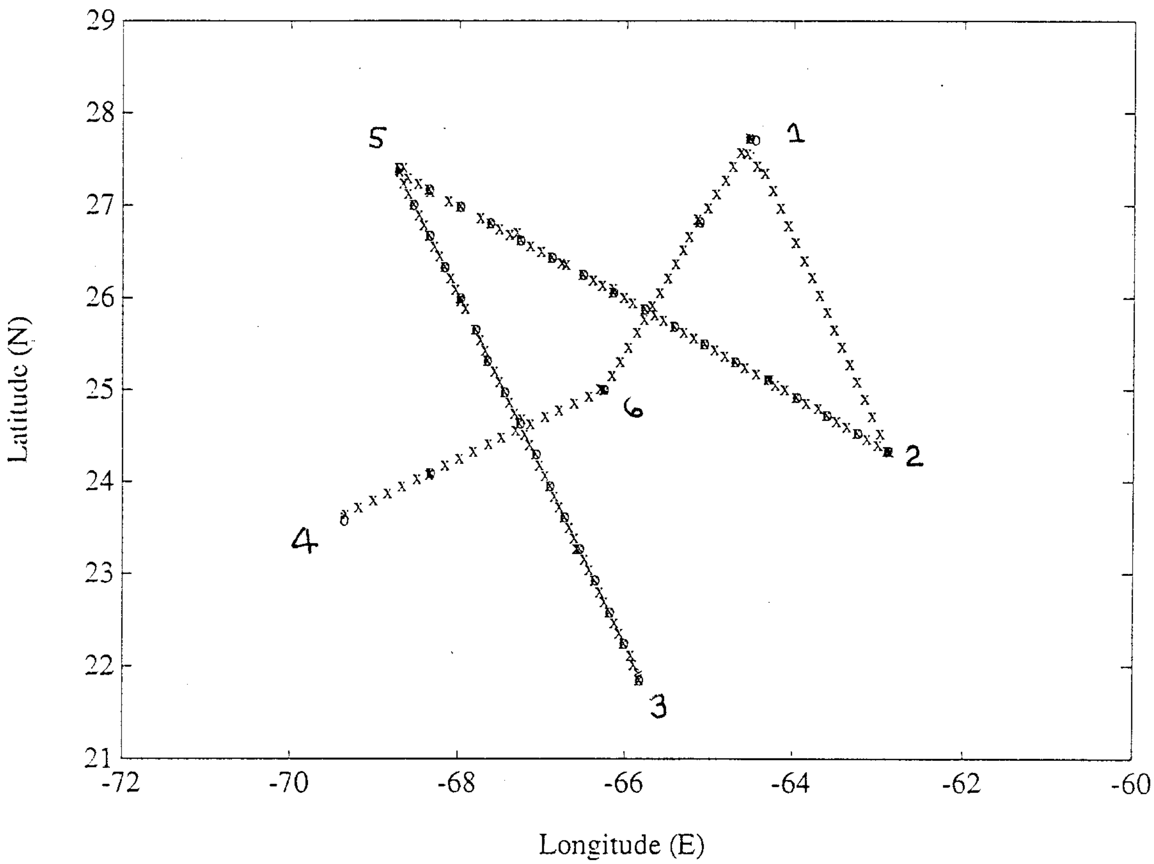

Figure 3. CTD (O) and XBT (X) data was collected on a subset of the paths between the tomographic locations (1–6) on the recovery cruise.

TABLE 1. AMODE source information.

Mooring	Latitude (north)	Longitude (west)	Source Depth (m)	No. of Array Elements	Trans. Law. (octal)	Delay (s)
1	27°43.2311′	64°31.1180′	985	4	5747	97
2	24°20.0499′	62°53.3475′	996	4	5351	97
3	21°53.9489′	65°49.8957′	1003	6	6141	97
4	23°38.2666′	69°21.5628′	1008	4	7603	97
5a	27°20.9586′	68°42.3087′	1014	6	6153	97
5b	27°21.102′	68°43.541′	979	4	5163	97
6	25°00.0124′	66°15.0823′	992	6	7047	0
7 (Bermuda)	31°54.924′	64°10.306′	956	0	2033	--[a]

[a] The Bermuda source is asynchronous with the AMODE sources. It transmits at 30 minutes after the hour, every 8 hours, starting at 0030 UTC.

(This table is a revision of the one given in Howe et al., "Acoustic Mid-Ocean Dynamics Experiment: 1991 Moving Ship Tomography Cruise," APL-UW TM18-91, December 1991.) Table 2 gives the current best estimate of both the mooring and transponder locations. Table 3 summarizes the dates on which the moorings were deployed and recovered. Appendix A contains drawings of all of the moorings. Each of the AMODE moorings had two Brancker temperature sensors in the main thermocline, plus the temperature and pressure sensors included in each AVATAR. The Bermuda source had only the AVATAR temperature and pressure sensors. The pressure and temperature time series for the entire year are given in Appendix B (A. Ganse and B. Howe, "Pressure and Temperature Data for AMODE," Applied Physics Laboratory, 24 January 1993, unpublished manuscript). There are a total of 15 moored transceiver pairs for which acoustic data are available. Raw travel times as a function of yearday are given in Appendix C. These data still need to be corrected for clock drift and mooring motion. Appendices D and E summarize the AVATAR clock performance and any anomalies observed in the operation of the instruments, respectively.

Bathymetric data. While the bathymetry in the AMODE region is among the better known bathymetry in the world, it is important to have accurate bathymetry along the tracks between the moorings in order to know when one of the deep turning acoustic ray paths interacts with the bottom. Appendix F gives the bathymetry measured on both the deployment and recovery cruises (A. Ganse and B. Howe, "Bathymetry Data for AMODE: Follow-up Report," Applied Physics Laboratory, University of Washington, 13 March 1993, unpublished manuscript). No unexpectedly high bathymetric features were found, except for a seamount that reaches approximately 3500 m on the path between moorings 1 and 5.

CTD and XBT data. CTD casts to within roughly 100 m of the bottom were made at each mooring site. In addition, the sound speed field along the sections between Moorings 2 and 5 and Moorings 5 and 3 were densely sampled using a combination of deep CTD's (to

TABLE 2. Locations of the moorings (releases) and transponders (WGS84). The transponders are I=1,4. The mooring release is I=5. Errors are in meters.

Mooring 1.

TIME	I	Lon	EX	Lat	EY	Z	EZ
79.558345	1	64:34.0671W	0.7	27:43.5745N	1.0	5485.6	0.4
79.558345	2	64:31.5503W	0.7	27:45.8026N	0.7	5478.4	0.4
79.558345	3	64:29.0805W	0.7	27:43.5605N	0.8	5501.9	0.4
79.558345	4	64:31.6250W	1.1	27:41.3989N	0.7	5487.4	0.5
79.558345	5	64:31.1180W	0.7	27:43.2311N	0.6	5394.5	0.4

Mooring 2 (Initial deployment–no data from initial deployment).

TIME	I	Lon	EX	Lat	EY	Z	EZ
77.155897	1	62:55.4957W	1.5	24:19.9497N	1.8	5874.5	0.4
77.155897	2	62:52.6998W	1.6	24:22.2965N	1.5	5883.8	0.4
77.155897	3	62:50.1339W	1.5	24:19.8877N	1.6	5847.8	0.4
77.155897	4	62:52.7291W	1.8	24:17.5093N	1.5	5800.7	0.4
77.155897	5	62:52.3674W	1.5	24:19.5424N	1.5	5776.6	0.4

Mooring 2 (Redeployment–same transponders as initial deployment).

TIME	I	Lon	EX	Lat	EY	Z	EZ
85.451487	1	62:55.4900W	2.3	24:19.9509N	2.8	5874.3	0.3
85.451487	2	62:52.6943W	3.0	24:22.2968N	2.3	5883.5	0.3
85.451487	3	62:50.1290W	2.3	24:19.8882N	3.4	5847.4	0.3
85.451487	4	62:52.7244W	3.1	24:17.5105N	2.3	5800.4	0.3
85.451487	5	62:53.3475W	2.3	24:20.0499N	2.3	5775.3	0.3

Mooring 3.

TIME	I	Lon	EX	Lat	EY	Z	EZ
71.880538	1	65:52.8307W	1.9	21:54.3079N	2.1	5591.3	0.4
71.880538	2	65:50.2170W	1.9	21:56.8287N	1.9	5654.7	0.4
71.880538	3	65:47.8410W	1.9	21:54.3177N	1.8	5660.7	0.4
71.880538	4	65:50.3308W	2.0	21:52.0622N	1.9	5629.4	0.4
71.880538	5	65:49.8957W	1.9	21:53.9489N	1.9	5550.5	0.4

Mooring 4.

TIME	I	Lon	EX	Lat	EY	Z	EZ
68.556655	1	69:24.0271W	0.6	23:38.4993N	1.0	5376.1	0.1
68.556655	2	69:21.7143W	0.9	23:40.5366N	0.7	5350.2	0.1
68.556655	3	69:19.5934W	0.7	23:38.5514N	0.7	5380.1	0.1
68.556655	4	69:21.7488W	0.8	23:36.5226N	0.7	5372.7	0.1
68.556655	5	69:21.5628W	0.6	23:38.2666N	0.7	5285.6	0.1

Mooring 5a (Initial deployment).

TIME	I	Lon	EX	Lat	EY	Z	EZ
66.599485	1	68:41.9178W	2.0	27:20.5035N	2.0	5317.8	0.4
66.599485	2	68:43.0577W	2.1	27:19.1169N	2.1	5310.7	0.5
66.599485	3	68:44.0213W	2.0	27:22.2239N	2.2	5334.1	0.4
66.599485	4	68:40.4152W	2.0	27:21.6981N	2.0	5340.0	0.4
66.599485	5	68:42.3087W	2.0	27:20.9586N	2.0	5227.5	0.4

Mooring 5b (Redeployment–same transponders as initial deployment).

new mooring: 68:43.541W 27:21.102N (done by Brad)

Mooring 6.

TIME	I	Lon	EX	Lat	EY	Z	EZ
75.562378	1	66:17.9099W	2.0	25: 0.3788N	2.0	5474.4	0.4
75.562378	2	66:15.5164W	2.1	25: 2.5788N	2.0	5489.5	0.4
75.562378	3	66:13.1339W	2.0	25: 0.3759N	2.1	5476.8	0.4
75.562378	4	66:15.5227W	2.0	24:58.2626N	2.0	5422.8	0.4
75.562378	5	66:15.0823W	2.0	25: 0.0124N	2.0	5302.7	0.4

Mooring 7 (Bermuda source–no transponders).

64:10.306W 31:54.924N (done by Brad)

TABLE 3. Mooring deployment and recovery times.

Mooring	Anchor Deployment			Anchor Release			Electronics	Source
	Year	Day	Time (UTC)	Year	Day	Time (UTC)	S/N	S/N
1	1991	079	0530	1992	063	1505	AVATAR 1	1
2	1991	085	0813	1992	064	1931	AVATAR 2	6
3	1991	069	2239	1992	072	1114	AVATAR 3	3
4	1991	068	0223	1992	076	1118	AVATAR 4	8
5a	1991	066	0349	1991	165	1218	AVATAR 5	5
5b	1991	167	0031	1992	068	1328	AVATAR 5	4
6	1991	075	0110	1992	077	1943	AVATAR 6	7
7	1991	163	2239	1992	082	1928	AVATAR 7	2

Notes:

1. Mooring 2 anchor deployment is the time at which the mooring was redeployed after repair. No data was saved from the initial short deployment.

2. Mooring 7 anchor deployment is the time at which the nylon lowering line was released.

within 100 m of the bottom), 2000-m CTD's, and Sippican T-7 XBT's. The measurements between moorings 2 and 5 and between moorings 5 and 3 were made immediately after source transmissions. The XBT/CTD casts between mooring 2 and mooring 5 were made after 7 transmissions (beginning at 064 00:00 Z) in 2 days, 22 hrs. The XBT/CTD casts between mooring 5 and mooring 3 were made after 5 transmissions (beginning at 068 00:00 Z) in 3 days, 2 hrs. Finally, the sound speed field along the sections between Moorings 1 and 2, 4 and 6, and 6 and 1 were somewhat less densely sampled using T-7 XBT's and a few deep CTD casts. The individual CTD profile data, as well as waterfall plots of the XBT data along each section, are given in Appendix G.

Appendix A. Mooring drawings

All six AMODE moorings are of similar design (Figures A1 through A7). Since Mooring 5 had to be recovered and redeployed at the beginning of the June 1991 Moving Ship Tomography cruise (due to failure of the HLF-5 source), drawings for the first and second deployment are included here (Moorings 5a and 5b). All of the AMODE moorings were taut, subsurface moorings to minimize mooring motion. The acoustic transceiver depths obtained from the AVATAR pressure sensors were consistently roughly 50 m deeper than computed by the mooring analysis program NOYFB using the measured bottom depths and the known mooring design. Both the NOYFB instrument depths and instrument depths computed using the pressure sensor are given in the mooring drawings. The depth obtained from the pressure sensor is consistent with that obtained from the long baseline acoustic tracking system. The reason for this discrepancy is not known.

The Bermuda source mooring design is quite different, with the protective cage surrounding the source directly coupled to an anchor in about 1000 m of water (Figure A8). The source is therefore effectively bottom-mounted. The entire mooring only extends about 10 m above the bottom.

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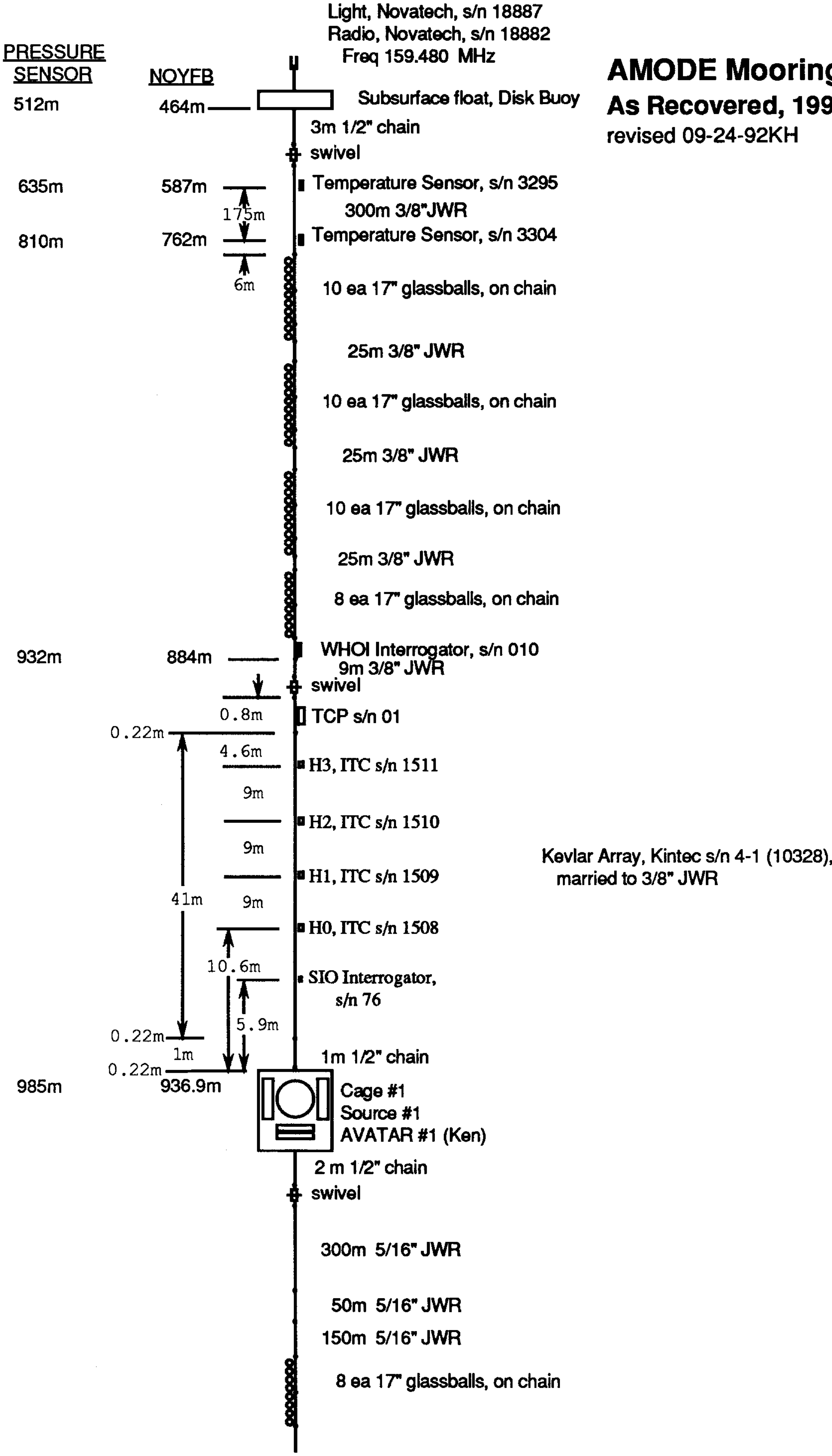
AMODE Mooring #1
As Recovered, 1992yd063
revised 09-24-92KH



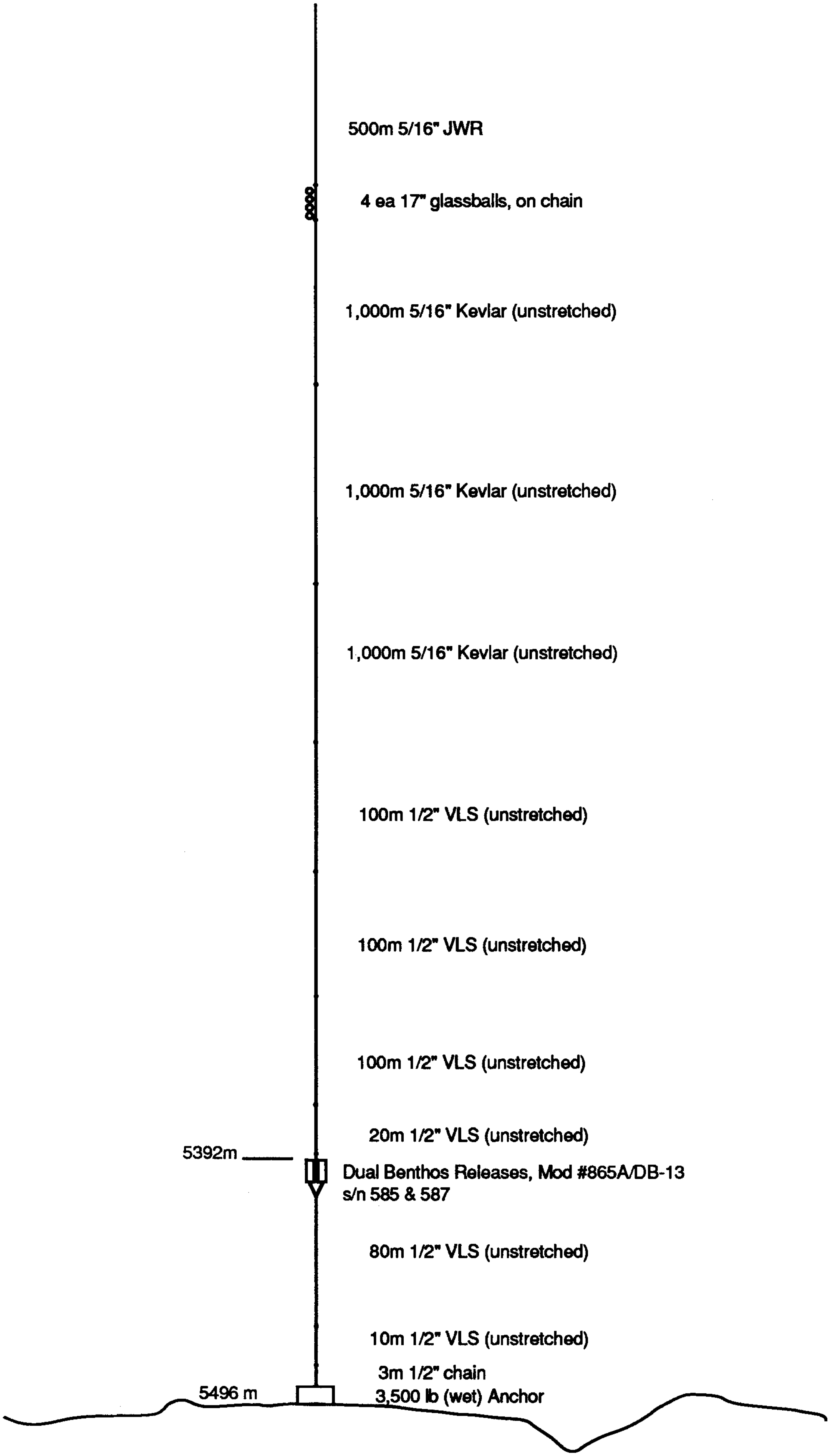
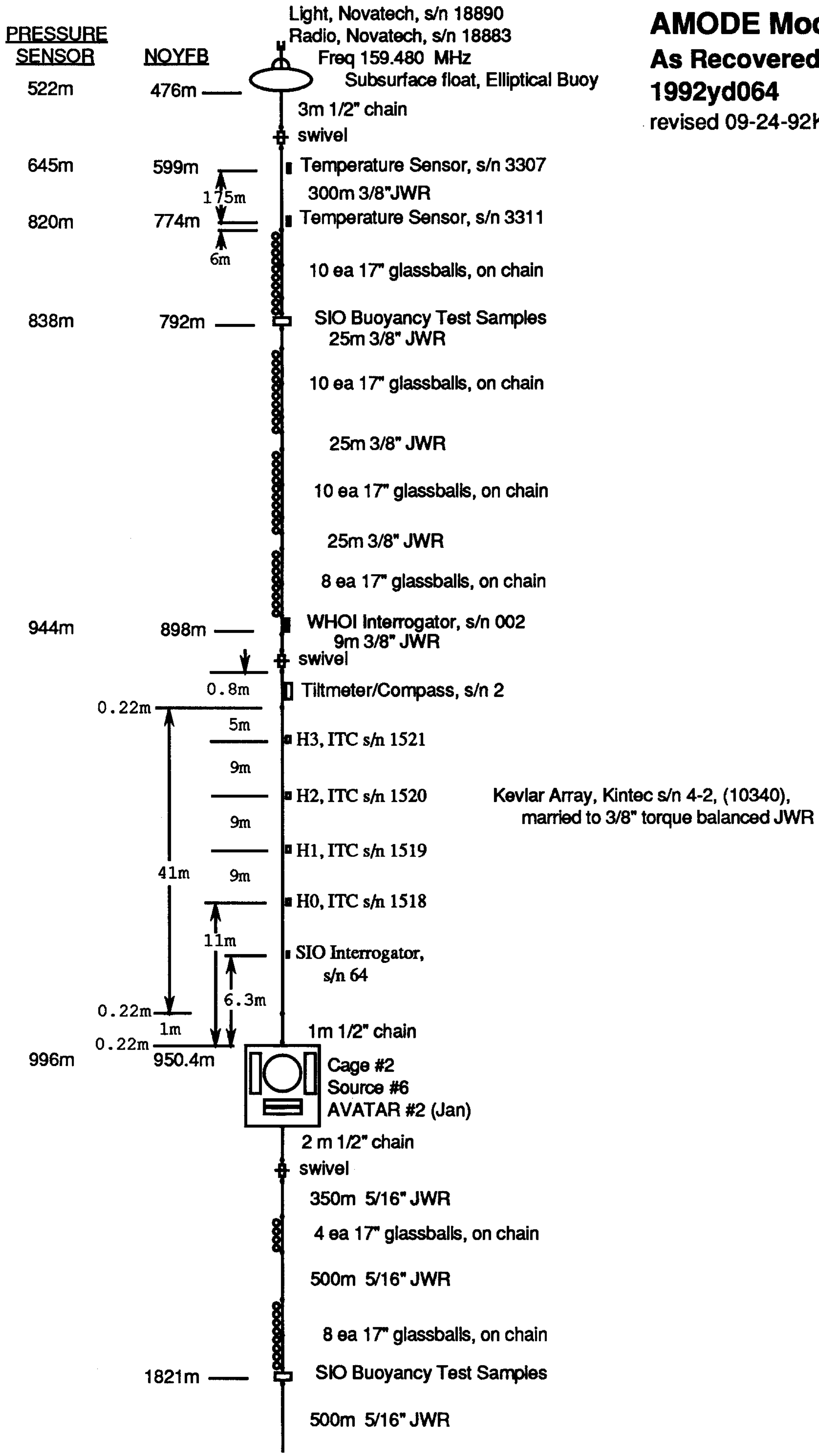

500m 5/16" JWR
4 ea 17" glassballs, on chain
1,000m 5/16" Kevlar (unstretched)
1,000m 5/16" Kevlar (unstretched)
1,000m 5/16" Kevlar (unstretched)
100m 1/2" VLS (unstretched)
100m 1/2" VLS (unstretched)
100m 1/2" VLS (unstretched)
20m 1/2" VLS (unstretched)
5392m
Dual Benthos Releases, Mod #865A/DB-13
s/n 585 & 587
80m 1/2" VLS (unstretched)
10m 1/2" VLS (unstretched)
3m 1/2" chain
5496 m
3,500 lb (wet) Anchor

Figure A1

AMODE Mooring #2
As Recovered.
1992yd064
revised 09-24-92KH



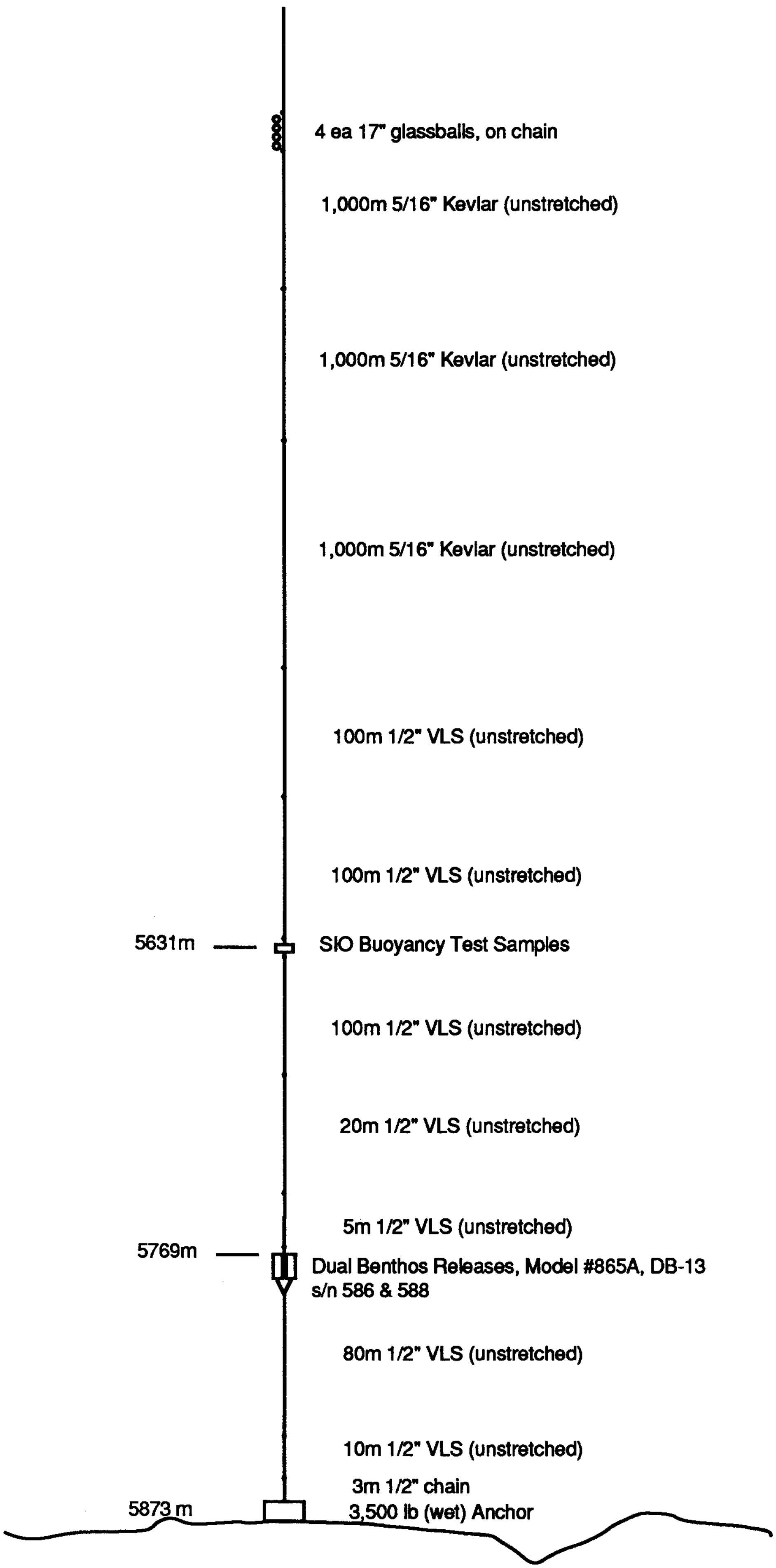
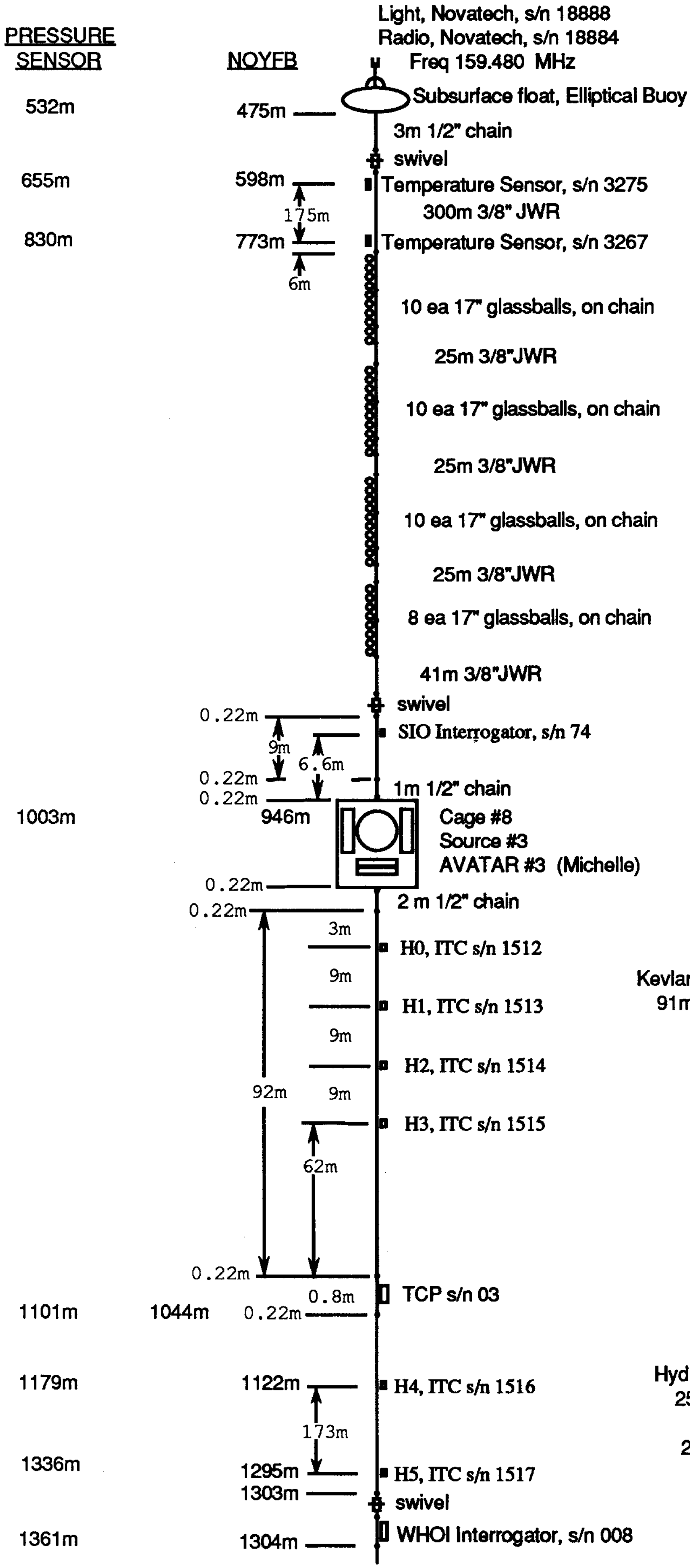

4 ea 17" glassballs, on chain
1,000m 5/16" Kevlar (unstretched)
1,000m 5/16" Kevlar (unstretched)
1,000m 5/16" Kevlar (unstretched)
100m 1/2" VLS (unstretched)
100m 1/2" VLS (unstretched)
5631m
SIO Buoyancy Test Samples
100m 1/2" VLS (unstretched)
20m 1/2" VLS (unstretched)
5m 1/2" VLS (unstretched)
5769m
Dual Benthos Releases, Model #865A, DB-13
s/n 586 & 588
80m 1/2" VLS (unstretched)
10m 1/2" VLS (unstretched)
3m 1/2" chain
5873 m
3,500 lb (wet) Anchor

Figure A2

AMODE Mooring #3
As Recovered, 1992yd072
revised 09-24-92KH



Kevlar array, Kintec s/n 6-3 (10320) married to
91m 5/16" torque balanced JWR

Hydrophone extension cables married to
258m 5/16" torque balanced JWR
(91m extension, Kintec s/n 10311;
258m extension, Kintec s/n 10318)

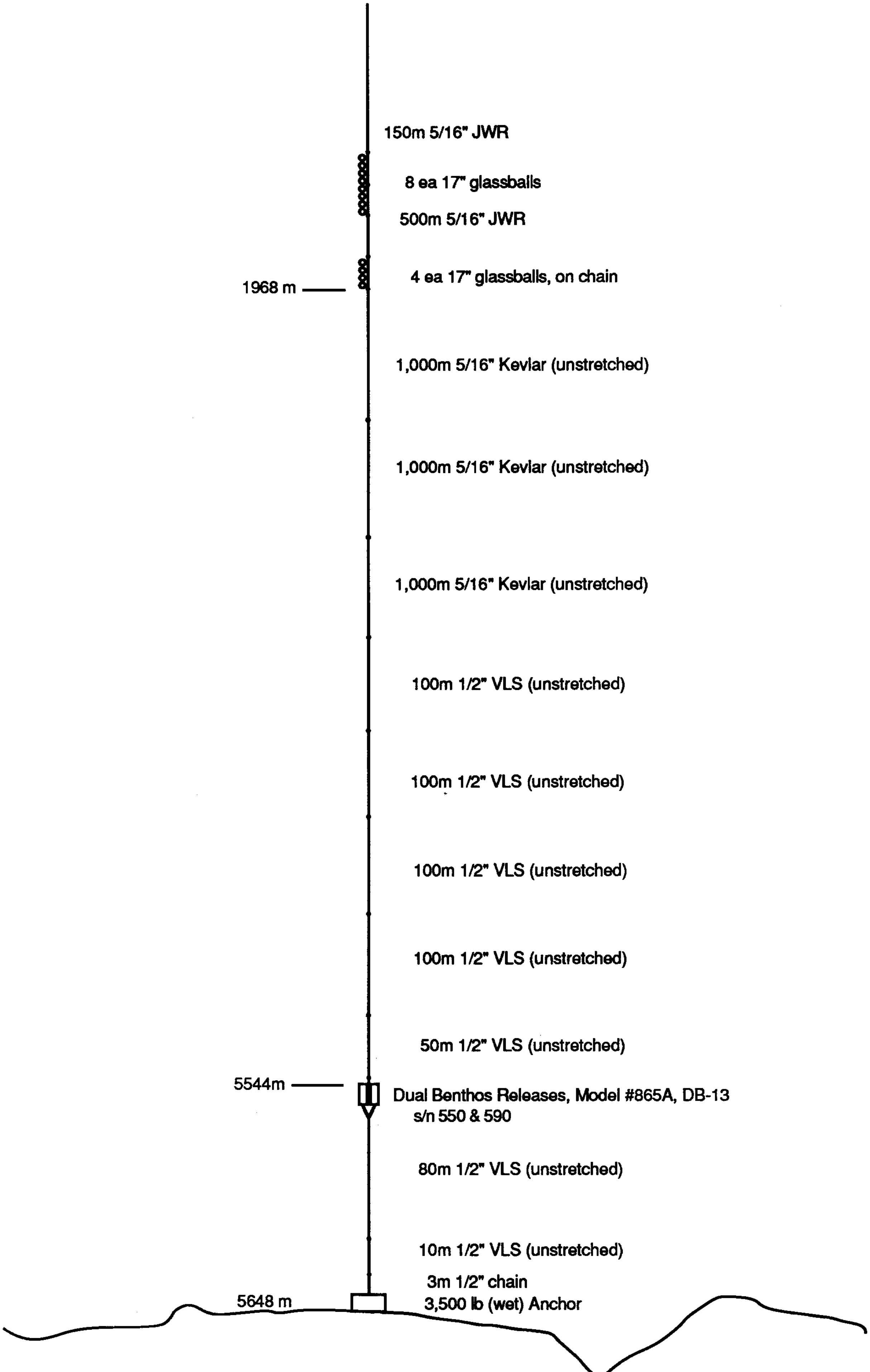
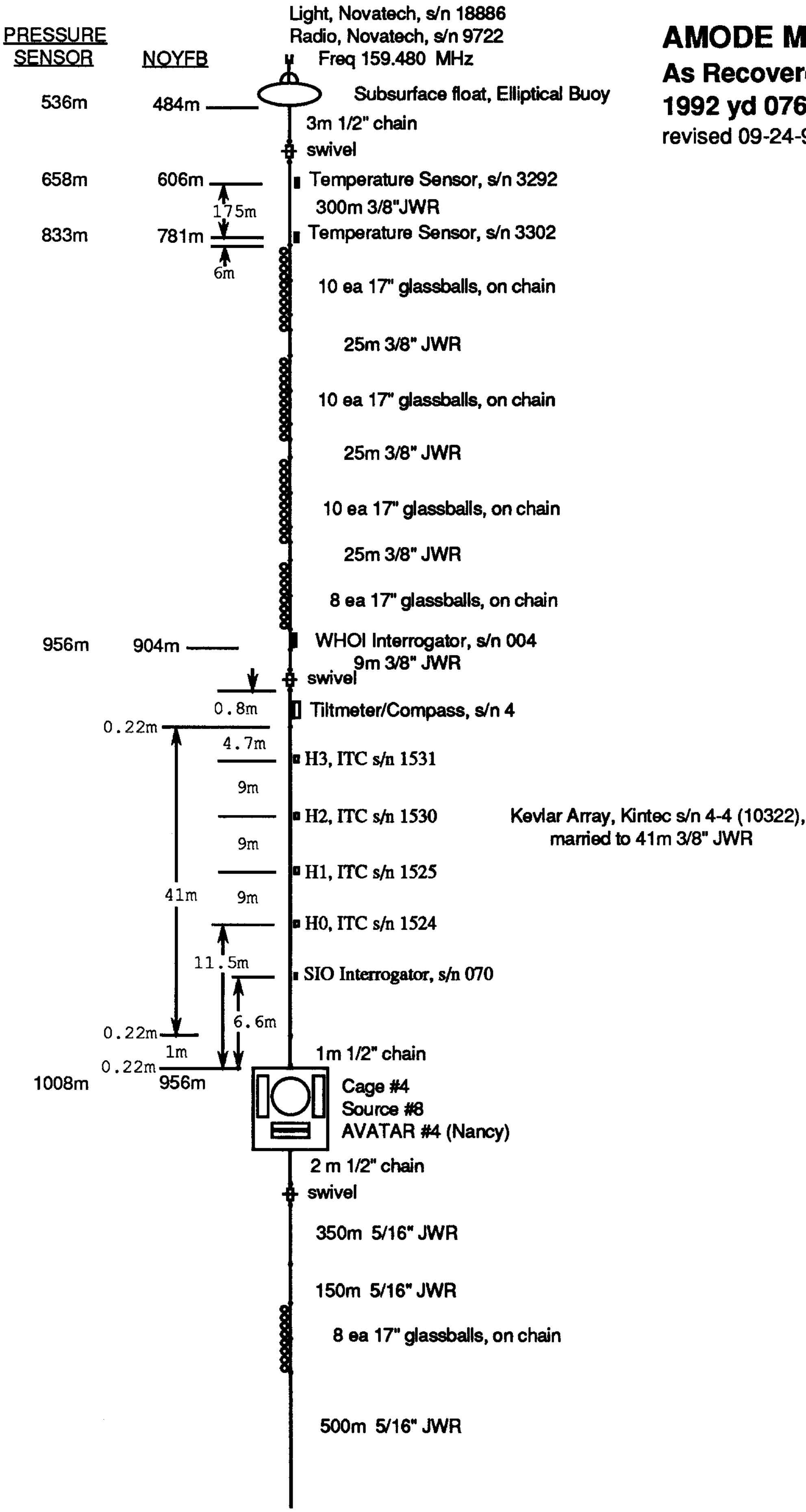

150m 5/16" JWR
8 ea 17" glassballs
500m 5/16" JWR
4 ea 17" glassballs, on chain
1968 m
1,000m 5/16" Kevlar (unstretched)
1,000m 5/16" Kevlar (unstretched)
1,000m 5/16" Kevlar (unstretched)
100m 1/2" VLS (unstretched)
100m 1/2" VLS (unstretched)
100m 1/2" VLS (unstretched)
100m 1/2" VLS (unstretched)
50m 1/2" VLS (unstretched)
5544m
Dual Benthos Releases, Model #865A, DB-13
s/n 550 & 590
80m 1/2" VLS (unstretched)
10m 1/2" VLS (unstretched)
3m 1/2" chain
5648 m
3,500 lb (wet) Anchor

Figure A3

AMODE Mooring #4
As Recovered, 1992 yd 076.
revised 09-24-92KH



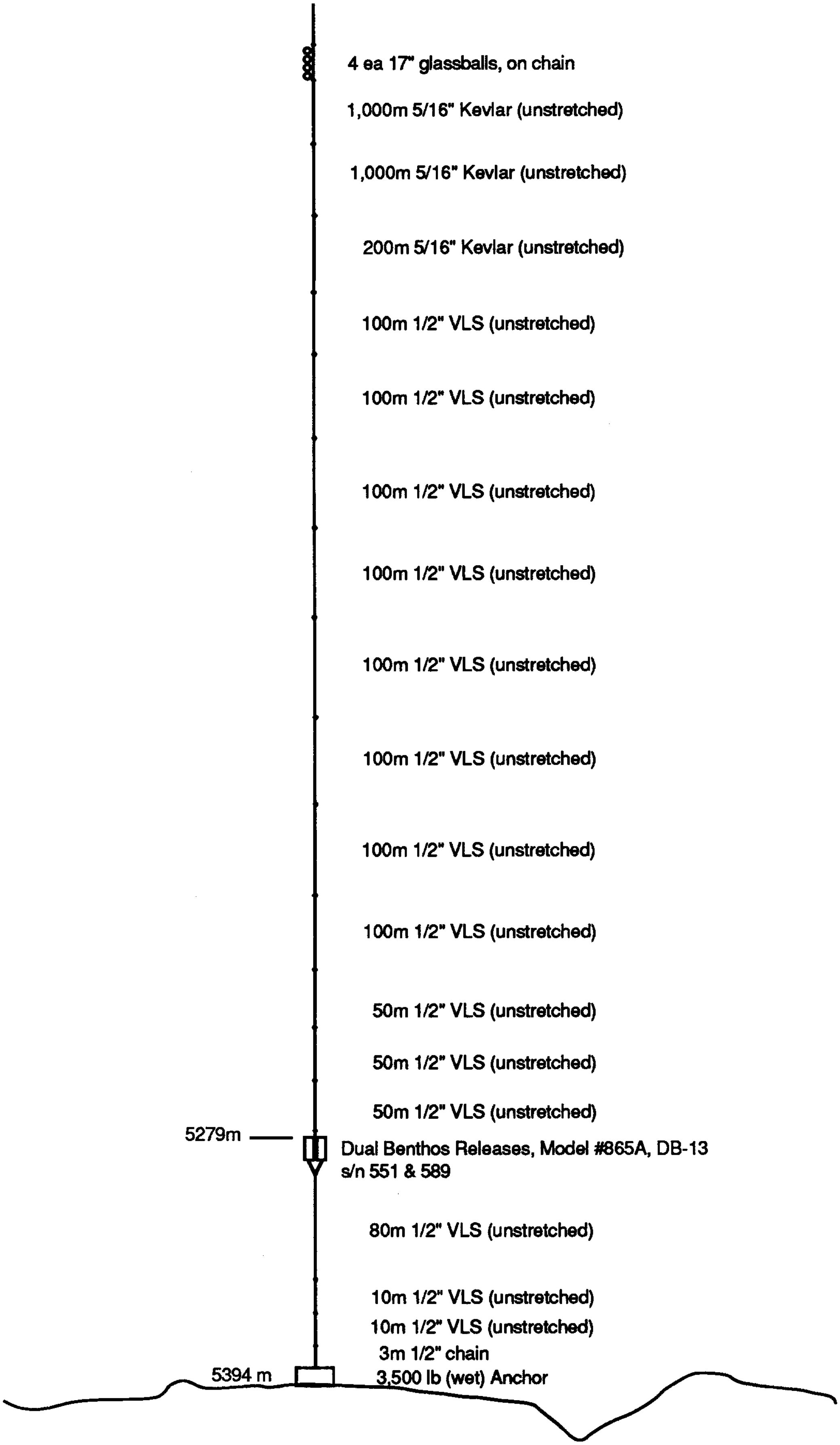
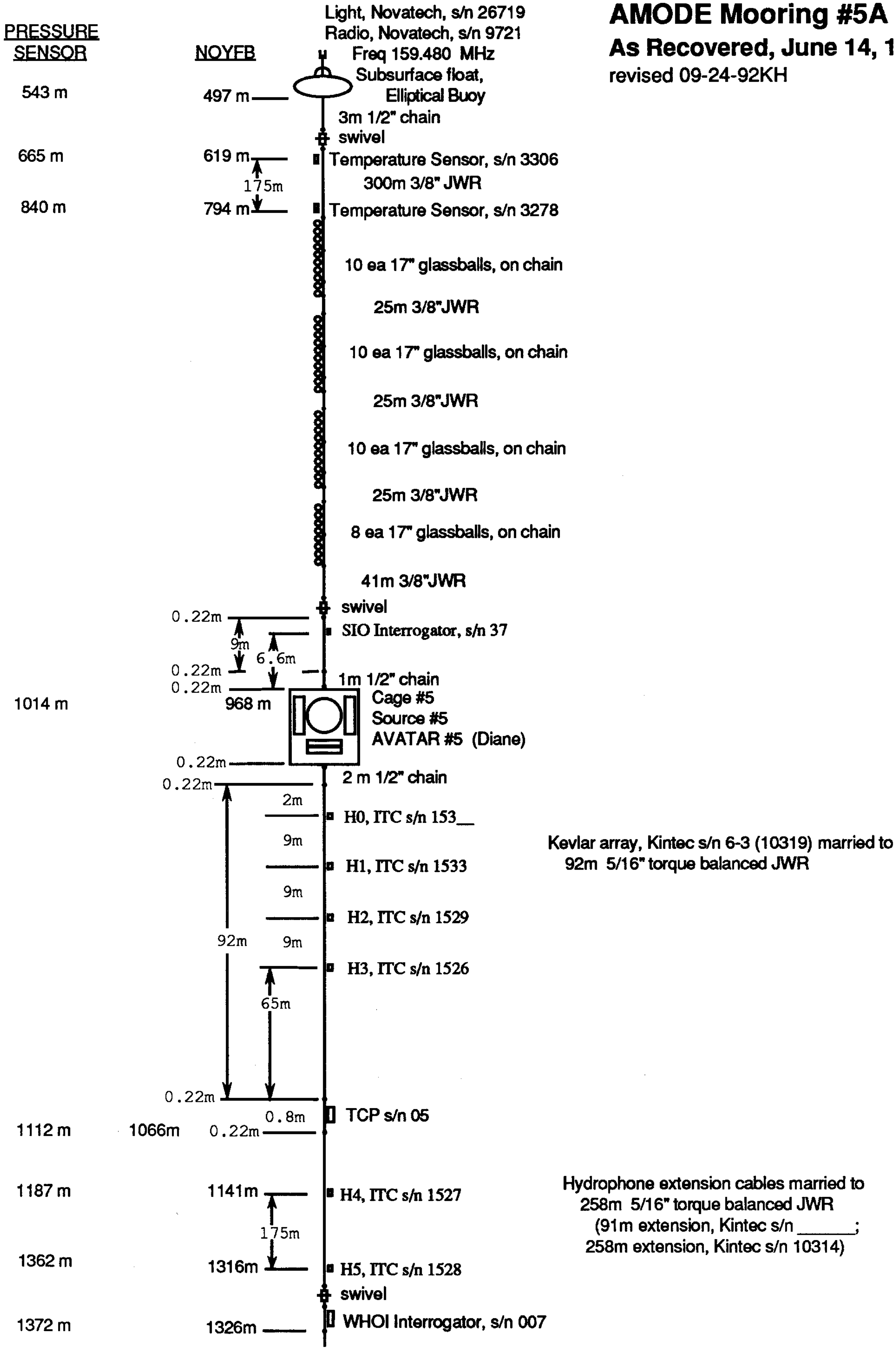

4 ea 17" glassballs, on chain
1,000m 5/16" Kevlar (unstretched)
1,000m 5/16" Kevlar (unstretched)
200m 5/16" Kevlar (unstretched)
100m 1/2" VLS (unstretched)
100m 1/2" VLS (unstretched)
100m 1/2" VLS (unstretched)
100m 1/2" VLS (unstretched)
100m 1/2" VLS (unstretched)
100m 1/2" VLS (unstretched)
100m 1/2" VLS (unstretched)
100m 1/2" VLS (unstretched)
50m 1/2" VLS (unstretched)
50m 1/2" VLS (unstretched)
50m 1/2" VLS (unstretched)
5279m
Dual Benthos Releases, Model #865A, DB-13
s/n 551 & 589
80m 1/2" VLS (unstretched)
10m 1/2" VLS (unstretched)
10m 1/2" VLS (unstretched)
3m 1/2" chain
5394 m
3,500 lb (wet) Anchor

Figure A4

AMODE Mooring #5A

As Recovered, June 14, 1991

revised 09-24-92KH



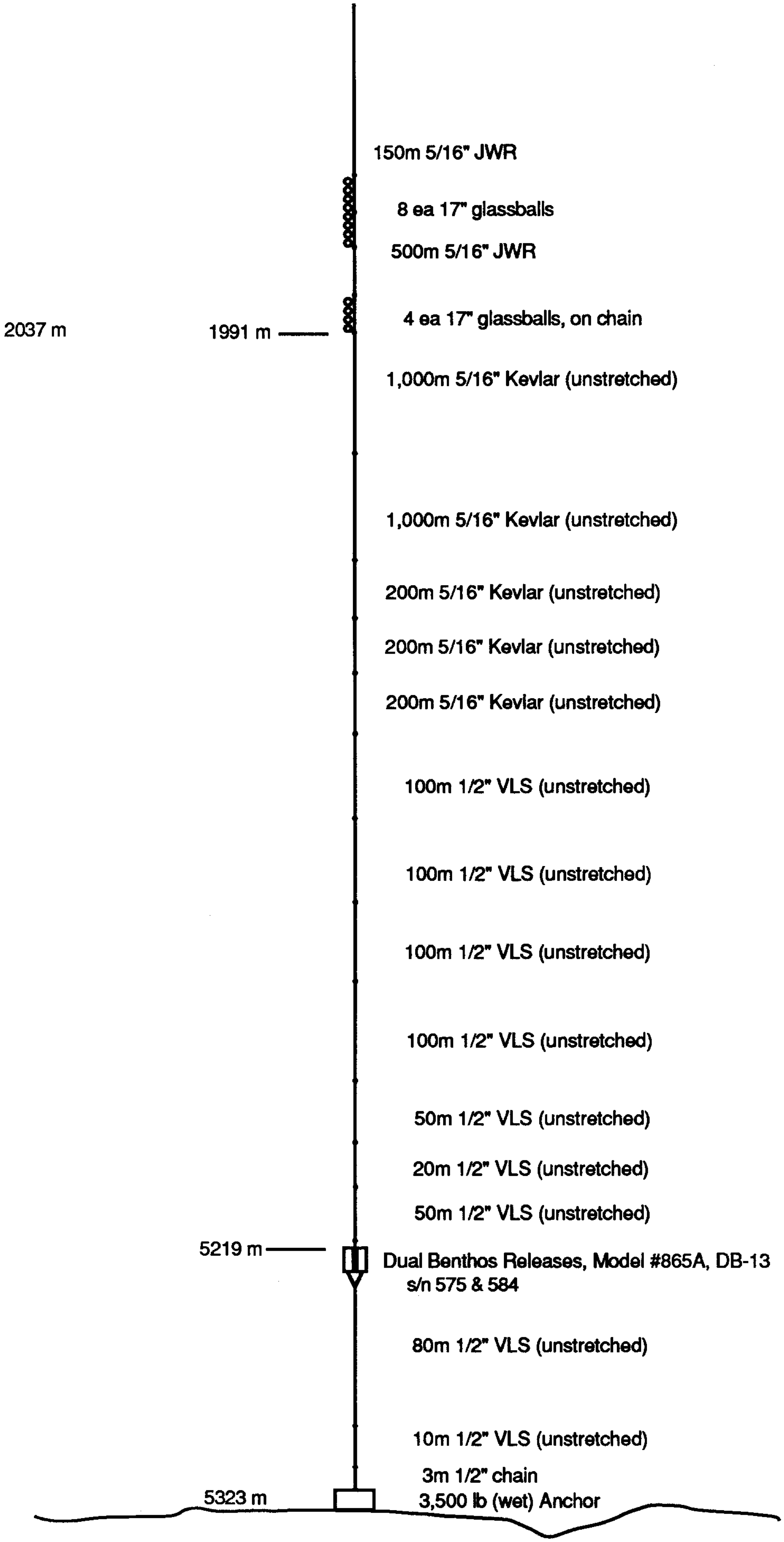
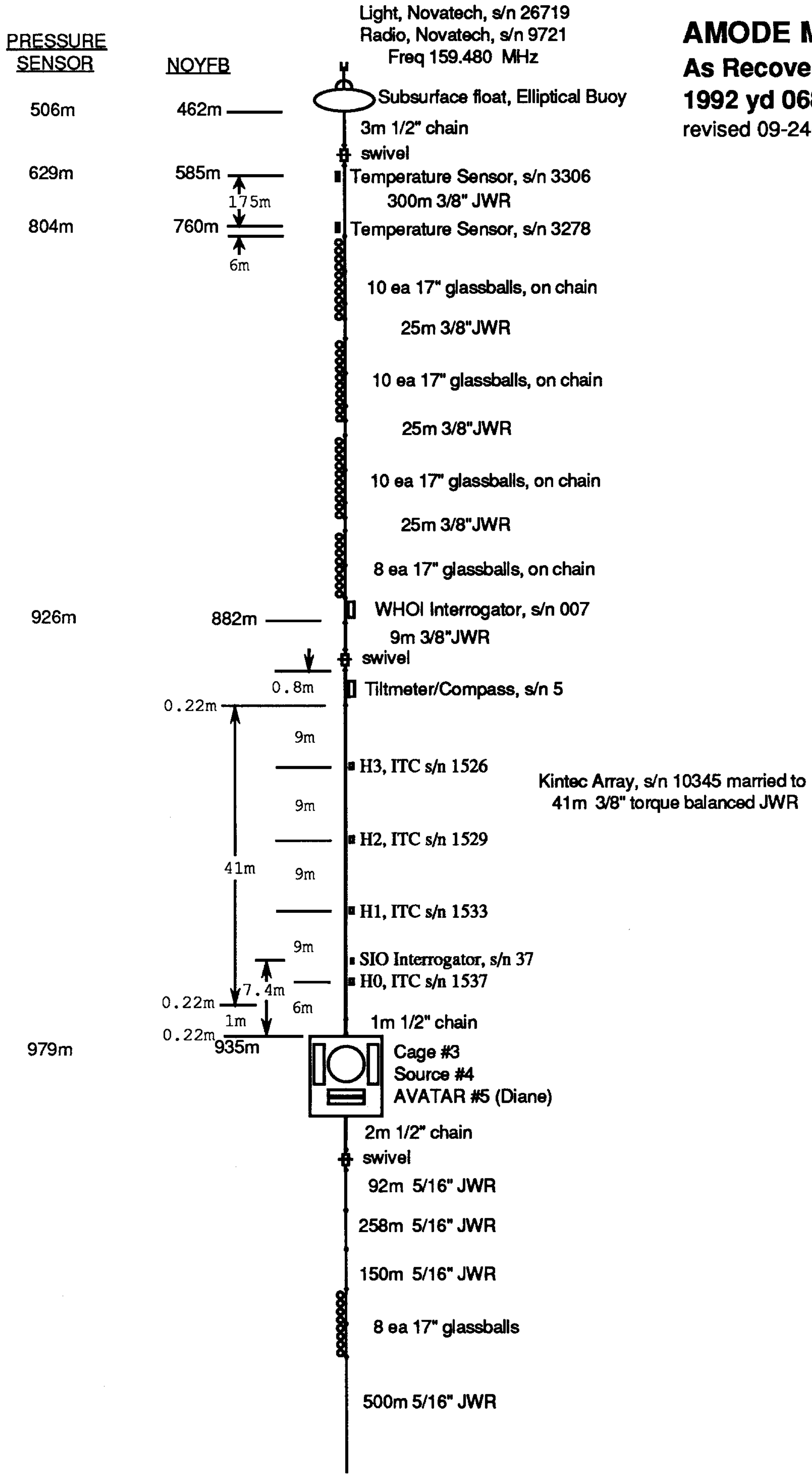

150m 5/16" JWR
8 ea 17" glassballs
500m 5/16" JWR
4 ea 17" glassballs, on chain
2037 m
1991 m
1,000m 5/16" Kevlar (unstretched)
1,000m 5/16" Kevlar (unstretched)
200m 5/16" Kevlar (unstretched)
200m 5/16" Kevlar (unstretched)
200m 5/16" Kevlar (unstretched)
100m 1/2" VLS (unstretched)
100m 1/2" VLS (unstretched)
100m 1/2" VLS (unstretched)
100m 1/2" VLS (unstretched)
50m 1/2" VLS (unstretched)
20m 1/2" VLS (unstretched)
50m 1/2" VLS (unstretched)
5219 m
Dual Benthos Releases, Model #865A, DB-13
s/n 575 & 584
80m 1/2" VLS (unstretched)
10m 1/2" VLS (unstretched)
3m 1/2" chain
5323 m
3,500 lb (wet) Anchor

Figure A5

AMODE Mooring #5B
As Recovered,
1992 yd 068.
revised 09-24-92KH



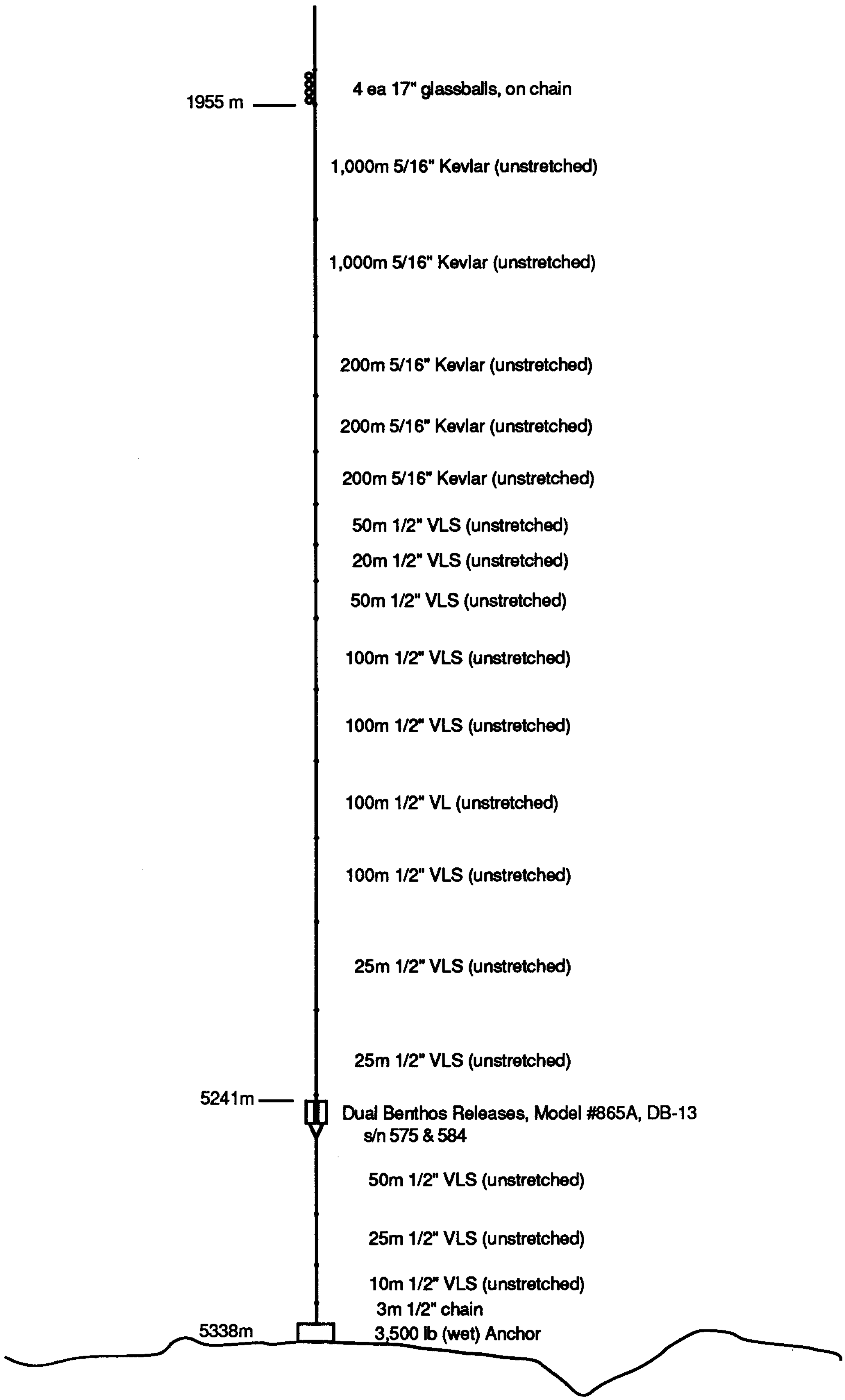
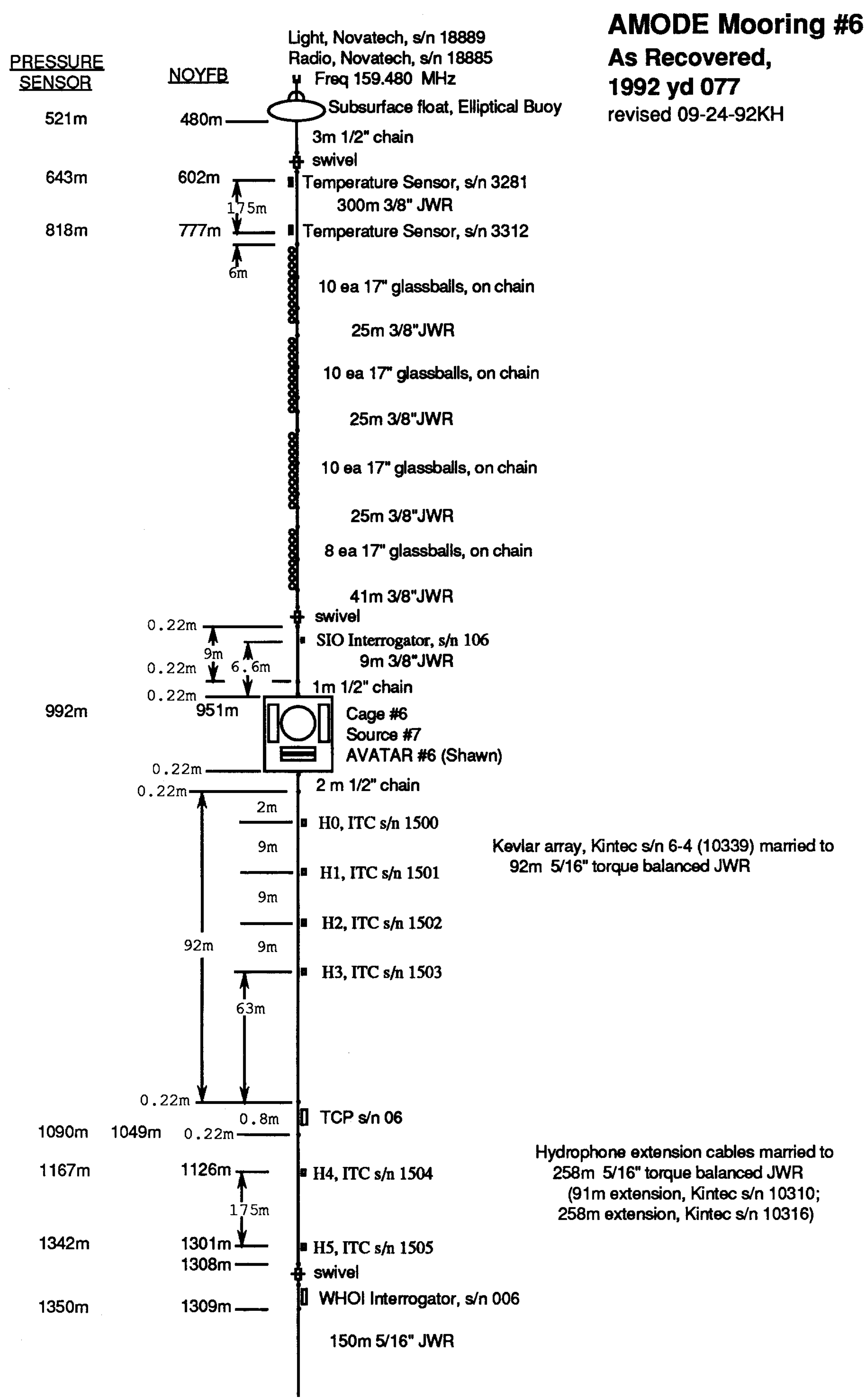

1955 m
4 ea 17" glassballs, on chain
1,000m 5/16" Kevlar (unstretched)
1,000m 5/16" Kevlar (unstretched)
200m 5/16" Kevlar (unstretched)
200m 5/16" Kevlar (unstretched)
200m 5/16" Kevlar (unstretched)
50m 1/2" VLS (unstretched)
20m 1/2" VLS (unstretched)
50m 1/2" VLS (unstretched)
100m 1/2" VLS (unstretched)
100m 1/2" VLS (unstretched)
100m 1/2" VL (unstretched)
100m 1/2" VLS (unstretched)
25m 1/2" VLS (unstretched)
25m 1/2" VLS (unstretched)
5241m
Dual Benthos Releases, Model #865A, DB-13
s/n 575 & 584
50m 1/2" VLS (unstretched)
25m 1/2" VLS (unstretched)
10m 1/2" VLS (unstretched)
3m 1/2" chain
5338m
3,500 lb (wet) Anchor

Figure A6


AMODE Mooring #6
As Recovered,
1992 yd 077
revised 09-24-92KH
PRESSURE SENSOR
NOYFB
Light, Novatech, s/n 18889
Radio, Novatech, s/n 18885
Freq 159.480 MHz
521m
480m
Subsurface float, Elliptical Buoy
3m 1/2" chain
swivel
643m
602m
Temperature Sensor, s/n 3281
175m
300m 3/8" JWR
818m
777m
Temperature Sensor, s/n 3312
6m
10 ea 17" glassballs, on chain
25m 3/8"JWR
10 ea 17" glassballs, on chain
25m 3/8"JWR
10 ea 17" glassballs, on chain
25m 3/8"JWR
8 ea 17" glassballs, on chain
41m 3/8"JWR
0.22m
swivel
9m
SIO Interrogator, s/n 106
0.22m
6.6m
9m 3/8"JWR
0.22m
1m 1/2" chain
992m
951m
Cage #6
Source #7
AVATAR #6 (Shawn)
0.22m
2 m 1/2" chain
0.22m
2m
H0, ITC s/n 1500
9m
H1, ITC s/n 1501
Kevlar array, Kintec s/n 6-4 (10339) married to
92m 5/16" torque balanced JWR
9m
H2, ITC s/n 1502
92m
9m
H3, ITC s/n 1503
63m
0.22m
TCP s/n 06
0.8m
1090m
1049m
0.22m
1167m
1126m
H4, ITC s/n 1504
Hydrophone extension cables married to
258m 5/16" torque balanced JWR
(91m extension, Kintec s/n 10310;
258m extension, Kintec s/n 10316)
175m
1342m
1301m
H5, ITC s/n 1505
1308m
swivel
1350m
1309m
WHOI Interrogator, s/n 006
150m 5/16" JWR

page 2
Mooring 6

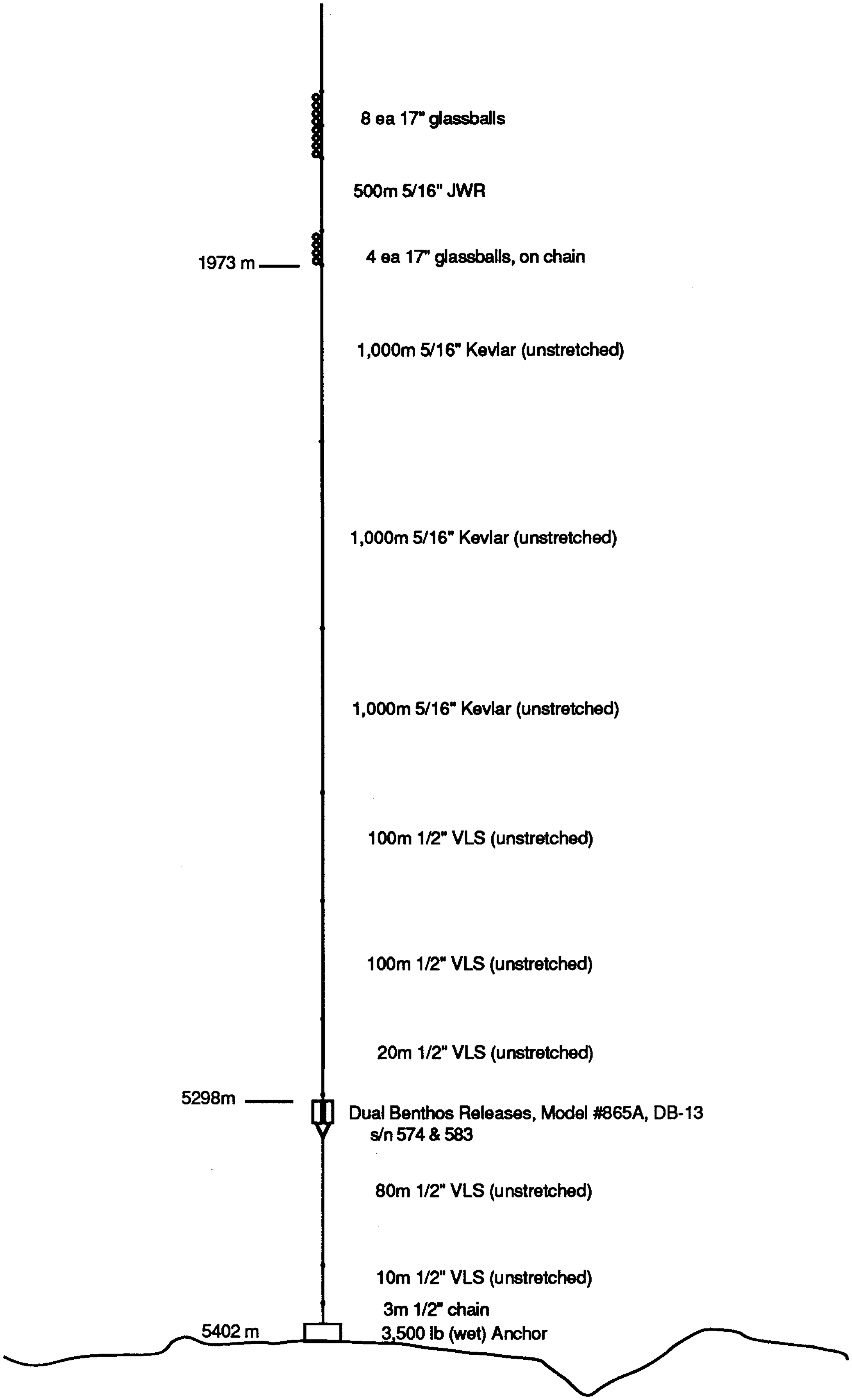


Figure A7

Bermuda Source Mooring
As Recovered, March 22, 1992
revised 09-24-92KH

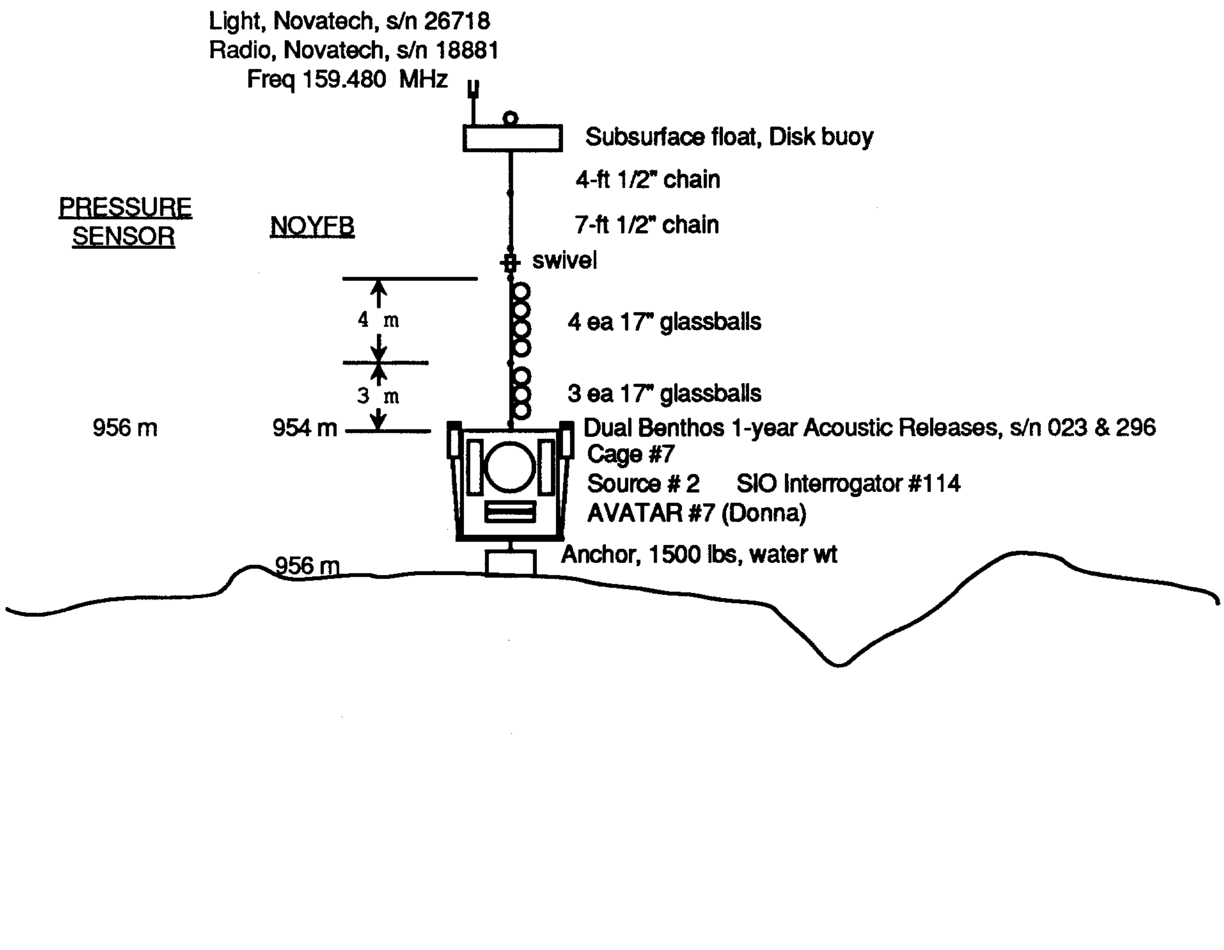
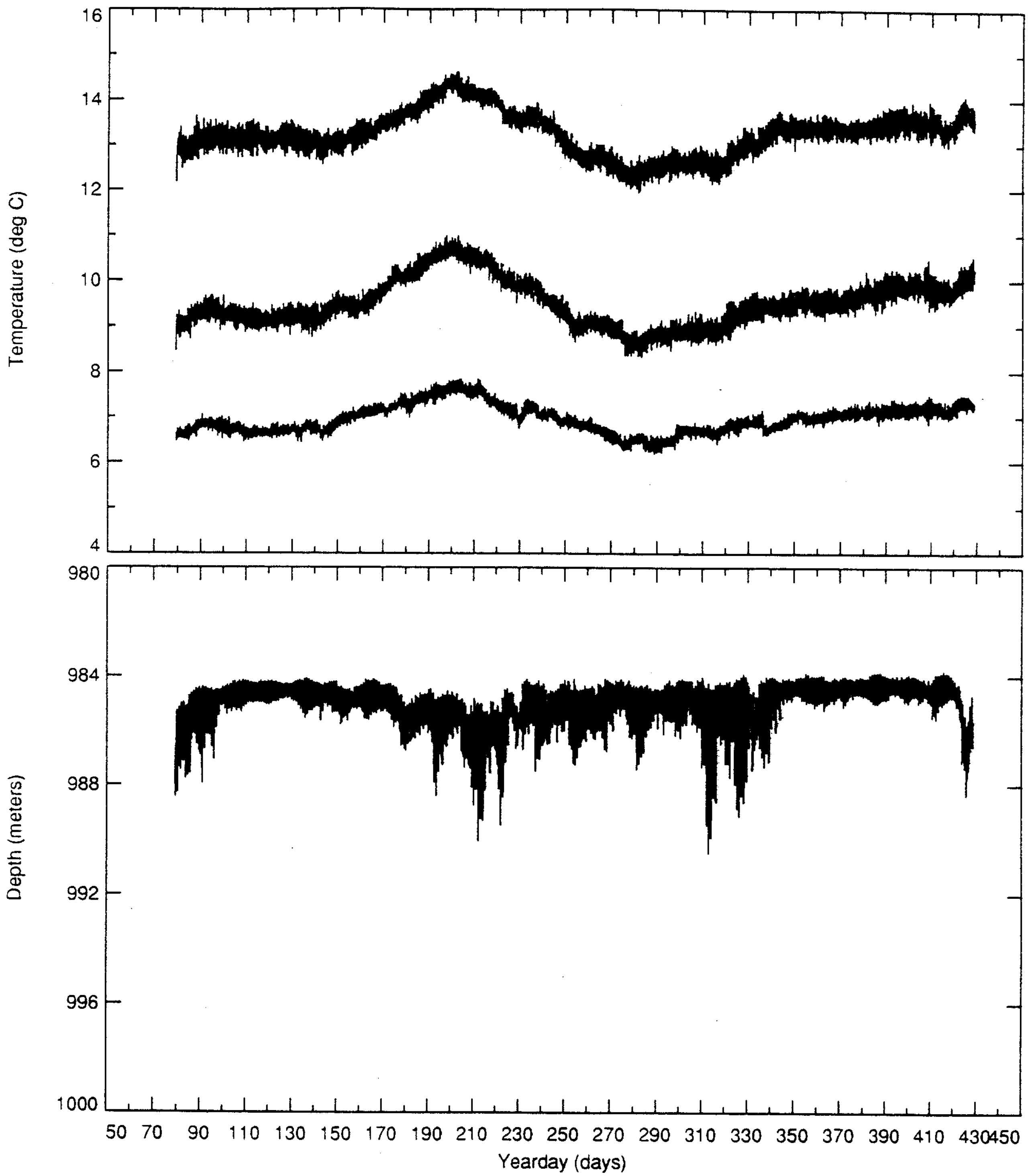


Figure A8

Appendix B. Moored temperature and pressure

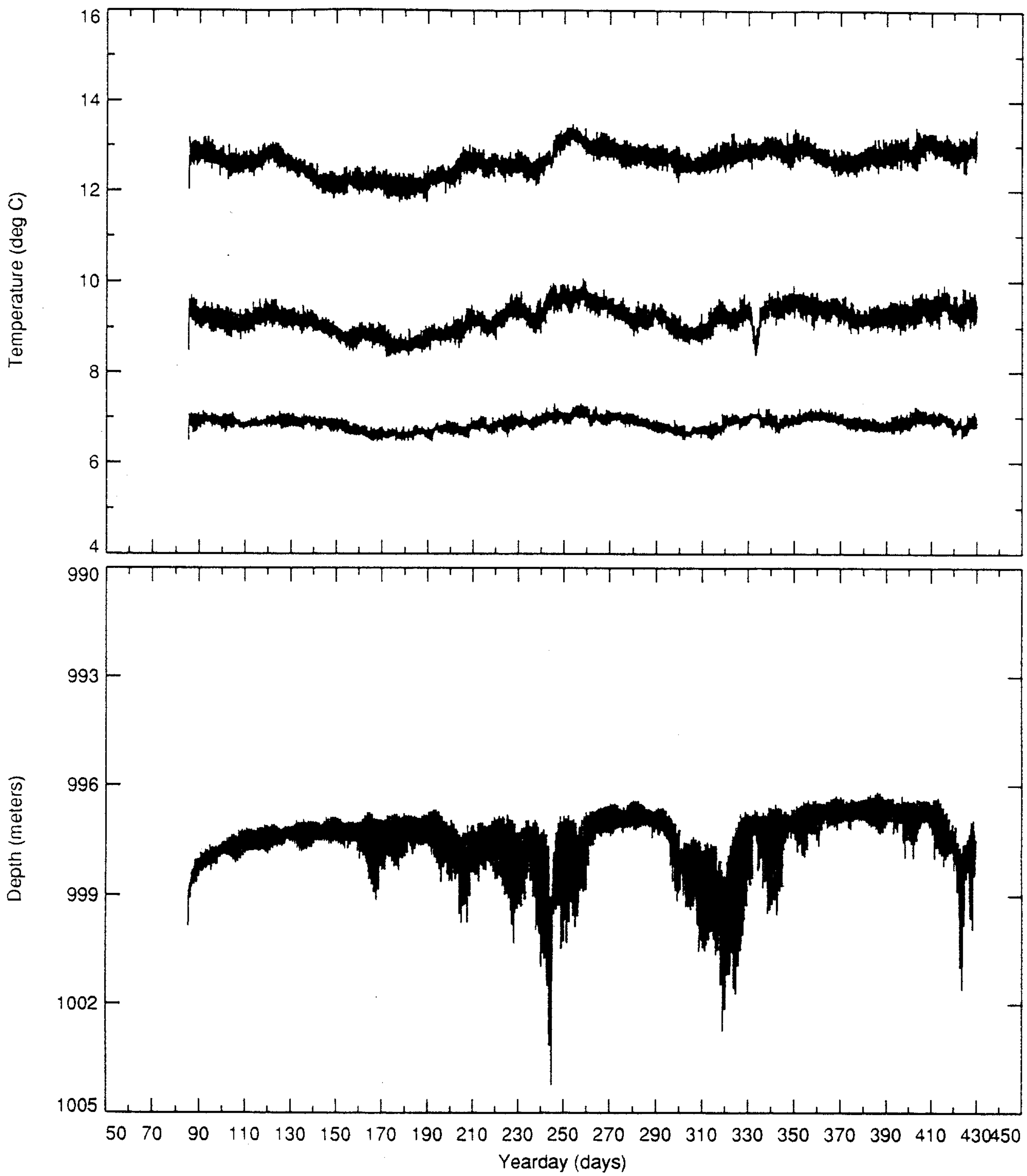
Temperatures and pressure for each of the moorings are given in Figures B1 through B7. The mooring 5 times series are from both mooring 5 deployments, all plotted on a single plot; the time at which the depth changes is the time at which the mooring was redeployed. The top two temperatures on moorings 1–6 were obtained using Brancker temperature sensors. Temperature and pressure were measured by all of the AVATAR's.

The Brancker temperature sensors made measurements at 20-min intervals. The least count resolution of the raw data ranges from 2 m°C at 0°C to 5 m°C at 25°C. The absolute accuracy of the calibrated temperature data is estimated to be better than 5 m°C. The AVATAR's measured pressure and temperature at 15-min intervals. The pressure and temperature least counts are approximately 0.1 psi and 0.0003° C, respectively. Converting the raw data to pressure and temperature using the precruise and postcruise calibrations gave pressure and temperature series that differed by -0.6±2.5 psi and -3.1±4.7m°C. The final values were simple averages of the values obtained using the precruise and postcruise calibration coefficients.



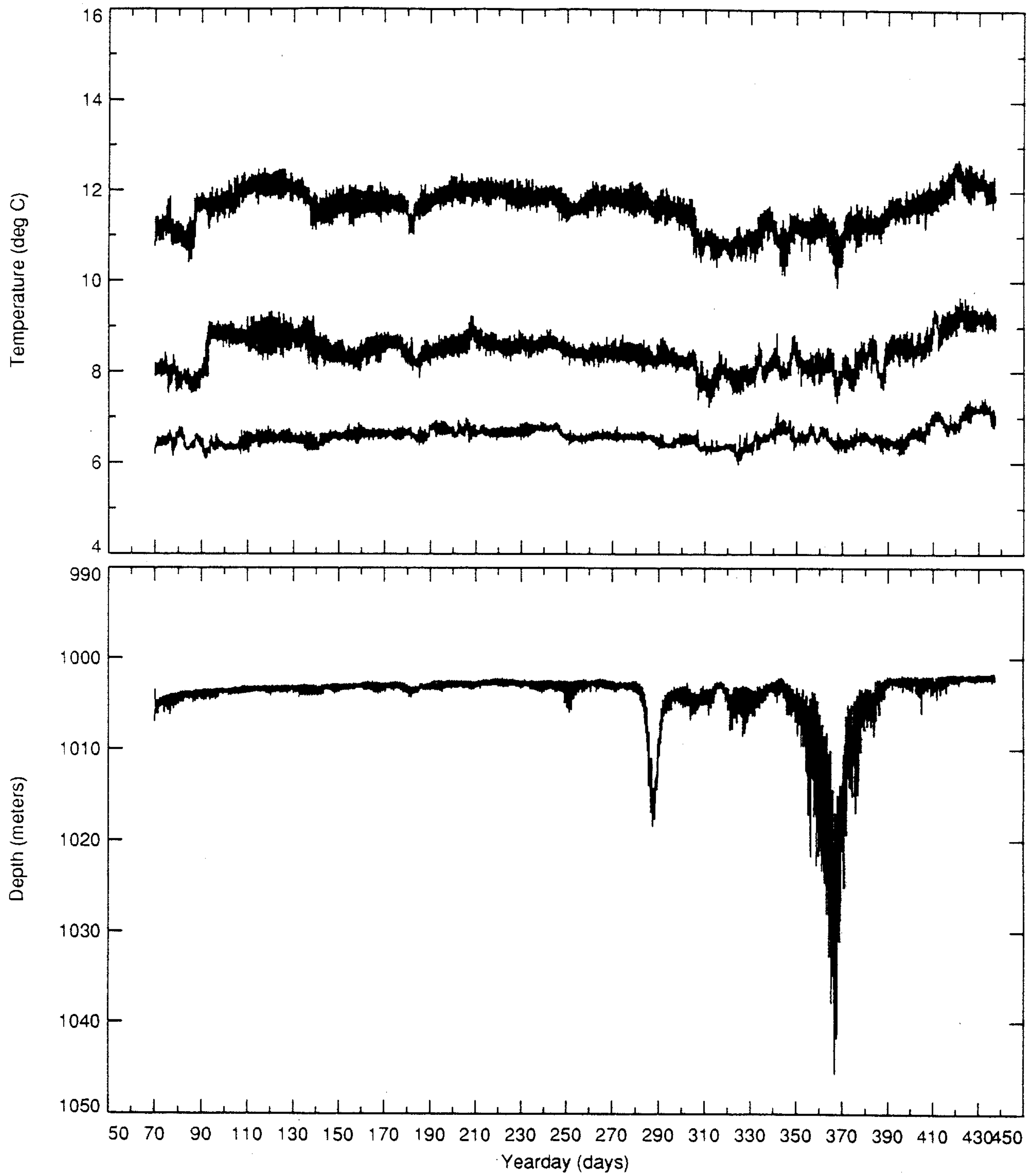
Depth and Temperature vs Yearday,
mooring1, original data

Figure B1



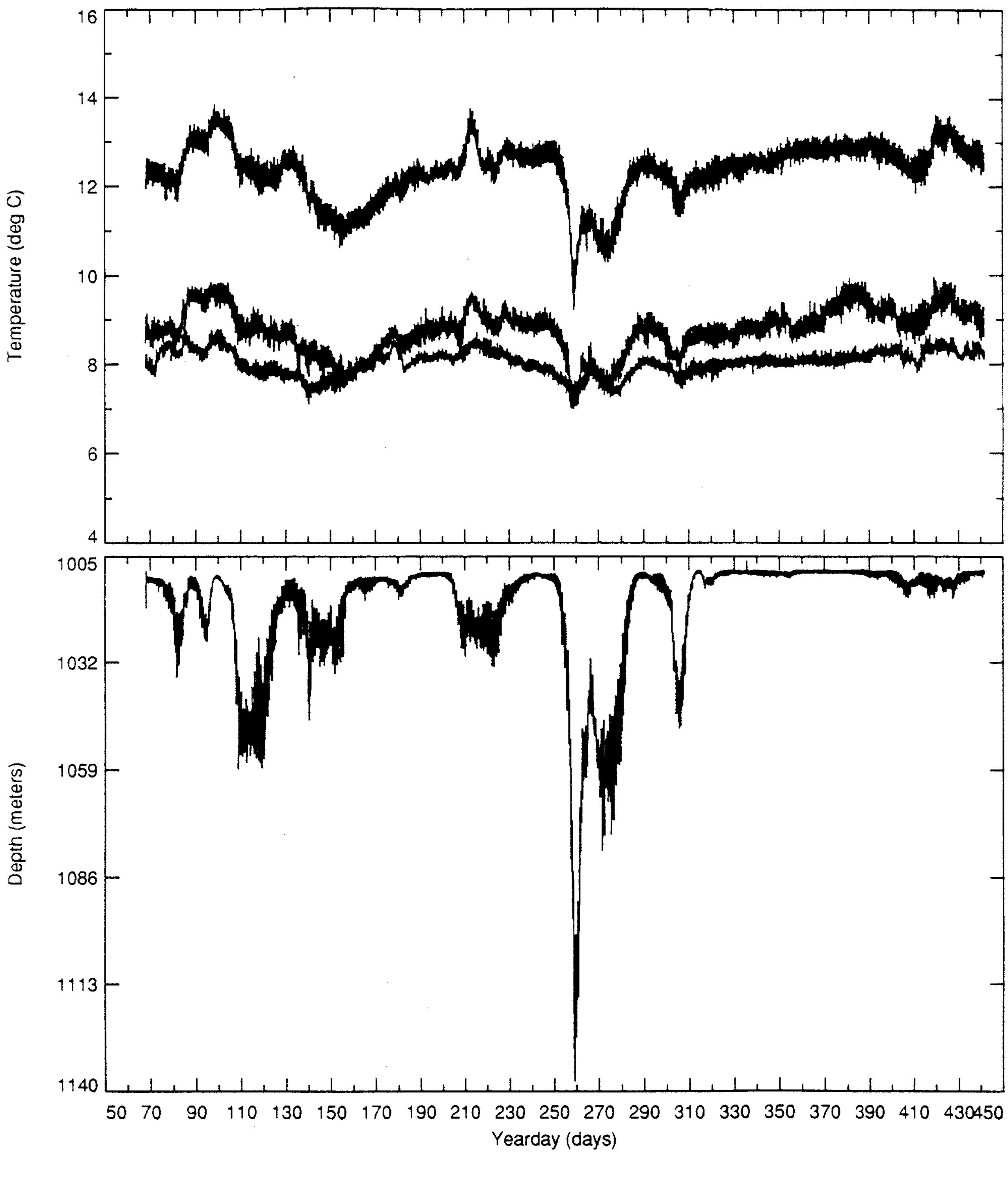
Depth and Temperature vs Yearday,
mooring2, original data

Figure B2



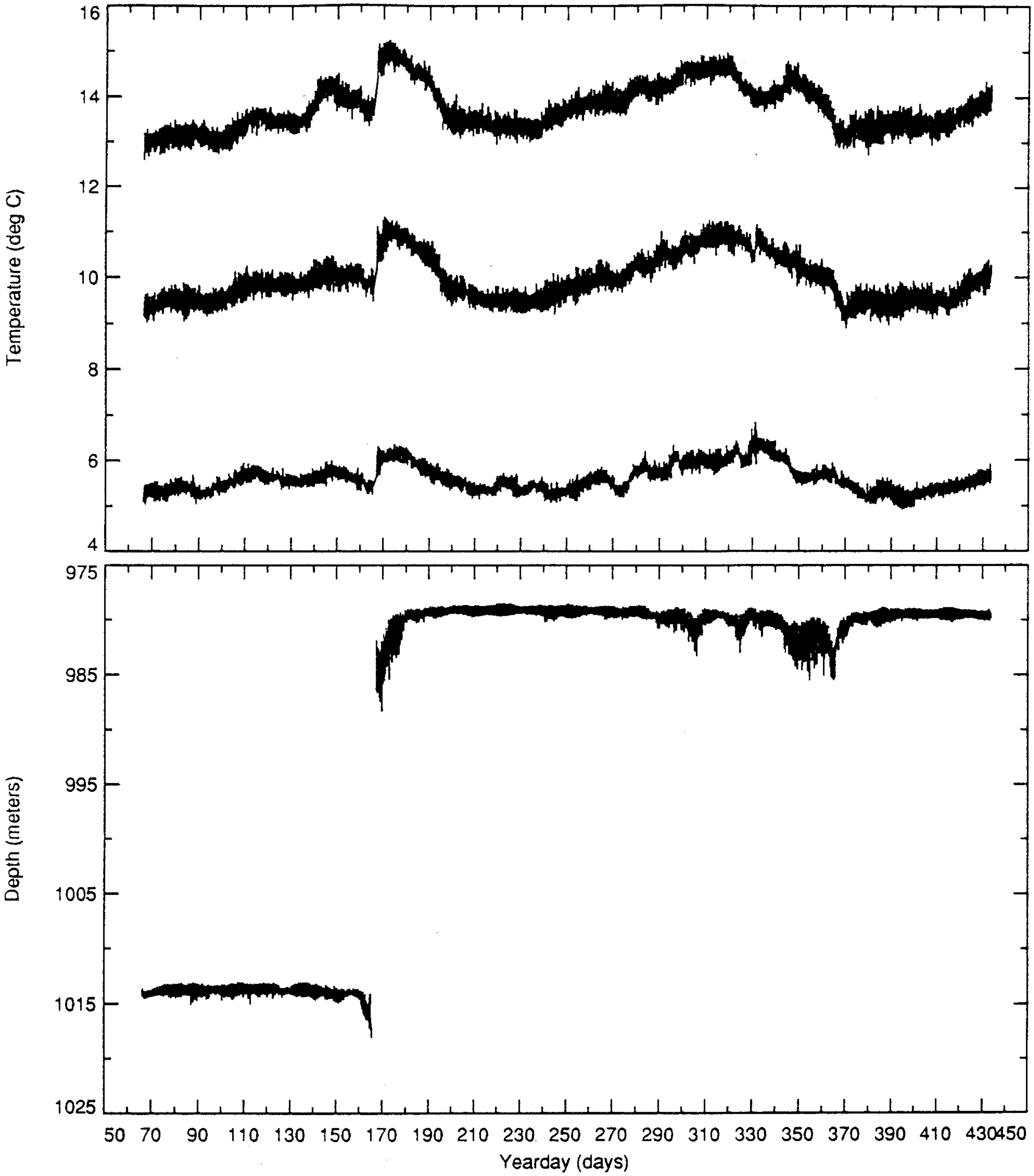
Depth and Temperature vs Yearday,
mooring3, original data

Figure B3



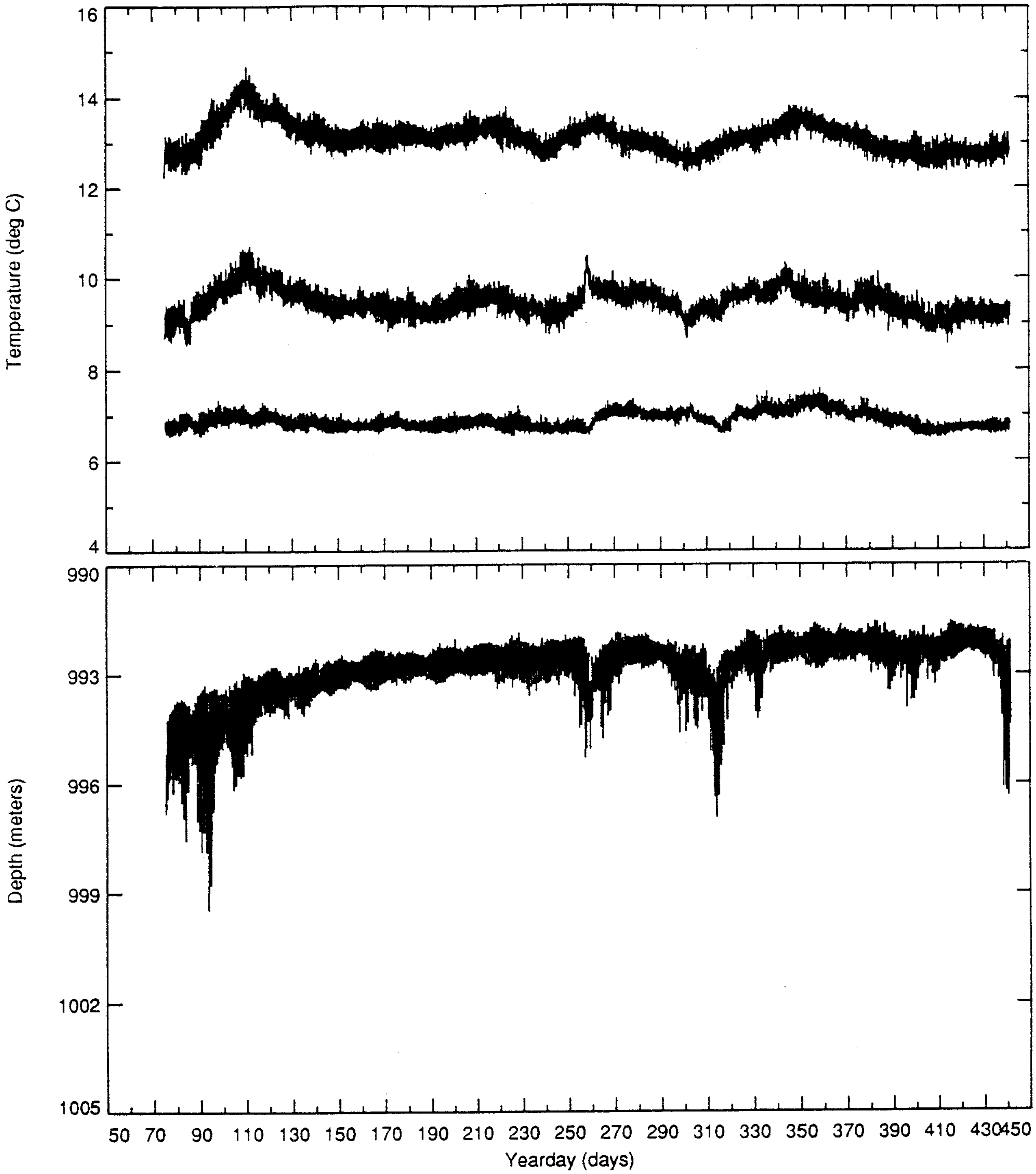
Depth and Temperature vs Yearday,
mooring4, original data

Figure B4



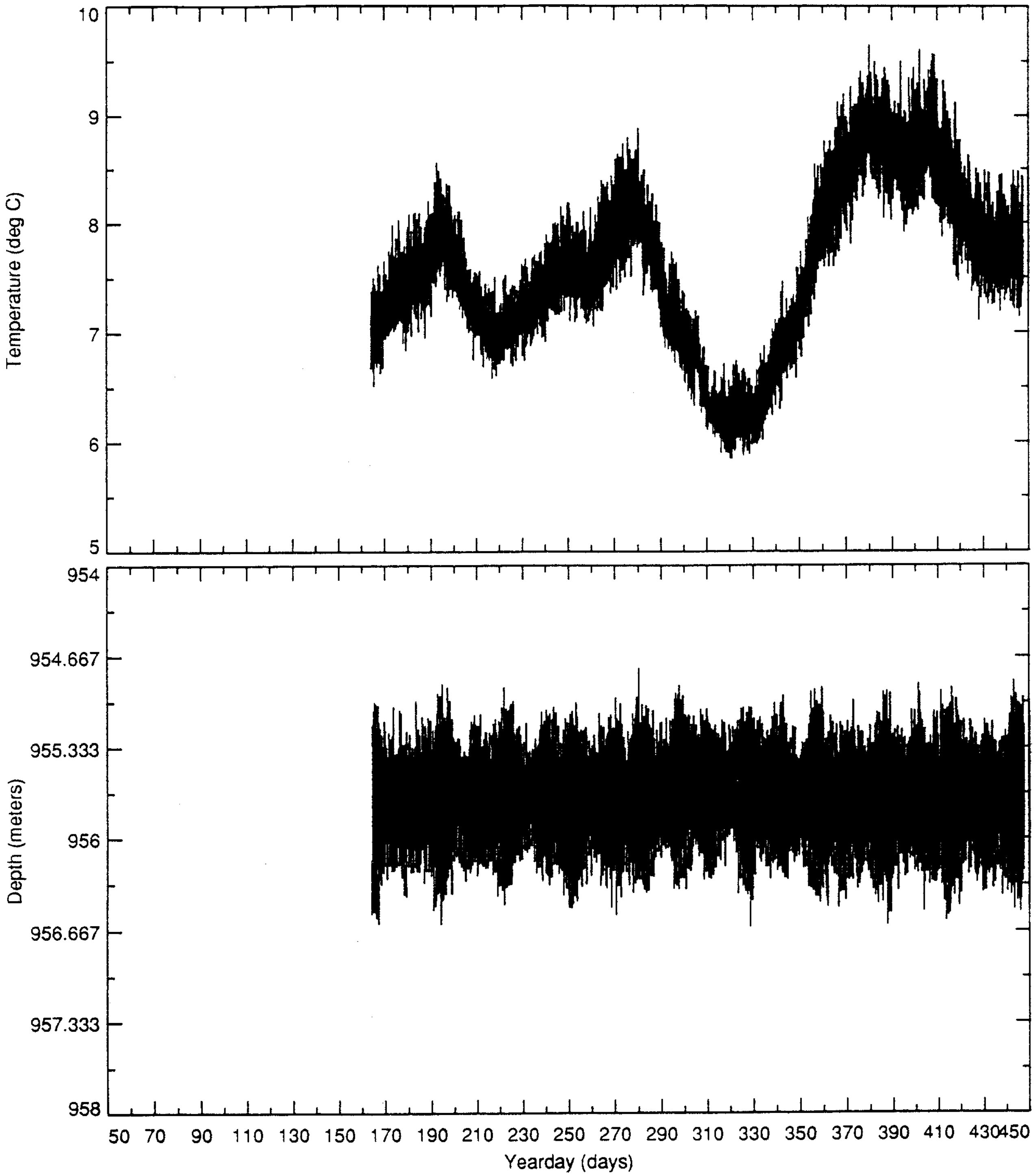
Depth and Temperature vs Yearday,
moorings 5a and 5b, original data

Figure B5



Depth and Temperature vs Yearday,
mooring6, original data

Figure B6



Depth and Temperature vs Yearday,
mooring 7, original data

Figure B7

Appendix C. Acoustic travel times

Raw travel times at hydrophone H0 (the one nearest the source) on moorings 1 through 6 are shown as a function of yearday in Fig. C1–C30. Data from moorings 5a and 5b has been combined in these plots. The travel time changes in the figures are due to a combination of changes in the ocean, clock drift, and mooring motion. Dot size is proportional to signal-to-noise ratio (SNR). In all cases, the SNR decreases toward the end of the experiment, presumably due to decreasing source battery voltage.

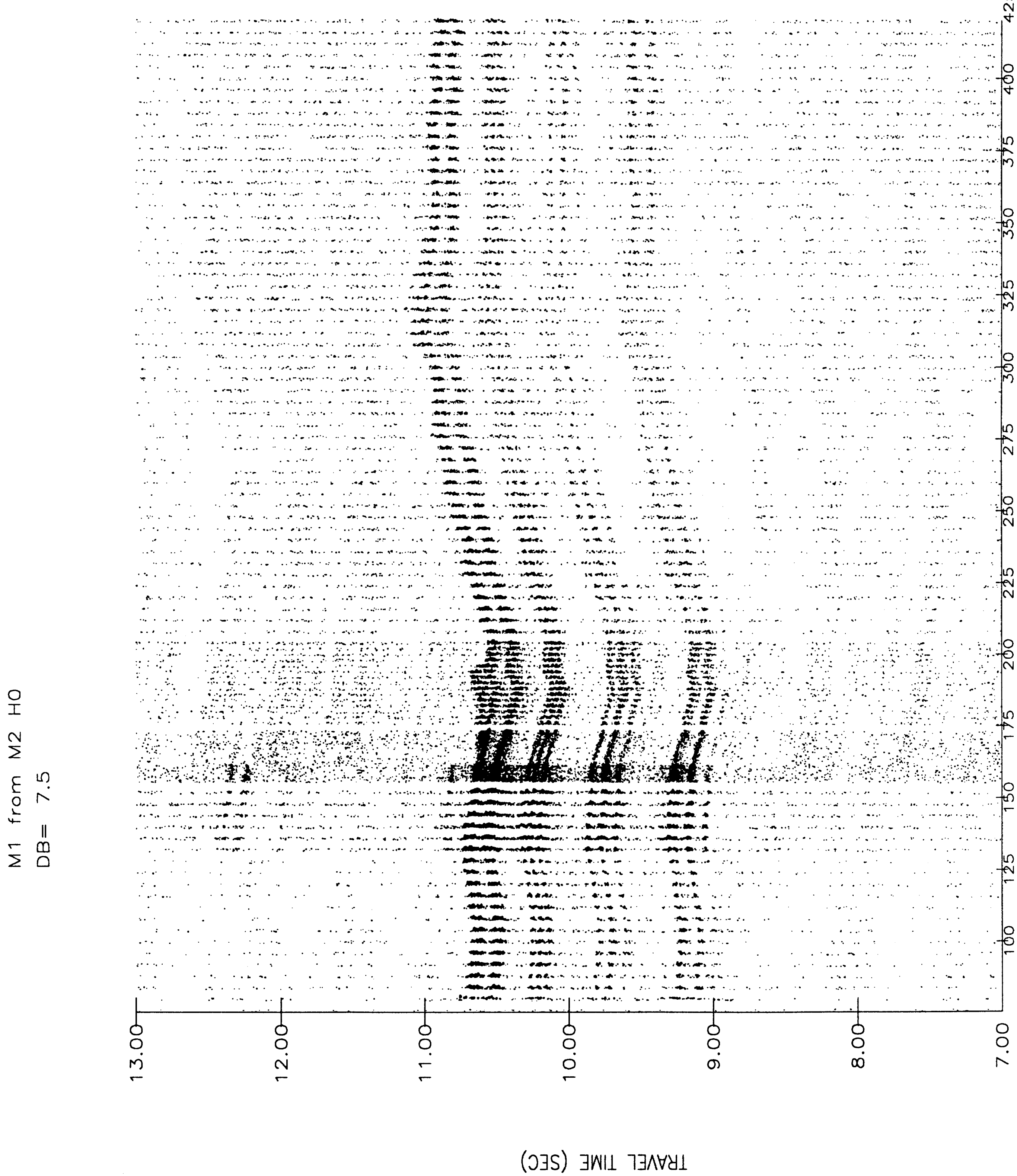

M1 from M2 H0
DB= 7.5
TRAVEL TIME (SEC)
13.00
12.00
11.00
10.00
9.00
8.00
7.00
100
125
150
175
200
225
250
275
300
325
350
375
400
425

Figure C1

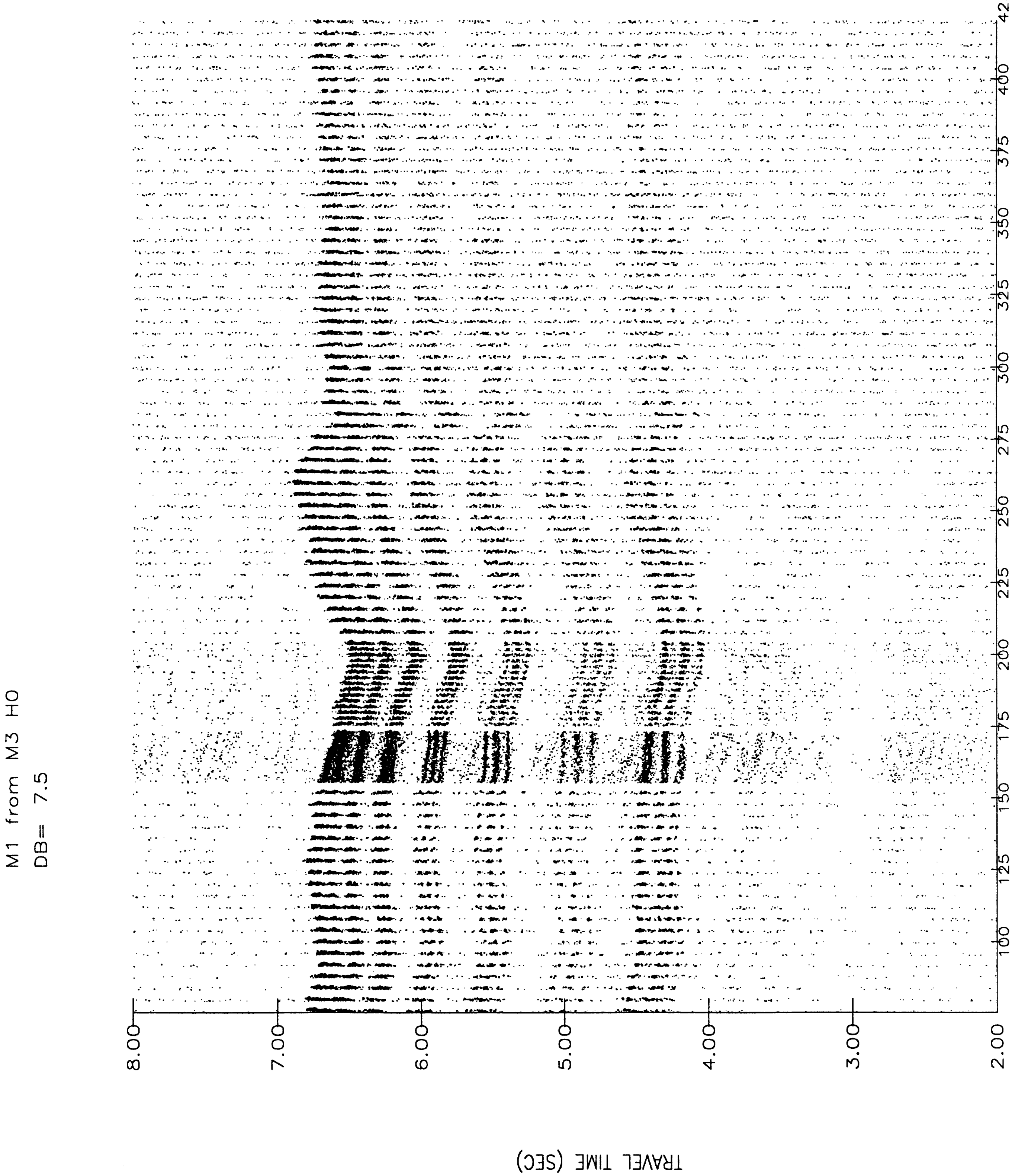
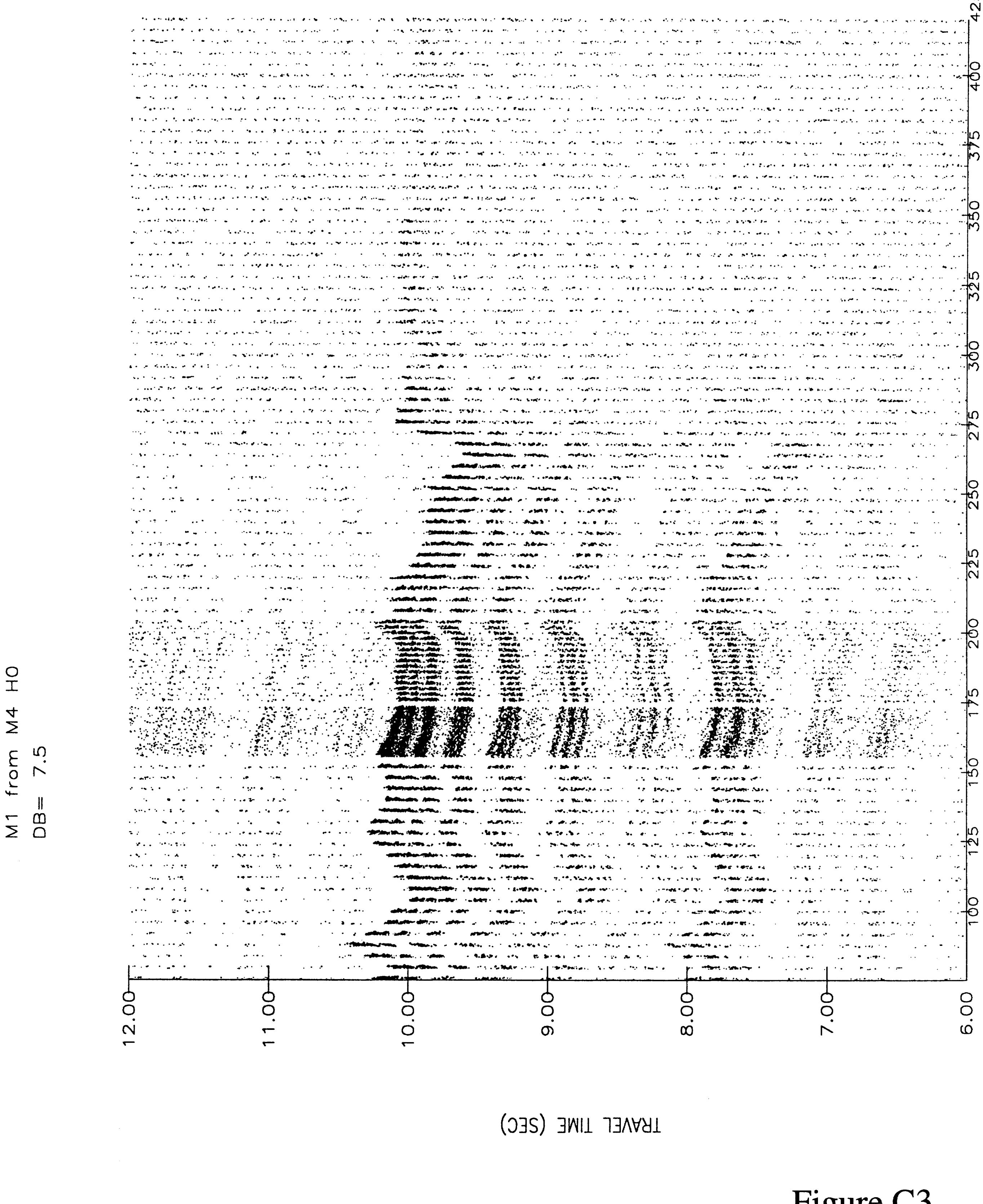
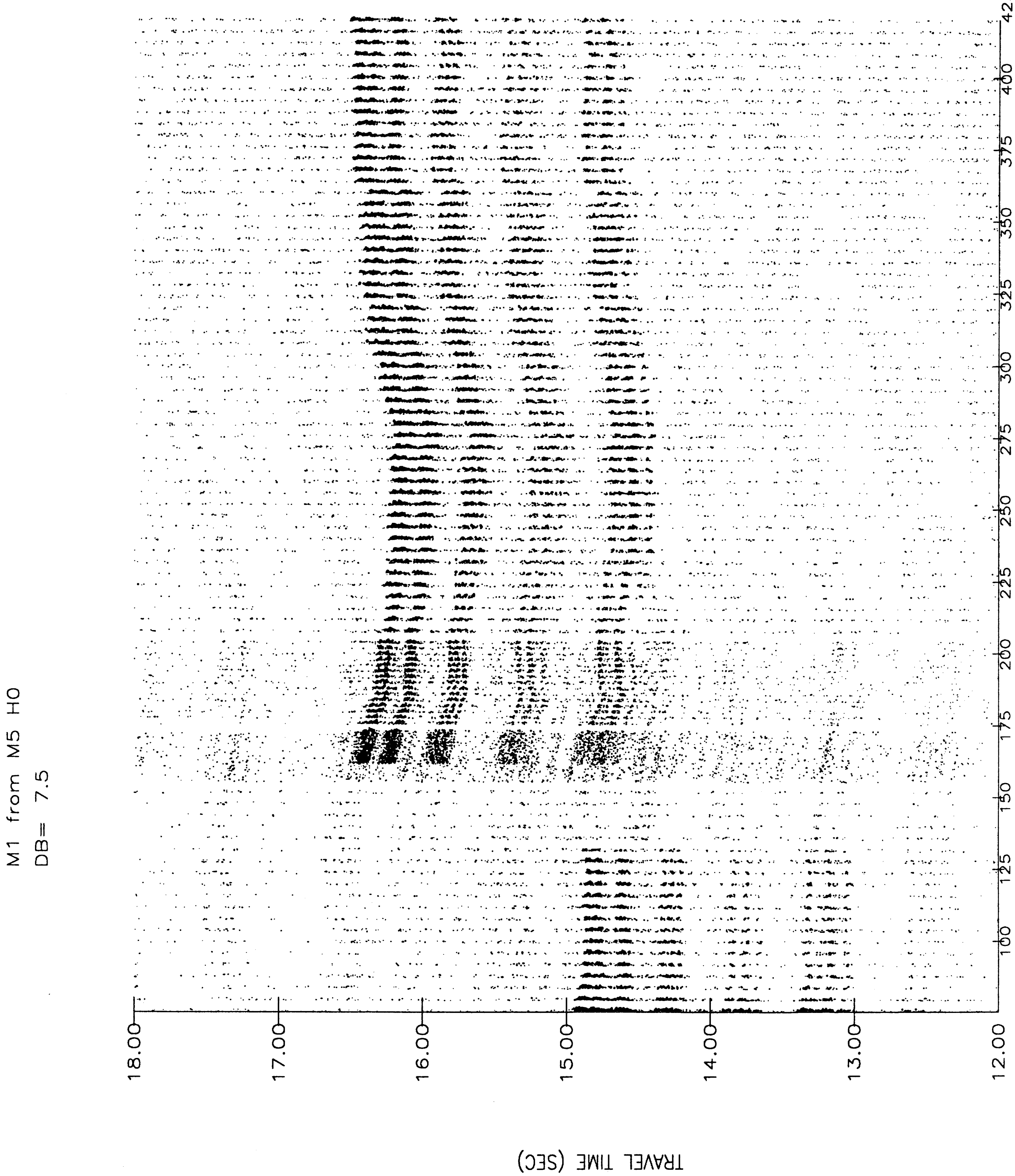

M1 from M3 H0
DB= 7.5
TRAVEL TIME (SEC)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
100
125
150
175
200
225
250
275
300
325
350
375
400
425

Figure C2



M1 from M4 H0
DB= 7.5
TRAVEL TIME (SEC)
12.00
11.00
10.00
9.00
8.00
7.00
6.00
100
125
150
175
200
225
250
275
300
325
350
375
400
425

Figure C3



M1 from M5 H0
DB= 7.5
TRAVEL TIME (SEC)
18.00
17.00
16.00
15.00
14.00
13.00
12.00
100
125
150
175
200
225
250
275
300
325
350
375
400
425

Figure C4

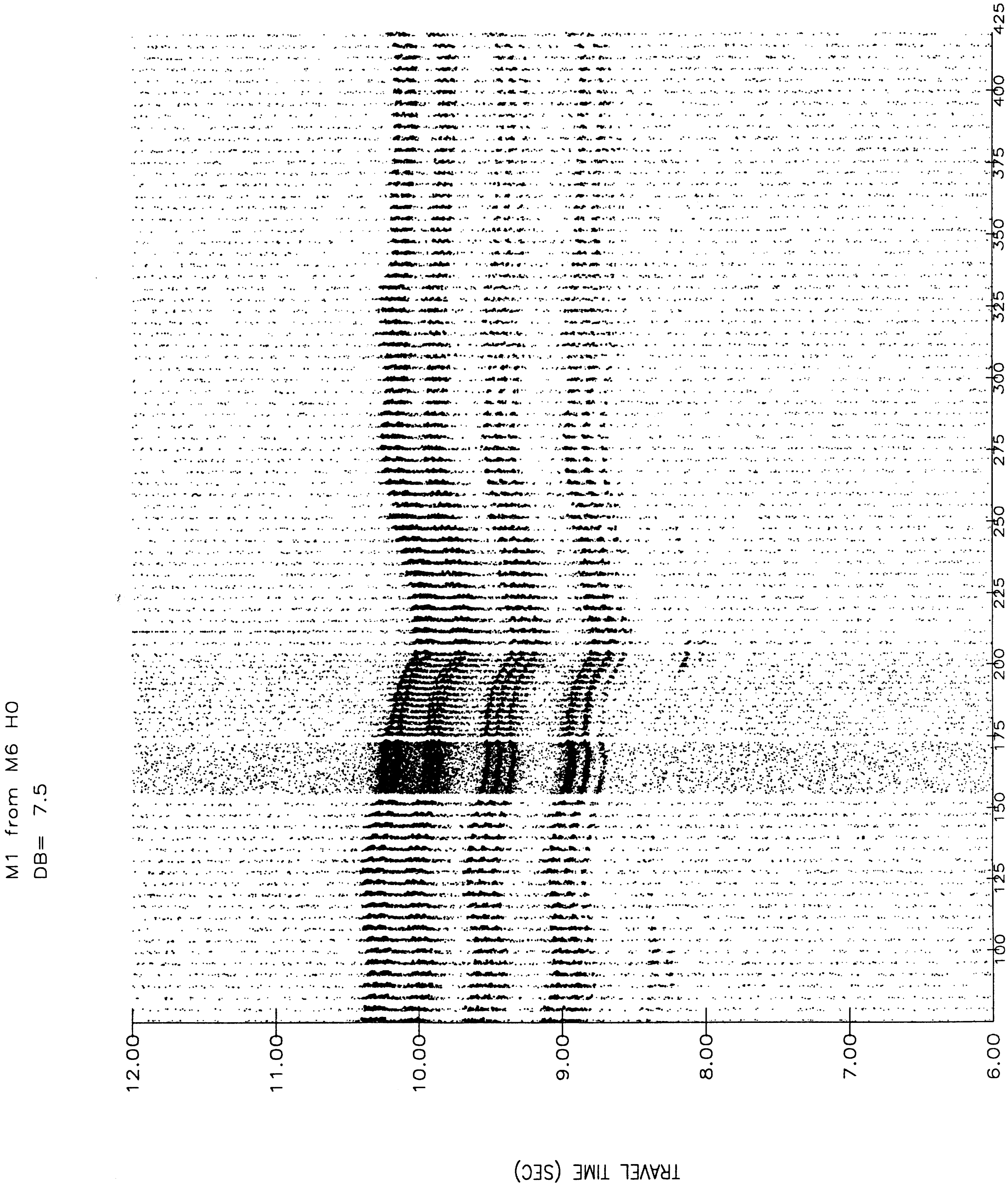

M1 from M6 HO
DB= 7.5
TRAVEL TIME (SEC)
12.00
11.00
10.00
9.00
8.00
7.00
6.00
100
125
150
175
200
225
250
275
300
325
350
375
400
425

Figure C5

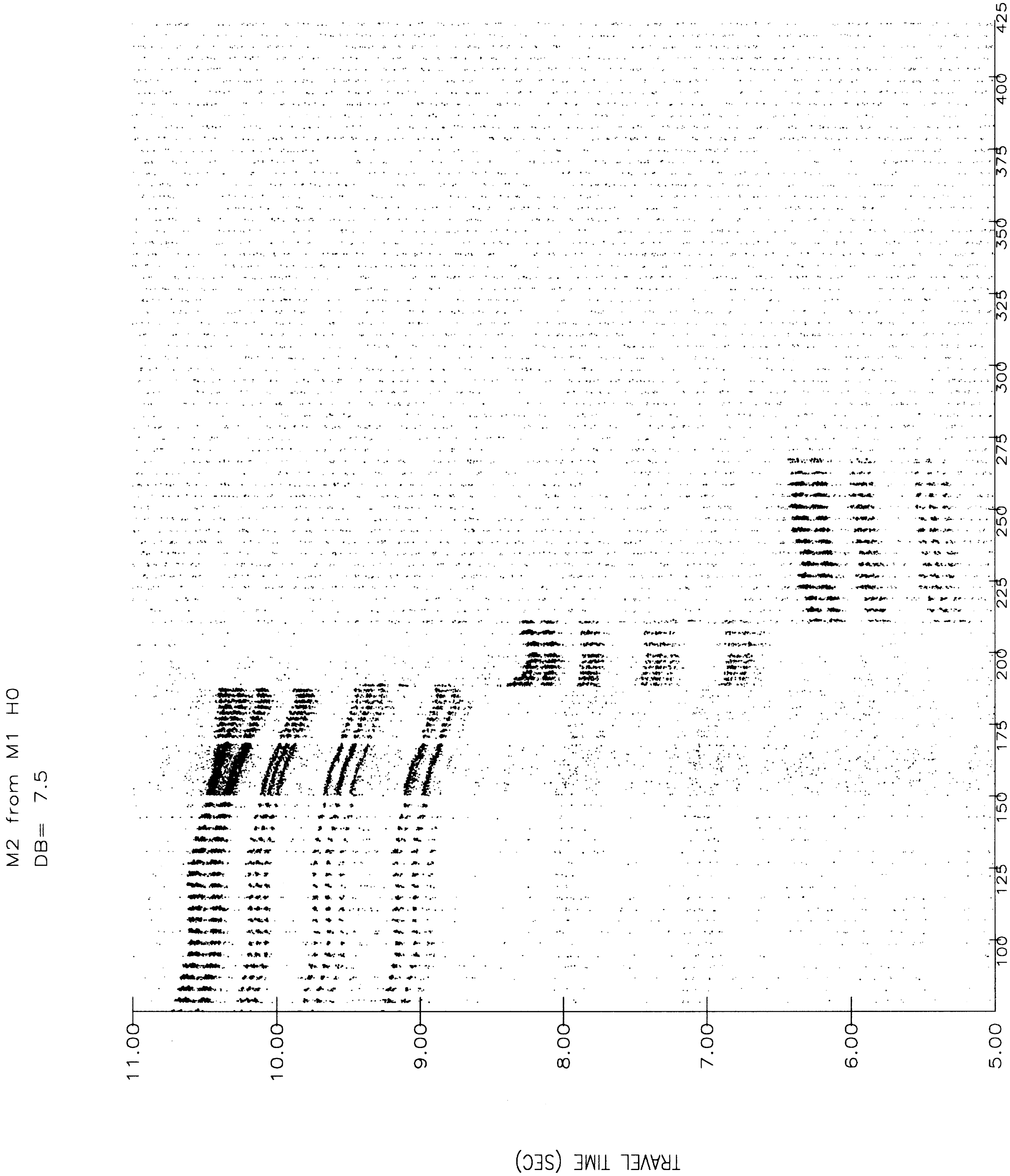

M2 from M1 HO
DB= 7.5
TRAVEL TIME (SEC)
11.00
10.00
9.00
8.00
7.00
6.00
5.00
100
125
150
175
200
225
250
275
300
325
350
375
400
425

Figure C6

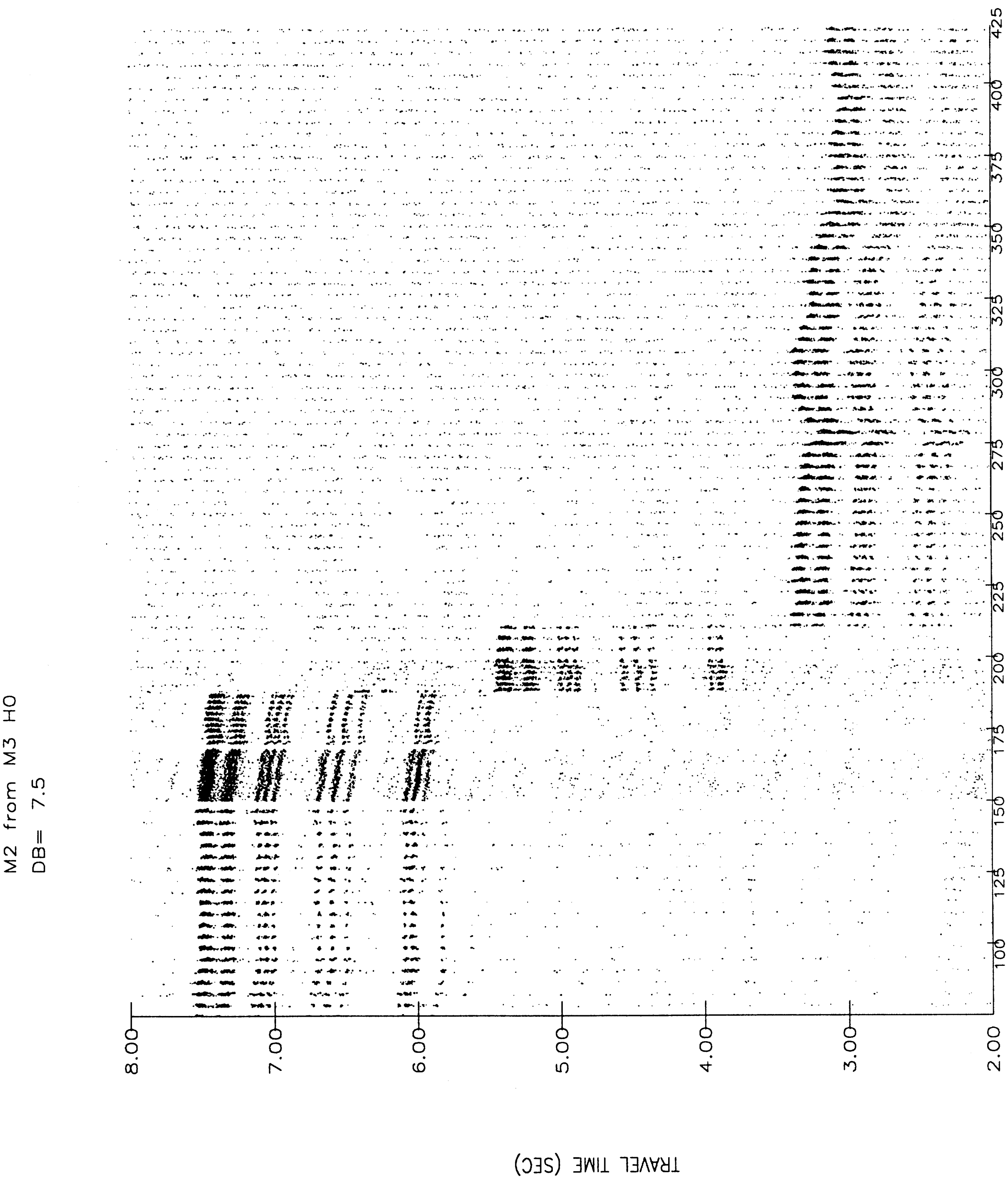

M2 from M3 HO
DB= 7.5
TRAVEL TIME (SEC)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
100
125
150
175
200
225
250
275
300
325
350
375
400
425

Figure C7

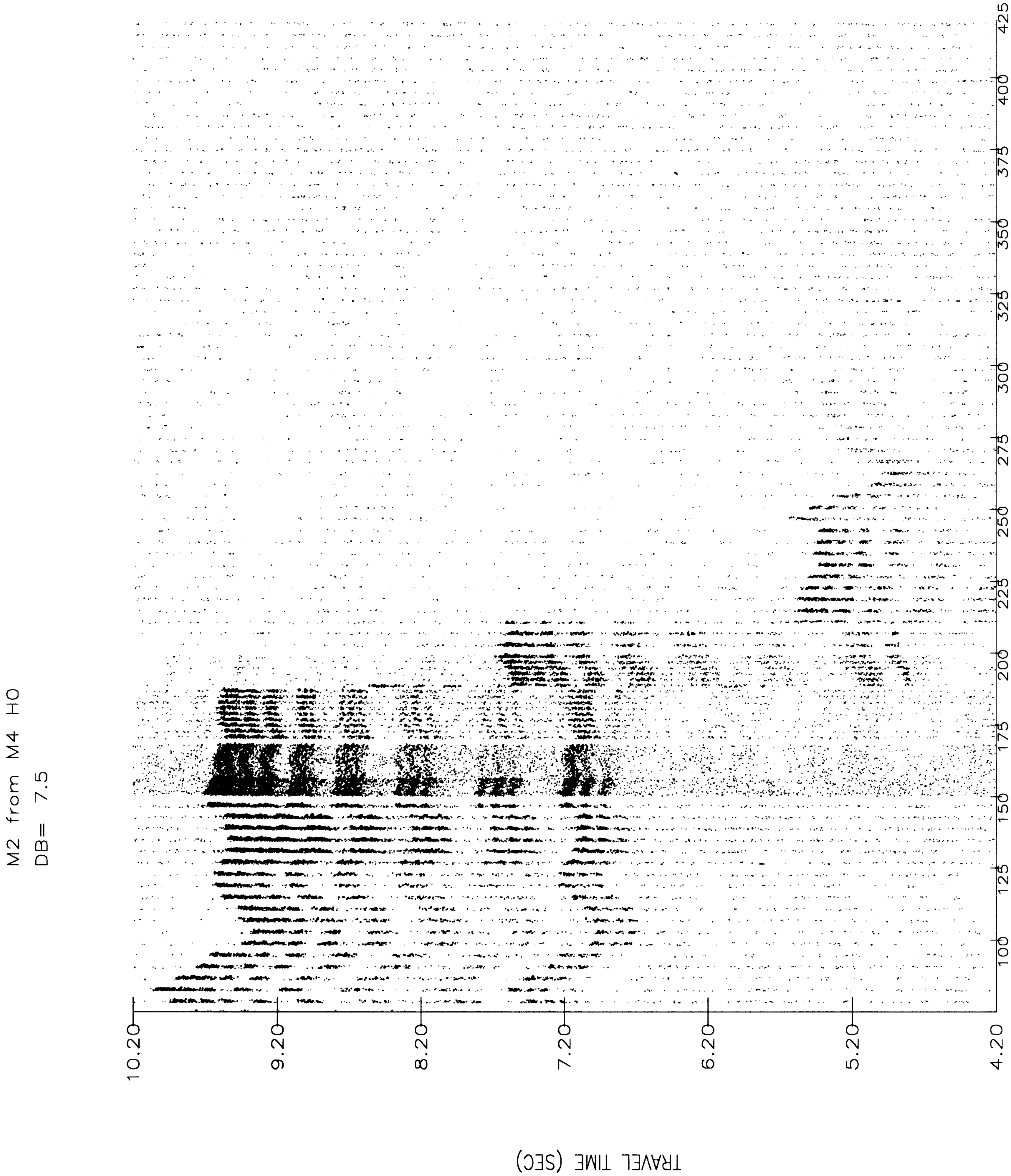

M2 from M4 HO
DB= 7.5
TRAVEL TIME (SEC)
10.20
9.20
8.20
7.20
6.20
5.20
4.20
100
125
150
175
200
225
250
275
300
325
350
375
400
425

Figure C8

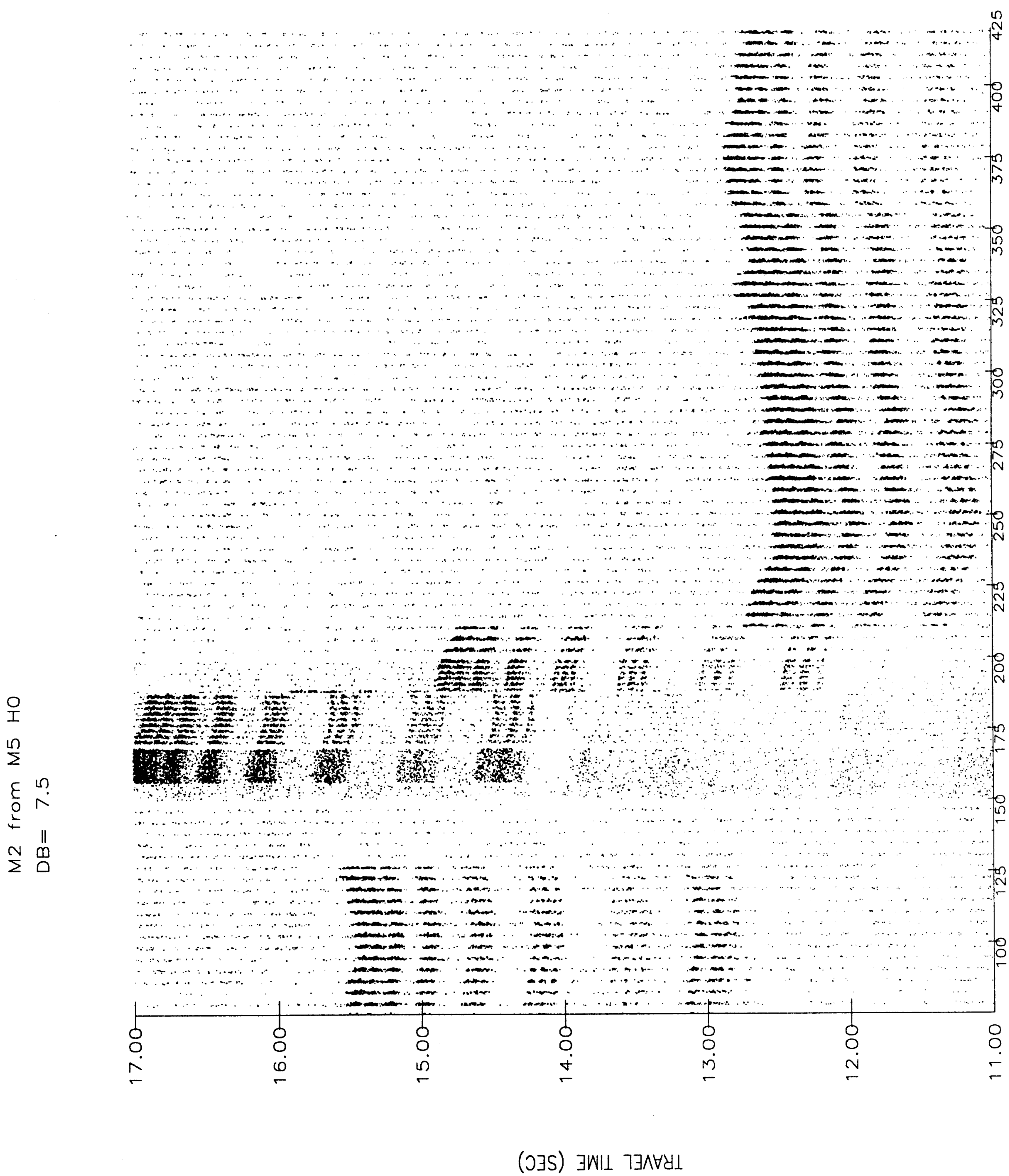

M2 from M5 HO
DB= 7.5
TRAVEL TIME (SEC)
17.00
16.00
15.00
14.00
13.00
12.00
11.00
100
125
150
175
200
225
250
275
300
325
350
375
400
425

Figure C9

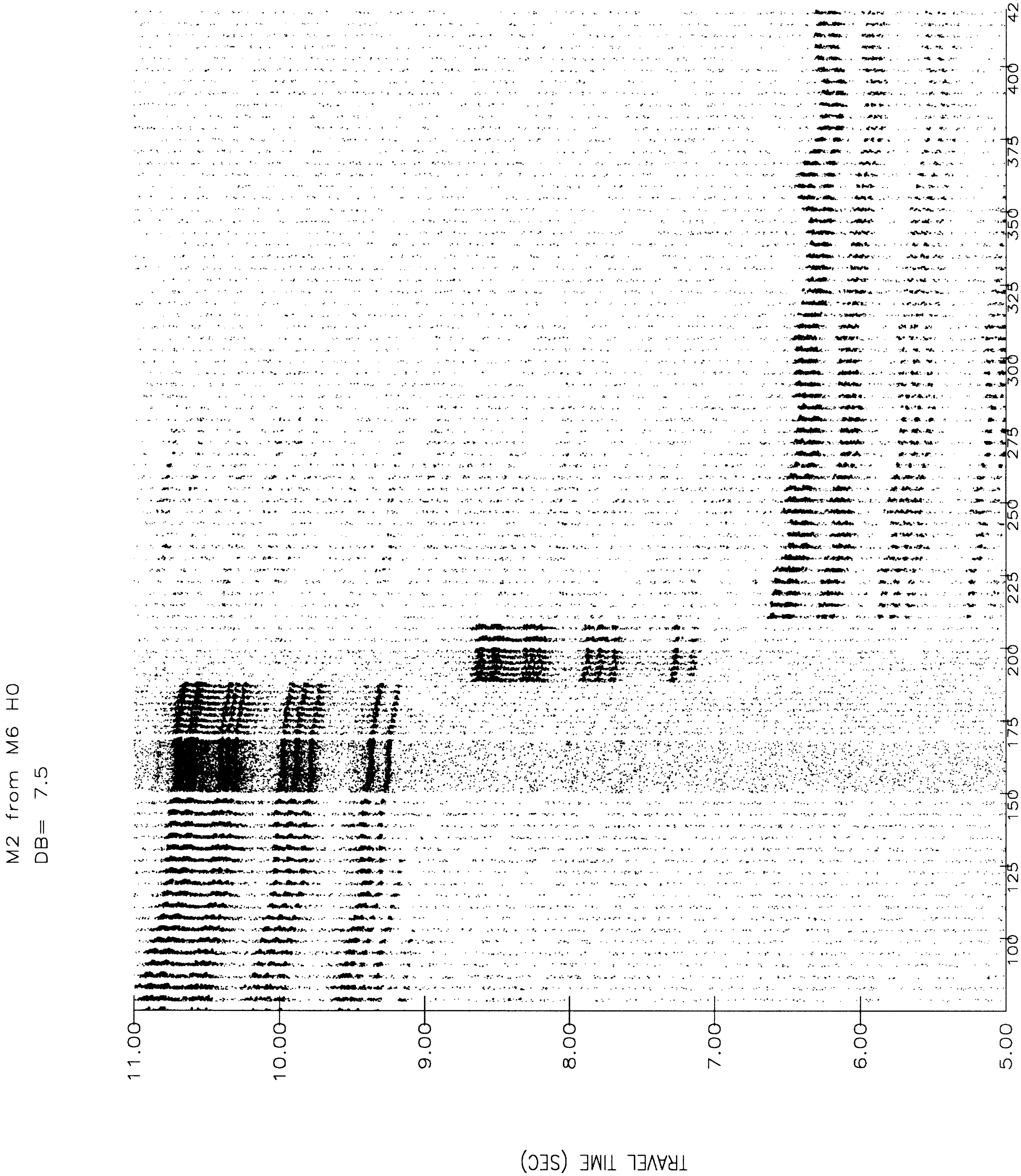
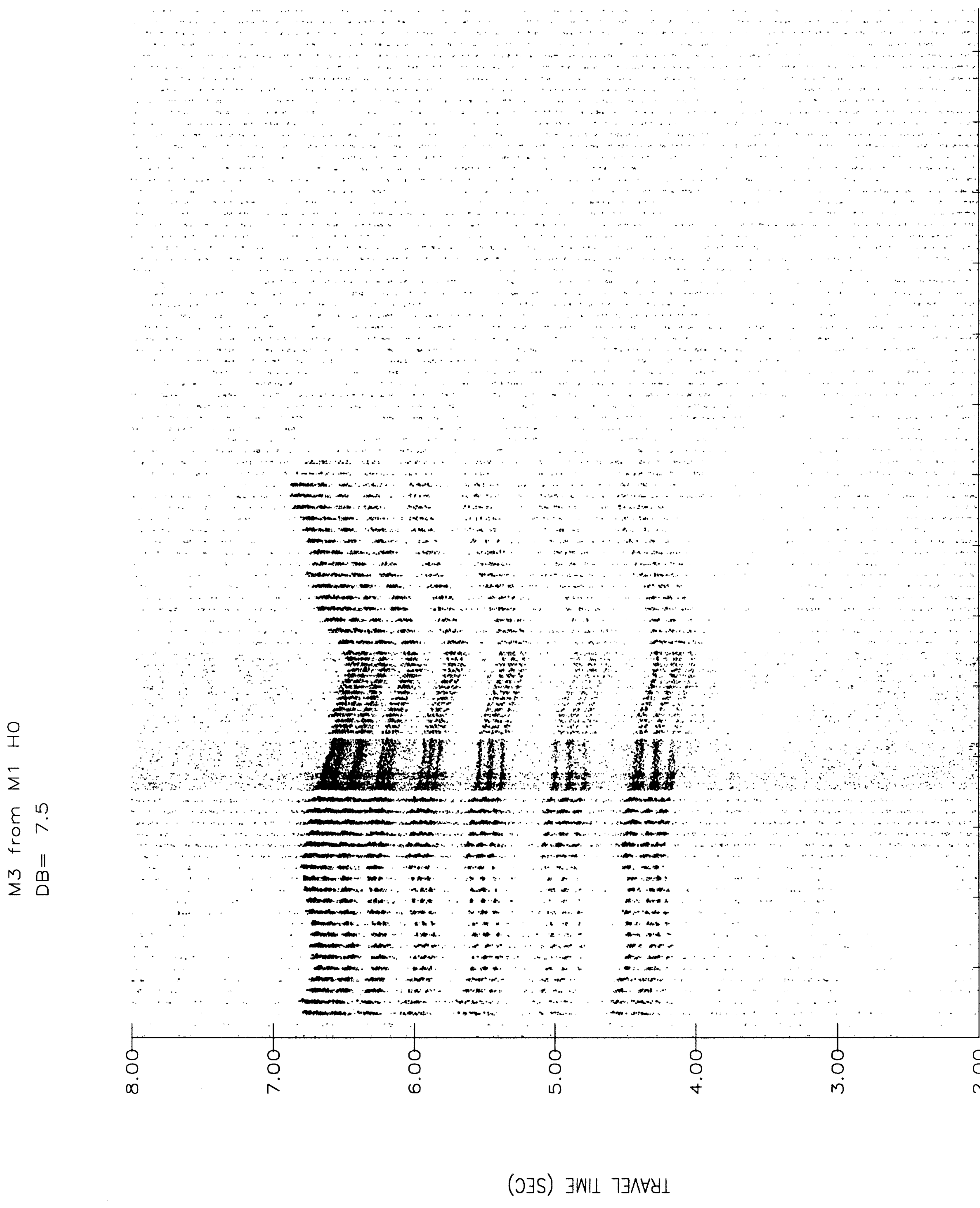

M2 from M6 HO
DB= 7.5
TRAVEL TIME (SEC)
11.00
10.00
9.00
8.00
7.00
6.00
5.00
100
125
150
175
200
225
250
275
300
325
350
375
400
425

Figure C10



M3 from M1 H0
DB= 7.5
TRAVEL TIME (SEC)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425

Figure C11

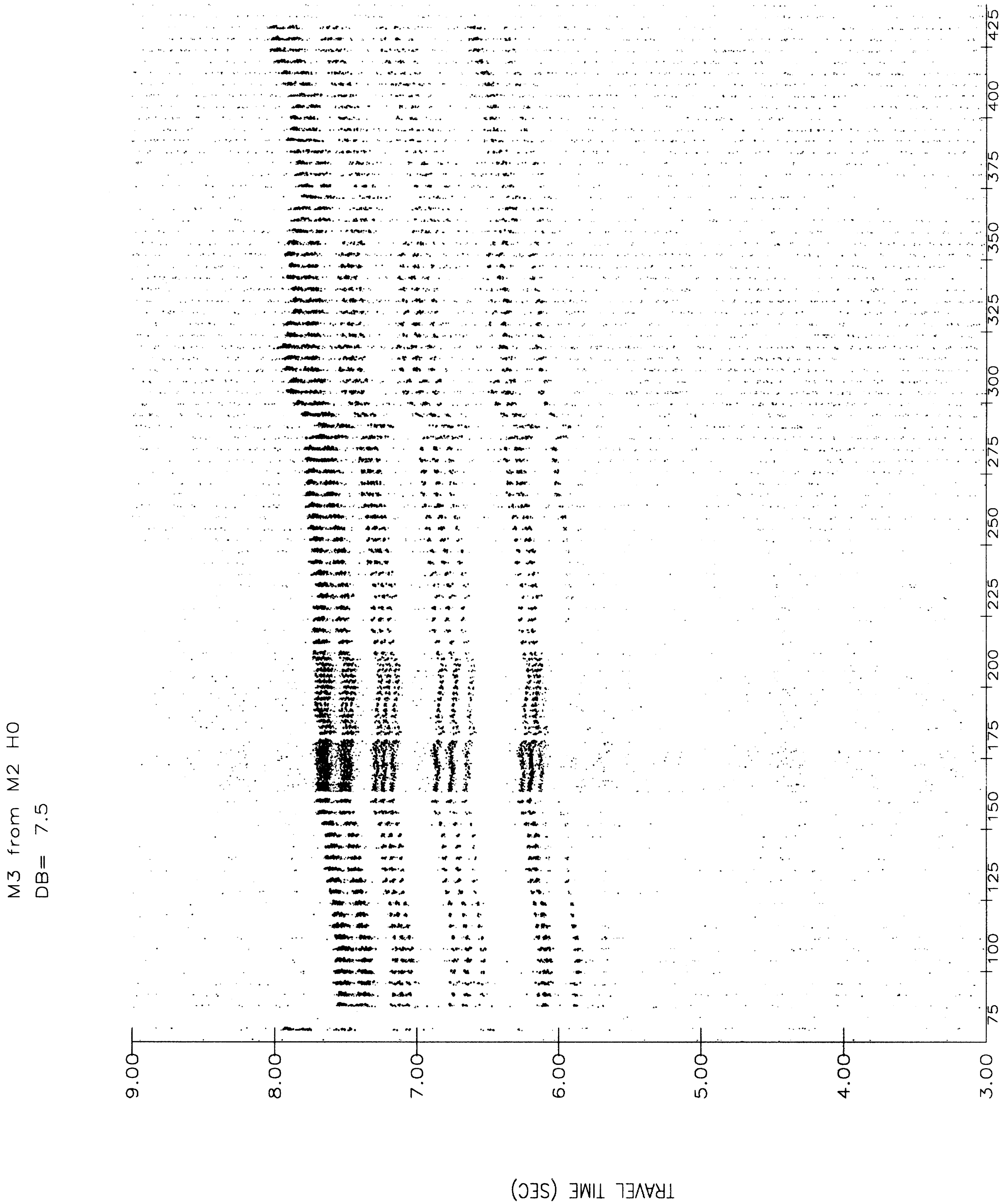

M3 from M2 HO
DB= 7.5
TRAVEL TIME (SEC)
9.00
8.00
7.00
6.00
5.00
4.00
3.00
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425

Figure C12

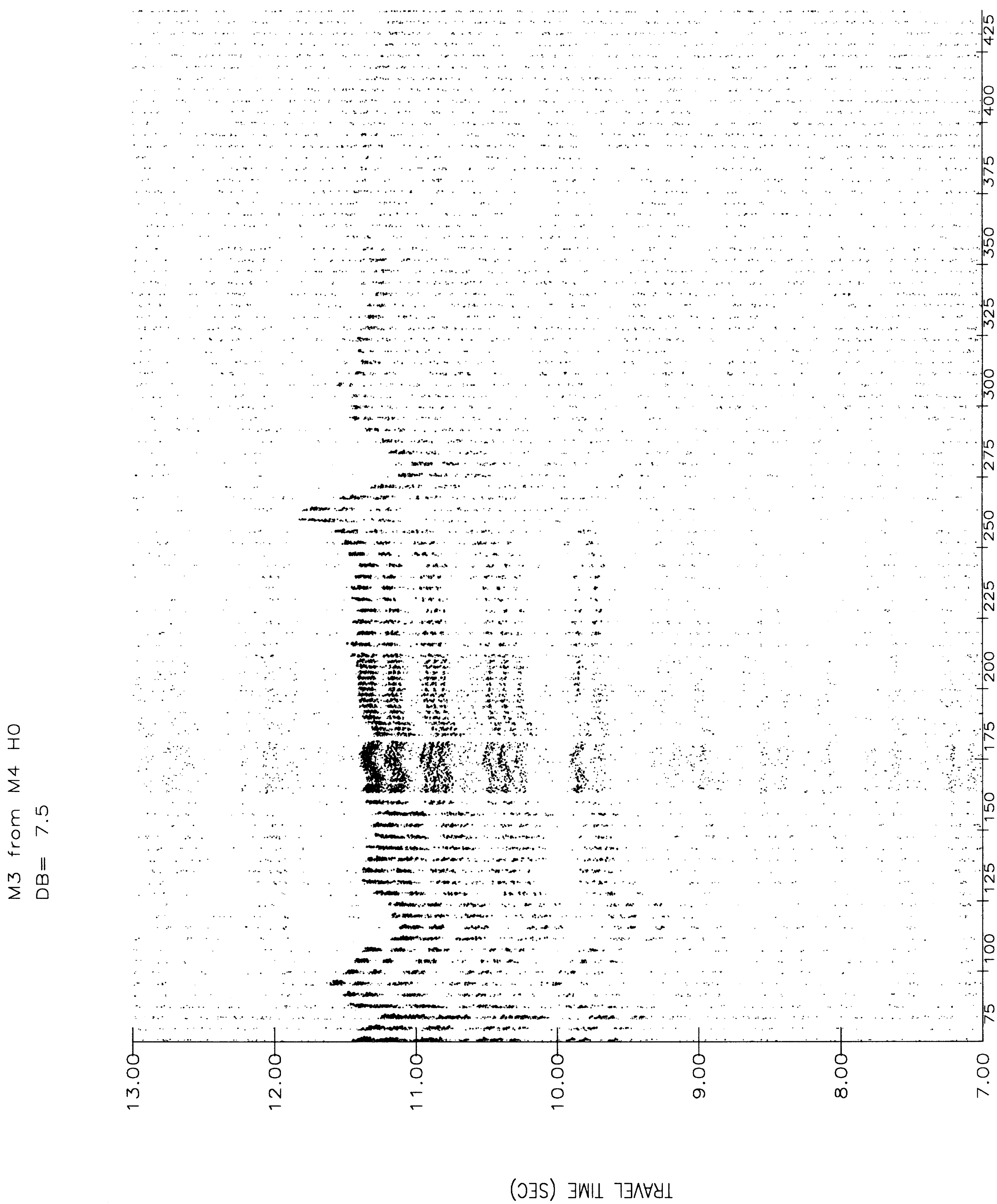

M3 from M4 HO
DB= 7.5
TRAVEL TIME (SEC)
13.00
12.00
11.00
10.00
9.00
8.00
7.00
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425

Figure C13

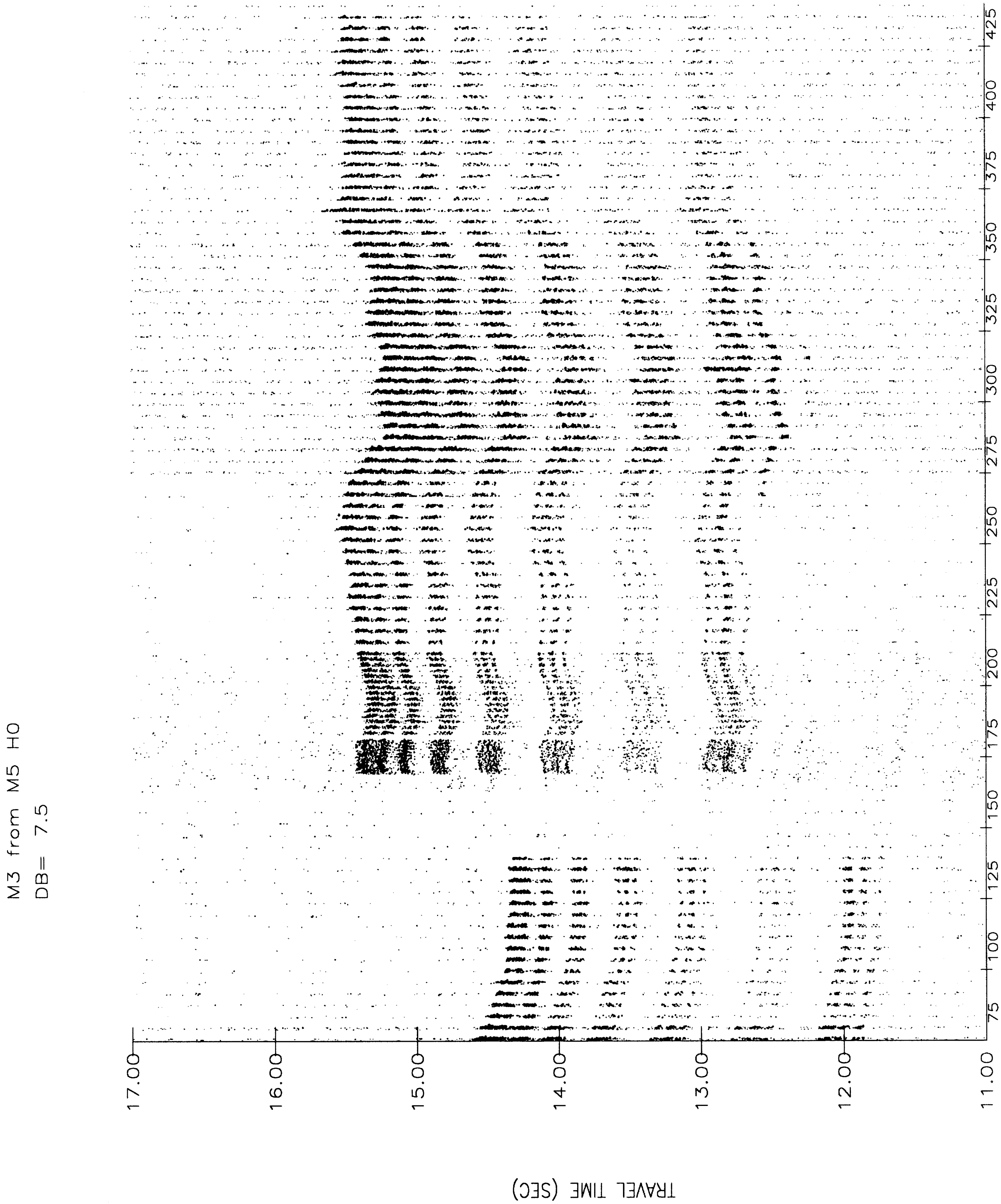

M3 from M5 H0
DB= 7.5
TRAVEL TIME (SEC)
17.00
16.00
15.00
14.00
13.00
12.00
11.00
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425

Figure C14

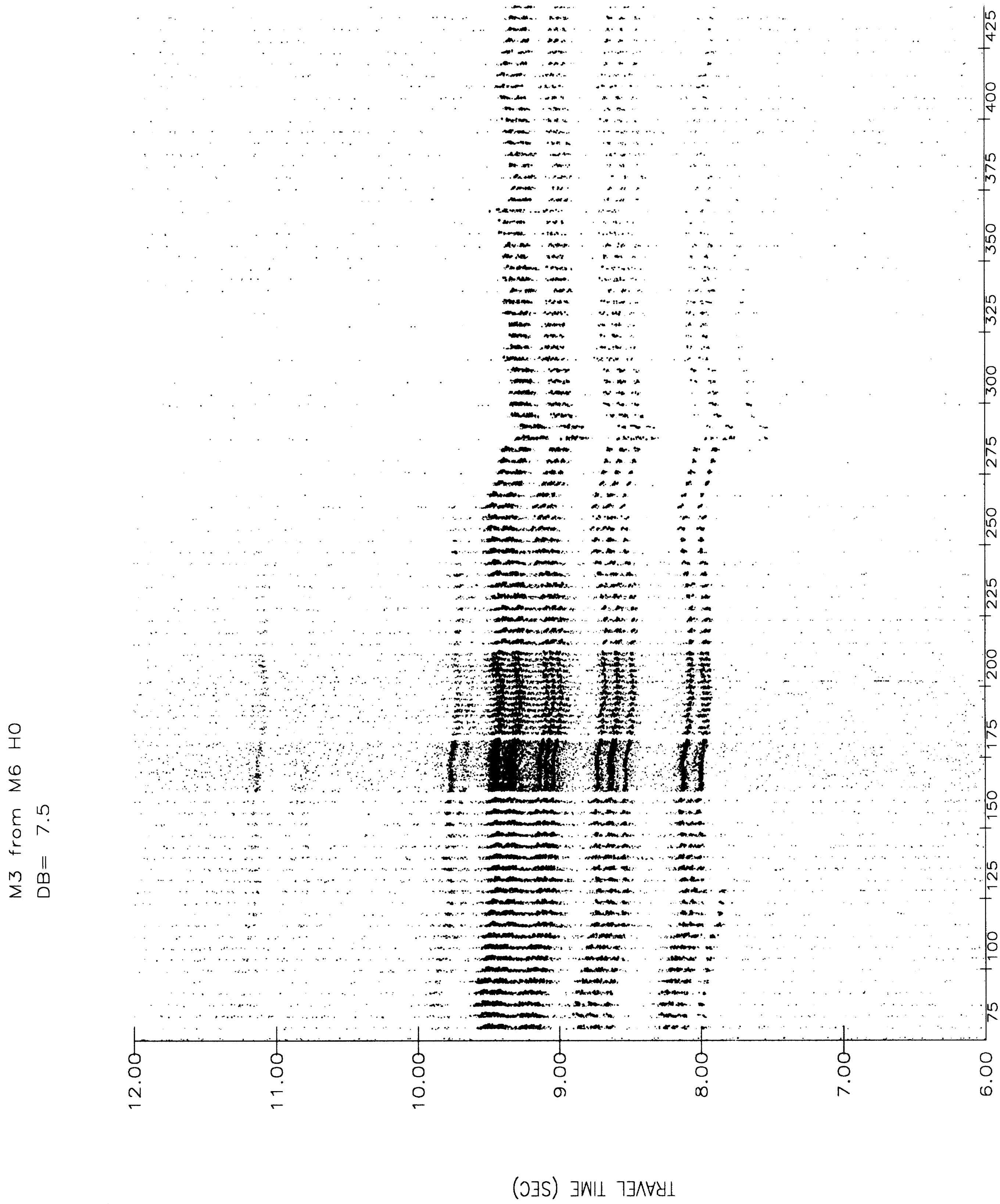
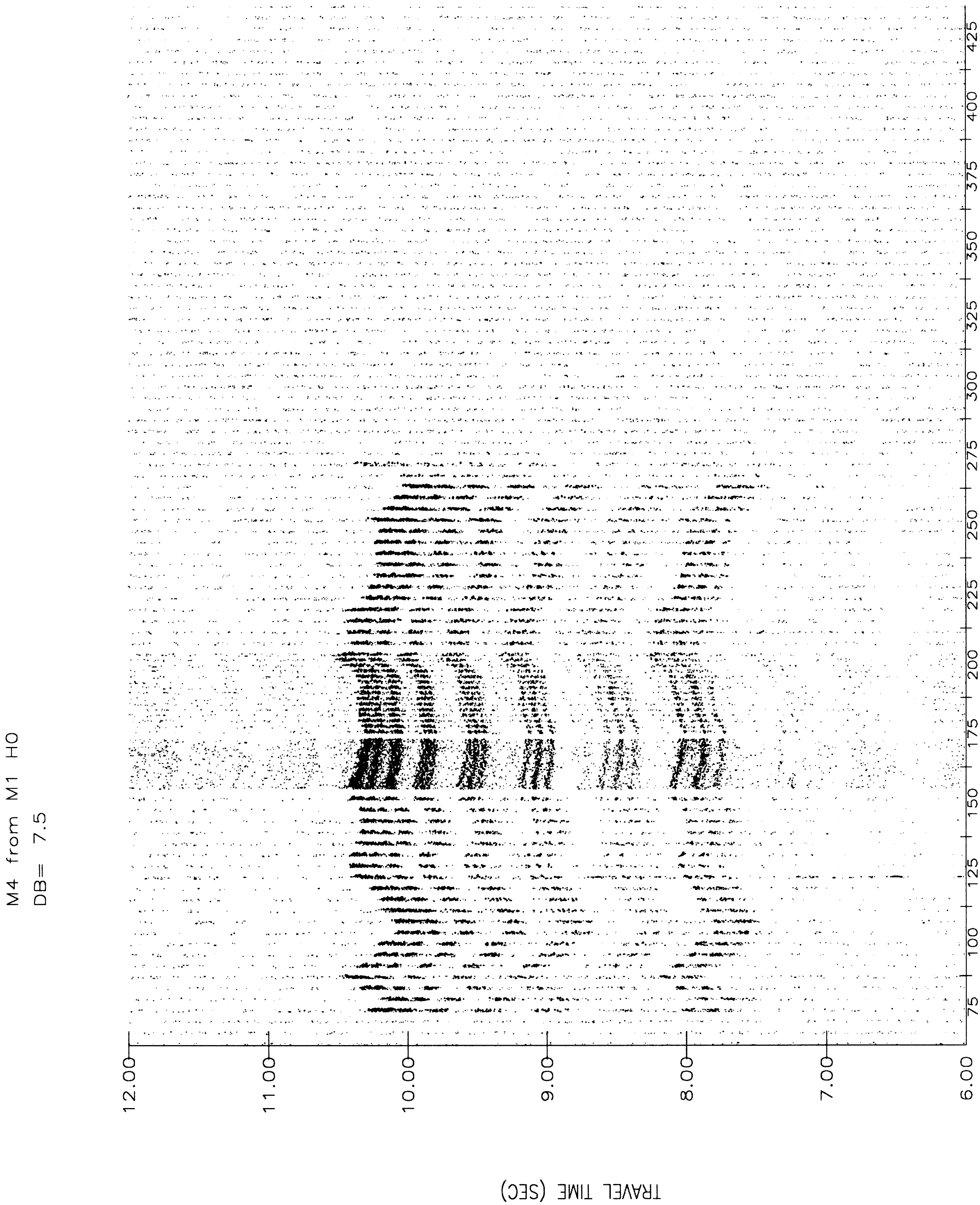

M3 from M6 H0
DB= 7.5
TRAVEL TIME (SEC)
12.00
11.00
10.00
9.00
8.00
7.00
6.00
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425

Figure C15



M4 from M1 HO
DB= 7.5
TRAVEL TIME (SEC)
12.00
11.00
10.00
9.00
8.00
7.00
6.00
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425

Figure C16

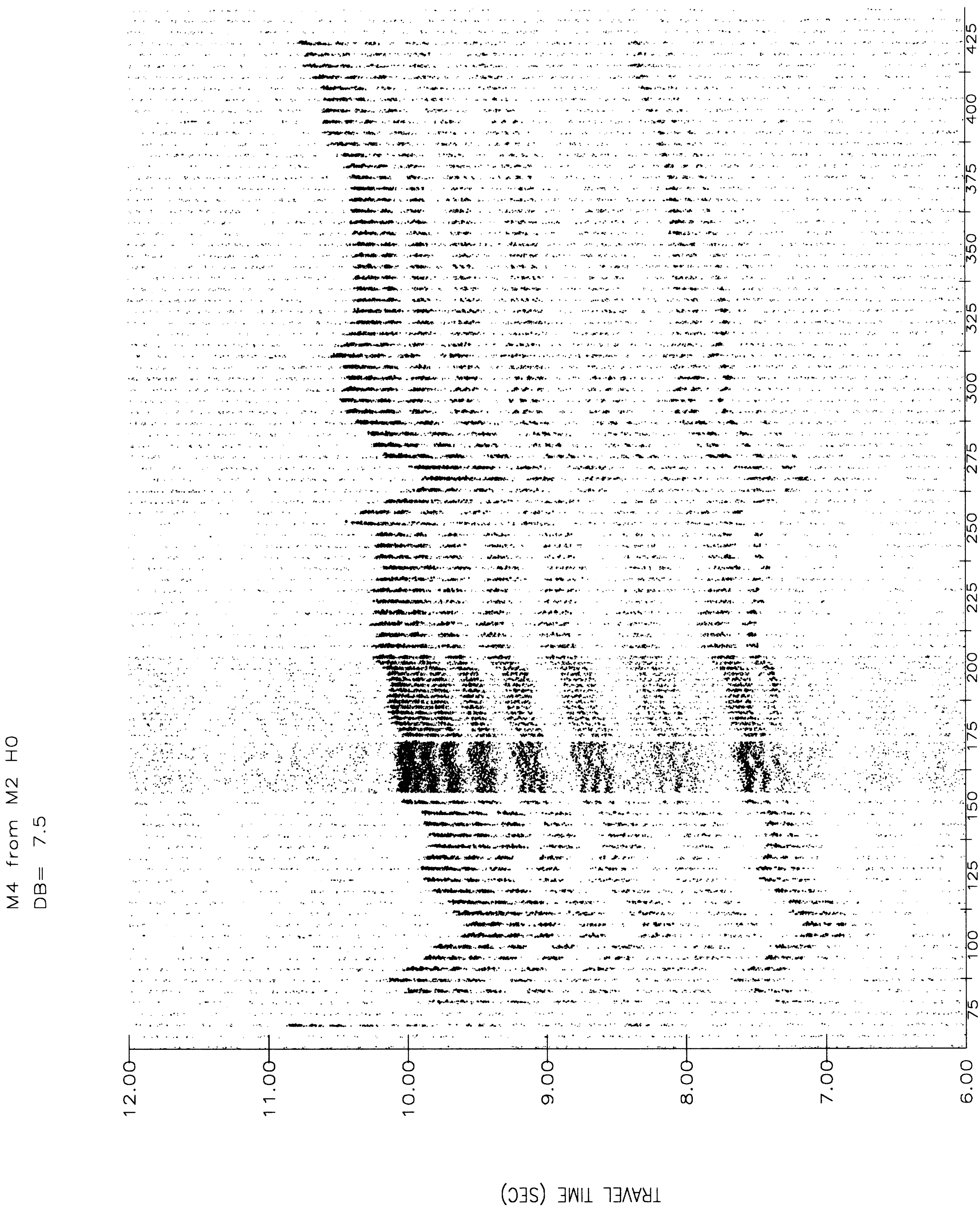

M4 from M2 H0
DB= 7.5
TRAVEL TIME (SEC)
12.00
11.00
10.00
9.00
8.00
7.00
6.00
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425

Figure C17

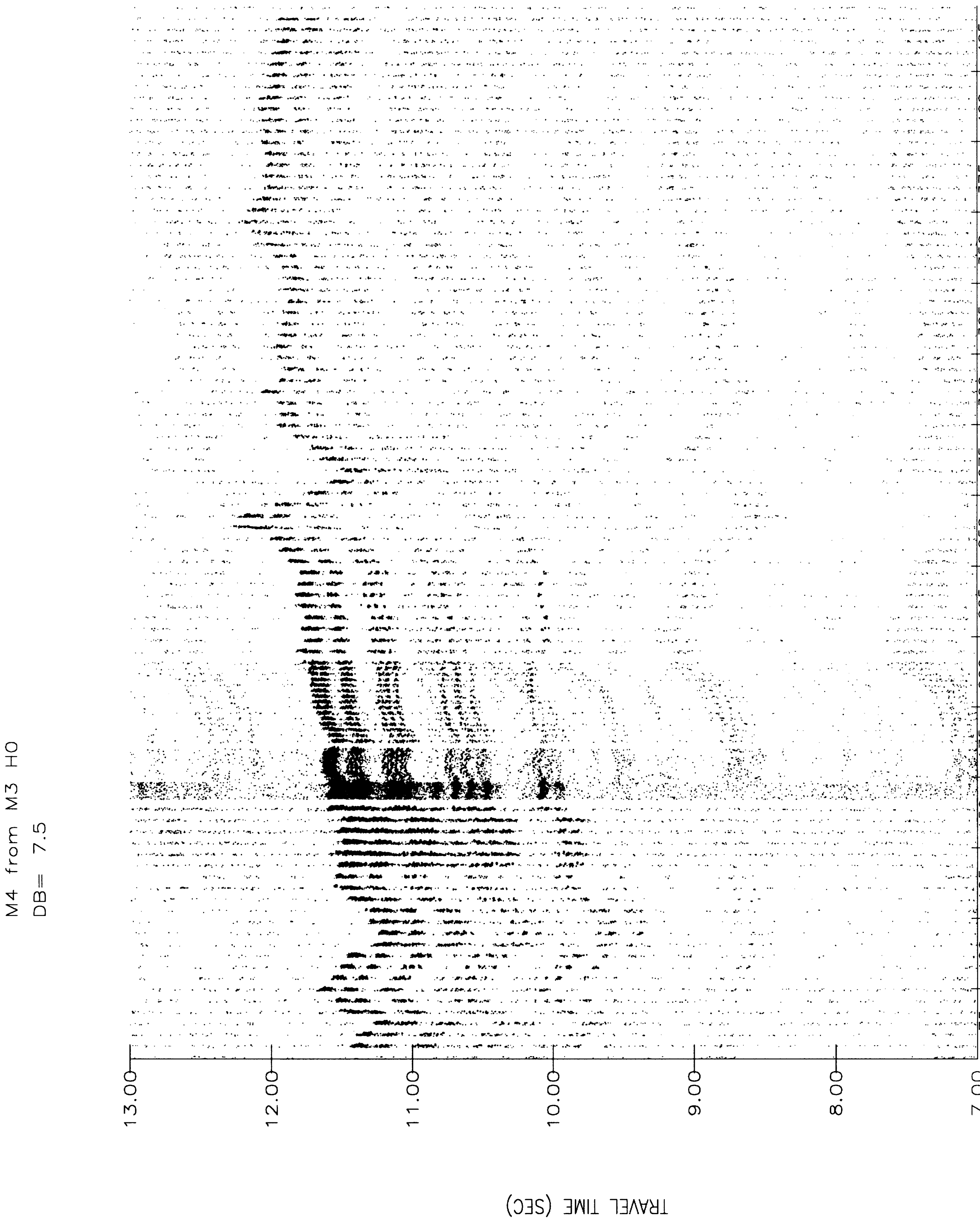

M4 from M3 HO
DB= 7.5
TRAVEL TIME (SEC)
13.00
12.00
11.00
10.00
9.00
8.00
7.00
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425

Figure C18

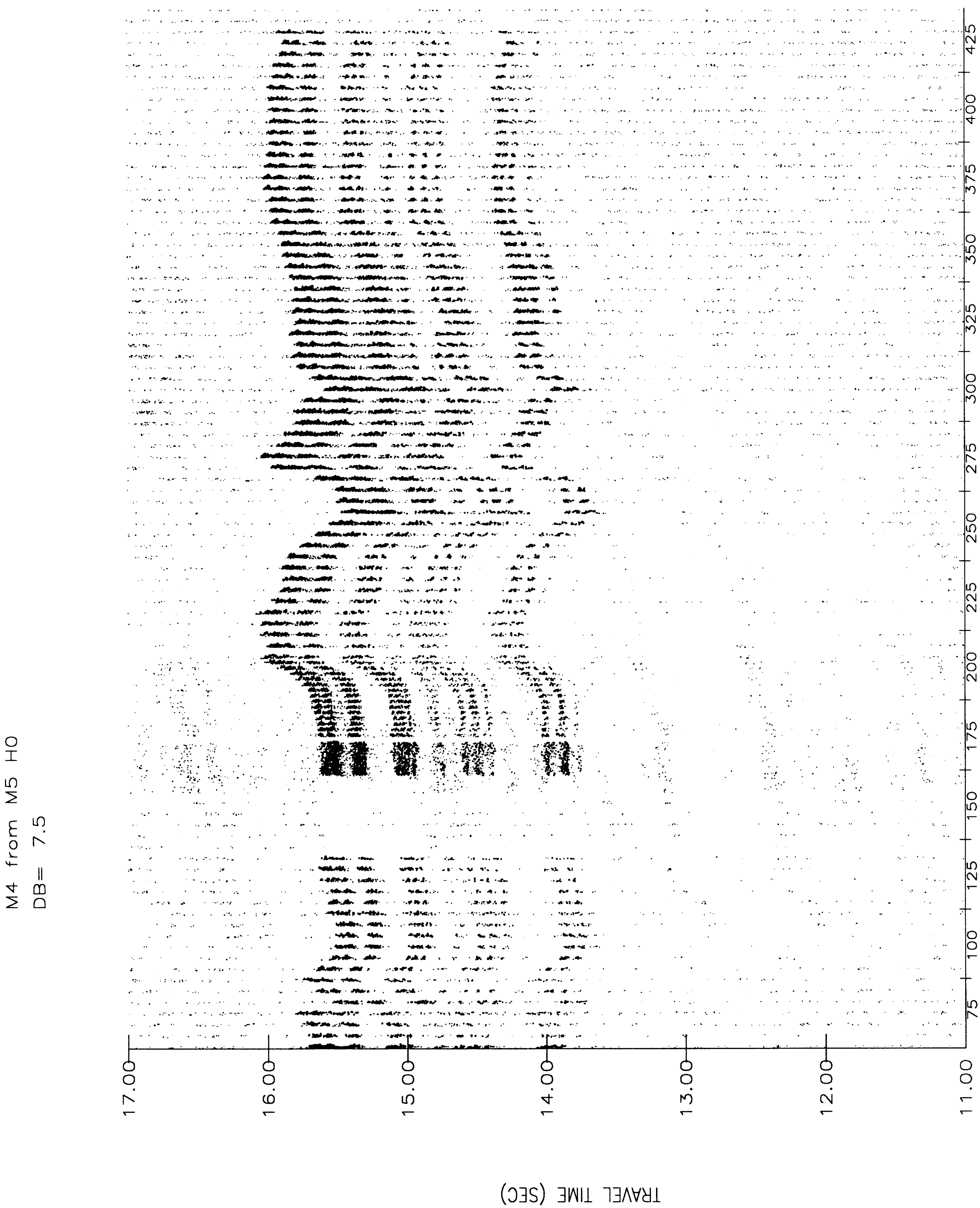

M4 from M5 H0
DB= 7.5
TRAVEL TIME (SEC)
17.00
16.00
15.00
14.00
13.00
12.00
11.00
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425

Figure C19

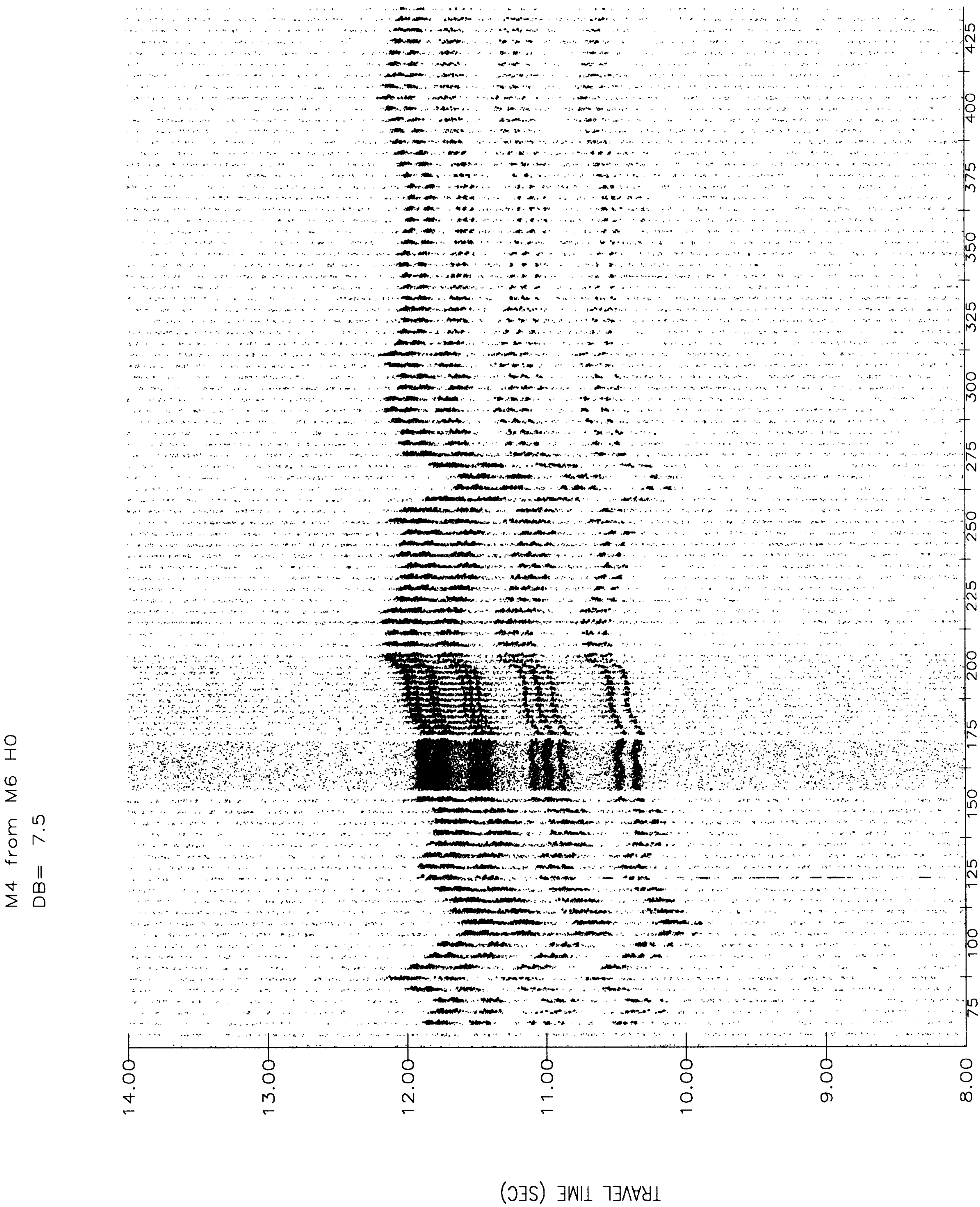
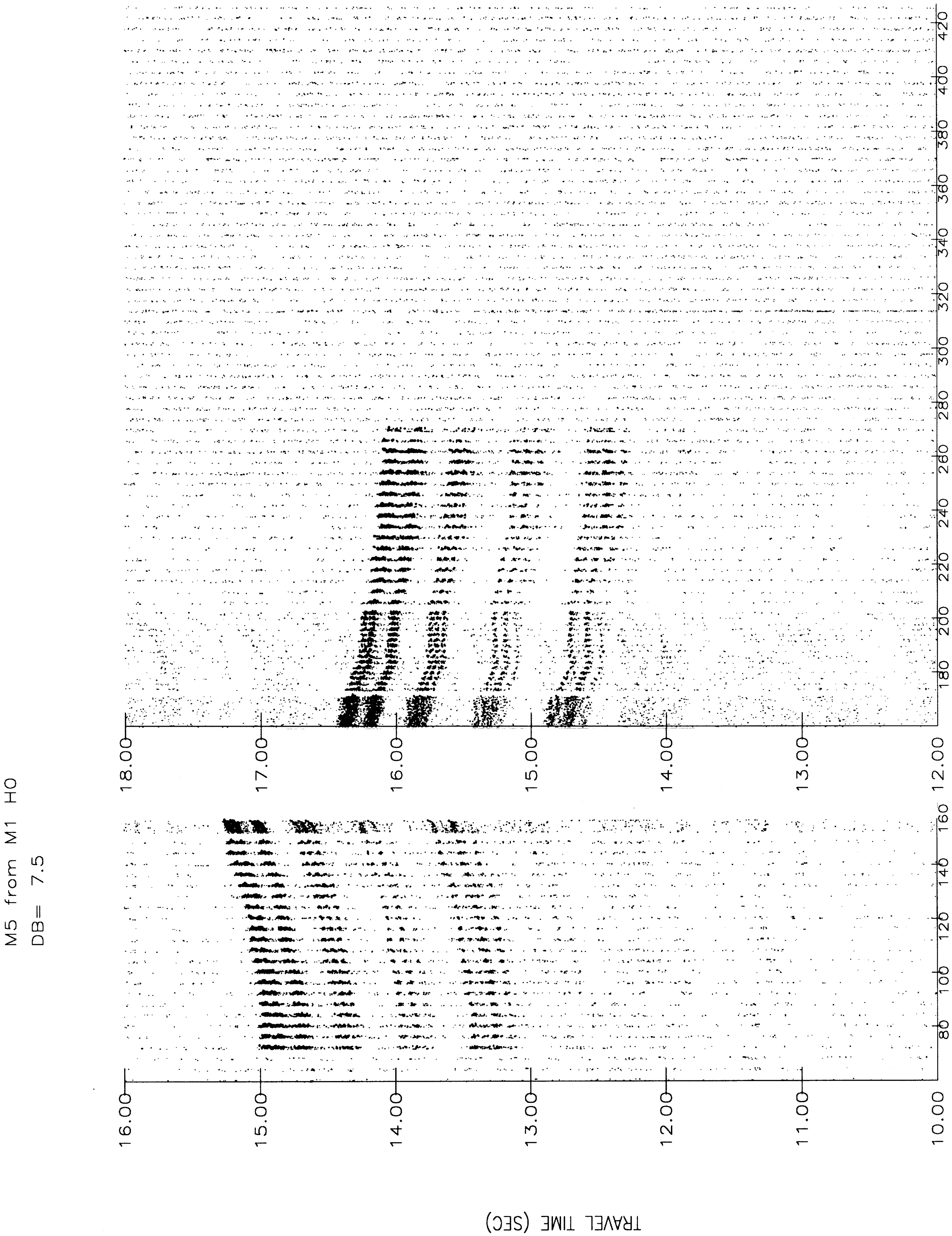
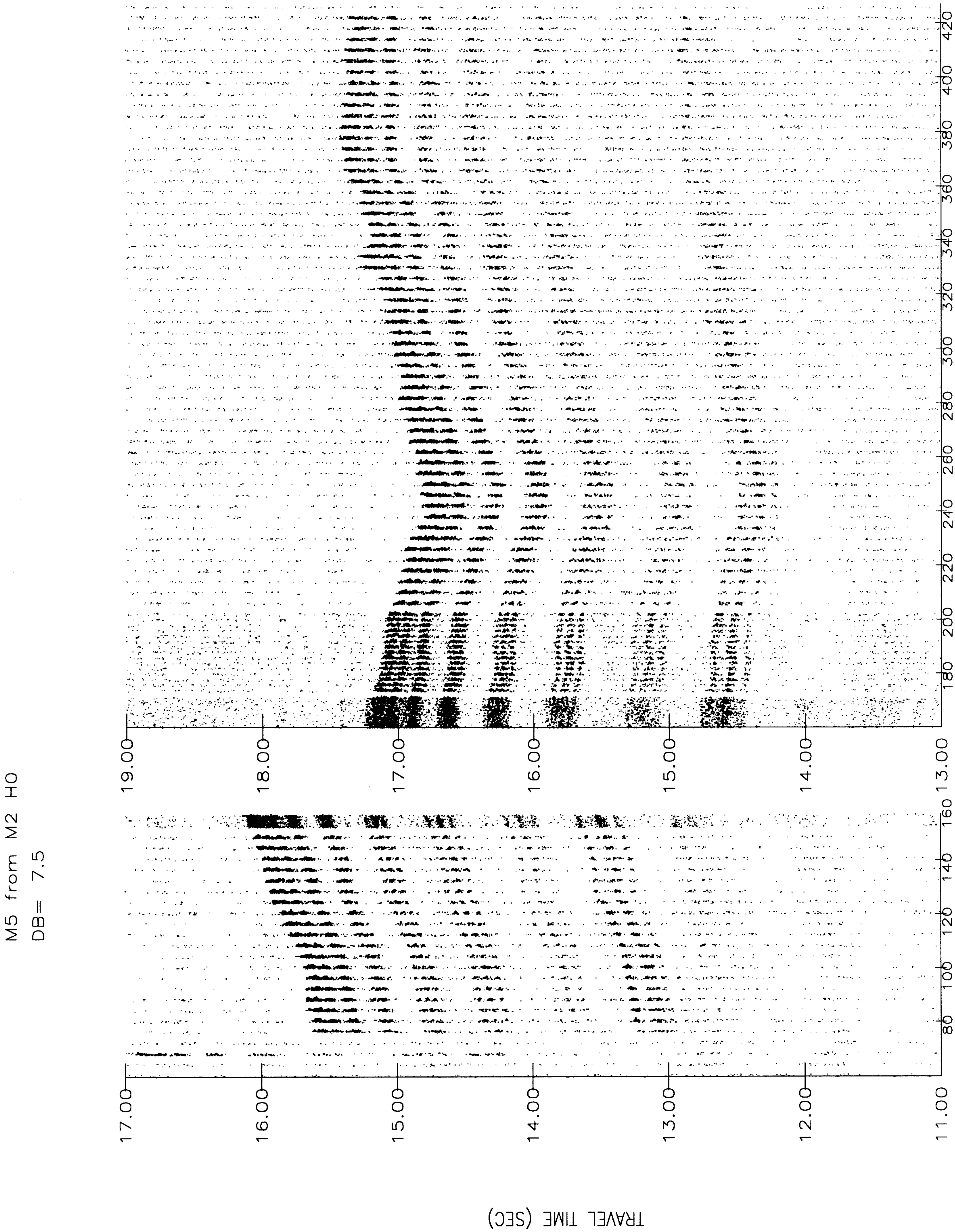

M4 from M6 HO
DB= 7.5
TRAVEL TIME (SEC)
14.00
13.00
12.00
11.00
10.00
9.00
8.00
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425

Figure C20



M5 from M1 HO
DB= 7.5
TRAVEL TIME (SEC)
18.00
17.00
16.00
15.00
14.00
13.00
12.00
16.00
15.00
14.00
13.00
12.00
11.00
10.00
180
200
220
240
260
280
300
320
340
360
380
400
420
80
100
120
140
160

Figure C21



M5 from M2 HO
DB= 7.5
TRAVEL TIME (SEC)
19.00
18.00
17.00
16.00
15.00
14.00
13.00
11.00
12.00
180
200
220
240
260
280
300
320
340
360
380
400
420
80
100
120
140
160

Figure C22

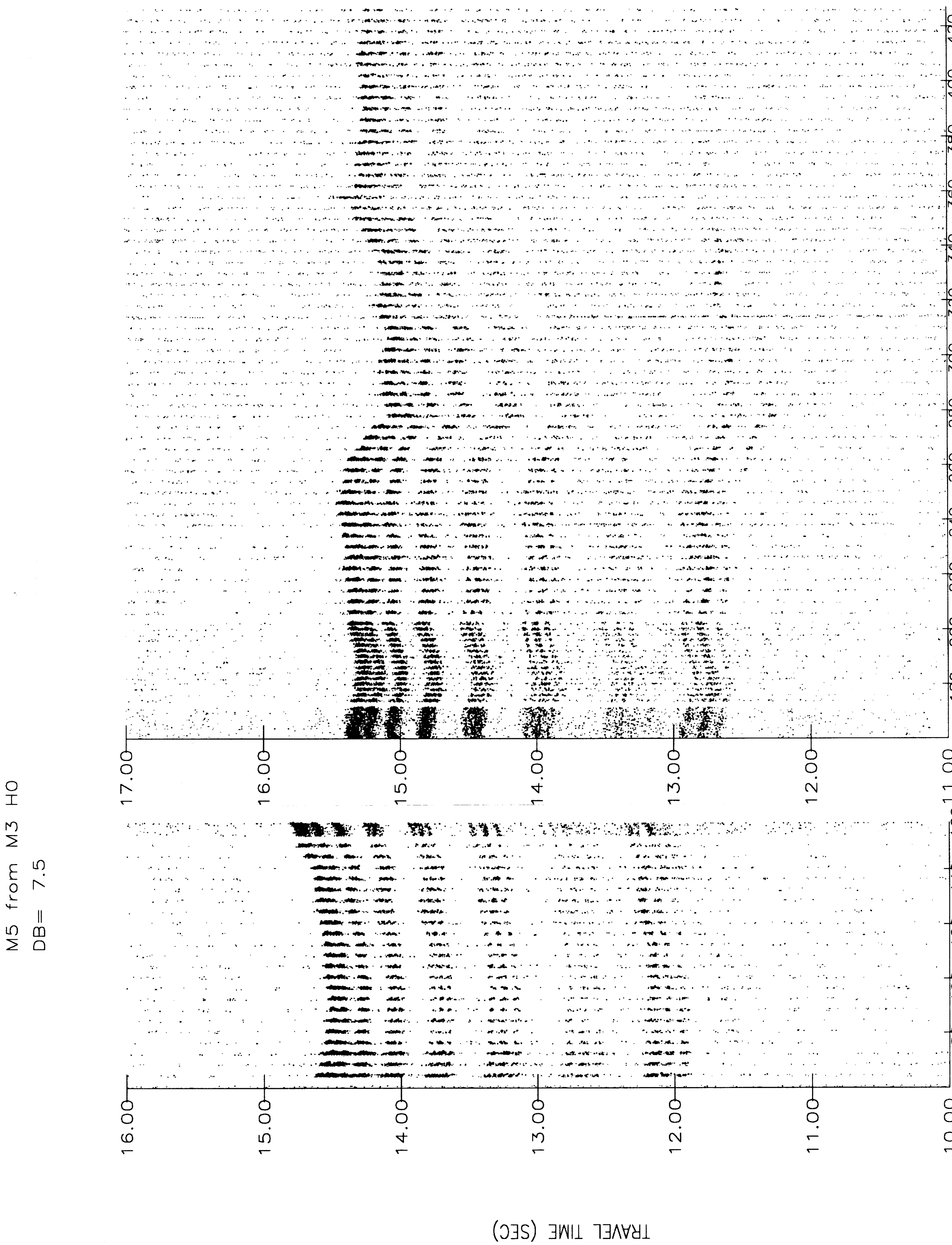


Figure C23

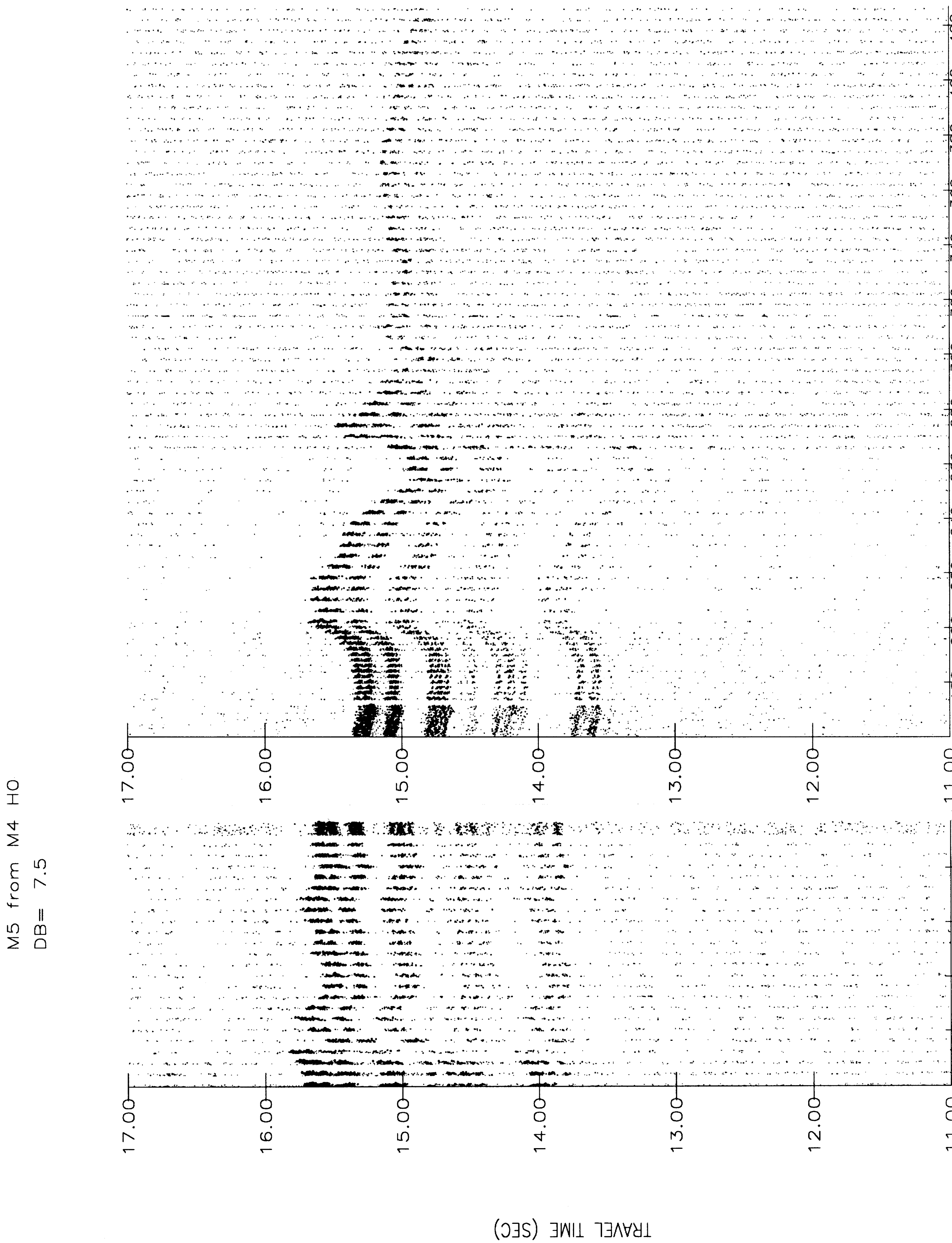
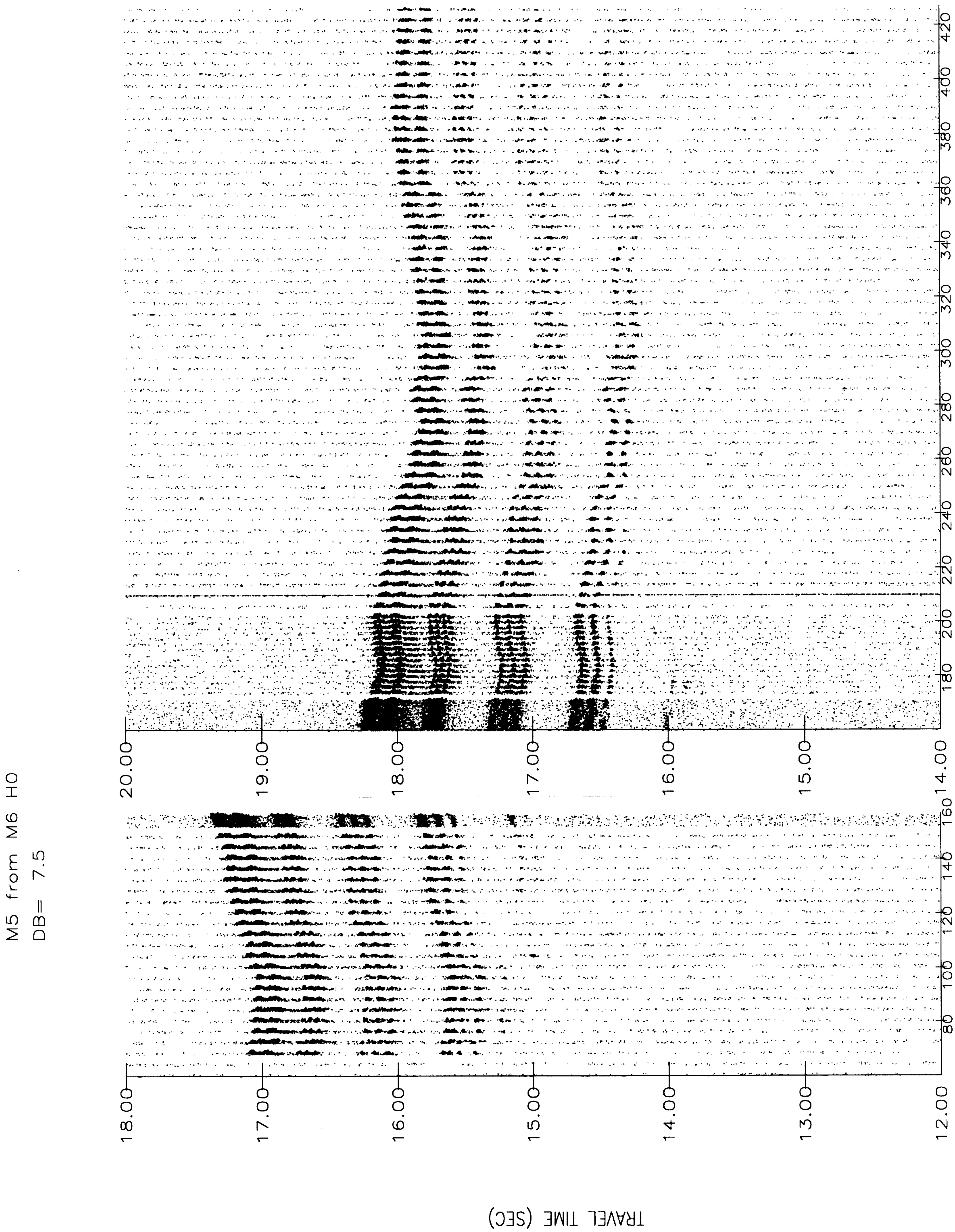

M5 from M4 HO
DB= 7.5
17.00
16.00
15.00
14.00
13.00
12.00
11.00
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
TRAVEL TIME (SEC)

Figure C24



M5 from M6 HO
DB= 7.5
TRAVEL TIME (SEC)
20.00
19.00
18.00
17.00
16.00
15.00
14.00
12.00
13.00
180
200
220
240
260
280
300
320
340
360
380
400
420
80
100
120
140
160

Figure C25

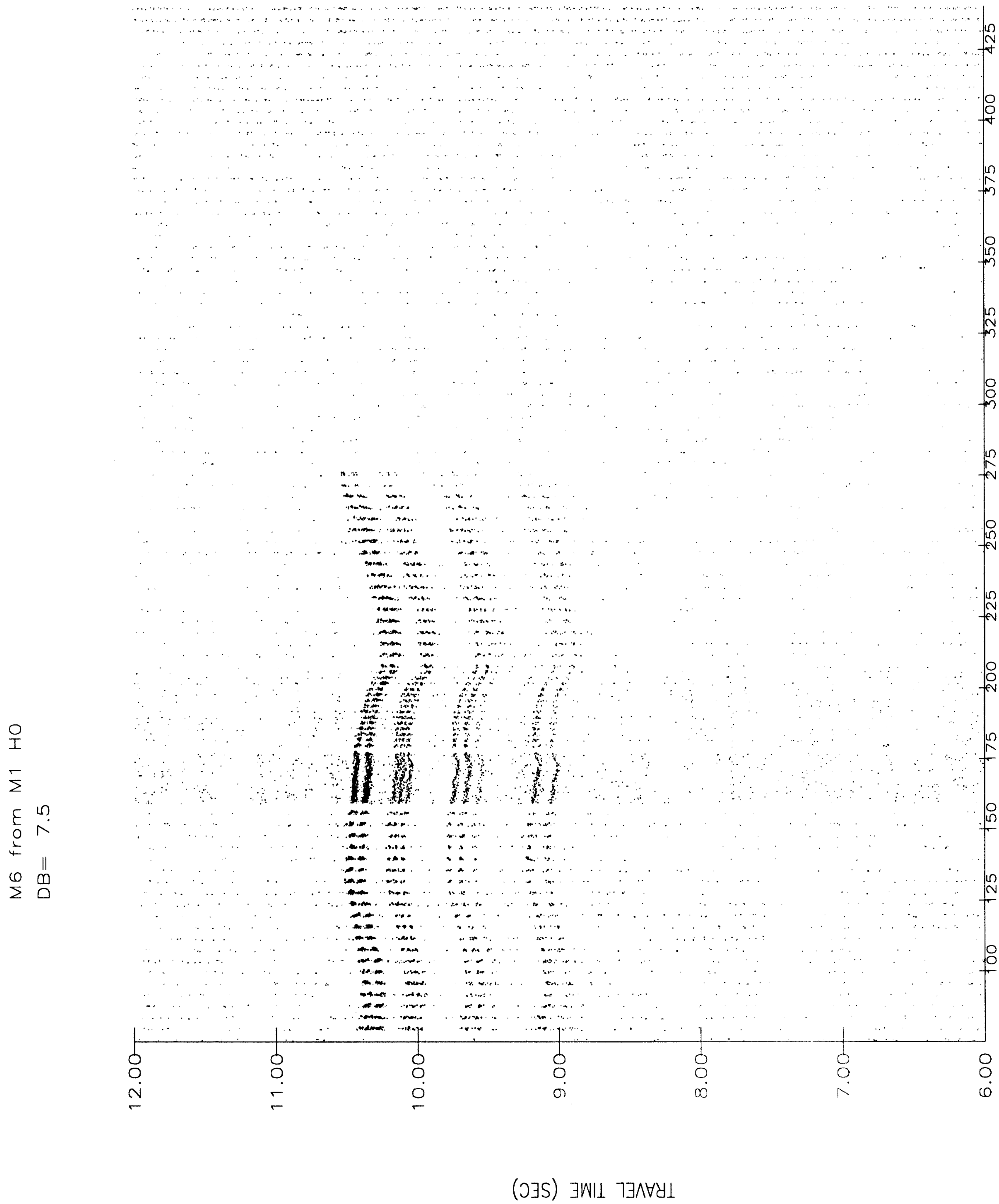

M6 from M1 H0
DB= 7.5
TRAVEL TIME (SEC)
12.00
11.00
10.00
9.00
8.00
7.00
6.00
100
125
150
175
200
225
250
275
300
325
350
375
400
425

Figure C26

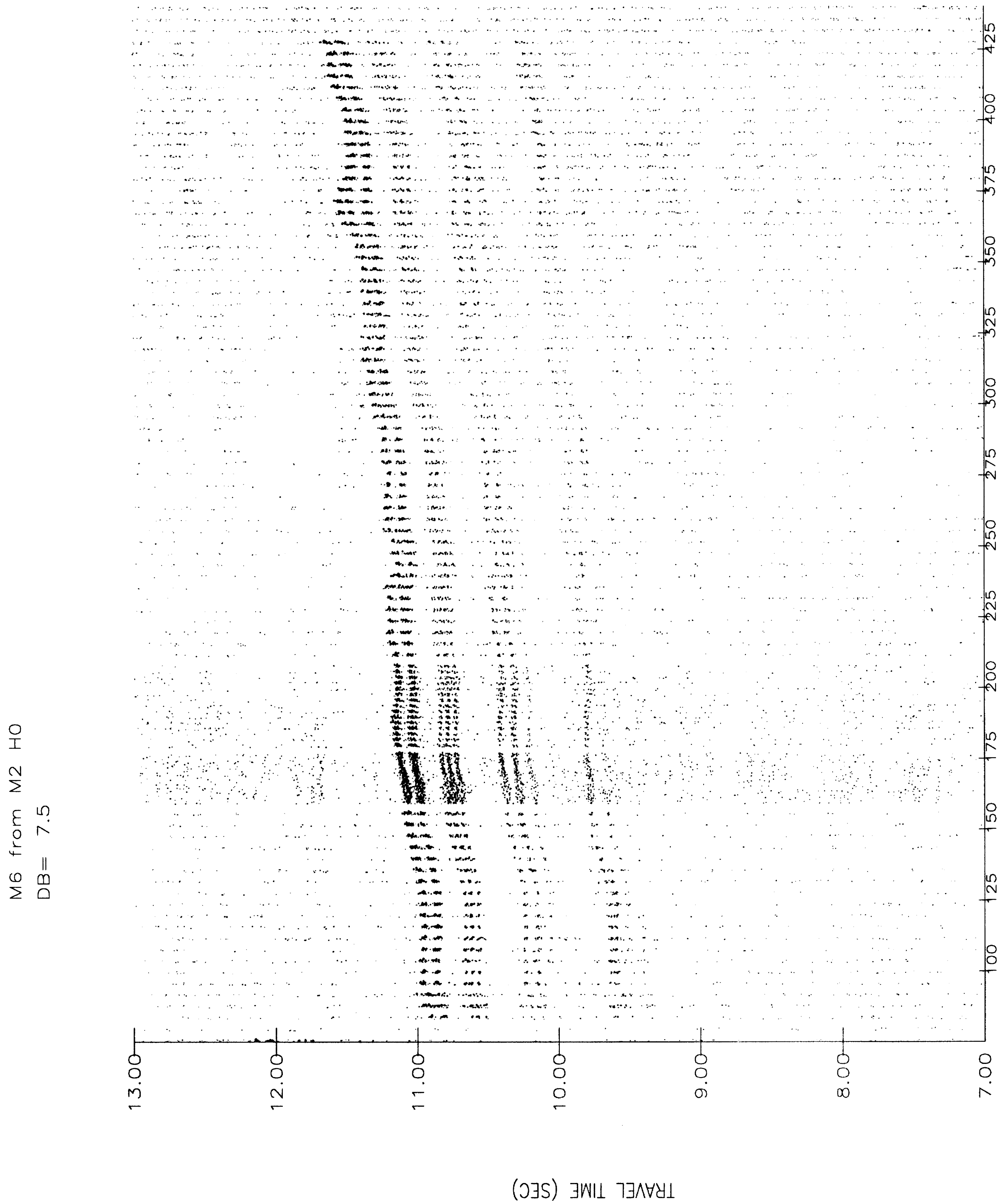

M6 from M2 H0
DB= 7.5
TRAVEL TIME (SEC)
13.00
12.00
11.00
10.00
9.00
8.00
7.00
100
125
150
175
200
225
250
275
300
325
350
375
400
425

Figure C27

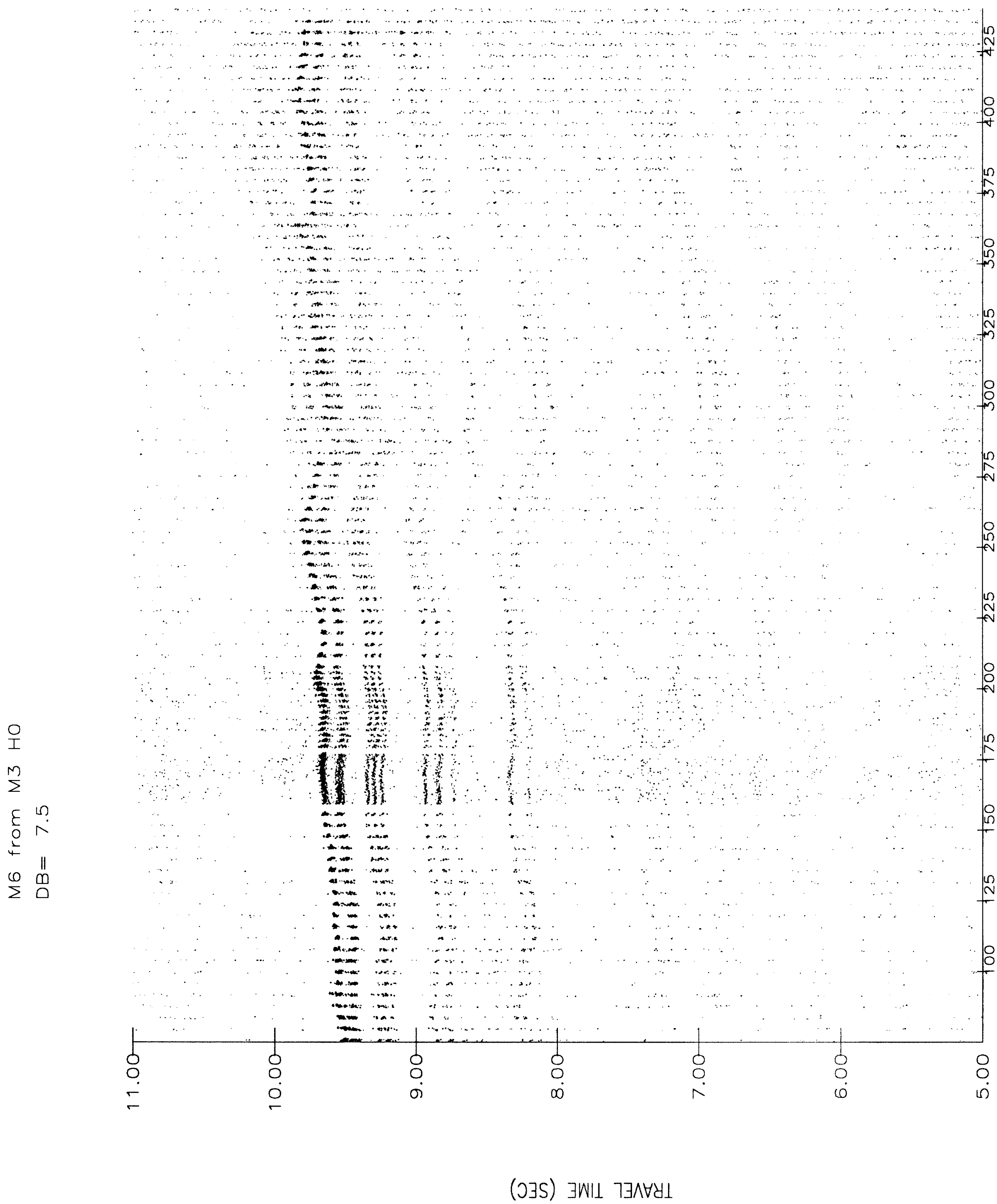
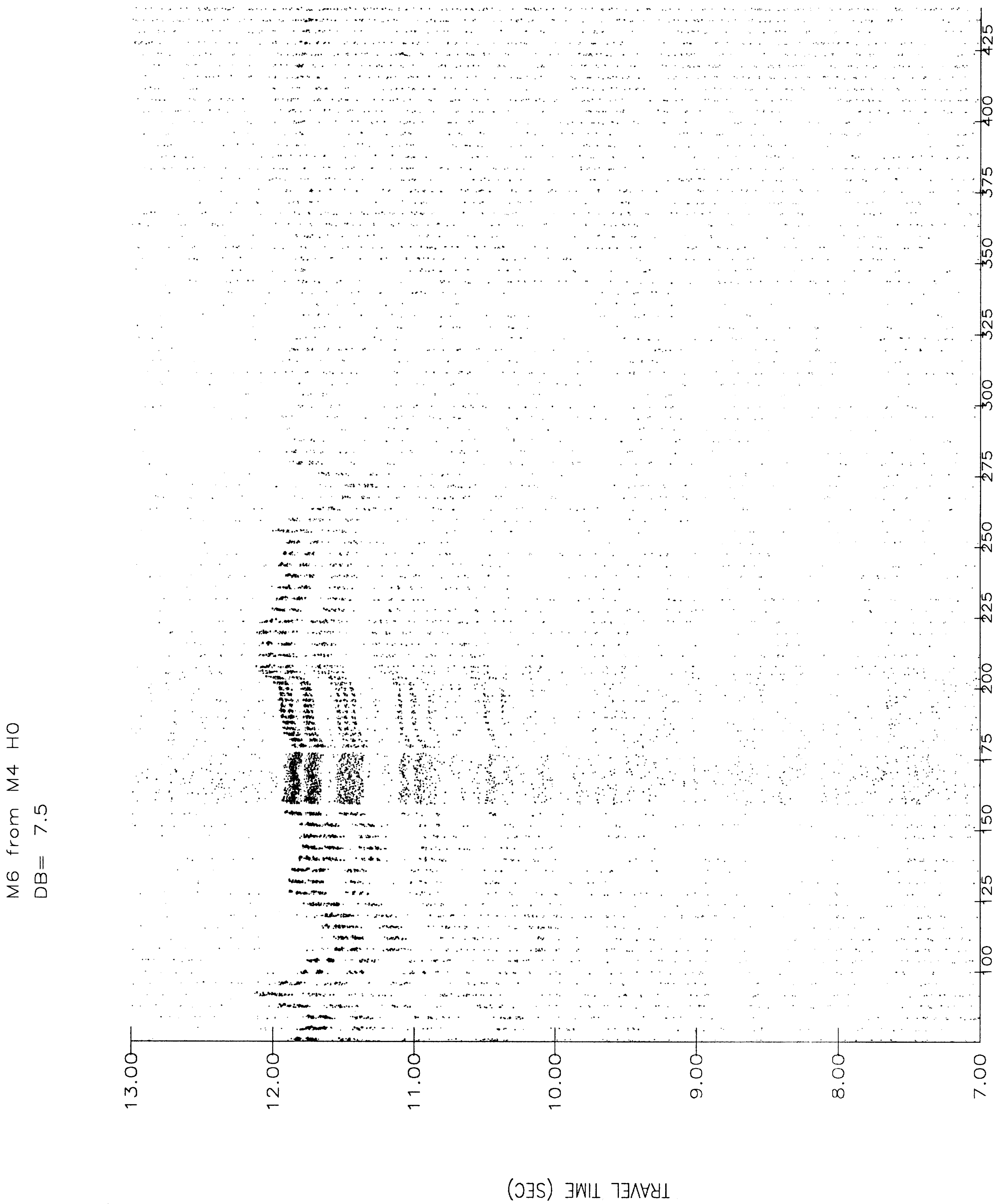
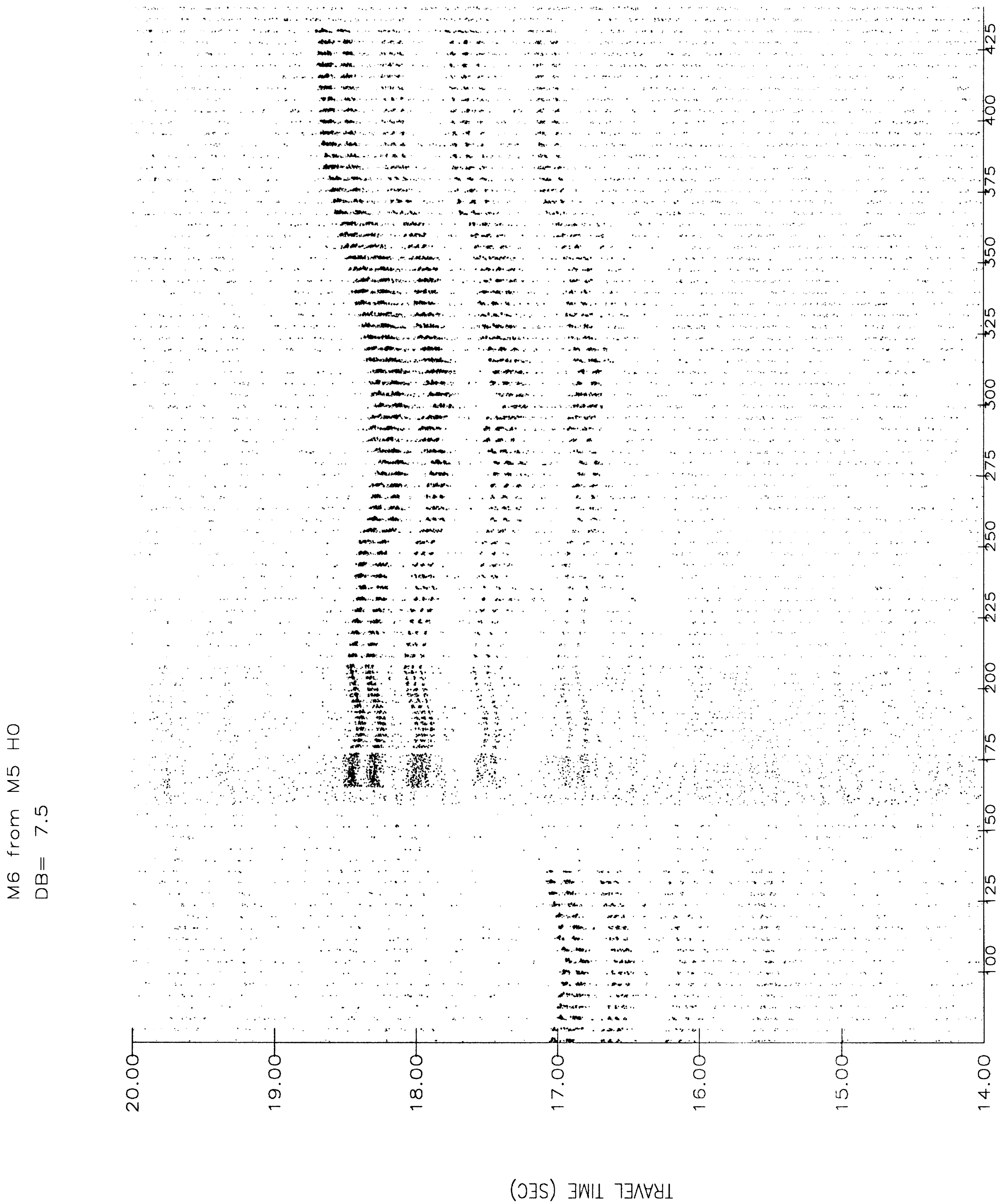

M6 from M3 HO
DB= 7.5
TRAVEL TIME (SEC)
11.00
10.00
9.00
8.00
7.00
6.00
5.00
100
125
150
175
200
225
250
275
300
325
350
375
400
425

Figure C28



M6 from M4 H0
DB= 7.5
TRAVEL TIME (SEC)
13.00
12.00
11.00
10.00
9.00
8.00
7.00
100
125
150
175
200
225
250
275
300
325
350
375
400
425

Figure C29



M6 from M5 HO
DB= 7.5
TRAVEL TIME (SEC)
20.00
19.00
18.00
17.00
16.00
15.00
14.00
100
125
150
175
200
225
250
275
300
325
350
375
400
425

Figure C30

Appendix D. AVATAR clock summary

The clock corrections computed from the Rb values differed from the final clock offsets measured after recovery on deck by less than 18 ms, except for mooring 2, which differed by 58.468 ms. Table D1 summarizes the clock behavior for moorings 1 through 7. A negative offset means that the leading edge of the AVATAR's 1-PPS came prior to the leading edge of the UTC 1-PPS. All times are UTC, with yearday 1 on 1 January 1991. The clock correction series were generated by adjusting the Rb offset (the amount by which the Rb frequency differs from exactly 10 MHz) to make the measured and computed final offsets agree. The second line in each entry gives the Rb correction required to give near zero residuals; the final clock correction series were generated using these Rb correction values, ensuring that the clock corrections give the measured offsets on deployment and recovery.

Table D1. Clock check summary.

	Start Time			Offset	End Time			Offset	Rb Correction	Residual
	Day	Hr	Min	(ms)	Day	Hr	Min	(ms)	$\times 10^{-10}$	(ms)
1	079	01	45	-0.016	428	18	22	-124.571	1.1	-0.431
									0.957	0.001
2	085	01	37	-0.021	429	22	22	326.237	-1.25	58.468
									18.375	-0.008
3	069	17	07	-0.029	437	14	36	-122.562	0.31	0.219
4	067	20	56	0.420	441	14	32	-495.852	0.835	-8.136
									-1.685	0.001
5a	065	20	21	0.020	165	15	42	-198.197	1.38	0.793
									2.30	-0.003
5b	166	19	41	-0.002	433	16	19	9.434	1.3	2.227
									2.266	-0.001
6	074	20	02	-0.020	442	22	25	-357.877	0.06	-10.939
									-3.38	0.001
7	163	19	10	0.180	447	21	01	-186.039	-0.66	-17.830
									-7.90	0.045

Notes:

Mooring 1. Some outliers removed from Rb series.

Mooring 2. Believe that there was only one good point. All others were shifted to "correct" level using Rb correction.

Mooring 4. There were a lot of +20 Rb outliers.

Mooring 6. There is a step of 70 units in the Rb series at day 160.

Mooring 7. Rb time series low frequency variation correlated with ambient temperature.

Appendix E. AVATAR instrument anomalies

This appendix briefly summarizes the anomalies observed in the operation of each instrument.

Mooring 1 (AVATAR 1).

1. Last transmissions were on yearday 281. The HLF-5 source failed, but the receiver continued to operate. The high pressure bottles had near zero pressure upon recovery. The needle value in the HLF-5 source had failed open, so that the high pressure bottles supplied air until their pressure equalized with the external pressure. This should not have caused a source failure, however.

2. AVATAR Rb gave variable offsets when measured against the lab FRT after recovery. After correcting for the FRT offset relative to Loran C, the values varied between -8.97E-10 and +2.03E-10. In spite of this apparent instability, the RB offset series looked reasonable, except for a relatively small number of outliers, concentrated between yeardays 180 and 280.

3. Navigation channel B (11.5 kHz) had many early returns, but still seemed to have a reasonable number of correct returns. The other channels performed adequately.

4. Absolute noise levels on hydrophone channels H0, H1, and H2 are in excellent agreement, with minimum noise levels of 62-63 dB re 1μPa/√(Hz). Hydrophone channel H3 is much noisier, with minimum noise level of about 78 dB re 1 μPa/√(Hz). The noise means are near zero for H0, H1, and H2, but differ significantly from 0 for H3.

5. Hydrophones H0, H1, and H2 report a significant number of saturations.

6. The hydrophone array cable appeared to be in generally good shape upon recovery, except for 10 Mohms insulation resistance between pins 1 and 2 (on 2000 Mohm scale). Manipulating the junction between the twisted pair and the pigtails on H3, we were able to vary the resistance between pins 7 and 8 from open on a 2000 Mohm scale to ~500 Mohms. Some bubbles were observed on the surface of the potting.

Mooring 2 (AVATAR 2).

1. A chip started to fail on receiver H4 IPB interface beginning about day 174, causing intermittent IPB transaction failures. One bit on the IPB was pulled down sufficiently strongly that the receiver IPB interfaces could not consistently overcome it. Other IPB transactions appeared more-or-less normal, however. Absolute noise levels and the noise means look plausible up to about yearday 199 (with precise day depending on channel). Acoustic data was obtained from all four hydrophones throughout the experiment, however. Beginning on yearday 199 all receptions appear exactly 2 seconds early, due to the reception being delayed by the error messages resulting from the IPB failures. Beginning on yearday 221 all receptions appear exactly 4 seconds early, due to an increase in the number of error messages generated.

2. We have no explanation for the 58.468 ms discrepancy between the measured and computed final clock offset, unless it is somehow related to the effect of the receiver H4 chip failure on the IPB.

3. The AVATAR navigation data is marginal at best. NAV's B, C, and D had MANY early returns. NAVB and NAVD are probably unusable part of the time. NAVC is probably mostly unusable. We may need to use the WHOI interrogator data to augment/replace the AVATAR NAV data (although the WHOI data is only available at 3 hr intervals).

4. Receiver H4 reported saturations from the beginning of the experiment, in spite of the fact that no hydrophone was connected to it. This may be related to the chip failure that affected

the remainder of the receivers later.

5. The hydrophone cable was in fairly bad shape after recovery. Insulation resistance values as low as 2 Mohms were observed. Manipulating the hot splice between the cable twisted pair and hydrophone H3 significantly changed the insulation resistance that was observed. We saw values as low as roughly 120 Mohms.

Mooring 3 (AVATAR 3).

1. Winchester drive 0 reported a large negative number of blocks at spin-down. Drives 1, 2, and 3 block counters looked plausible. Upon reading the disks and looking at sacred RAM, it appeared that the block counter for drive 0 was blown. The drive contained data for the beginning of the experiment and the end of the experiment, but none in the middle. It appears that after the block counter for drive 0 was damaged, it did not write data during the middle of the experiment because to do so with the incorrect counter caused it to attempt to write to disk locations that already contained data. Near the time when the drive 0 counter was blown, the other 3 drives were also missing a few hours of data.

2. Drive 3 had a broken firmware PROM socket. We were able to read it after recovery by C-clamping the socket together.

3. The navigation data contains a few early returns and a few late (surface bounce?) returns, but in general looks good.

4. Absolute noise levels on hydrophone channels H0, H1, H2, and H3 are in excellent agreement, with minimum noise levels of 64-65 dB re 1 μPa/$\sqrt{(Hz)}$. Hydrophone channels H4 and H5 are significantly noisier, with much greater variability. H4 and H5 seem to get worse as the experiment progresses. The noise means from H4 and H5 also show much more variability after about yearday 250.

5. The hydrophone array cable showed insulation resistances as low as 70 Mohms between pin 4 and pin 13.

6. The AVATAR interrogator transducer (S/N 74) was dead after recovery, although it seemed to work well during the pre-recovery timechecks.

7. WHOI interrogator S/N 008 was not working upon recovery. Logic power voltage was only 1.42 VDC. By suppling power from an external supply we were able to read the data in memory. The scheduler was correct except for the time, which was grossly off. At the beginning of the experiment bottom transponder replies were recorded at 11.5 kHz and 12.0 kHz, but not at 12.5 kHz.

Mooring 4 (AVATAR 4).

1. AVATAR S/N 4 memory locations 70000H and 78000H had an address space conflict upon recovery. This corresponds to the 2nd reception buffer (6 min 25 s) for hydrophone H3. We do not know when this memory problem started.

2. The AVATAR temperature series appears normal, but post-recovery tests of sensor S/N 739 indicate that its output became unstable at about the time the buoy reached the surface after release.

3. The Rubidium series appears to have a number of data points offset by about 16 counts relative to the majority of the series. All points for which the correct value appears to be slightly greater than 160 are reported offset by +16 counts relative to the rest of the series.

4. The navigation data contains a few early returns and a quite a few late (surface bounce?) returns, but in general looks good.

5. Absolute noise levels on hydrophone channels H0, H1, and H2 are in excellent agreement, with minimum noise levels of 60-61 dB re 1 $\mu Pa/\sqrt{Hz}$. Hydrophone channels H3 is significantly noisier, with an apparent noise floor at 77-78 dB re 1 $\mu Pa/\sqrt{Hz}$.

7. The hydrophone array cable had insulation resistances as low as 40 Mohms between the hydrophone leads and other wires in the cable. There was only 5 kohms insulation resistance between pins 9 (TCP + power) and 11 (TCP ground). Other TCP leads had insulation resistances as low as 2.9 Mohms.

Mooring 5a (AVATAR 5).

1. No anomalies observed, other than failure of HLF-5 source.

Mooring 5b (AVATAR 5).

1. While the AVATAR navigation data contains a few early returns, on the whole it looks quite good.

2. The hydrophone array cable had insulation resistances as low as 72 Mohms after recovery, although most values were higher than that.

Mooring 6 (AVATAR 6).

1. The Rubidium series changes sharply on about day 160.

2. The navigation data for NAVB, NAVC, NAVD, and NAVE contain few useful replies. Most of the time these channels timed out. NAVE successfully received 2 timechecks prior to recovery, but none post-deployment. Since NAVA performed normally, it appears that the 4-channel navigation receiver card is less sensitive than it should be or has failed. It will almost certainly be necessary to use the WHOI navigation data (although the interrogator was at about 1350 m, rather than near the AVATAR at 992 m).

3. The X-tilt and Y-tilt values are near zero, but show an odd step-like behavior that is greater than the least count.

4. Absolute noise levels on hydrophone channels H0, H1, H2, and H3 are in excellent agreement, with minimum noise levels of 63-64 dB re 1 $\mu Pa/\sqrt{(Hz)}$. Hydrophone channels H4 and

H5 have similar minimum levels, but show much greater variability with many noise peaks not present on H0-H3.

5. Many saturations are reported for all hydrophone channels through roughly day 280.

6. The 2 vent valves on the HLF-5 source apparently failed to vent upon release, causing the burst disk to rupture and flooding the source with seawater.

Mooring 7 (AVATAR 7).

1. No anomalies observed.

Appendix F. Bathymetric data

During the March 1992 AMODE recovery cruise, bathymetry was measured along 4 of the 15 paths between the six moorings. Bathymetry along an additional six of the 15 paths was measured on the AMODE deployment cruise in March 1991, giving a total of 10 paths for which we have detailed bathymetry. The measured data are shown together with the ETOPO5 bathymetry in Fig. F1 and F2. Figure F3 gives the ETOPO5 data for the paths for which direct measurements are not available. The ETOPO5 depths have been increased by 73 m in these plots to have the same mean depth as the AMODE measurements.

Bottom depth was measured on the recovery cruise using the Raytheon 12 kHz Precision Depth Recorder (PDR) on board the R/V ENDEAVOR. While transiting between mooring locations, uncorrected depths were read off the PDR chart recorder at 5 minute intervals and manually logged. GPS positions from an Ashtech XII P-code receiver were routinely logged with the uncorrected depths, although there were brief periods each day for which GPS data were not available and it was necessary to use dead-reckoning positions from the ship's SAT-NAV receiver.

The PDR on board the R/V ENDEAVOR was set internally to correct for the depth of the transducer below the water line (16.2 feet). The raw PDR depths were subsequently corrected using a linear fit to the Area 13 corrections found in "Echo-Sounding Correction Tables," by D. J. T. Carter.

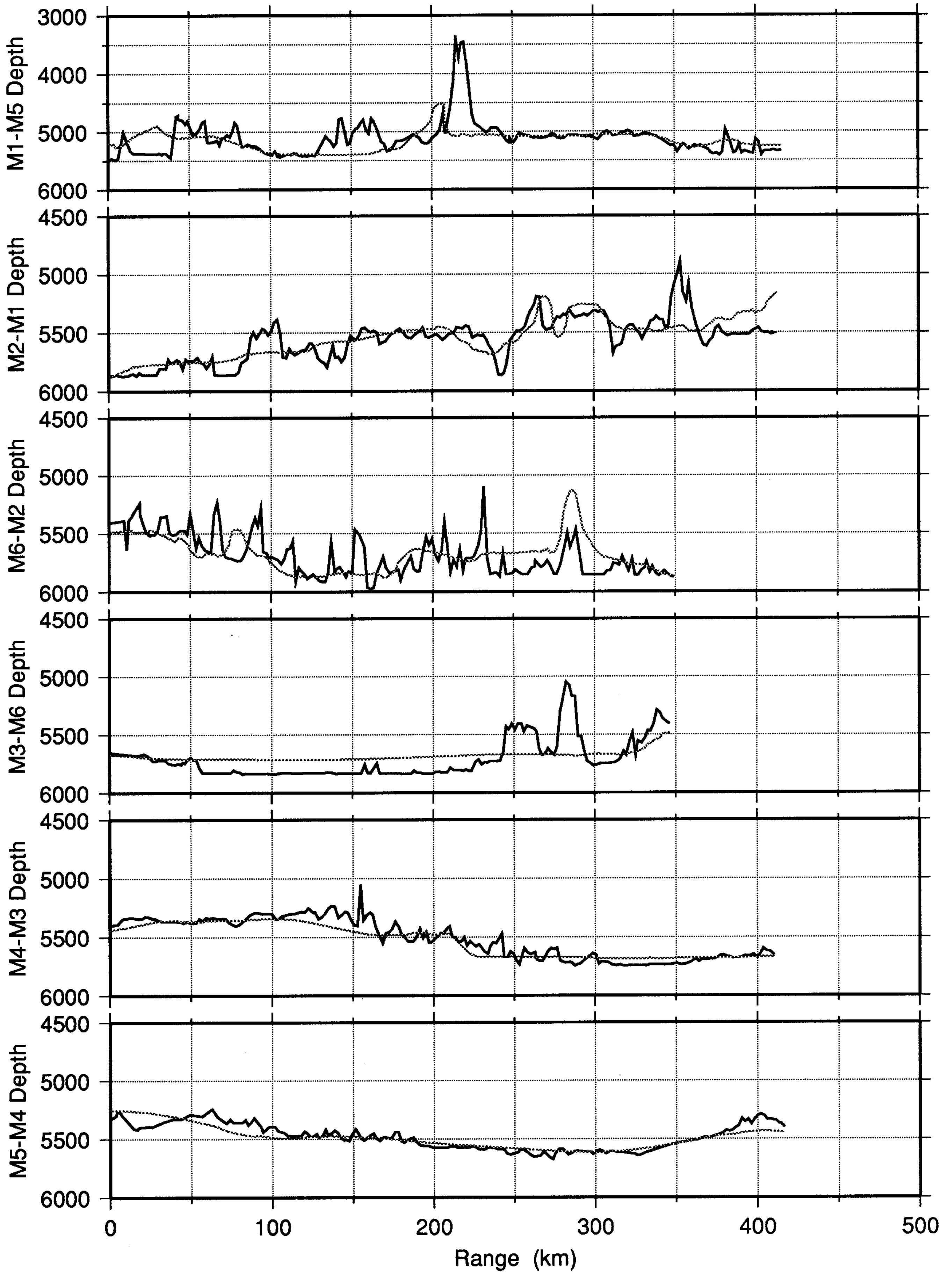
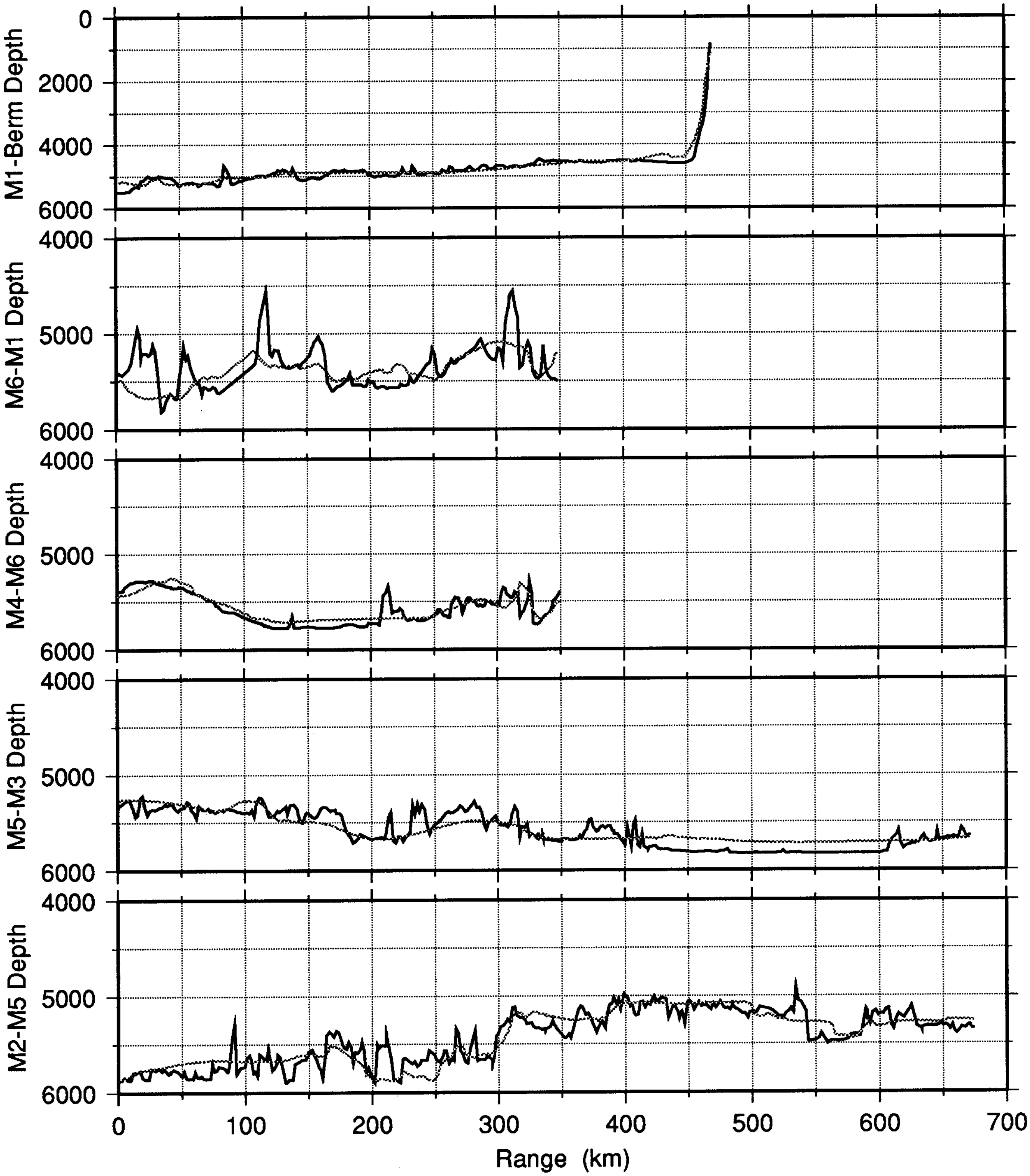

3000
4000
5000
6000
M1-M5 Depth
4500
5000
5500
6000
M2-M1 Depth
4500
5000
5500
6000
M6-M2 Depth
4500
5000
5500
6000
M3-M6 Depth
4500
5000
5500
6000
M4-M3 Depth
4500
5000
5500
6000
M5-M4 Depth
0
100
200
300
400
500
Range (km)

Figure F1



0
2000
4000
6000
M1-Berm Depth
4000
5000
6000
M6-M1 Depth
4000
5000
6000
M4-M6 Depth
4000
5000
6000
M5-M3 Depth
4000
5000
6000
M2-M5 Depth
0
100
200
300
400
500
600
700
Range (km)

Figure F2

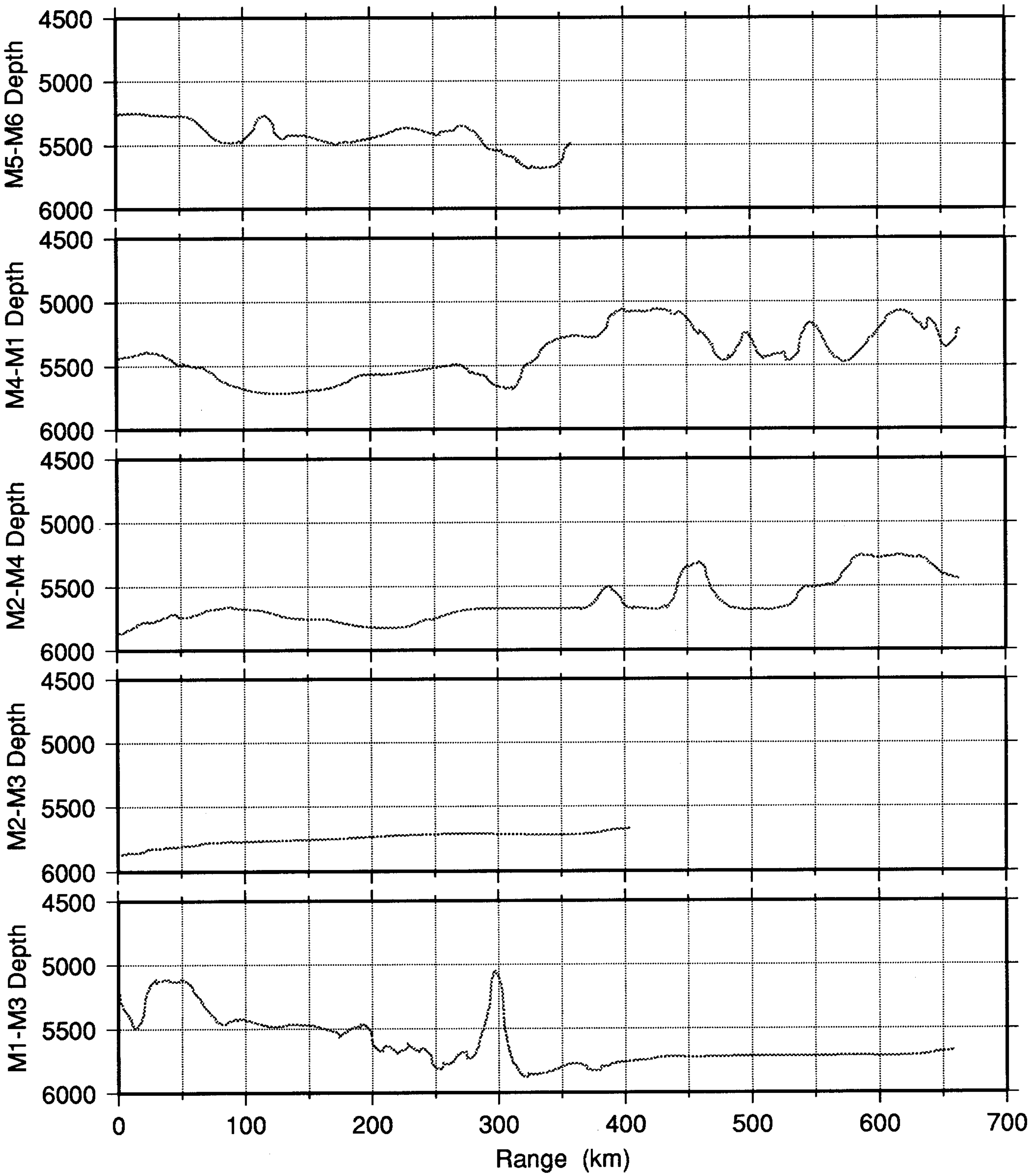

M5-M6 Depth
M4-M1 Depth
M2-M4 Depth
M2-M3 Depth
M1-M3 Depth
4500
5000
5500
6000
0
100
200
300
400
500
600
700
Range (km)

Figure F3

Appendix G. Recovery cruise CTD and XBT data

CTD data were obtained using the APL-UW Sea-Bird Electronics (SBE) 9/11 (S/N 91685). This system has redundant temperature and conductivity sensors and a modified pumped, ducted flow system so that the temperature and conductivity sensors see the same water with a known time delay. The pressure sensor is a 0–6000 m Paroscientific Digiquartz sensor. All sensors were calibrated before and after the cruise (Table G1). Data were collected at 1 sample per second, after 24 scans had been averaged in the deck unit. The locations and times of the 41 CTD casts are listed in Table G2. In Fig. G1–G4, all of the temperature, salinity, density, and sound speed profiles are overlaid to show the variability in the data. Fig. G5 contains all of the T–S plots. The individual cast data are plotted in Fig. G6–G46.

Sippican T-7 XBT probes were used for all of the casts. The probes used for the M2-M5 and M5-M3 sections were all from the same batch, which was purchased expressly for the recovery cruise. Probes remaining from previous experiments were used for the M1-M2, M4-M6, and M6-M1 sections. The data were digitally logged using a Roemmich–Cornuelle deck unit. The locations and times of the casts are listed in Table G3. Fig. G47 shows the XBT profiles collected on each section.

The XBT probes were calibrated by dropping an XBT immediately prior to each CTD cast. Different XBT batches appear to have different fall rate equations. XBT casts taken prior to a CTD cast between moorings 2 and 5 and between moorings 5 and 3 (all from the same batch), with the corresponding CTD temperature profile removed, show a systematic error in depth or temperature, most likely due to fall rate error (Fig. G48,G49 – top). Increasing the XBT depths by 3%, gives much better agreement (Fig. G48,G49 – bottom). In a layered ocean an XBT fall rate error will cause spikes in the XBT/CTD comparison because of the disparity in measured temperature interface depth. Correcting the XBT depths by 3% removes some of the spikyness in the XBT/CTD differences.

The older XBT probes used on the second leg of the recovery cruise required a different depth correction, however. Fig. G50 shows that a 5% increase is more appropriate, though this number is not as well determined as for the newer XBT probes, for which more comparisons were available.

TABLE G1. CTD calibration dates.

Sensor	S/N	Precruise Calibration	Postcruise Calibration
Temperature (Primary)	843	23 Aug 91	10 Apr 92
Temperature (Secondary)	844	23 Aug 91	10 Apr 92
Conductivity (Primary)	484	05 Sep 91	10 Apr 92
Conductivity (Secondary)	485	23 Aug 91	27 Apr 92

Notes:

1. The secondary conductivity sensor was cleaned and replatinized prior to the 27 Apr 92 calibration, so the calibration is not applicable to the AMODE recovery cruise data.

TABLE G2. CTD start times and locations at the beginning of each cast.

ctd	filename	yd hr mi	lat (N)	lon (W)	depth (m)	
ctd1	ct063102.avg	63 10 54	27 41.4	64 27.6	5401	Mooring 1
ctd2	ct065031.avg	65 03 01	24 20.0	62 53.3	5764	Mooring 2
ctd3	ct065091.avg	65 09 52	24 31.8	63 14.4	2005	
ctd4	ct065131.avg	65 13 44	24 42.0	63 36.0	2032	
ctd5	ct065171.avg	65 17 48	24 55.1	63 57.3	2034	
ctd6	ct065211.avg	65 21 44	25 06.8	64 17.4	4491	
ctd7	ct066031.avg	66 03 15	25 18.0	64 40.8	2028	
ctd8	ct066061.avg	66 06 53	25 29.6	65 02.9	2022	
ctd9	ct066101.avg	66 10 23	25 41.1	65 24.7	2015	
ctd10	ct066131.avg	66 13 55	25 52.5	65 46.4	5245	
ctd11	ct066191.avg	66 19 08	26 03.3	66 08.7	2051	
ctd12	ct066221.avg	66 22 45	26 15.1	66 30.3	2021	
ctd13	ct067031.avg	67 03 00	26 26.2	66 52.6	2081	
ctd14	ct067061.avg	67 06 31	26 37.5	67 14.8	5062	
ctd15	ct067121.avg	67 12 19	26 48.5	67 36.8	2065	
ctd16	ct067161.avg	67 16 00	26 59.2	67 59.2	2047	
ctd17	ct067201.avg	67 20 38	27 10.2	68 21.5	2038	
ctd18	ct068001.avg	68 00 50	27 24.2	68 43.4	5254	Mooring 5
ctd19	ct068231.avg	68 23 31	27 00.3	68 32.6	2040	
ctd20	ct069031.avg	69 03 04	26 40.4	68 21.2	2037	
ctd21	ct069061.avg	69 06 41	26 19.7	68 10.4	605	Winch problem
ctd22	ct069161.avg	69 16 31	26 20.0	68 10.2	2028	
ctd23	ct069201.avg	69 20 25	25 59.7	67 59.0	5278	
ctd24	ct070011.avg	70 01 33	25 39.3	67 47.9	2030	
ctd25	ct070051.avg	70 05 01	25 18.9	67 38.8	2108	
ctd26	ct070081.avg	70 08 31	24 58.4	67 25.8	2048	
ctd27	ct070121.avg	70 12 43	24 38.1	67 14.8	5534	
ctd28	ct070181.avg	70 18 37	24 17.9	67 03.5	2030	
ctd29	ct070221.avg	70 22 07	23 57.1	66 53.3	2036	
ctd30	ct071011.avg	71 01 38	23 36.6	66 42.6	2030	
ctd31	ct071051.avg	71 05 05	23 16.1	66 32.0	5573	
ctd32	ct071101.avg	71 10 53	22 55.6	66 21.1	2040	
ctd33	ct071151.avg	71 15 04	22 35.0	66 10.7	2039	
ctd34	ct071181.avg	71 18 23	22 14.7	66 00.5	2050	
ctd35	ct072011.avg	72 01 11	21 50.8	65 49.7	5534	Mooring 3
ctd36	ct076051.avg	76 05 00	23 34.7	69 21.9	5313	Mooring 4
ctd37	ct077001.avg	77 00 40	24 05.6	68 20.0	5643	
ctd38	ct078031.avg	78 03 22	25 00.0	66 15.1	5282	Mooring 6
ctd39	ct078171.avg	78 17 40	26 49.1	65 06.4	5415	
ctd40	ct079021.avg	79 02 04	27 43.4	64 30.7	5389	Mooring 1
ctd41	ct080031.avg	80 03 13	31 54.5	65 09.9	1521	Bermuda source

TABLE G3. XBT cast locations and times.

XBT	date yd hr mi	lat(N)	lon(W)	ctd
1	63 23 11	27 33.3	64 32.3	Mooring 1 (CTD 1)
2	64 00 06	27 25.5	64 25.5	
3	64 00 44	27 20.6	64 19.9	
4	64 01 50	27 09.4	64 14.4	
5	64 02 55	26 58.1	64 08.8	
6	64 04 01	26 46.8	64 03.4	
7	64 05 04	26 35.8	63 58.2	
8	64 06 12	26 24.0	63 52.1	
9	64 07 15	26 13.0	63 46.6	
10	64 08 17	26 01.4	63 41.3	
11	64 09 16	25 50.4	63 35.8	
12	64 10 16	25 39.1	63 30.7	
13	64 11 17	25 27.8	63 25.3	
14	64 12 18	25 16.5	63 19.9	
15	64 13 19	25 05.2	63 14.6	
16	64 14 17	24 53.9	63 09.2	
17	64 15 15	24 42.6	63 03.9	
18	64 16 11	24 31.3	62 58.6	
19	64 17 13	24 20.1	62 53.7	|
20	65 02 51	24 20.0	62 53.3	Deep CTD 2 Mooring 2
21	65 07 24	24 19.6	62 52.0	|
22	65 08 09	24 23.7	63 00.0	
23	65 08 52	24 27.9	63 07.8	
24	65 09 45	24 31.7	63 14.6	Shallow CTD 3
25	65 12 08	24 35.7	63 21.9	
26	65 12 49	24 39.5	63 29.1	
27	65 13 39	24 43.3	63 36.1	Shallow CTD 4
28	65 15 58	24 48.0	63 42.0	
29	65 16 40	24 51.2	63 50.7	
30	65 17 27	24 55.1	63 57.6	Shallow CTD 5
31	65 20 11	25 00.1	64 05.7	
32	65 20 48	25 03.0	64 12.2	
33	65 21 39	25 06.8	64 17.4	Deep CTD 6
34	66 00 35	25 06.7	64 16.0	|
35	66 01 50	25 10.2	64 25.9	
36	66 02 35	25 14.3	64 33.8	
37	66 03 17	25 18.1	64 40.9	Shallow CTD 7
38	66 05 30	25 21.8	64 48.3	
39	66 06 05	25 25.7	64 55.6	
40	66 06 46	25 29.6	65 02.8	Shallow CTD 8
41	66 08 58	25 33.4	65 10.1	
42	66 09 34	25 37.2	65 17.4	

43 66 10 17	25 41.1	65 24.7	Shallow CTD 9
44 66 12 30	25 45.2	65 32.6	
45 66 13 03	25 48.6	65 39.1	
46 66 13 48	25 52.4	65 46.4	Deep CTD 10
47 66 17 45	25 56.4	65 55.0	
48 66 18 17	25 59.9	66 01.1	
49 66 18 59	26 03.2	66 08.8	Shallow CTD 11
50 66 20 39	26 05.8	66 08.5	
51 66 21 13	26 07.9	66 16.4	
52 66 21 55	26 11.2	66 22.9	
53 66 22 42	26 15.1	66 30.3	Shallow CTD 12
54 67 01 50	26 21.4	66 42.1	
55 67 02 10	26 22.3	66 45.2	
56 67 02 55	26 26.0	66 52.4	Shallow CTD 13
57 67 05 07	26 29.8	66 59.9	
NO 58			
59 67 05 45	26 33.6	67 07.6	
60 67 06 25	26 37.4	67 14.7	Deep CTD 14
61 67 10 23	26 42.3	67 16.8	
62 67 10 57	26 40.8	67 22.2	
63 67 11 35	26 44.7	67 29.7	
64 67 12 13	26 48.3	67 36.8	Shallow CTD 15
65 67 14 30	26 51.8	67 44.1	
66 67 15 57	26 59.2	67 59.2	Shallow CTD 16
67 67 18 49	27 02.7	68 07.2	
68 67 19 44	27 08.8	68 20.8	
69 67 20 24	27 10.3	68 21.8	Shallow CTD 17
70 67 22 50	27 13.9	68 29.1	
71 67 23 30	27 17.5	68 36.6	
72 68 00 47	27 24.2	68 43.4	Deep CTD 18 Mooring 5
73 68 04 19	27 24.4	68 39.7	
74 68 21 29	27 21.7	68 42.8	
75 68 22 10	27 14.2	68 40.2	
76 68 22 47	27 07.4	68 36.4	
77 68 23 31	27 00.4	68 32.5	Shallow CTD 19
78 69 01 39	26 53.7	68 28.7	
79 69 02 16	26 47.1	68 25.0	
80 69 02 58	26 40.5	68 21.4	Shallow CTD 20
81 69 05 11	26 33.2	68 17.5	
82 69 05 46	26 26.8	68 13.9	
83 69 06 26	26 19.9	68 10.2	Shallow CTD 21 (600 m)
84 69 16 24	26 20.0	68 10.1	Shallow CTD 22
85 69 18 37	26 12.7	68 05.8	
86 69 19 19	26 05.2	68 02.5	
87 69 20 25	25 59.6	67 59.0	Deep CTD 23
88 69 23 40	25 57.7	67 58.5	
89 70 00 16	25 52.8	67 55.2	
90 70 01 33	25 39.3	67 47.9	Shallow CTD 24
91 70 03 43	25 32.3	67 44.2	
92 70 04 21	25 25.5	67 40.5	

93	70 05 01	25 18.9	67 38.8	Shallow CTD 25
94	70 07 08	25 12.0	67 33.2	
95	70 07 46	25 05.2	67 29.6	
96	70 08 30	24 58.4	67 25.8	Shallow CTD 26
97	70 10 35	24 51.6	67 22.3	
98	70 11 13	24 44.5	67 18.5	
99	70 11 54	24 37.9	67 15.0	Deep CTD 27
100	70 16 06	24 40.9	67 13.5	|
NO 101				
102	70 17 11	24 30.7	67 11.3	
103	70 17 47	24 24.2	67 07.8	
104	70 18 33	24 17.9	67 03.5	Shallow CTD 28
105	70 20 44	24 10.6	67 00.6	
106	70 21 23	24 03.6	66 56.7	
107	70 22 03	23 57.1	66 53.3	Shallow CTD 29
108	71 00 16	23 50.1	66 49.8	
109	71 00 53	23 43.4	66 46.3	
110	71 01 36	23 36.6	66 42.7	Shallow CTD 30
111	71 03 40	23 29.8	66 39.2	
112	71 04 18	23 22.9	66 35.6	
113	71 05 05	23 16.1	66 32.0	Deep CTD 31
114	71 08 31	23 16.2	66 33.9	|
115	71 09 25	23 09.1	66 28.4	
116	71 10 04	23 02.4	66 24.9	
117	71 10 46	22 55.5	66 21.2	Shallow CTD 32
118	71 13 42	22 48.0	66 17.6	
119	71 14 17	22 41.7	66 14.3	
120	71 15 03	22 35.0	66 10.7	Shallow CTD 33
121	71 17 06	22 28.0	66 07.3	
122	71 17 46	22 21.2	66 03.6	
123	71 18 22	22 14.7	66 00.5	Shallow CTD 34
124	71 21 01	22 06.9	65 55.6	
125	71 21 41	22 00.9	65 53.5	
126	72 01 12	21 50.8	65 49.7	Deep CTD 35 Mooring 3
127	72 04 21	21 50.9	65 49.4	|
128	76 18 53	23 38.7	69 20.3	Deep CTD 36 Mooring 4
129	76 19 46	23 43.0	69 11.3	
130	76 20 41	23 47.6	69 00.9	
131	76 21 38	23 52.2	68 50.8	
132	76 22 35	23 56.8	68 40.4	
133	76 23 34	24 01.7	68 29.4	
134	77 00 40	24 05.6	68 20.0	Deep CTD 37
135	77 03 52	24 04.6	68 20.4	|
136	77 05 11	24 10.6	68 09.4	
137	77 06 09	24 15.1	67 59.1	
138	77 07 05	24 19.7	67 49.1	
139	77 08 04	24 24.7	67 37.6	
140	77 09 01	24 28.8	67 28.1	
141	77 10 04	24 33.3	67 17.6	
142	77 11 08	24 37.7	67 07.3	

143	77	12	15	24 42.3	66 56.8			
144	77	13	20	24 46.7	66 46.7			
145	77	14	27	24 51.1	66 35.9			
146	77	15	32	24 55.6	66 25.5			
147	77	16	34	24 59.7	66 15.6	Mooring 6		
148	78	03	22	25 00.0	66 15.1	Deep CTD 38		
149	78	06	26	25 00.6	66 17.7			
150	78	07	23	25 09.1	66 09.4			
151	78	08	23	25 18.2	66 03.7			
152	78	09	19	25 27.3	65 58.0			
153	78	10	16	25 37.1	65 52.0			
154	78	11	09	25 45.5	65 46.6			
155	78	12	04	25 54.5	65 40.9			
156	78	13	00	26 03.0	65 35.4			
157	78	13	57	26 12.7	65 29.5			
158	78	14	52	26 21.8	65 23.7			
159	78	15	45	26 30.8	65 18.0			
160	78	16	38	26 39.7	65 13.6			
161	78	17	37	26 49.1	65 06.4	Deep CTD 39		
162	78	20	55	26 51.0	65 07.5			
163	78	21	46	26 58.1	65 00.4			
164	78	22	36	27 07.1	64 54.6			
165	78	23	26	27 16.1	64 48.1			
166	79	00	16	27 25.2	64 42.8			
167	79	01	03	27 34.2	64 36.9			
168	79	02	02	27 43.3	64 30.8	Deep CTD 40 Mooring 1		

AMODE Recovery - Temperature Profiles

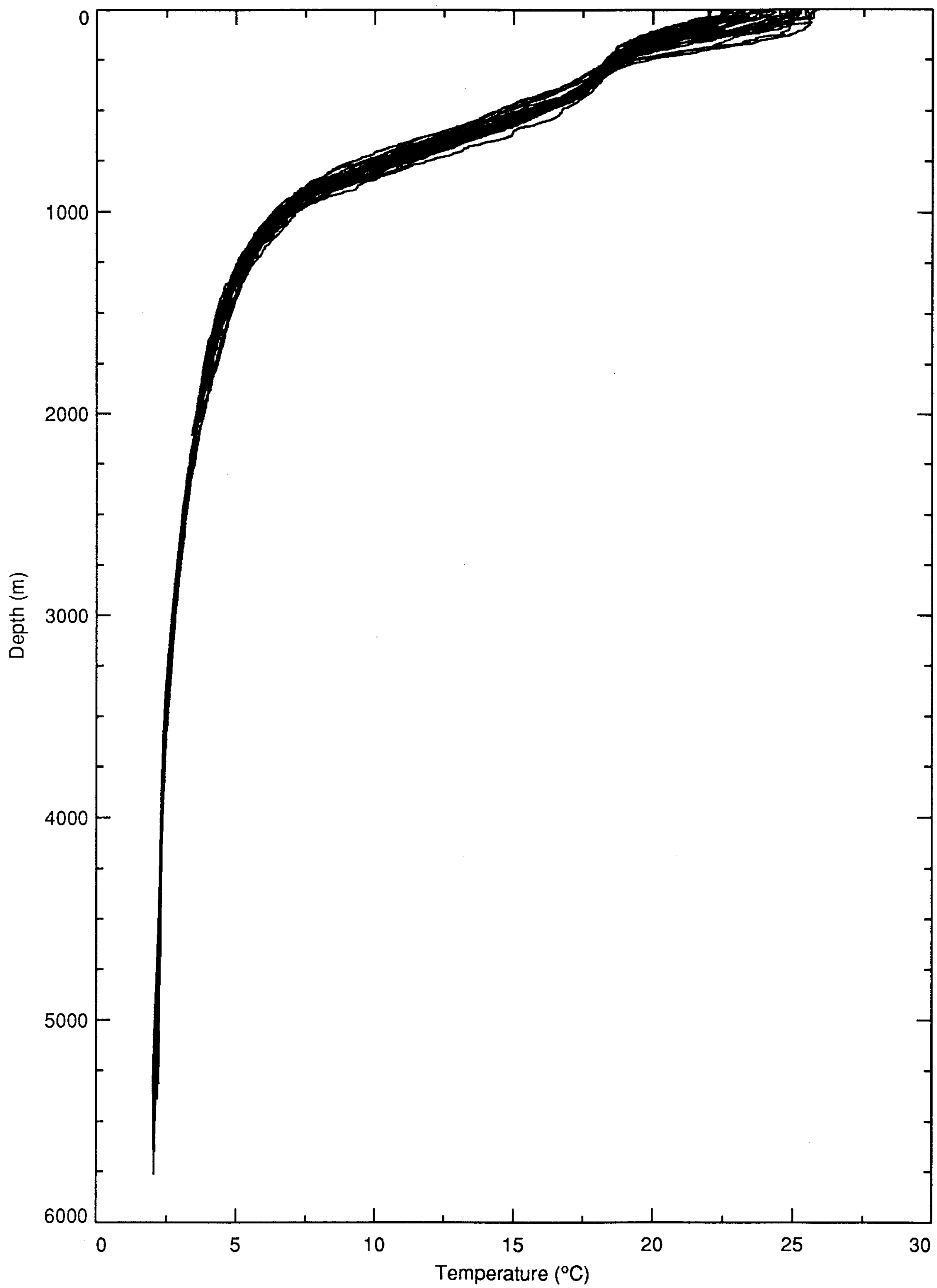


Figure G1

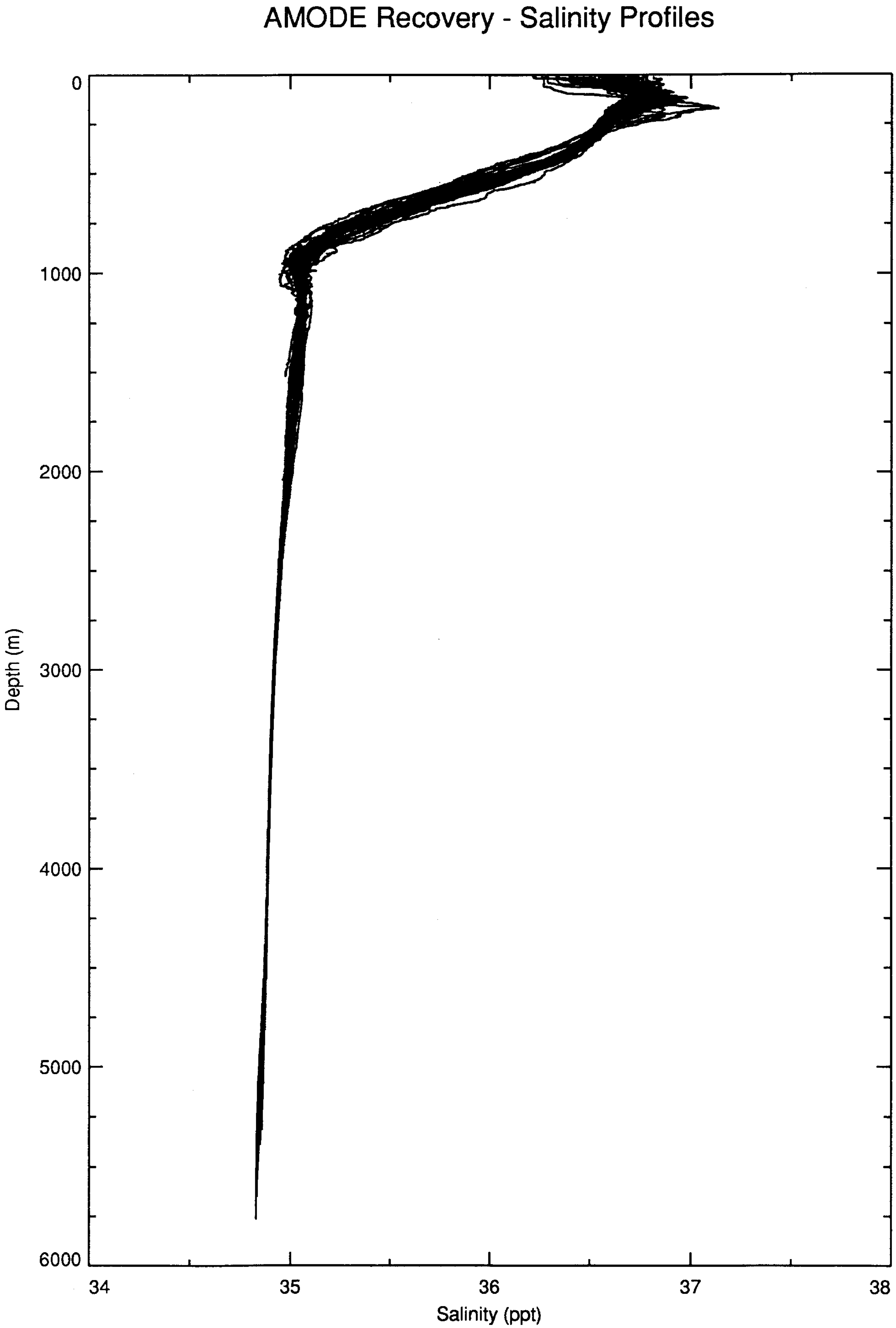
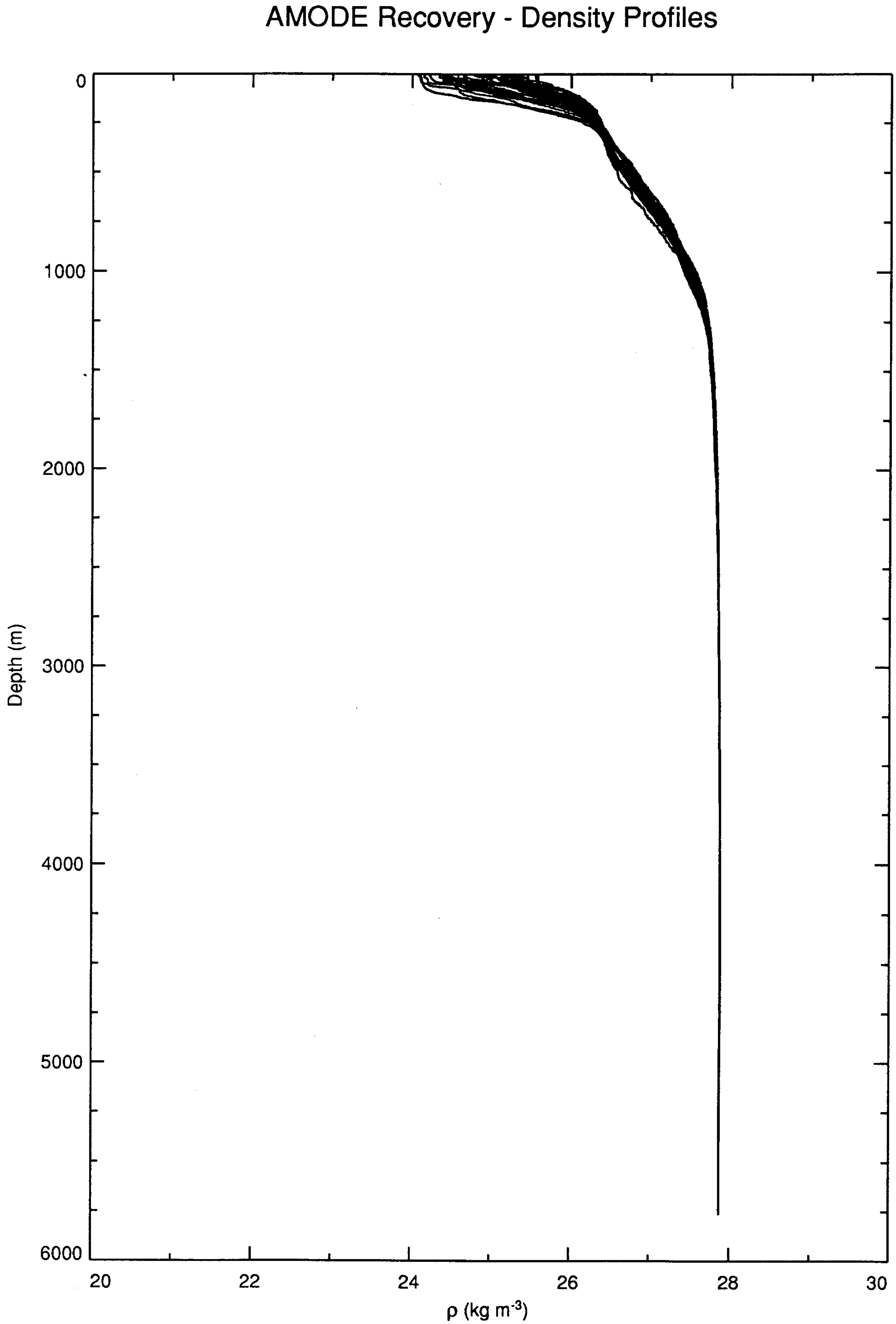
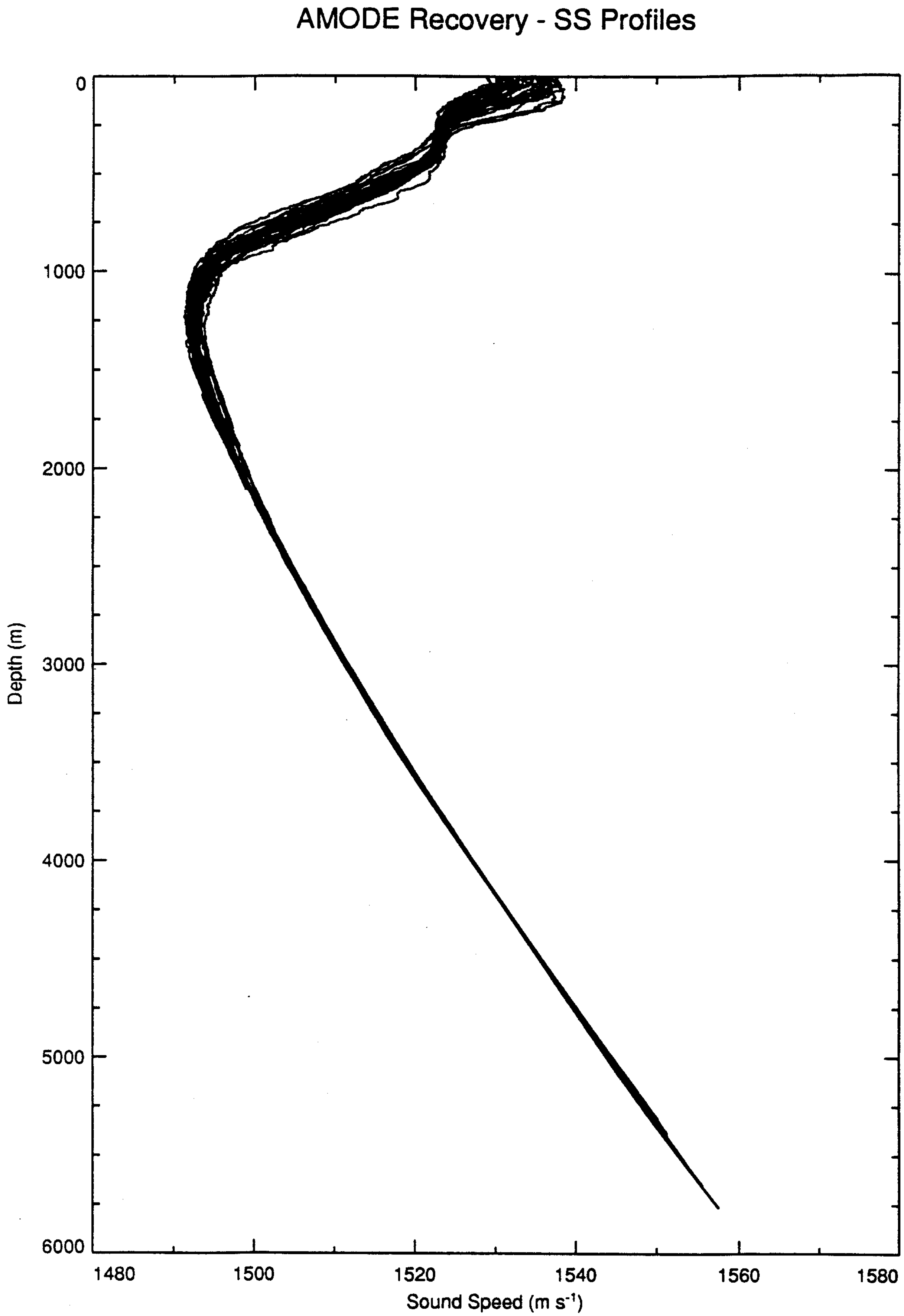

AMODE Recovery - Salinity Profiles
0
1000
2000
3000
4000
5000
6000
Depth (m)
34
35
36
37
38
Salinity (ppt)

Figure G2



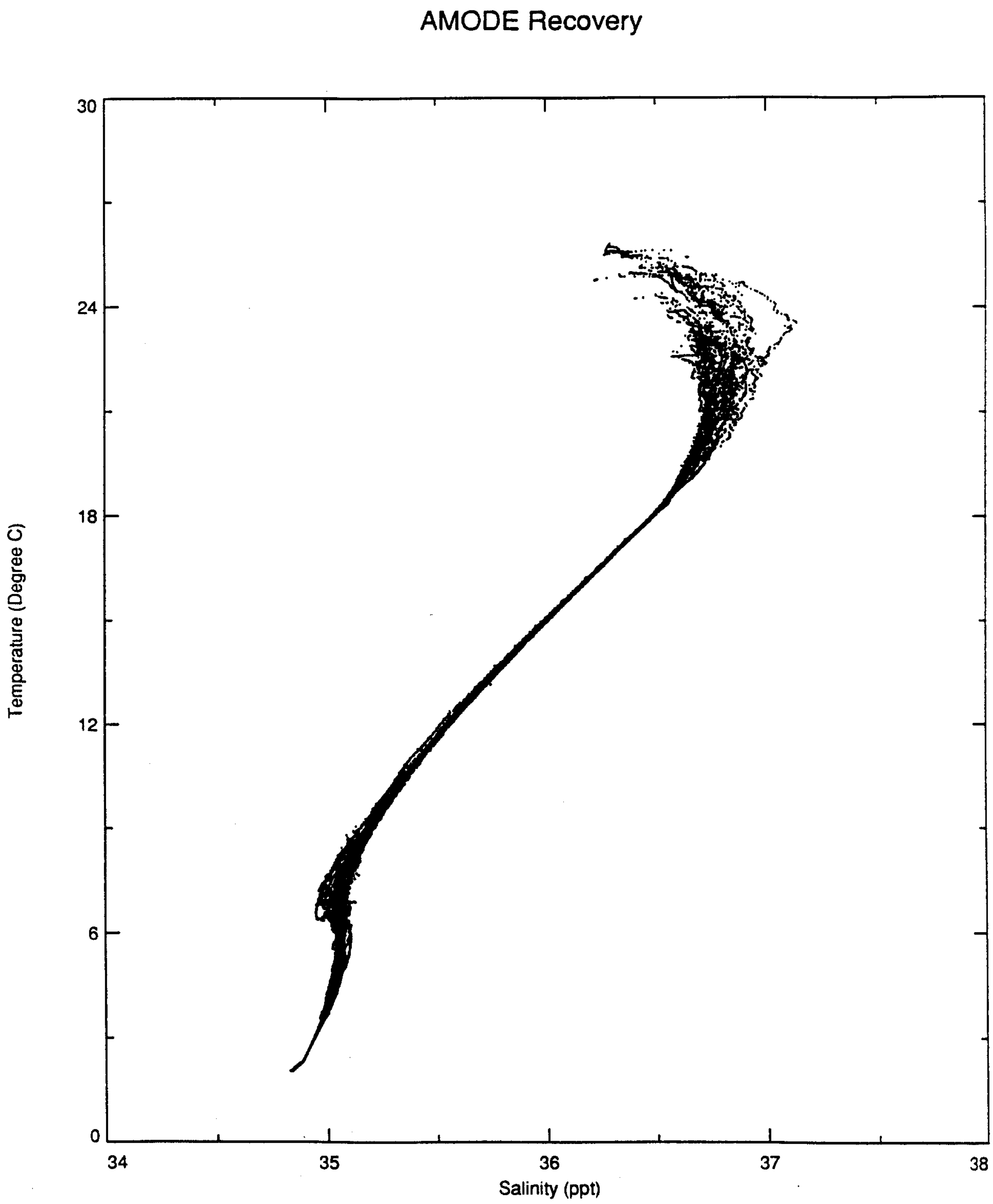
AMODE Recovery - Density Profiles
0
1000
2000
3000
4000
5000
6000
Depth (m)
20
22
24
26
28
30
ρ (kg m-3)

Figure G3



AMODE Recovery - SS Profiles
Depth (m)
0
1000
2000
3000
4000
5000
6000
1480
1500
1520
1540
1560
1580
Sound Speed (m s-1)

Figure G4



AMODE Recovery
30
24
18
12
6
0
Temperature (Degree C)
34
35
36
37
38
Salinity (ppt)

Figure G5

AMODE Recovery - CTD Cast 063102

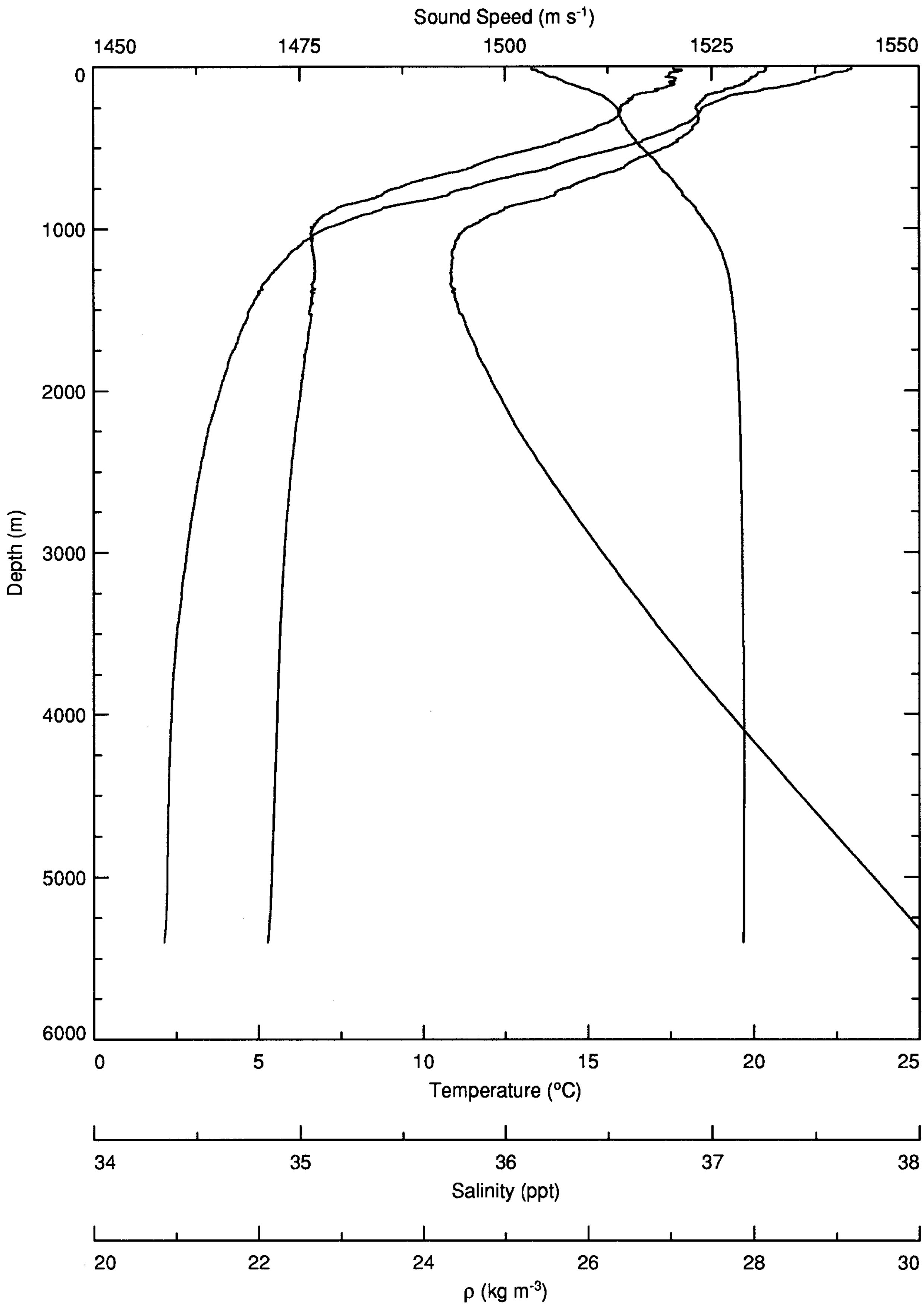


Figure G6

AMODE Recovery - CTD Cast 065031

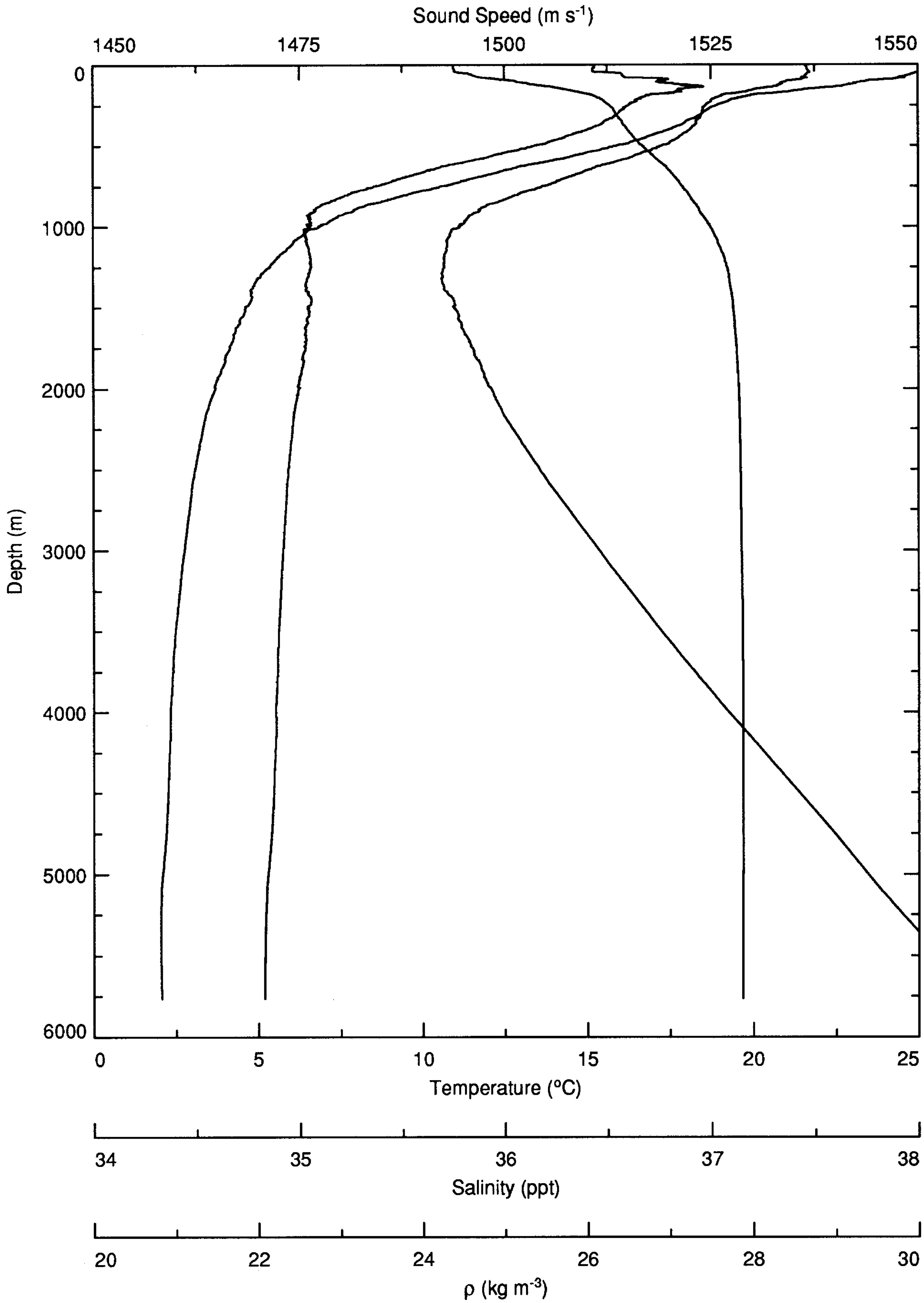


Figure G7

AMODE Recovery - CTD Cast 065091

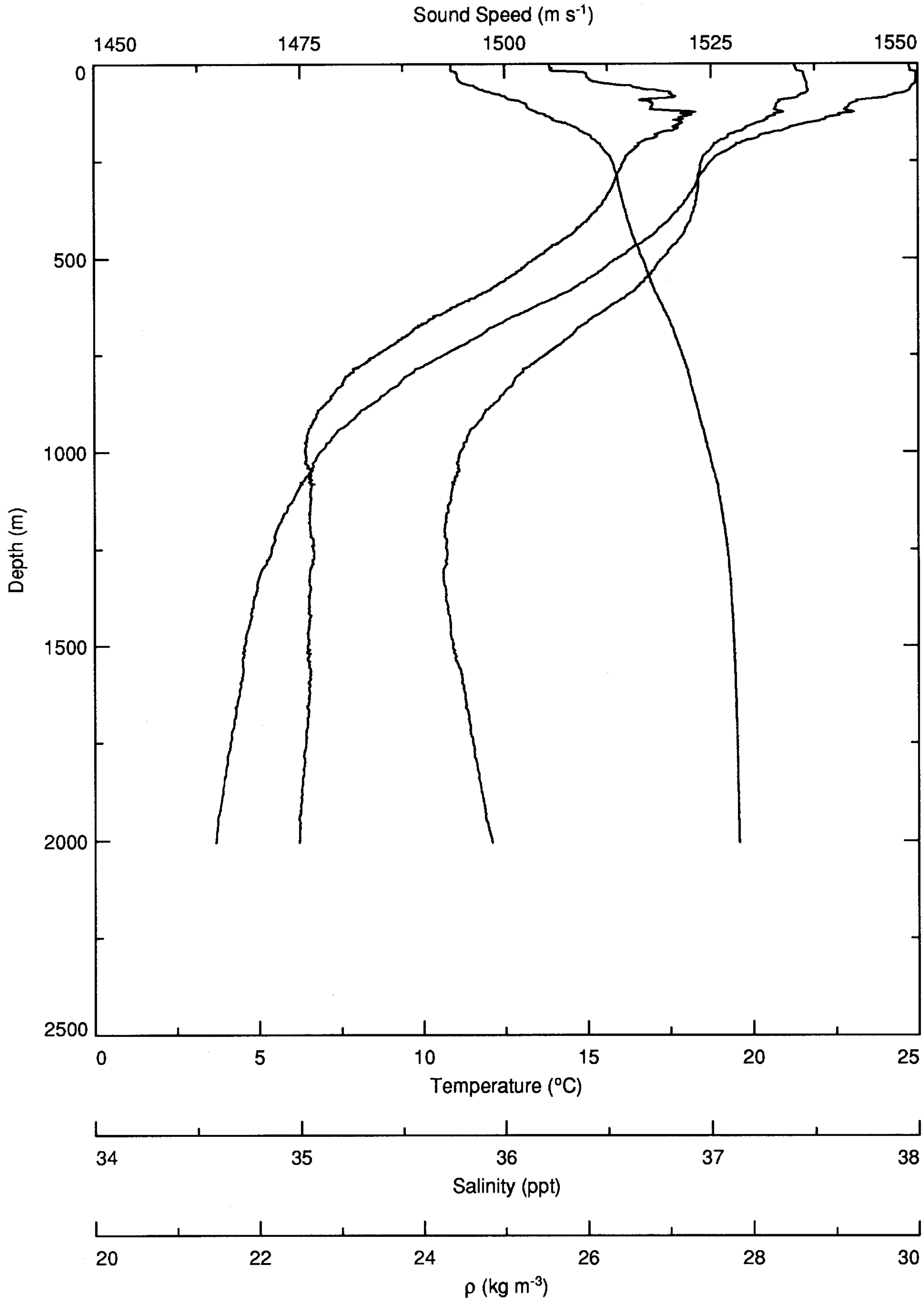


Figure G8

AMODE Recovery - CTD Cast 065131

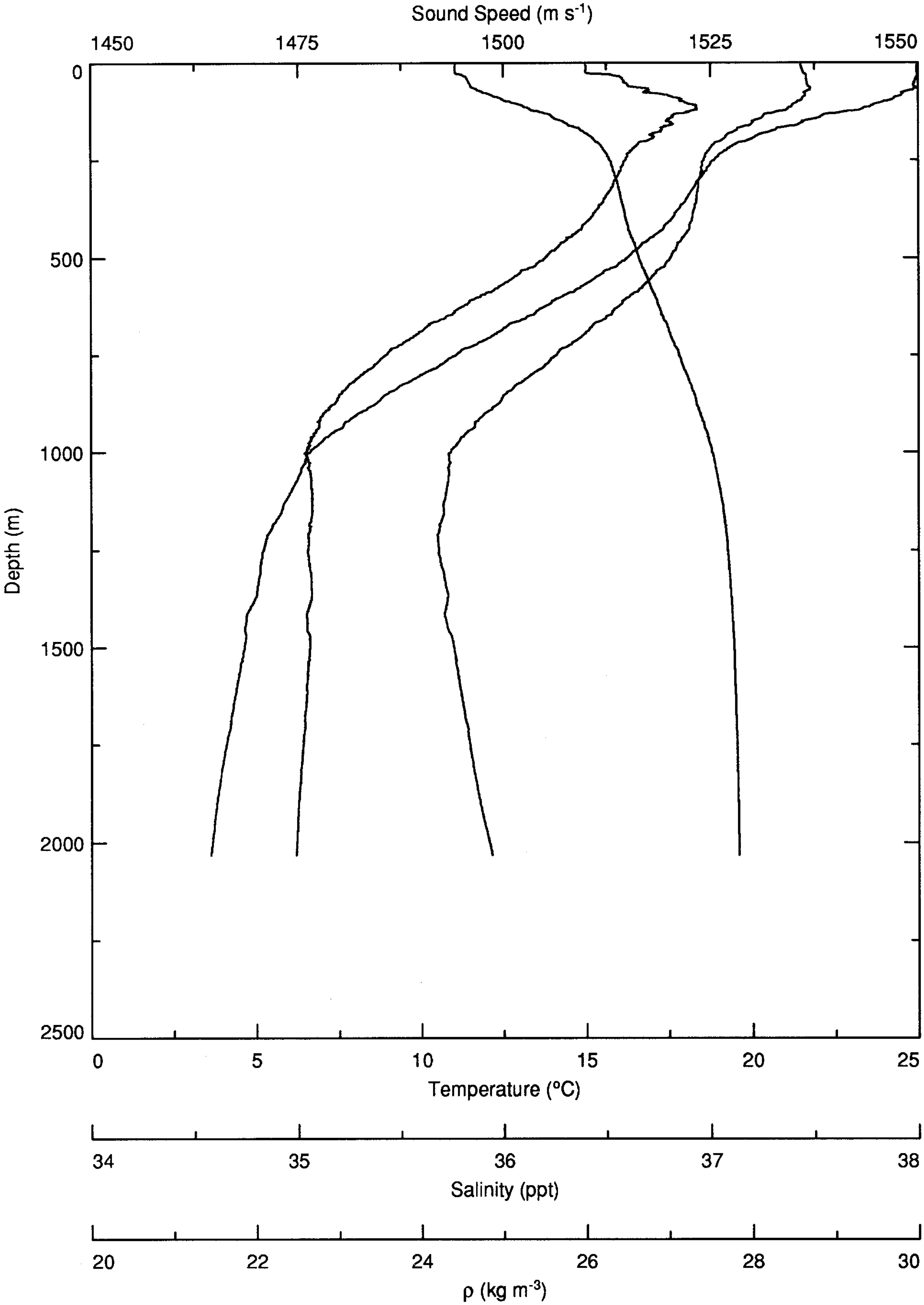


Figure G9

AMODE Recovery - CTD Cast 065171

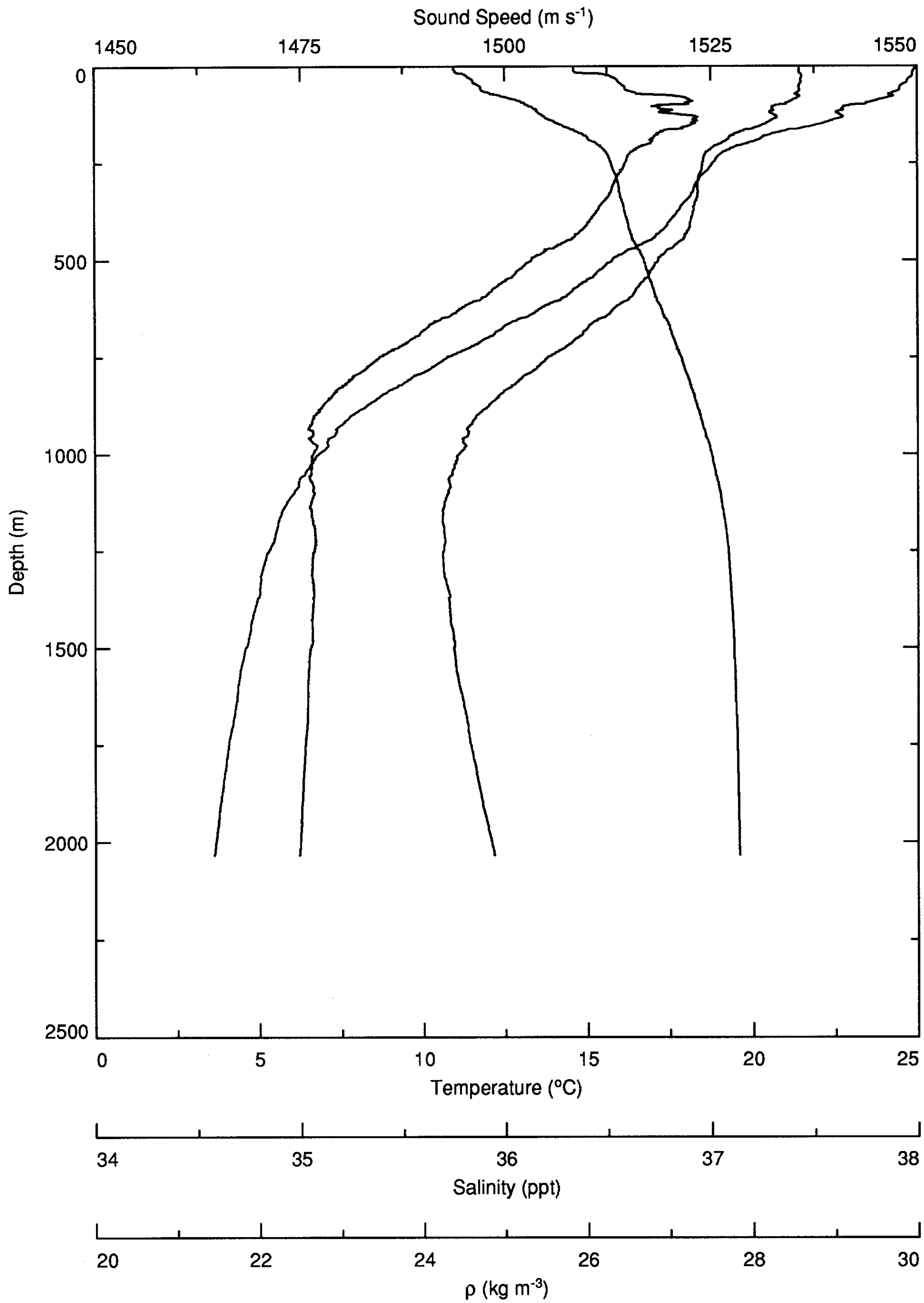


Figure G10

AMODE Recovery - CTD Cast 065211

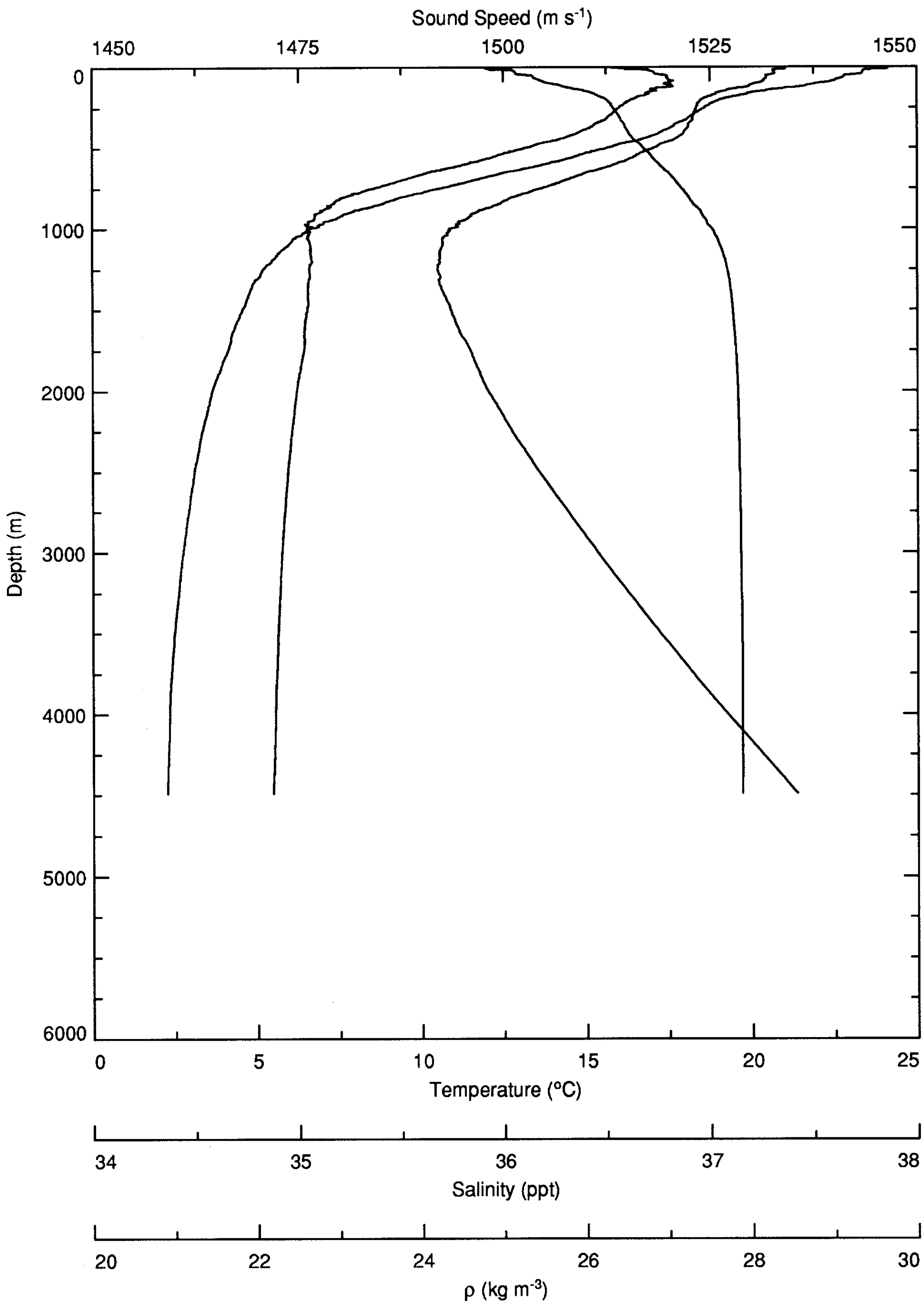


Figure G11

AMODE Recovery - CTD Cast 066031

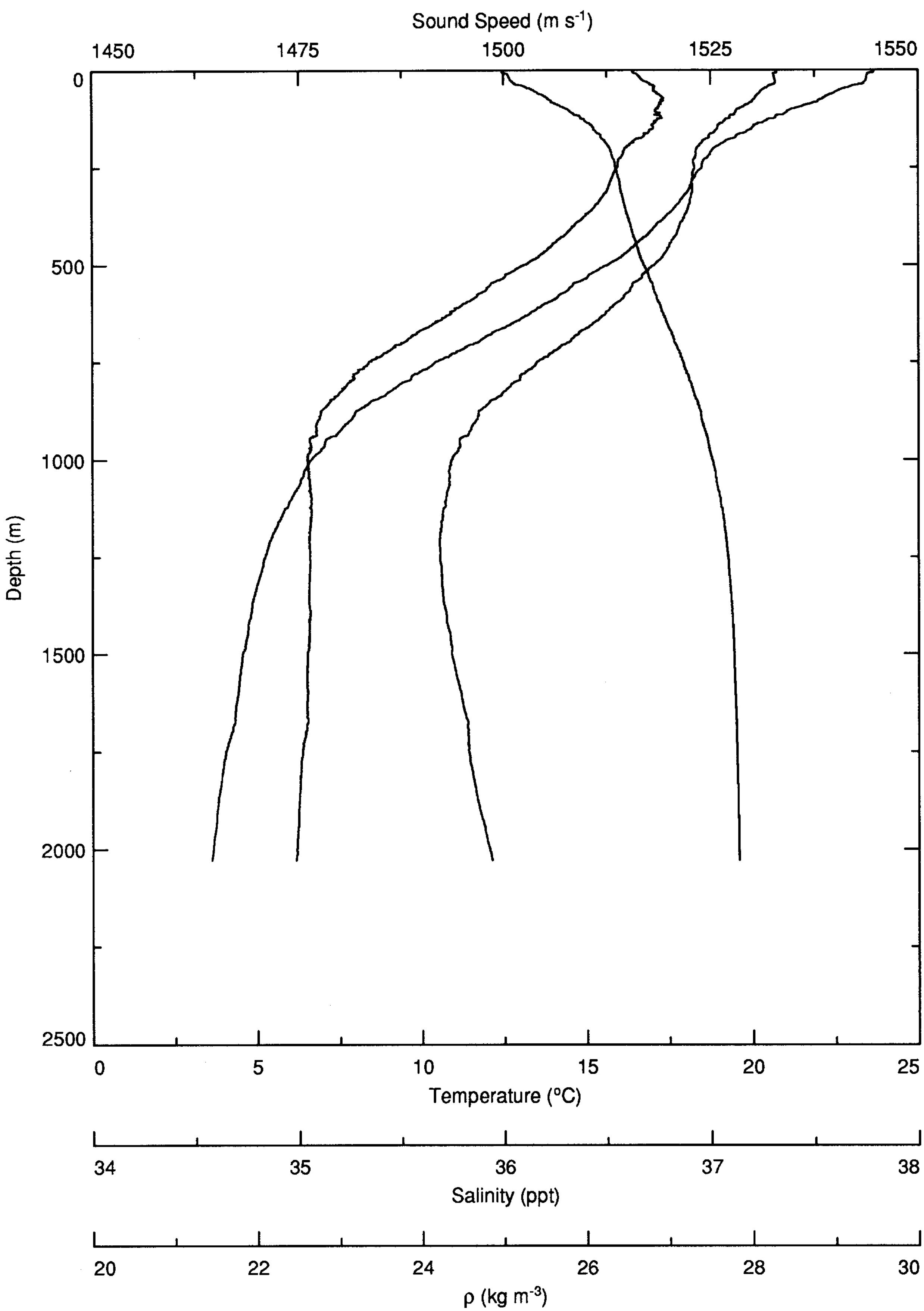


Figure G12

AMODE Recovery - CTD Cast 066061

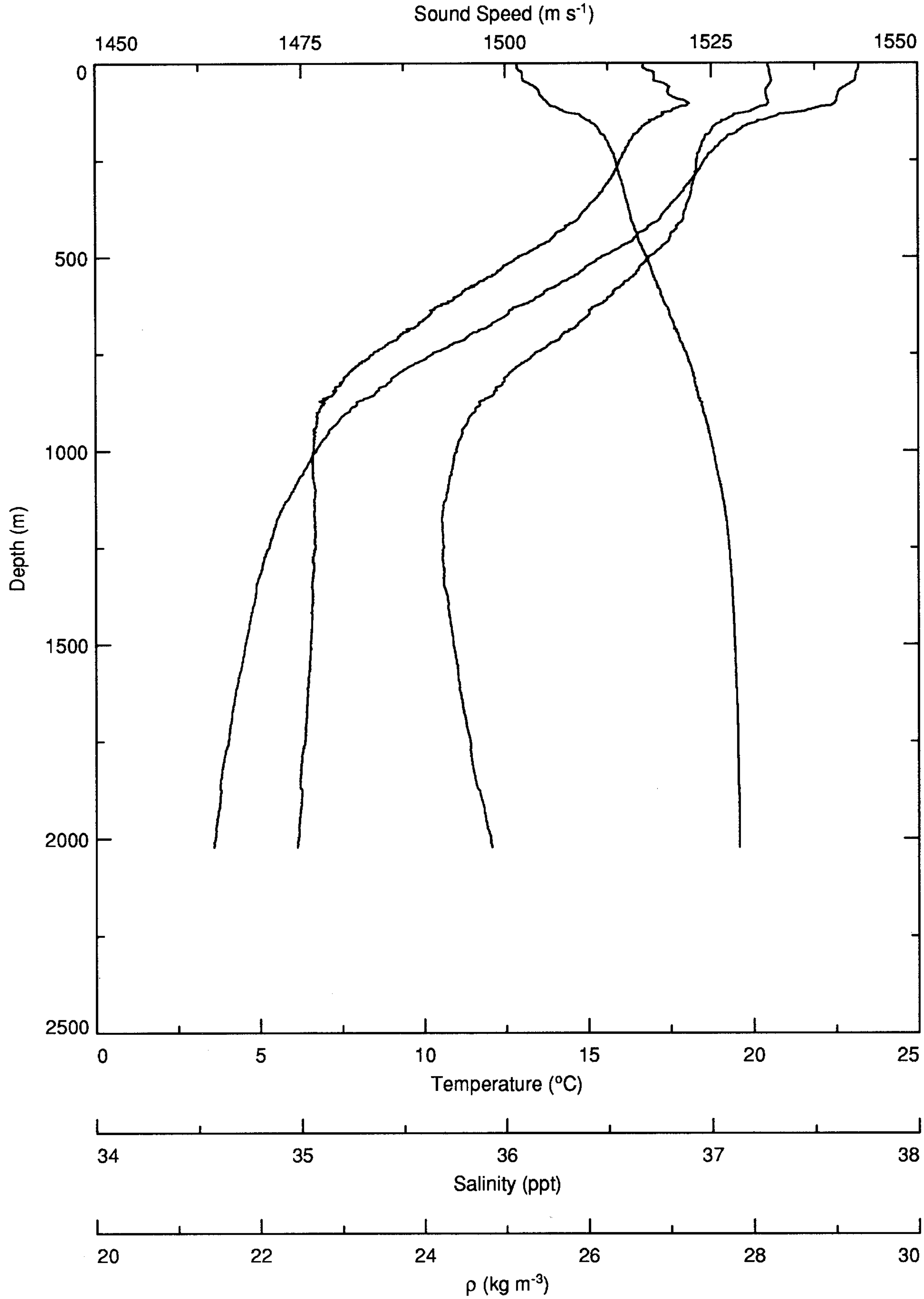


Figure G13

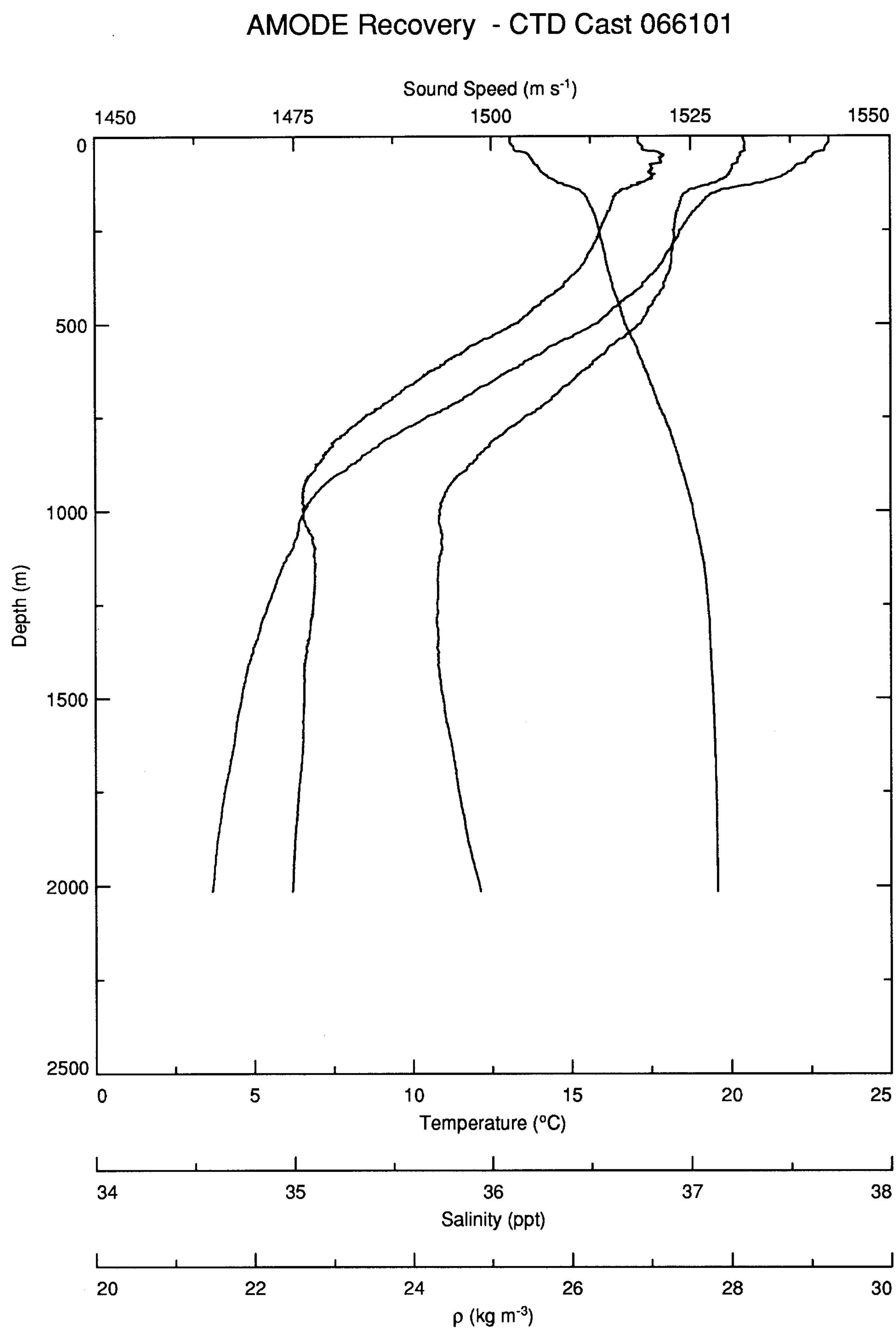

AMODE Recovery - CTD Cast 066101
Sound Speed (m s-1)
1450
1475
1500
1525
1550
Depth (m)
0
500
1000
1500
2000
2500
0
5
10
15
20
25
Temperature (°C)
34
35
36
37
38
Salinity (ppt)
20
22
24
26
28
30
ρ (kg m-3)

Figure G14

AMODE Recovery - CTD Cast 066131

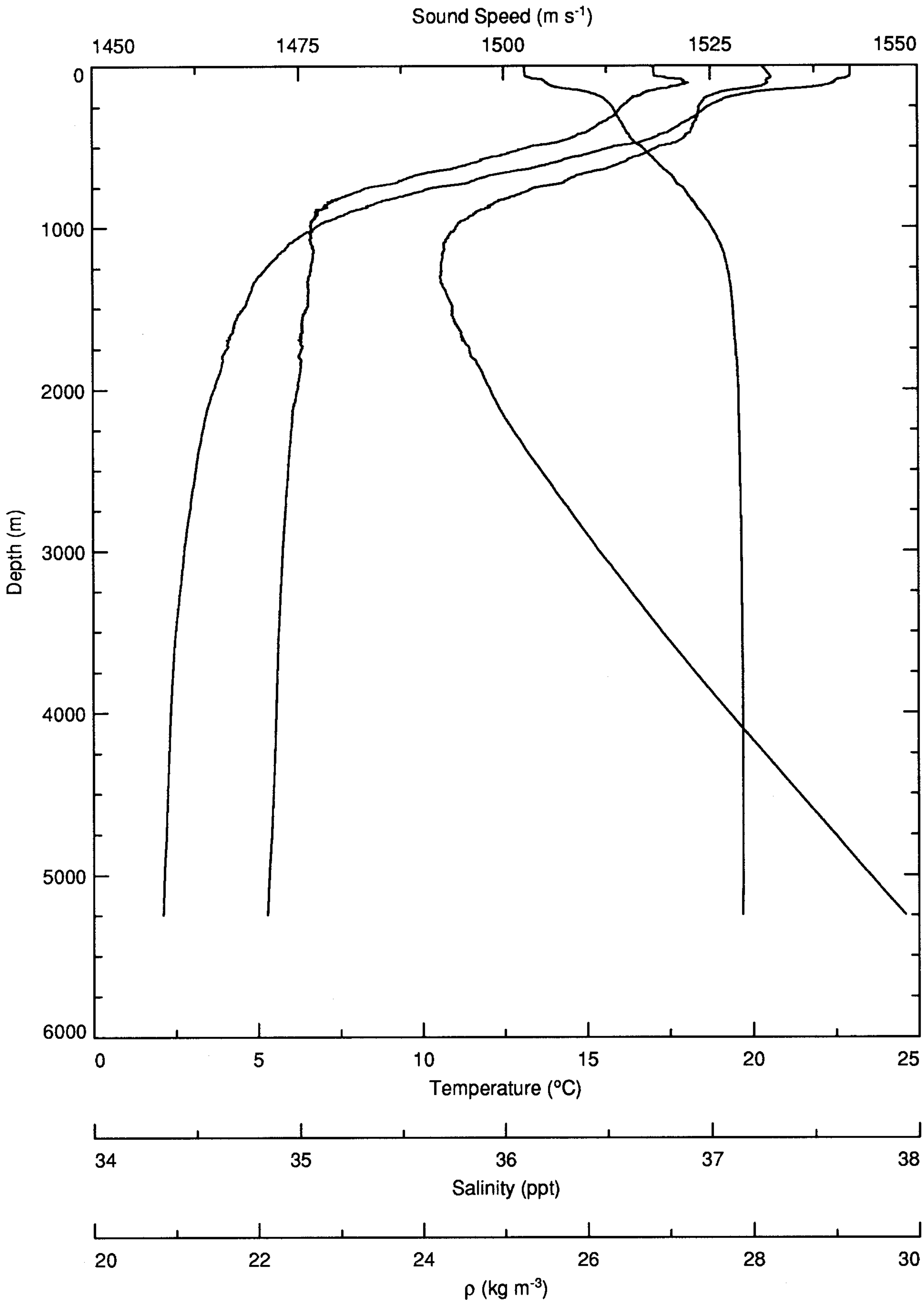


Figure G15

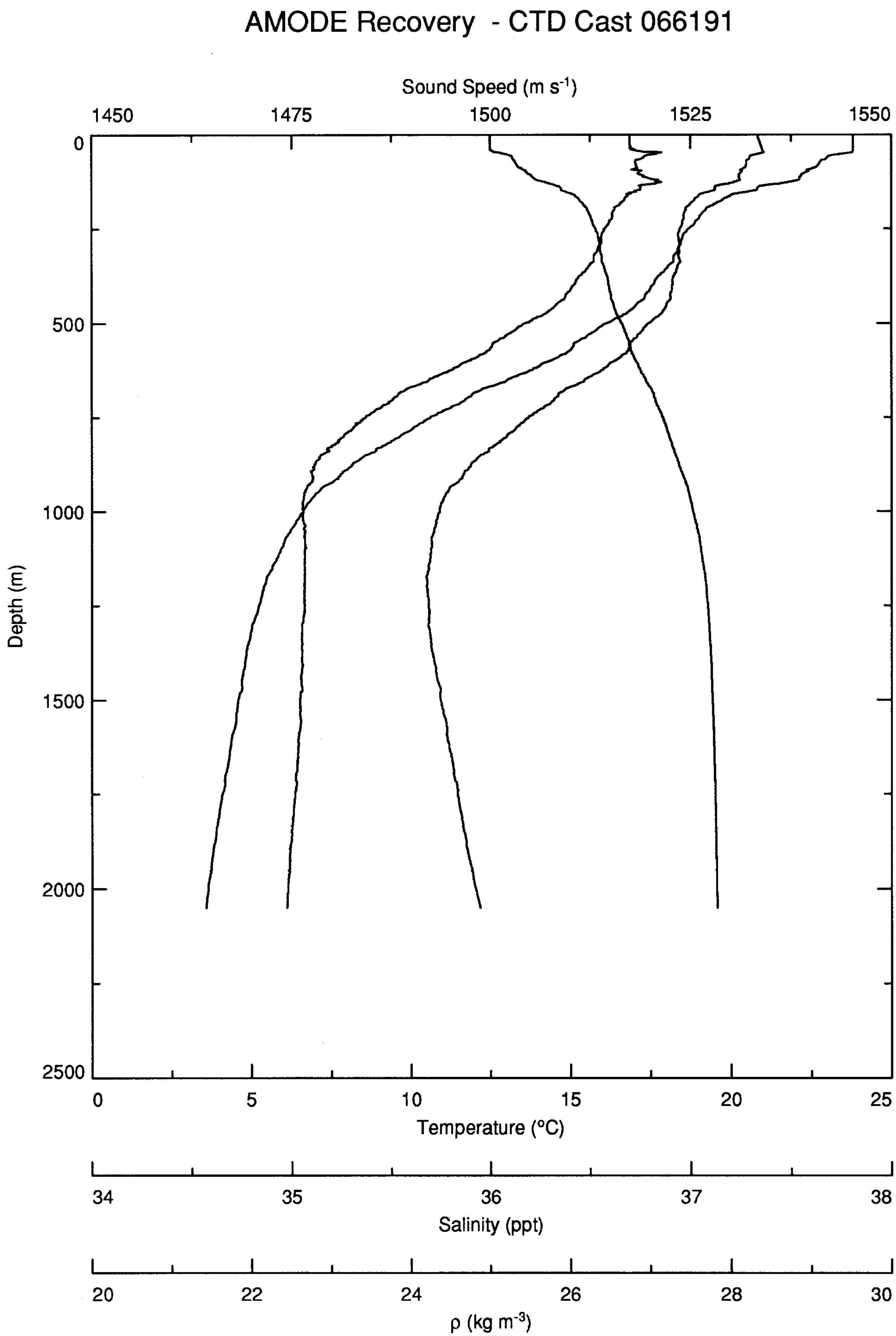
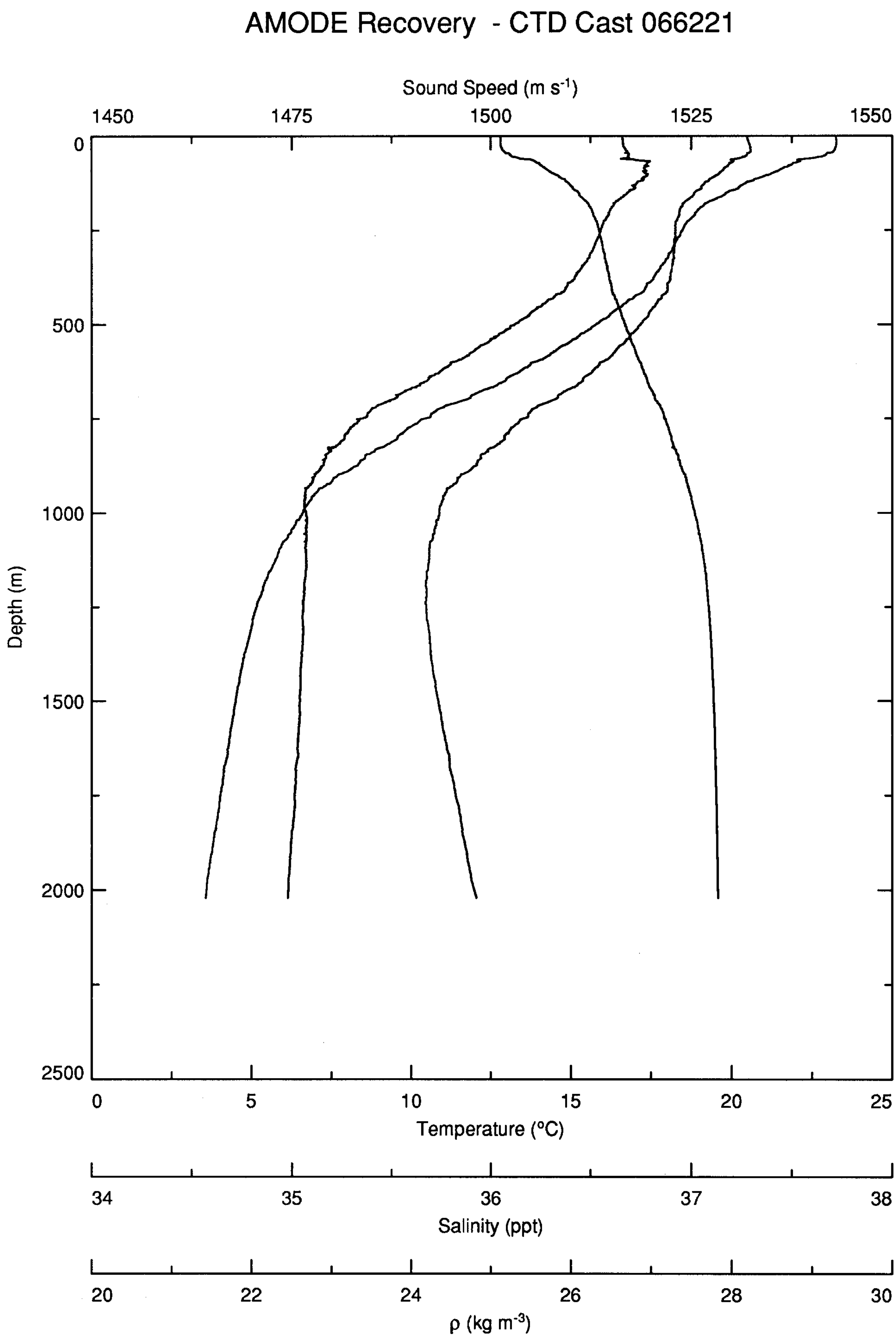

AMODE Recovery - CTD Cast 066191
Sound Speed (m s⁻¹)
1450
1475
1500
1525
1550
Depth (m)
0
500
1000
1500
2000
2500
0
5
10
15
20
25
Temperature (°C)
34
35
36
37
38
Salinity (ppt)
20
22
24
26
28
30
ρ (kg m⁻³)

Figure G16



AMODE Recovery - CTD Cast 066221
Sound Speed (m s-1)
1450
1475
1500
1525
1550
Depth (m)
0
500
1000
1500
2000
2500
0
5
10
15
20
25
Temperature (°C)
34
35
36
37
38
Salinity (ppt)
20
22
24
26
28
30
ρ (kg m-3)

Figure G17

AMODE Recovery - CTD Cast 067031

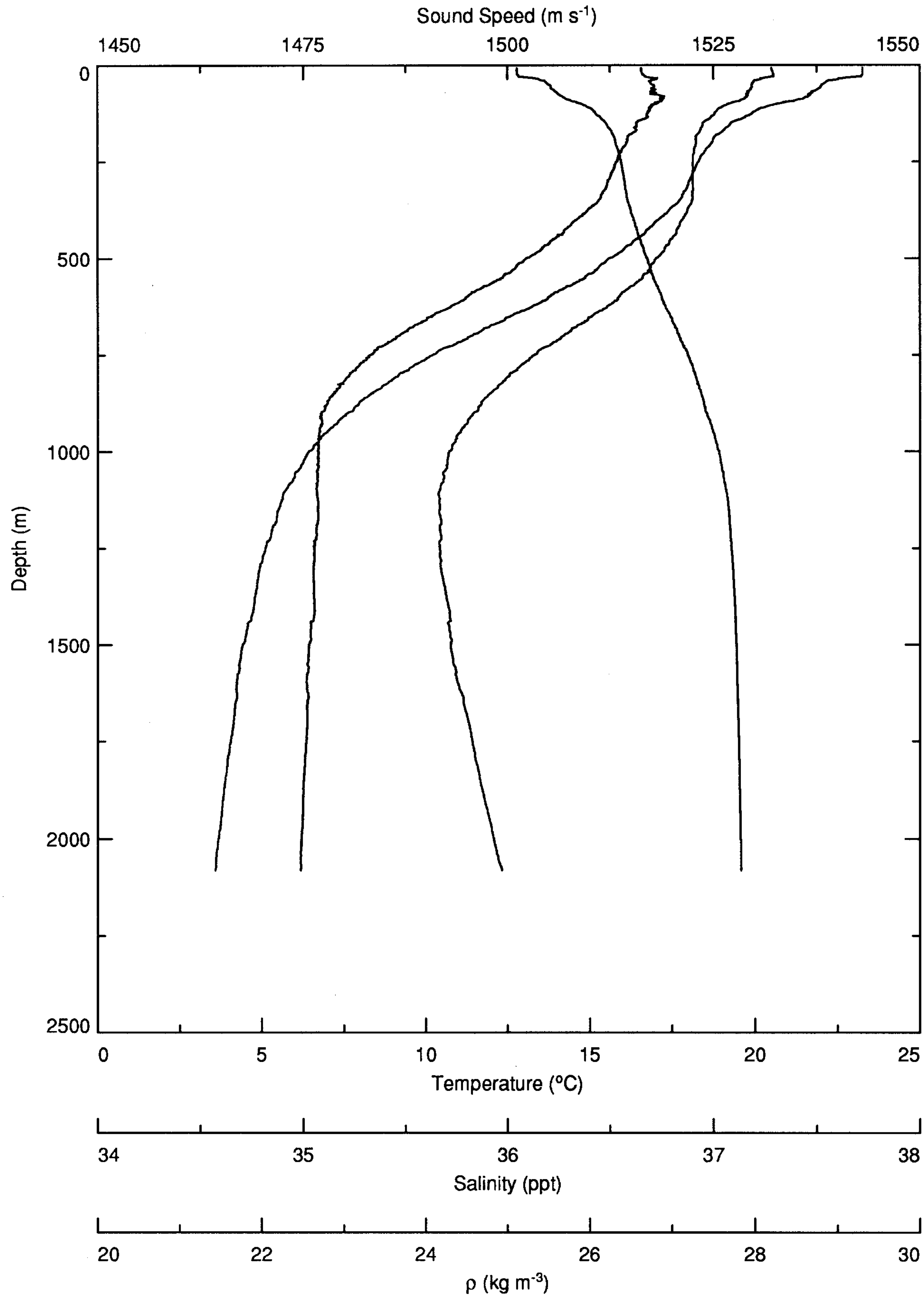


Figure G18

AMODE Recovery - CTD Cast 067061

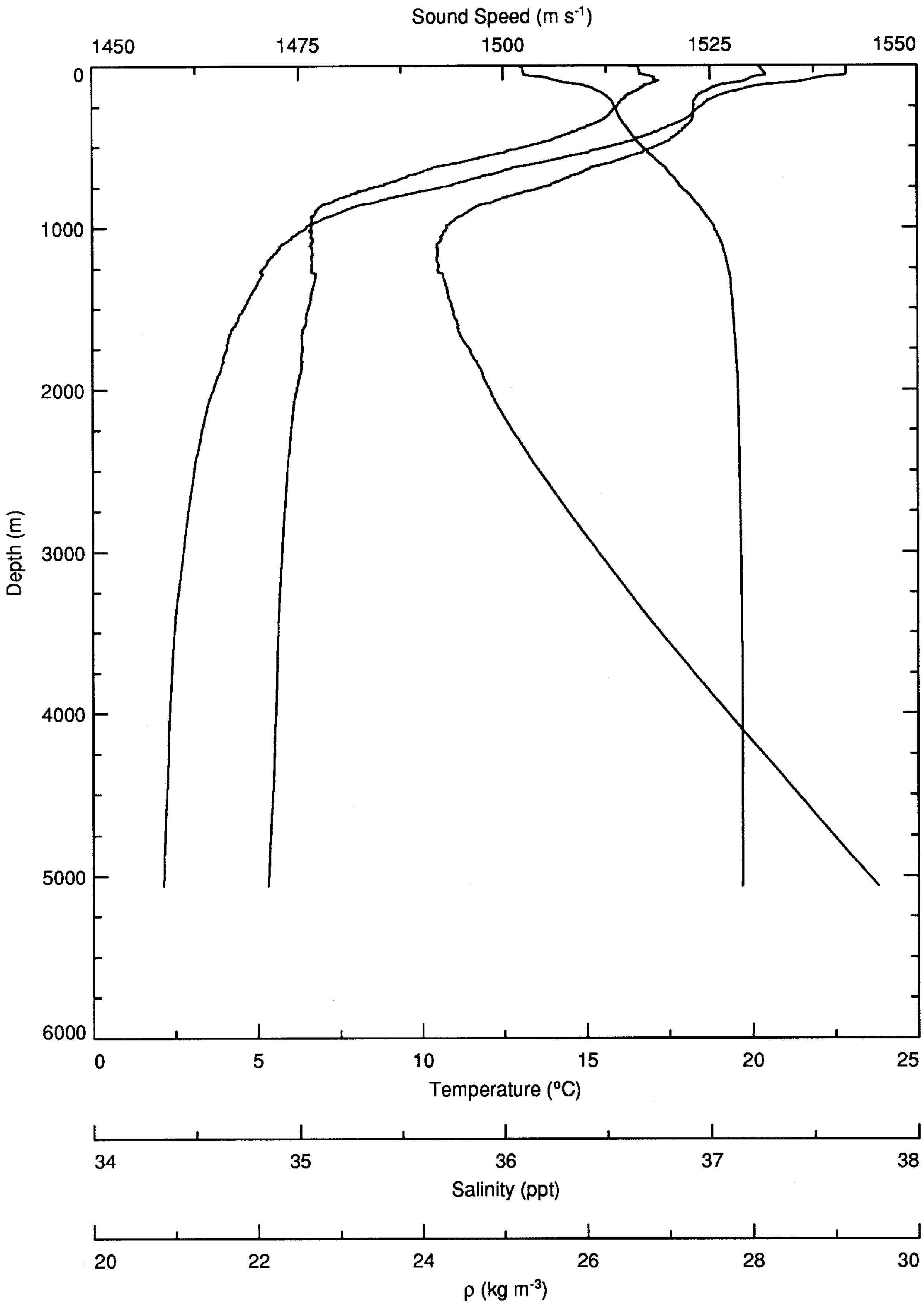


Figure G19

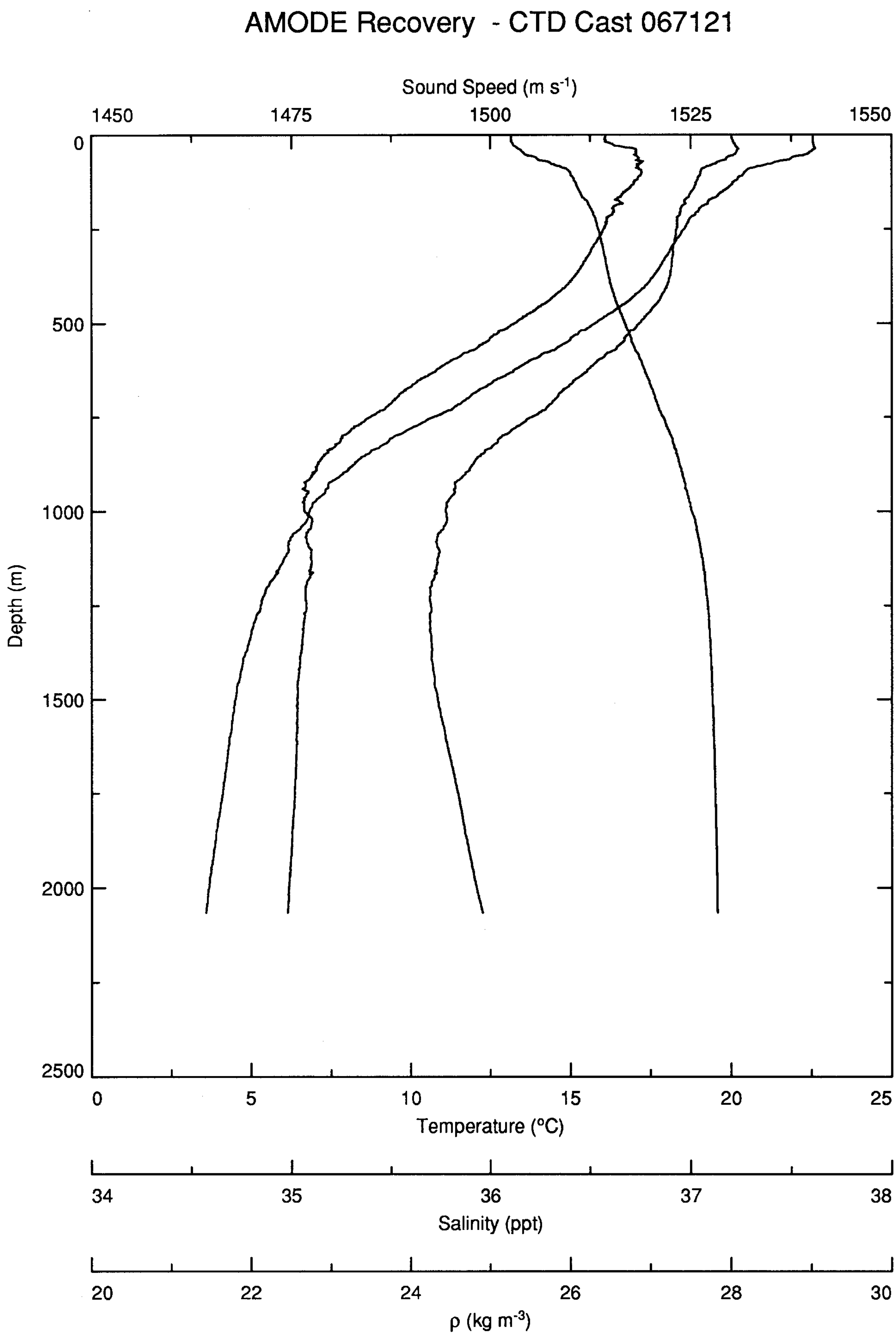

AMODE Recovery - CTD Cast 067121
Sound Speed (m s-1)
1450
1475
1500
1525
1550
Depth (m)
0
500
1000
1500
2000
2500
0
5
10
15
20
25
Temperature (°C)
34
35
36
37
38
Salinity (ppt)
20
22
24
26
28
30
ρ (kg m-3)

Figure G20

AMODE Recovery - CTD Cast 067161

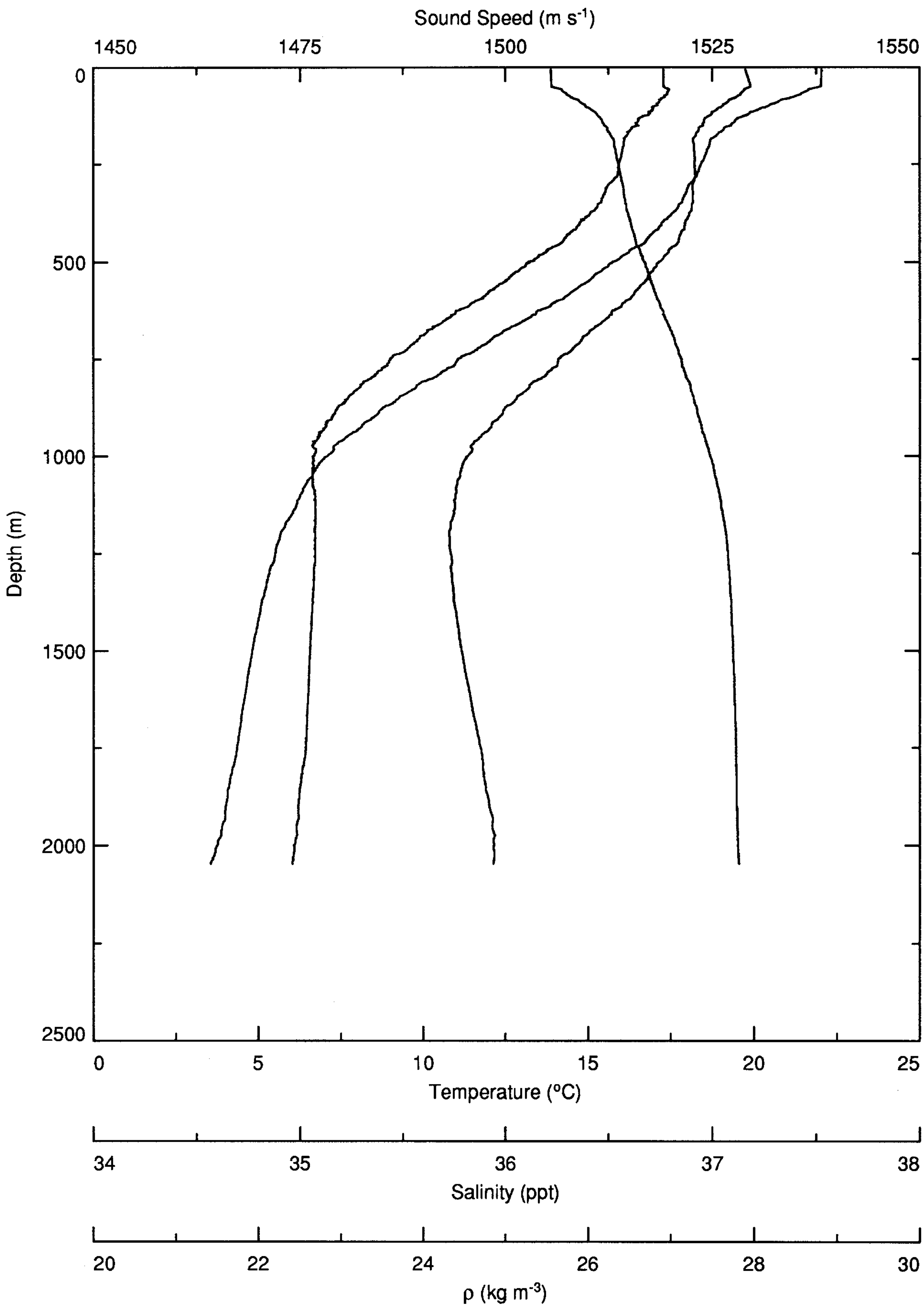


Figure G21

AMODE Recovery - CTD Cast 067201

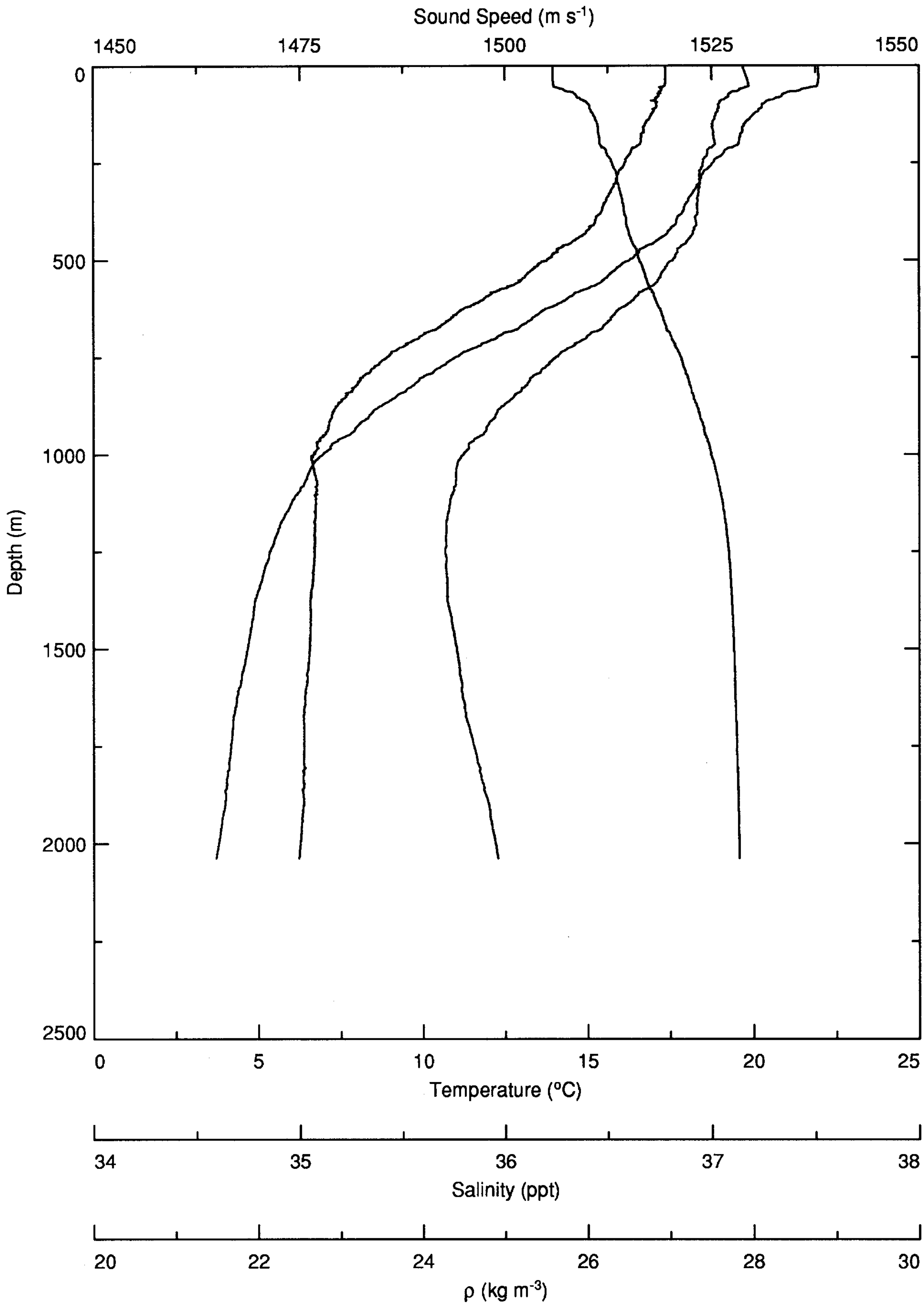


Figure G22

AMODE Recovery - CTD Cast 068001

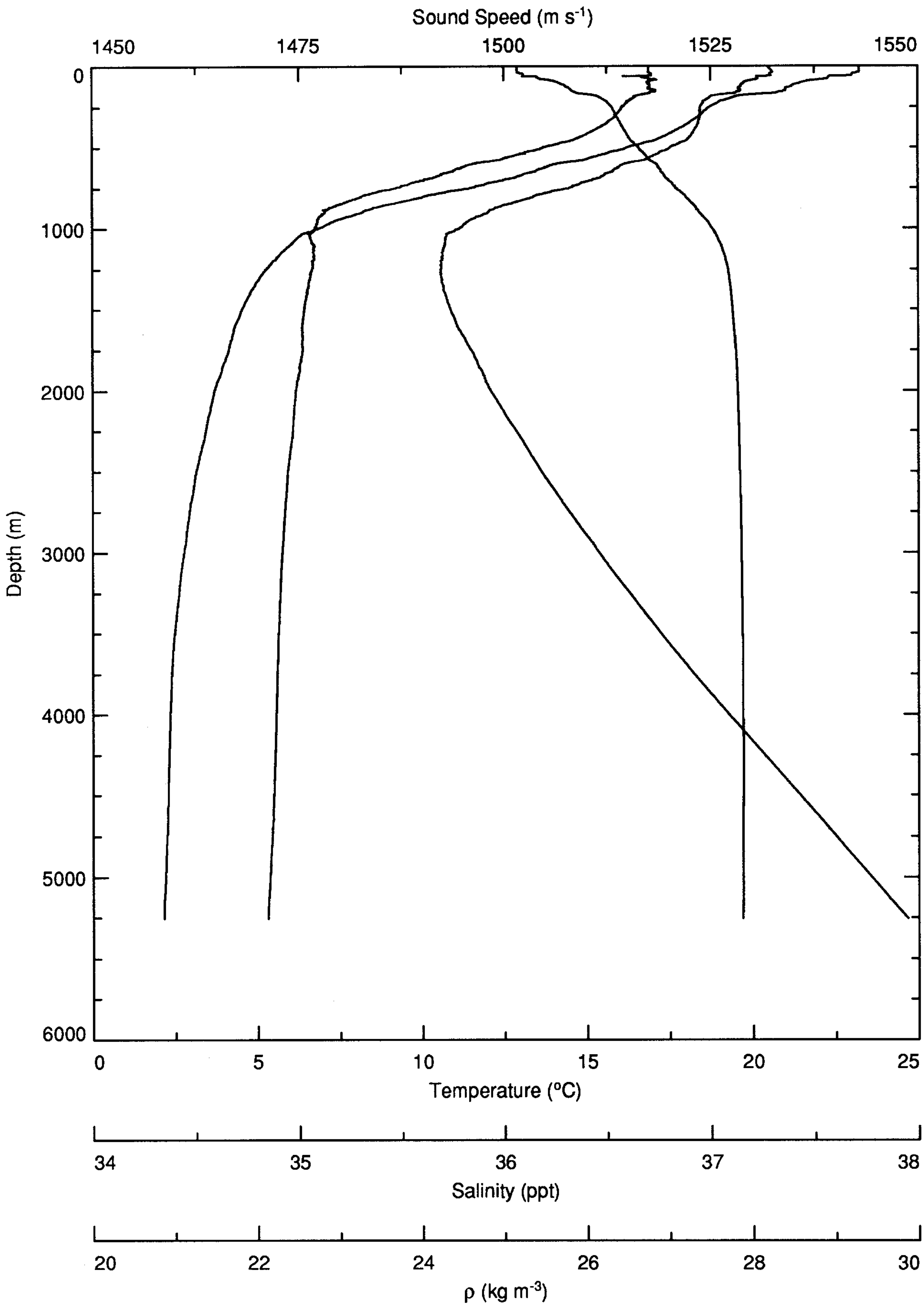


Figure G23

AMODE Recovery - CTD Cast 068231

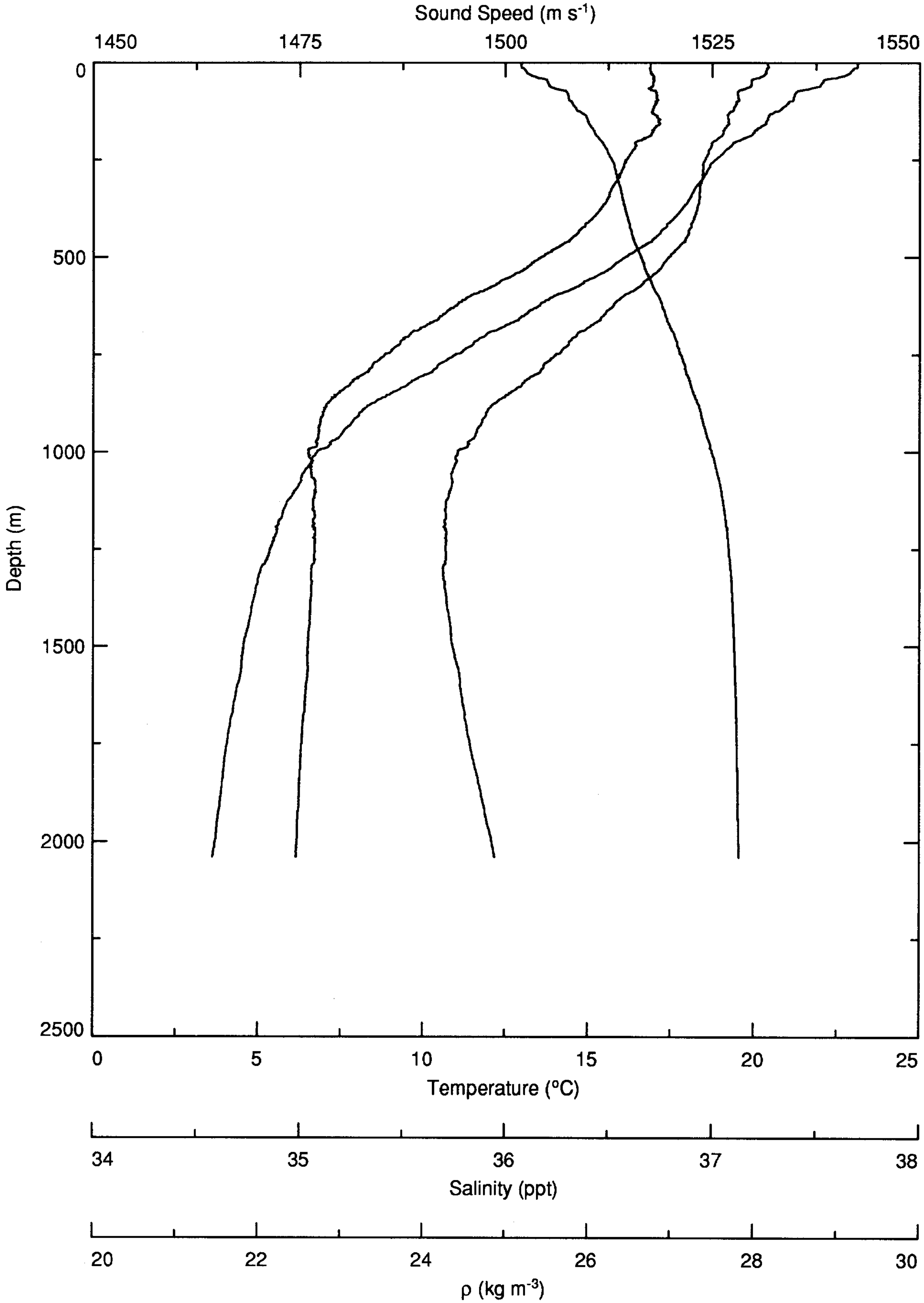


Figure G24

AMODE Recovery - CTD Cast 069031

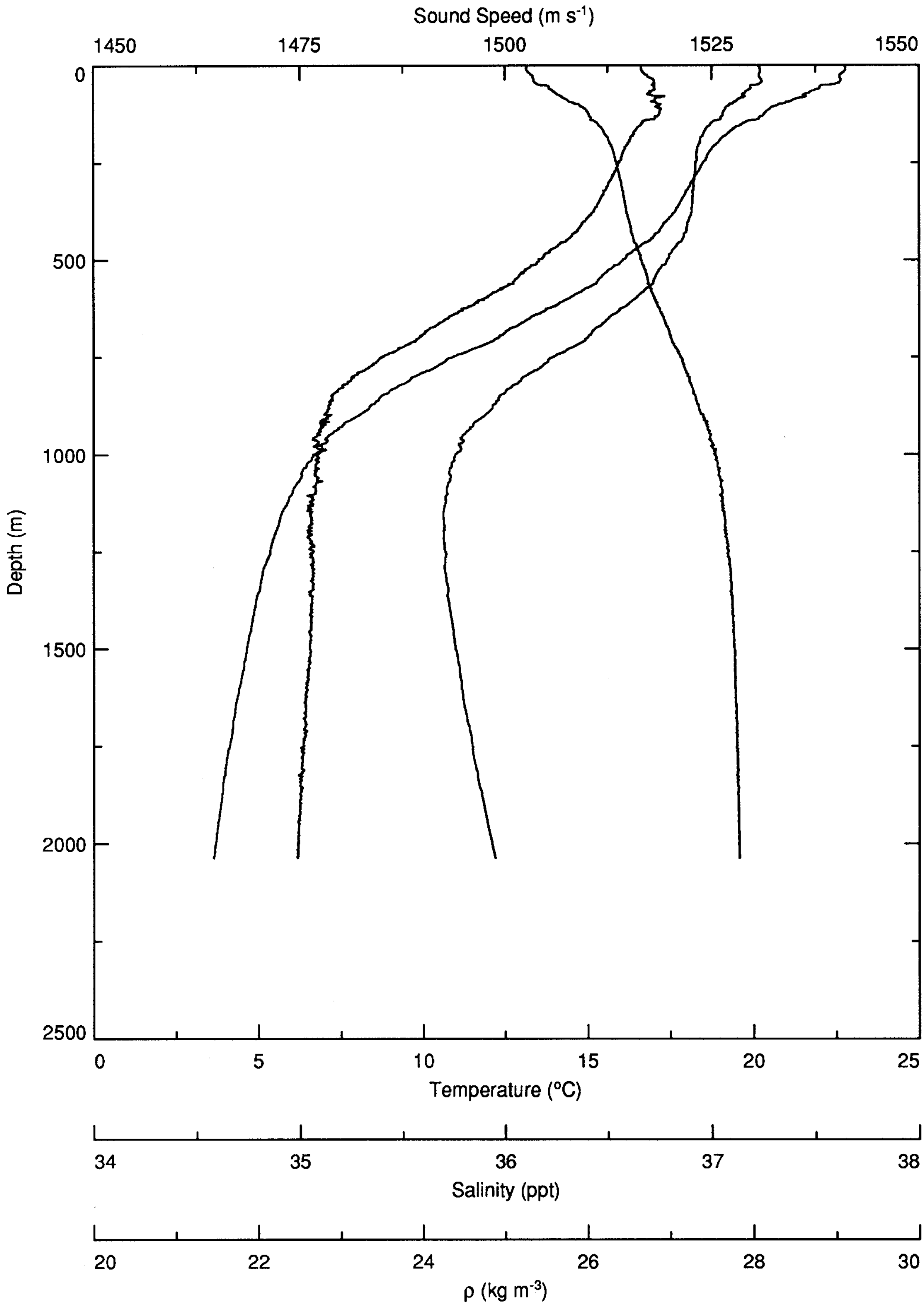


Figure G25

AMODE Recovery - CTD Cast 069061

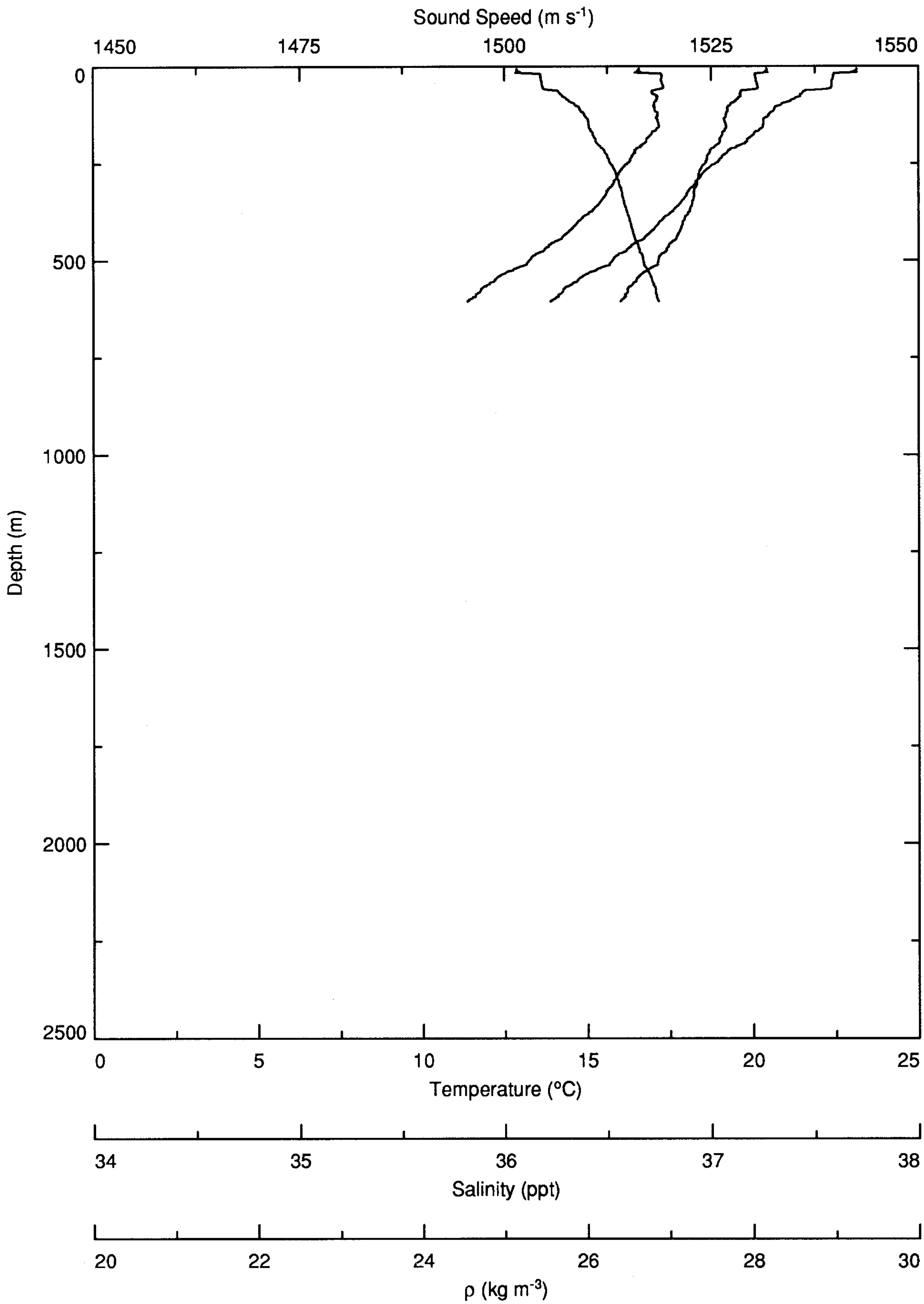


Figure G26

AMODE Recovery - CTD Cast 069161

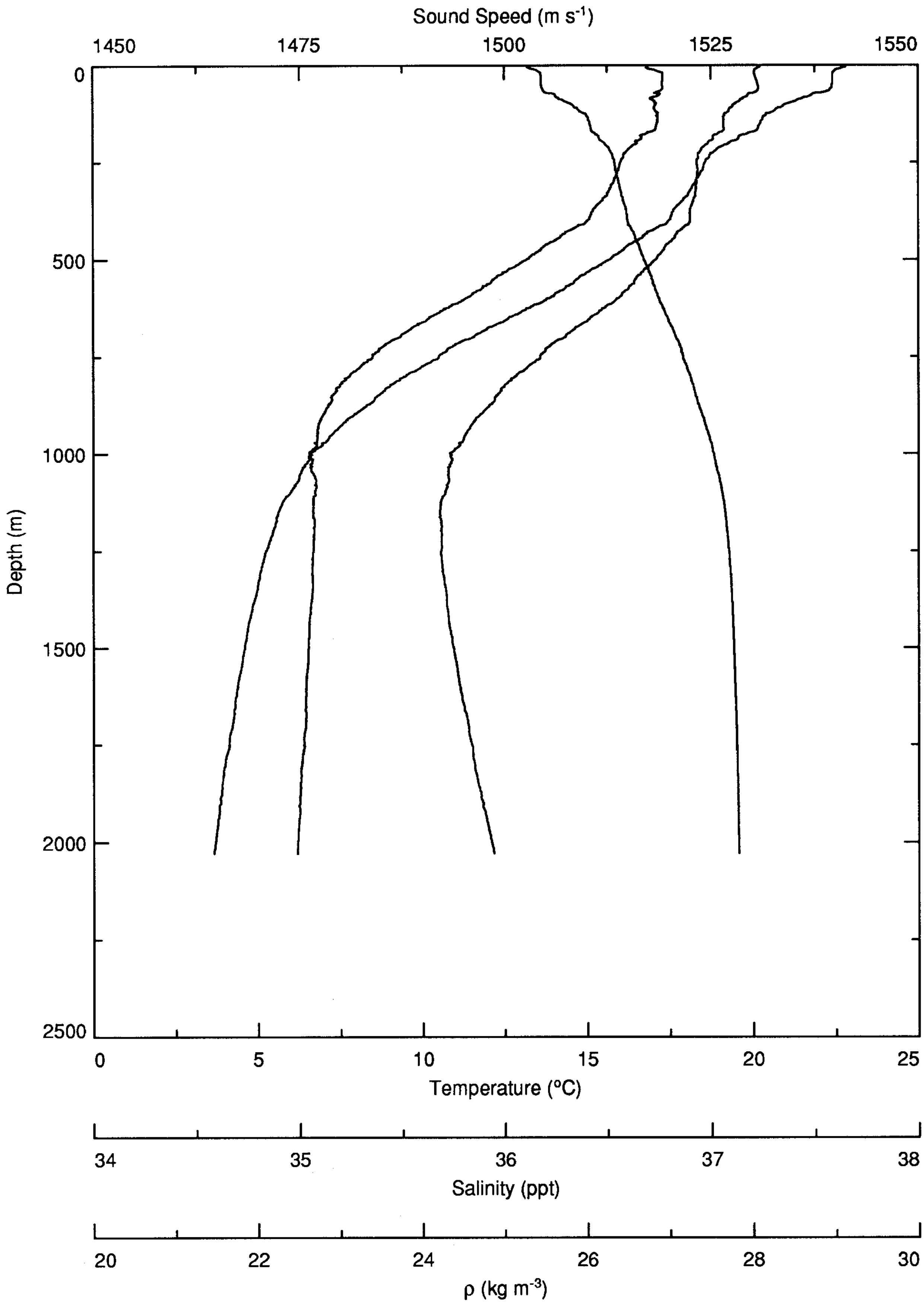


Figure G27

AMODE Recovery - CTD Cast 069201

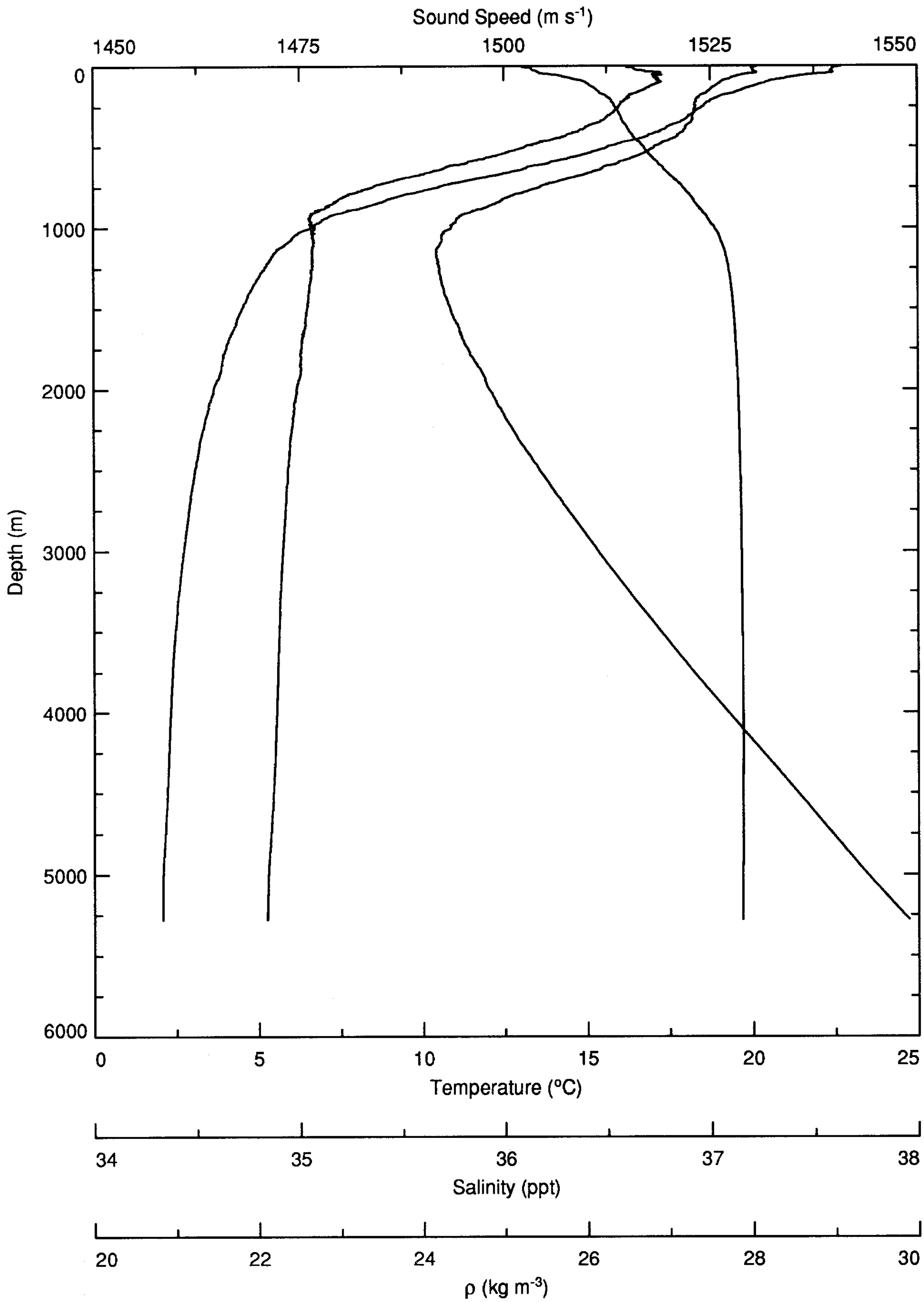


Figure G28

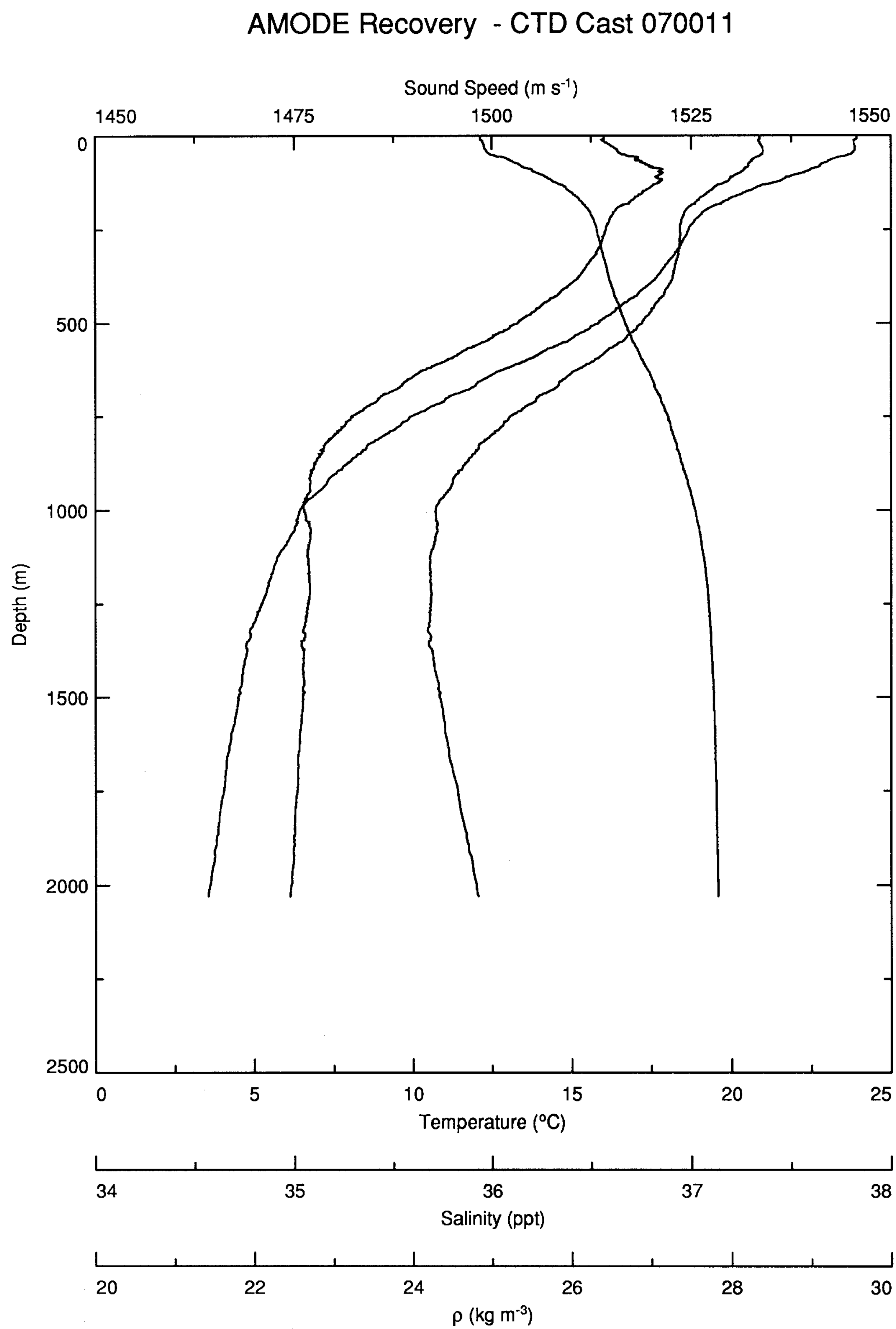

AMODE Recovery - CTD Cast 070011
Sound Speed (m s^{-1})
1450
1475
1500
1525
1550
Depth (m)
0
500
1000
1500
2000
2500
0
5
10
15
20
25
Temperature (°C)
34
35
36
37
38
Salinity (ppt)
20
22
24
26
28
30
ρ (kg m^{-3})

Figure G29

AMODE Recovery - CTD Cast 070031

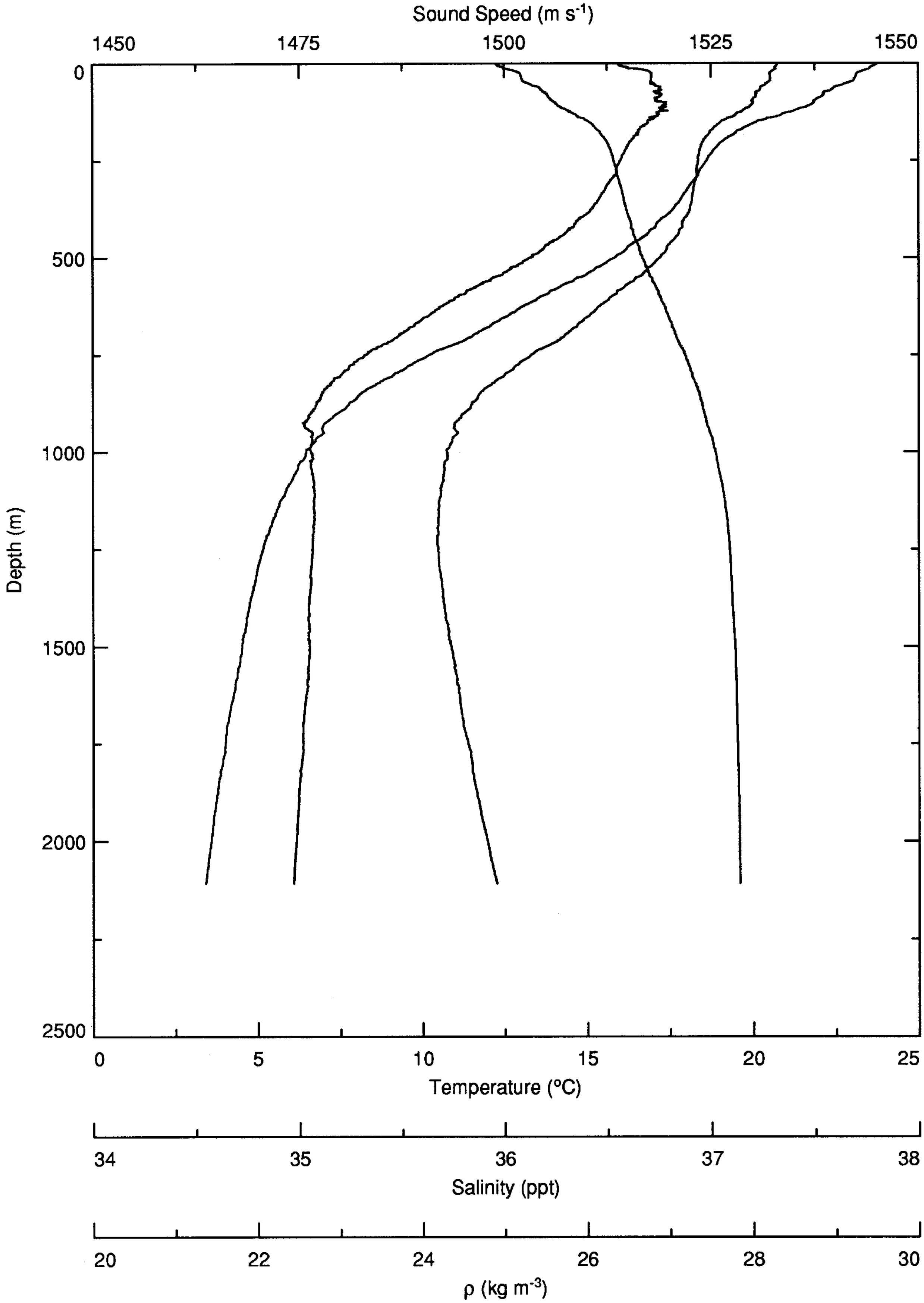


Figure G30

AMODE Recovery - CTD Cast 070081

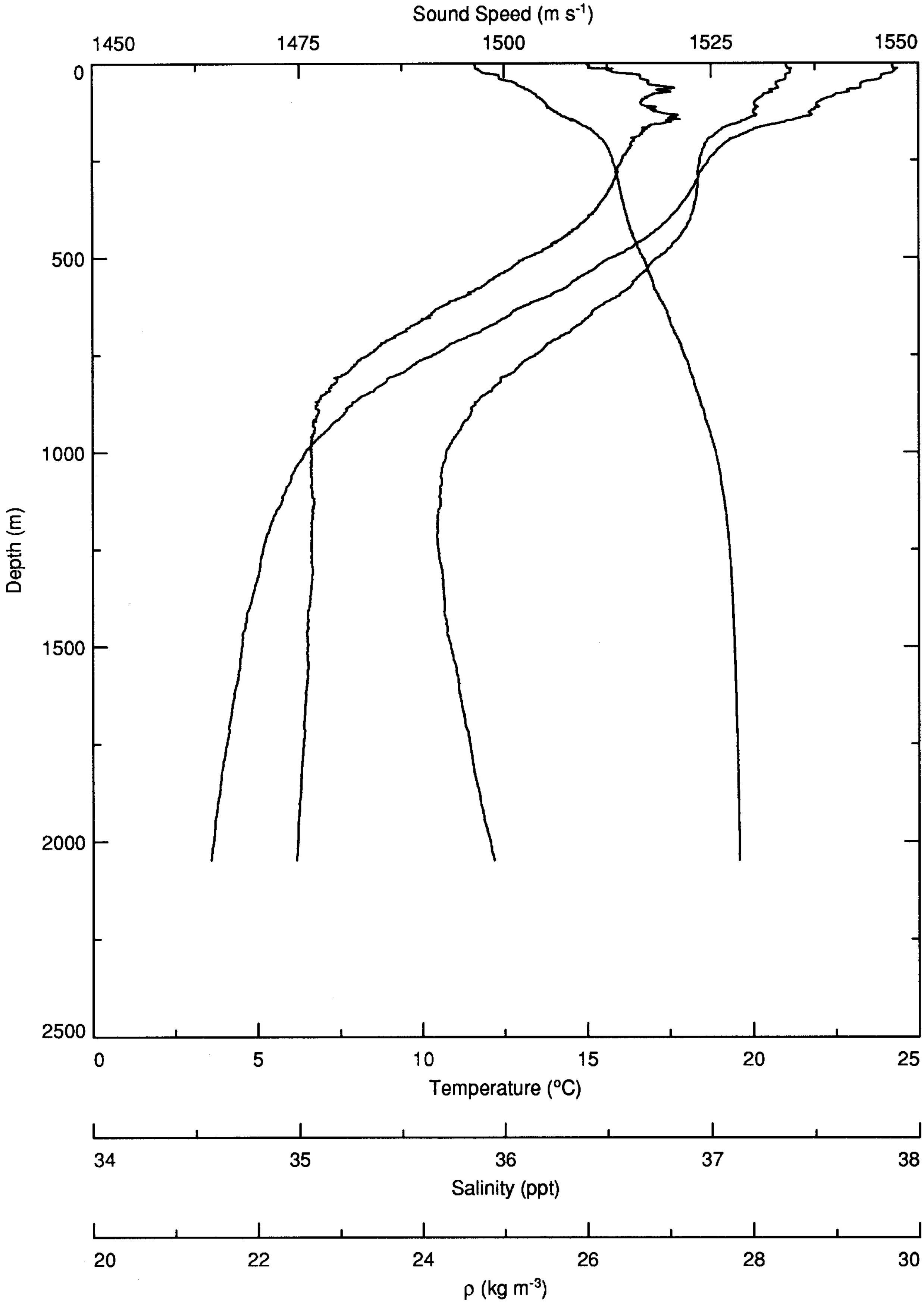


Figure G31

AMODE Recovery - CTD Cast 070121

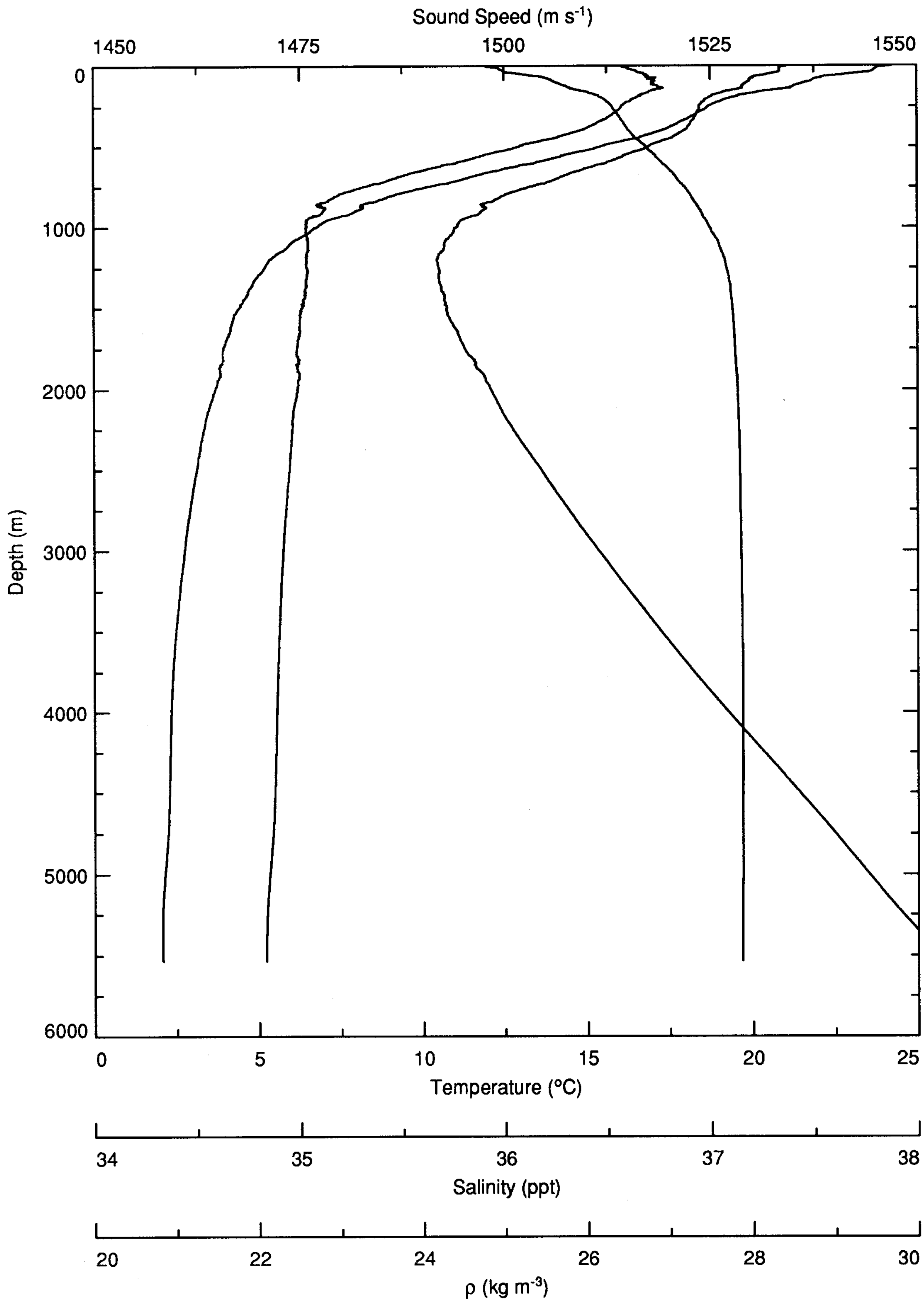


Figure G32

AMODE Recovery - CTD Cast 070181

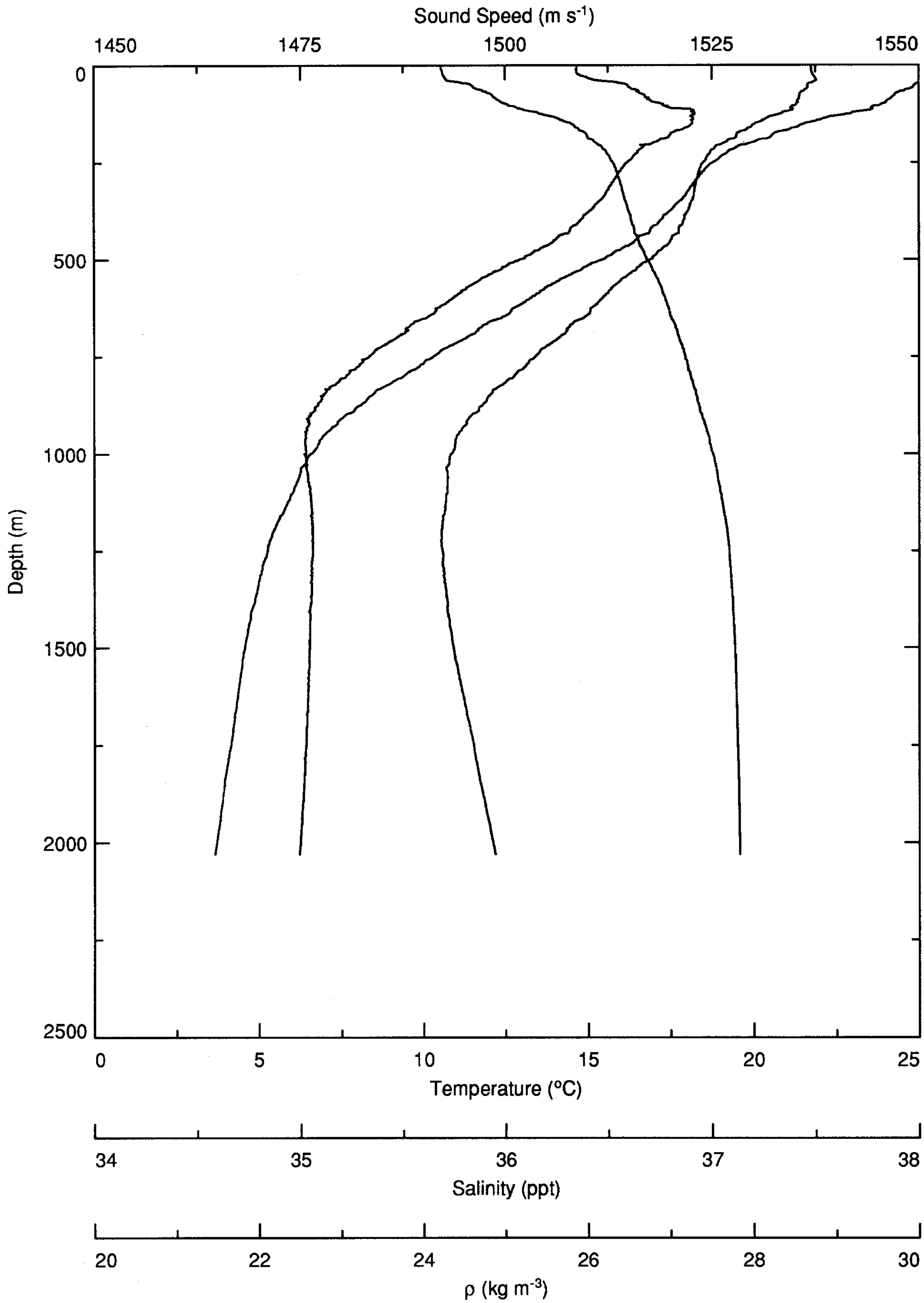
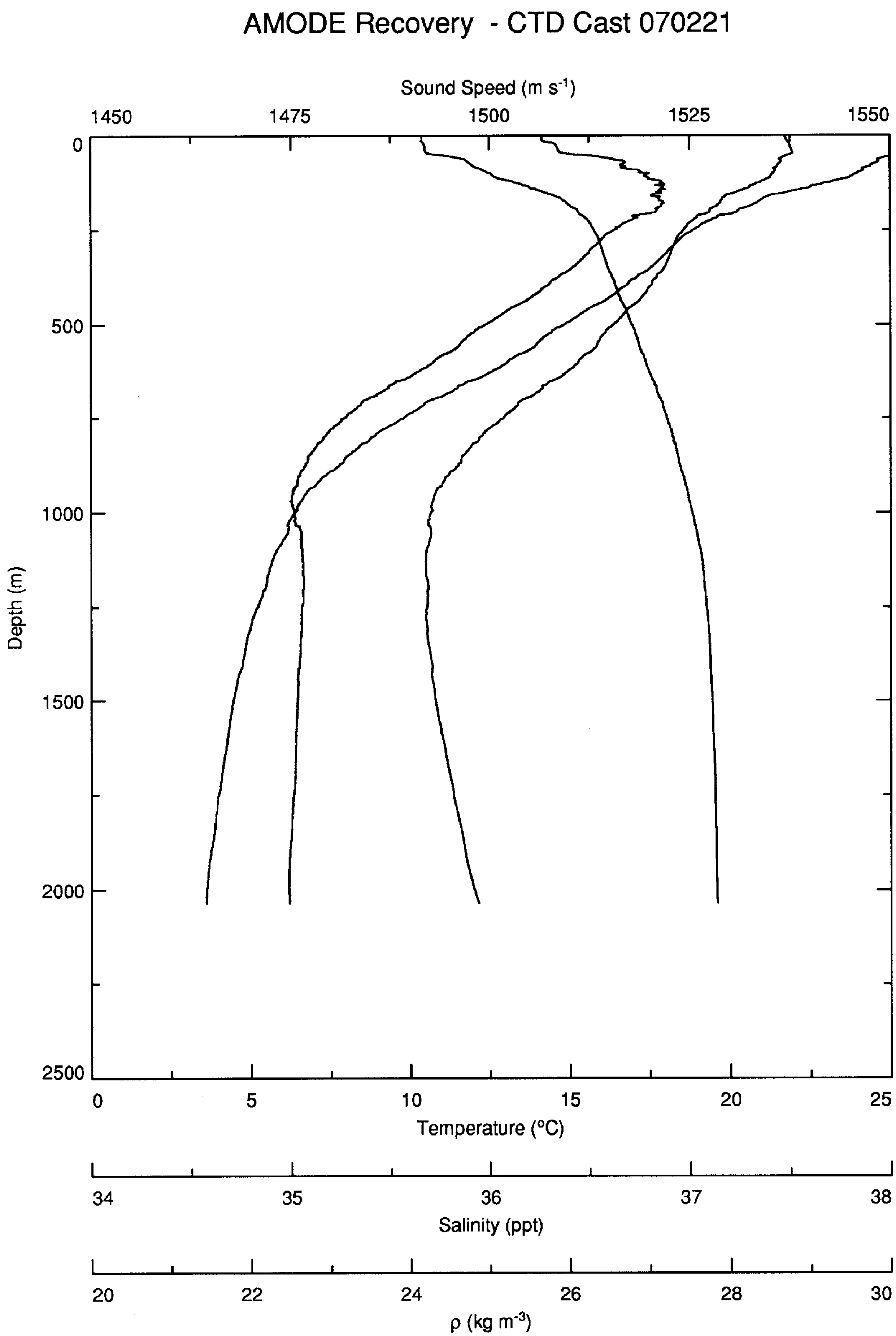


Figure G33



AMODE Recovery - CTD Cast 070221
Sound Speed (m s-1)
1450
1475
1500
1525
1550
Depth (m)
0
500
1000
1500
2000
2500
0
5
10
15
20
25
Temperature (°C)
34
35
36
37
38
Salinity (ppt)
20
22
24
26
28
30
ρ (kg m-3)

Figure G34

AMODE Recovery - CTD Cast 071011

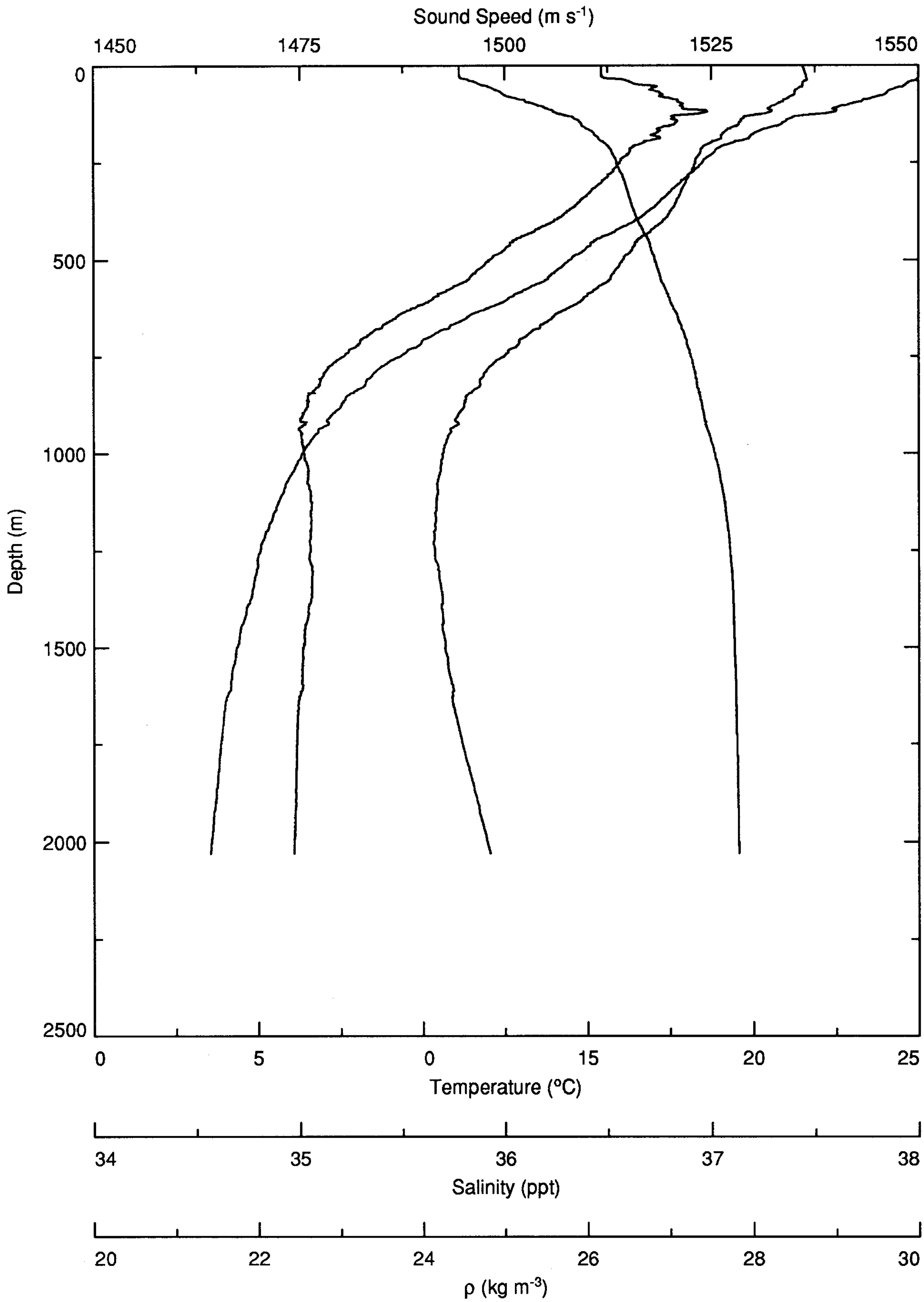


Figure G35

AMODE Recovery - CTD Cast 071051

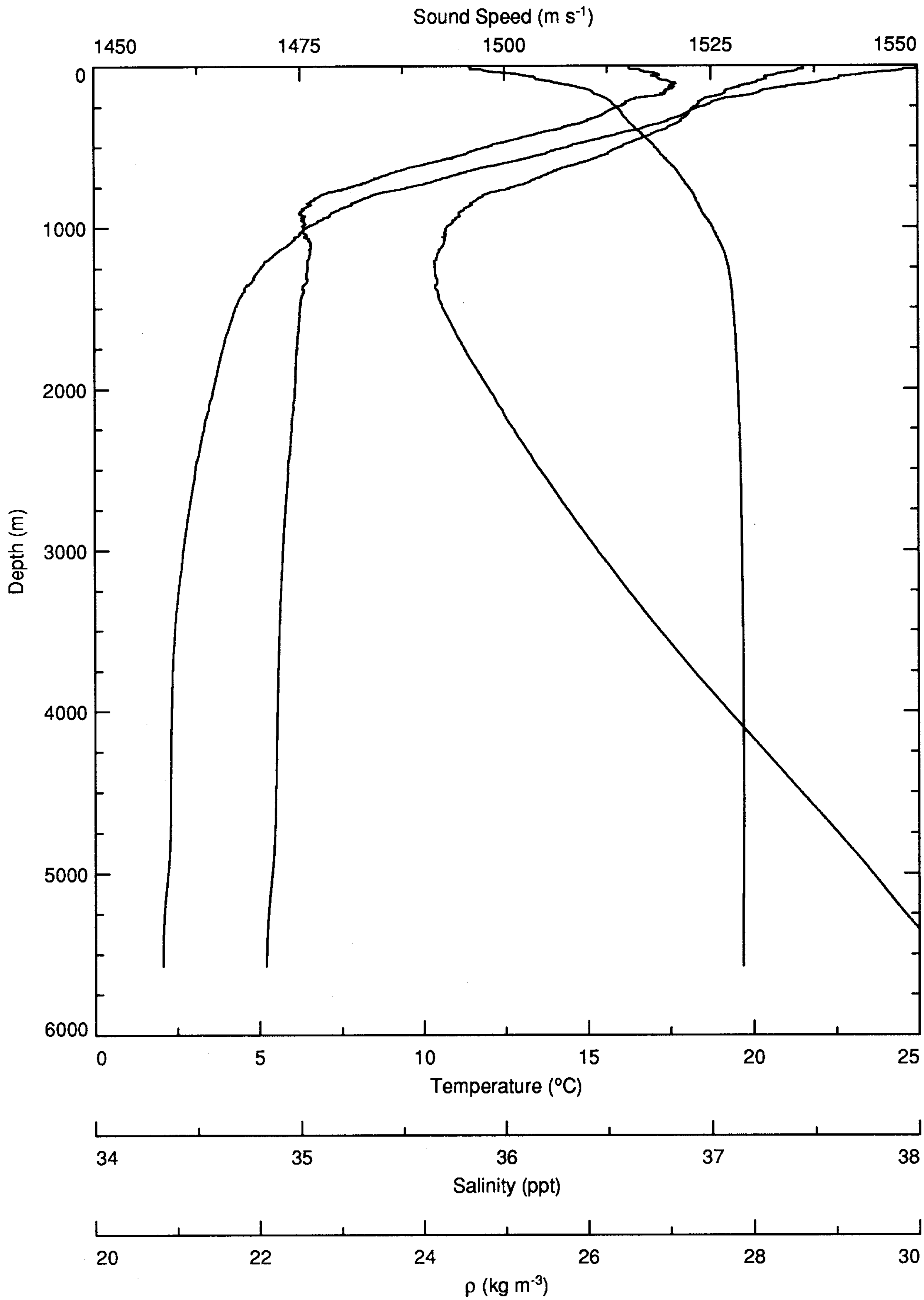
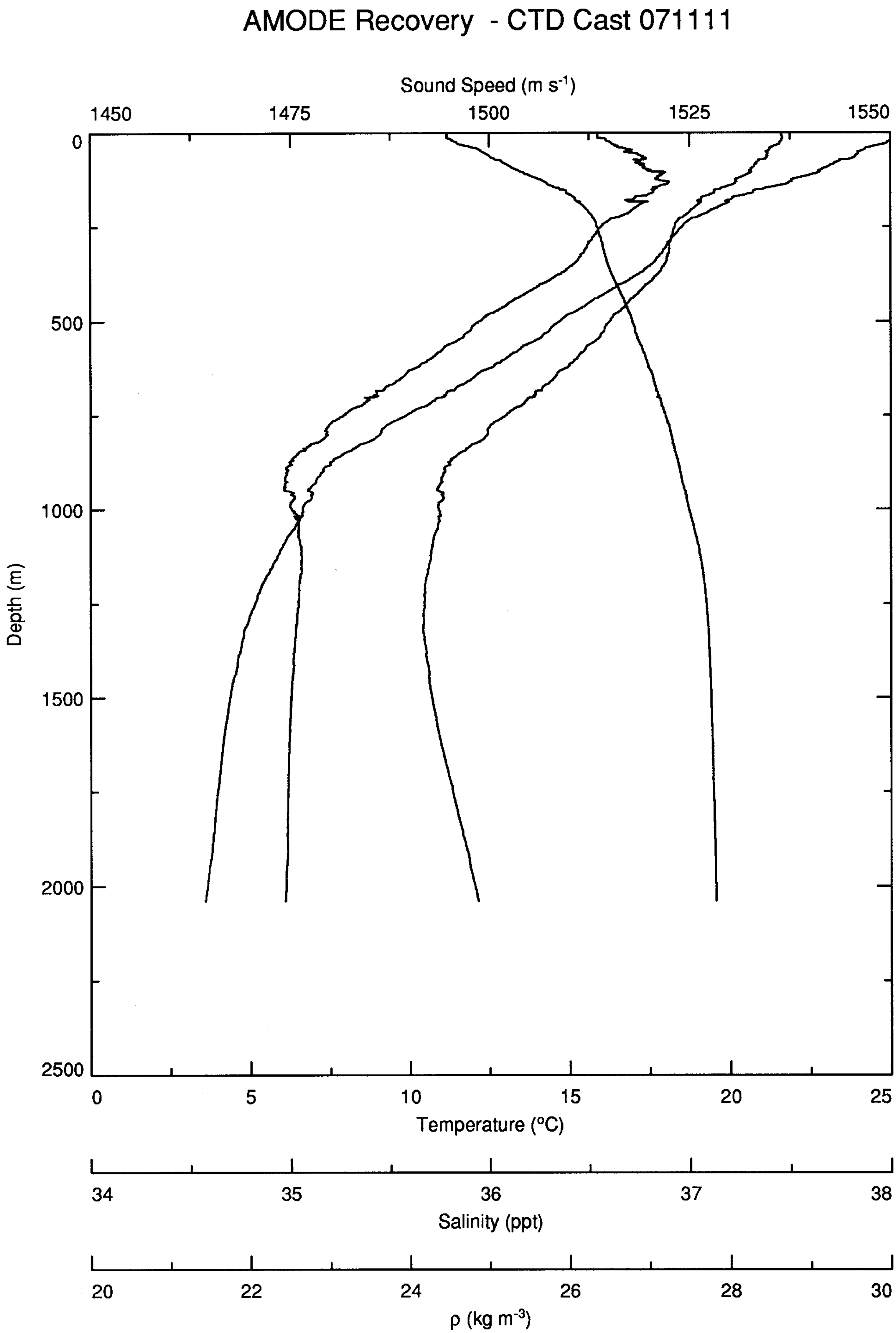


Figure G36



AMODE Recovery - CTD Cast 071111
Sound Speed (m s^{-1})
1450
1475
1500
1525
1550
Depth (m)
0
500
1000
1500
2000
2500
0
5
10
15
20
25
Temperature (°C)
34
35
36
37
38
Salinity (ppt)
20
22
24
26
28
30
ρ (kg m^{-3})

Figure G37

AMODE Recovery - CTD Cast 071151

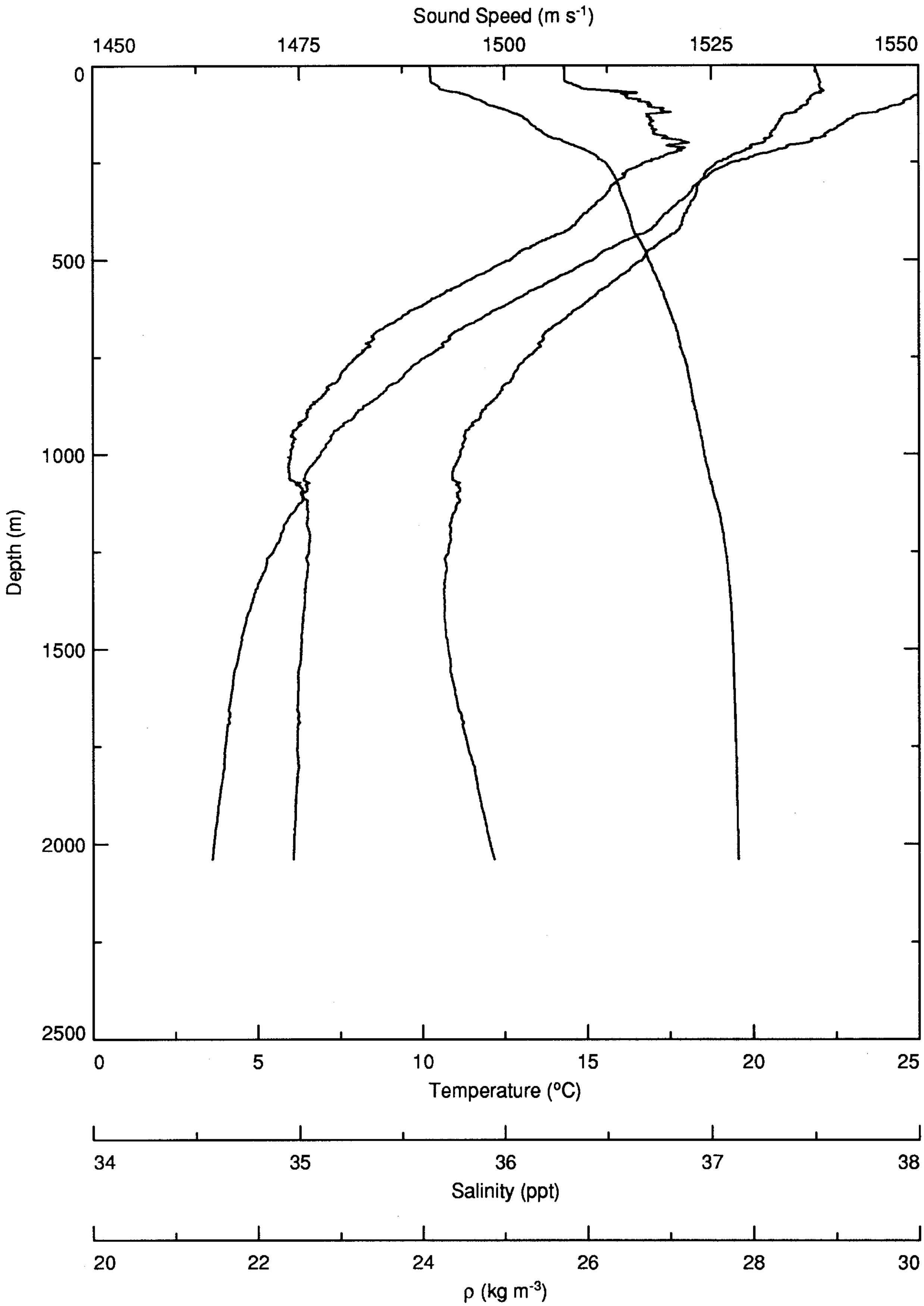


Figure G38

AMODE Recovery - CTD Cast 071181

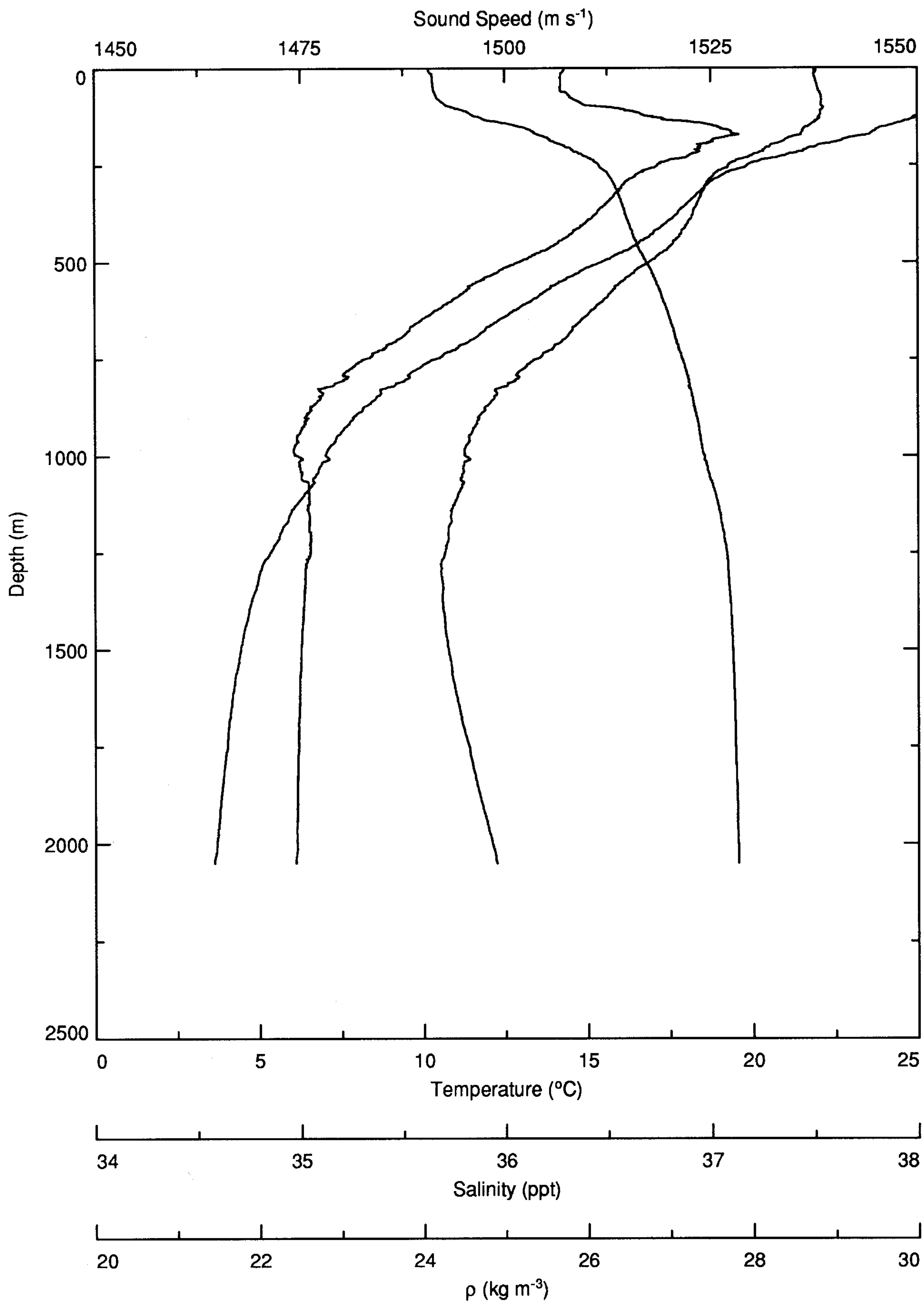
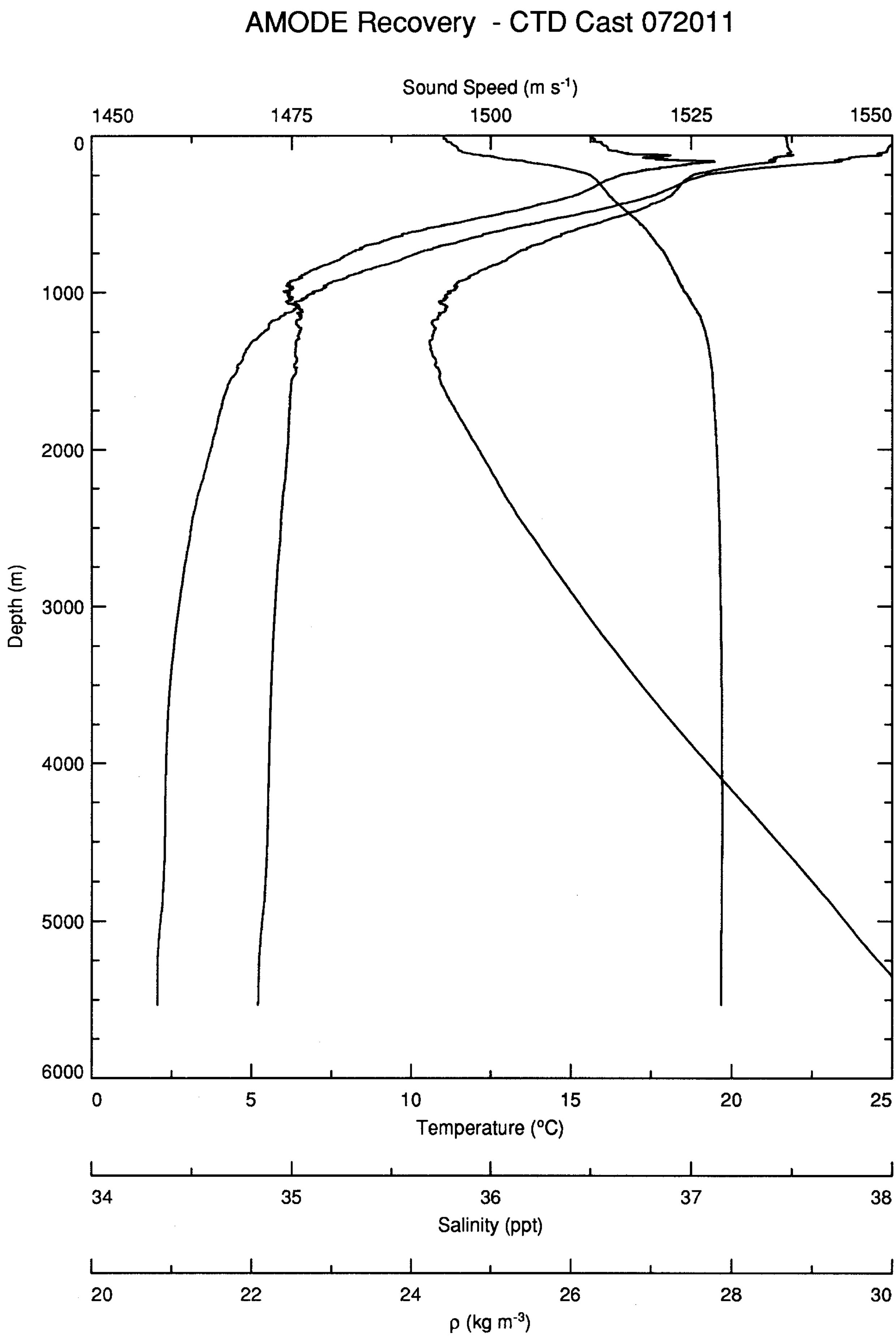


Figure G39



AMODE Recovery - CTD Cast 072011
Sound Speed (m s-1)
1450
1475
1500
1525
1550
Depth (m)
0
1000
2000
3000
4000
5000
6000
0
5
10
15
20
25
Temperature (°C)
34
35
36
37
38
Salinity (ppt)
20
22
24
26
28
30
ρ (kg m-3)

Figure G40

AMODE Recovery - CTD Cast 076041

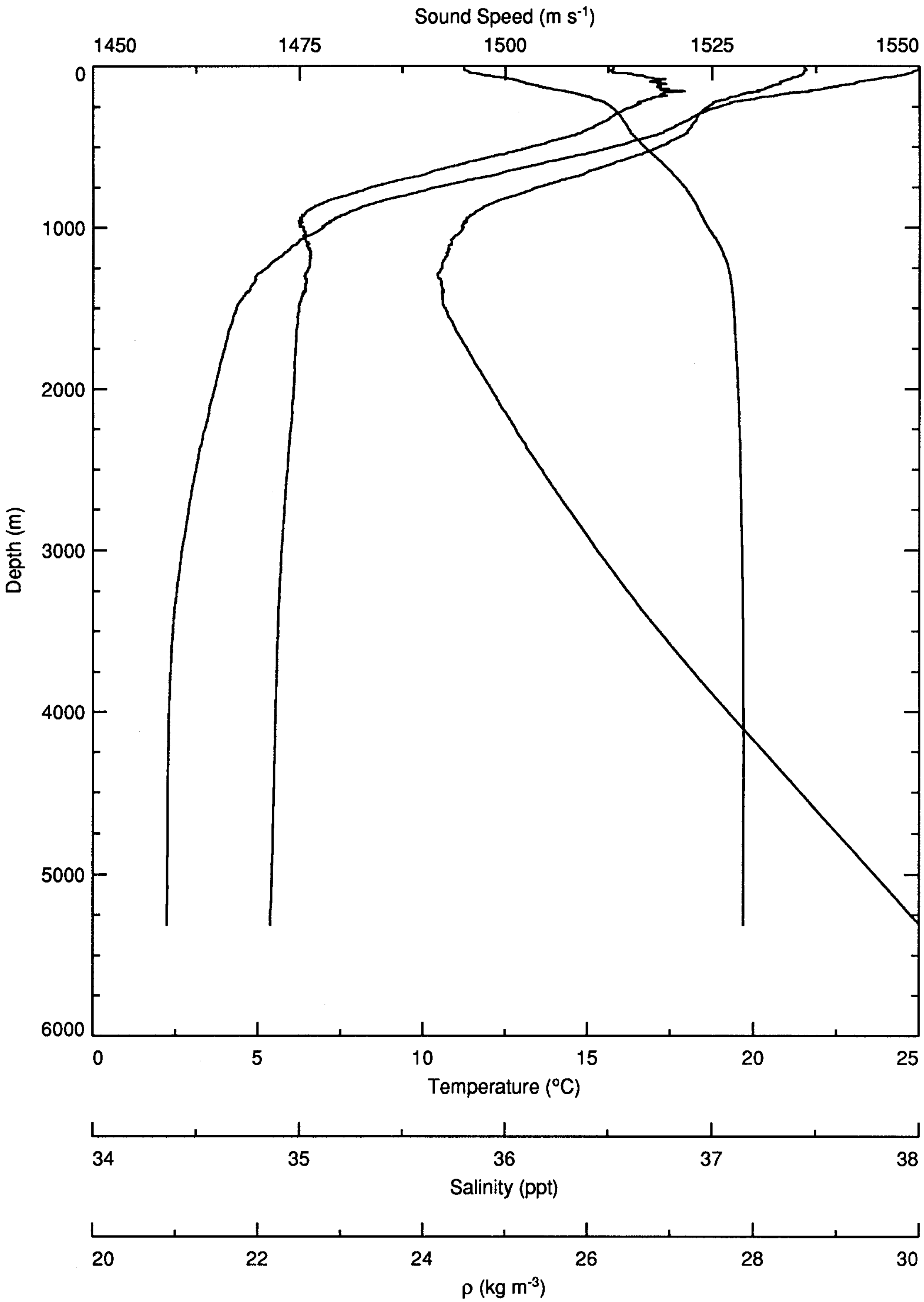


Figure G41

AMODE Recovery - CTD Cast 077001

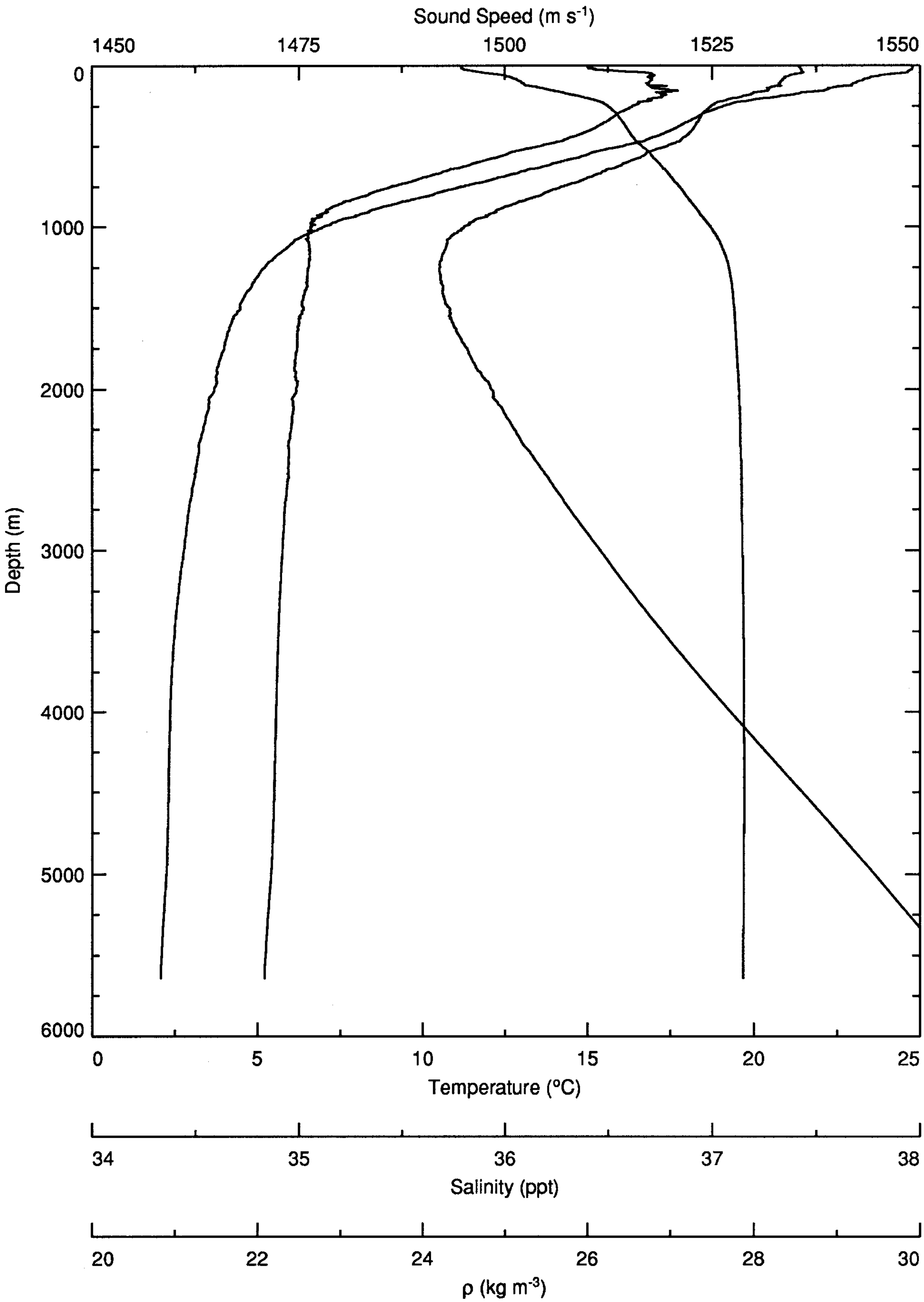


Figure G42

AMODE Recovery - CTD Cast 078031

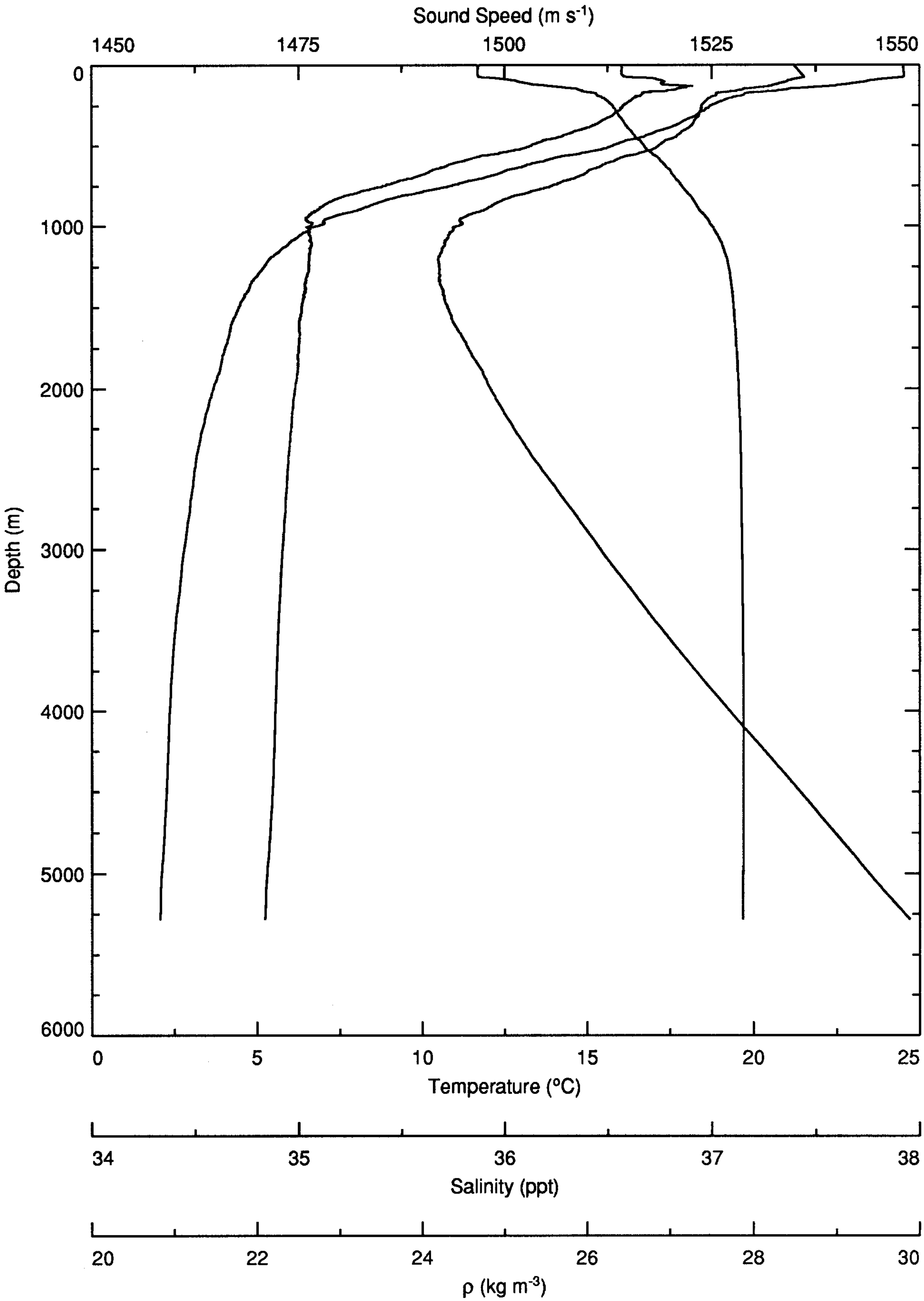


Figure G43

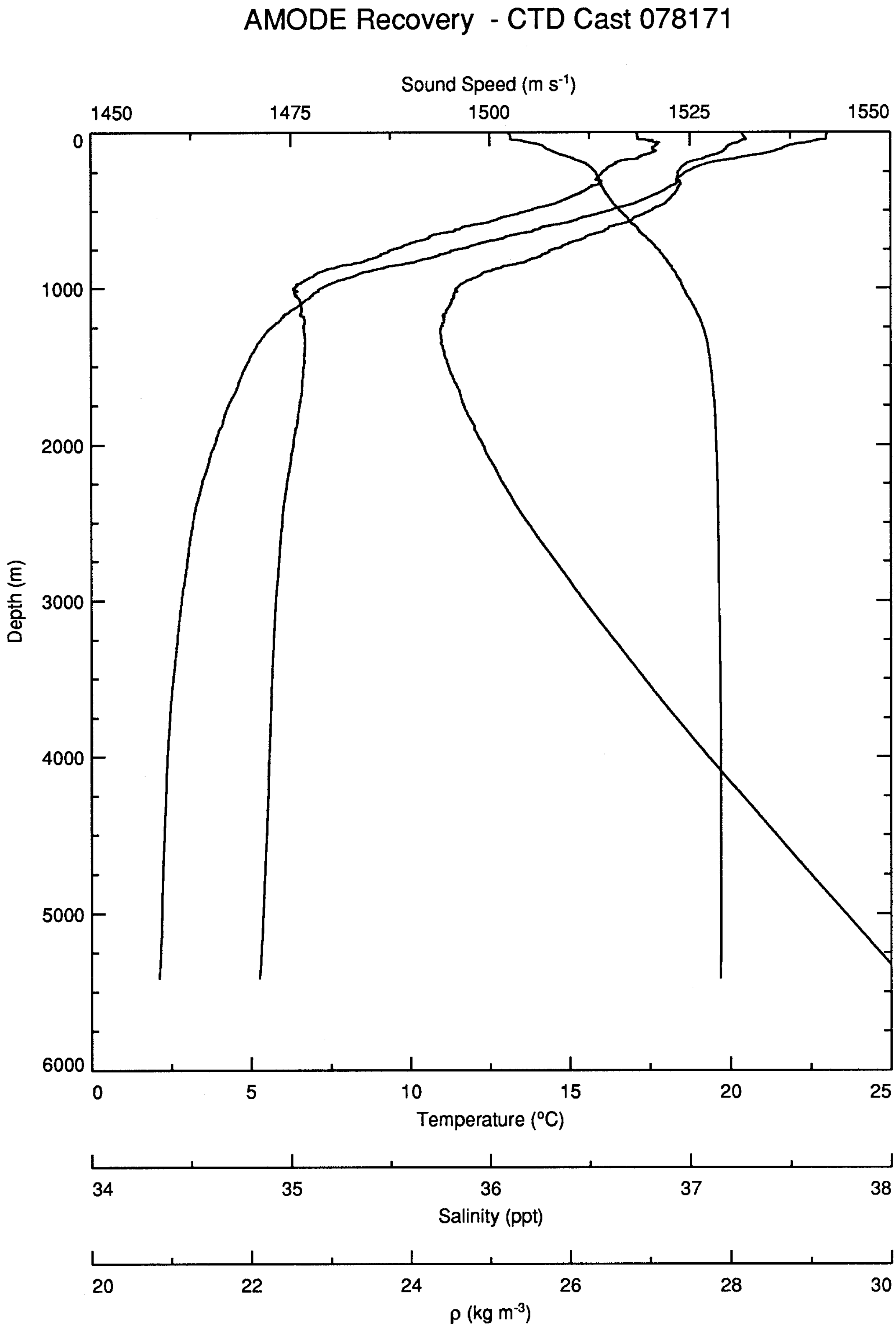

AMODE Recovery - CTD Cast 078171
Sound Speed (m s-1)
1450
1475
1500
1525
1550
Depth (m)
0
1000
2000
3000
4000
5000
6000
0
5
10
15
20
25
Temperature (°C)
34
35
36
37
38
Salinity (ppt)
20
22
24
26
28
30
ρ (kg m-3)

Figure G44

AMODE Recovery - CTD Cast 079021

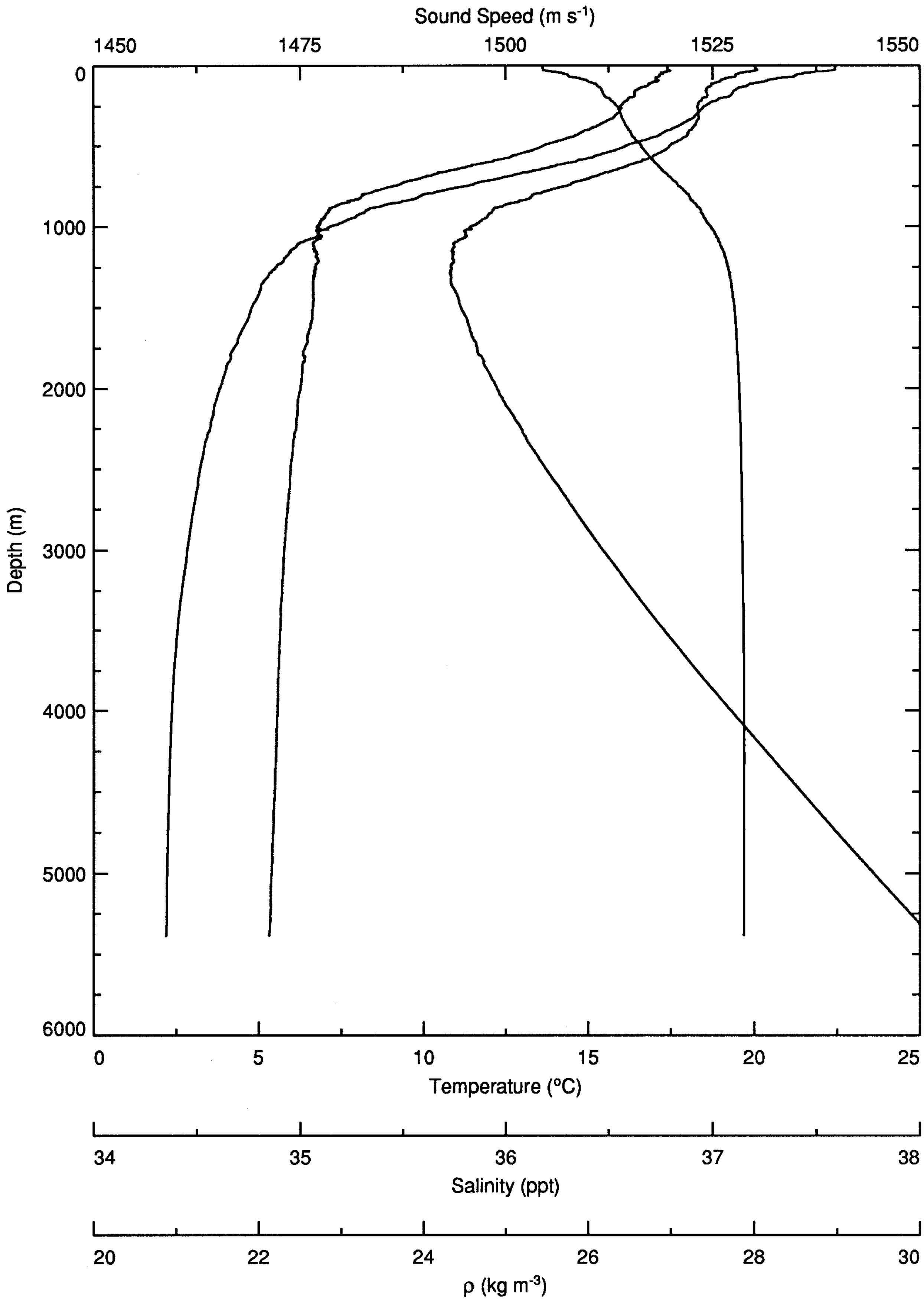


Figure G45

AMODE Recovery - CTD Cast 080031

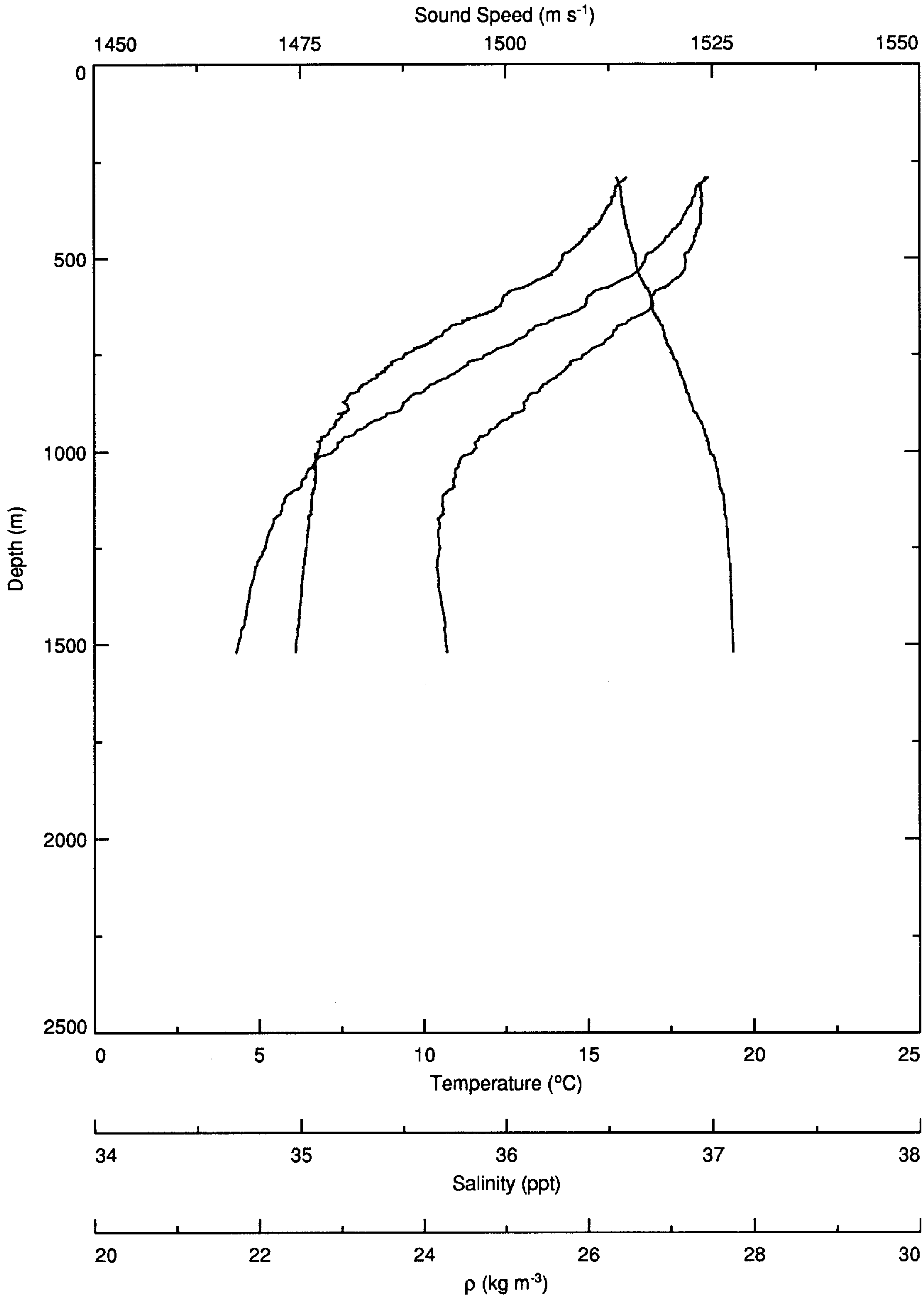
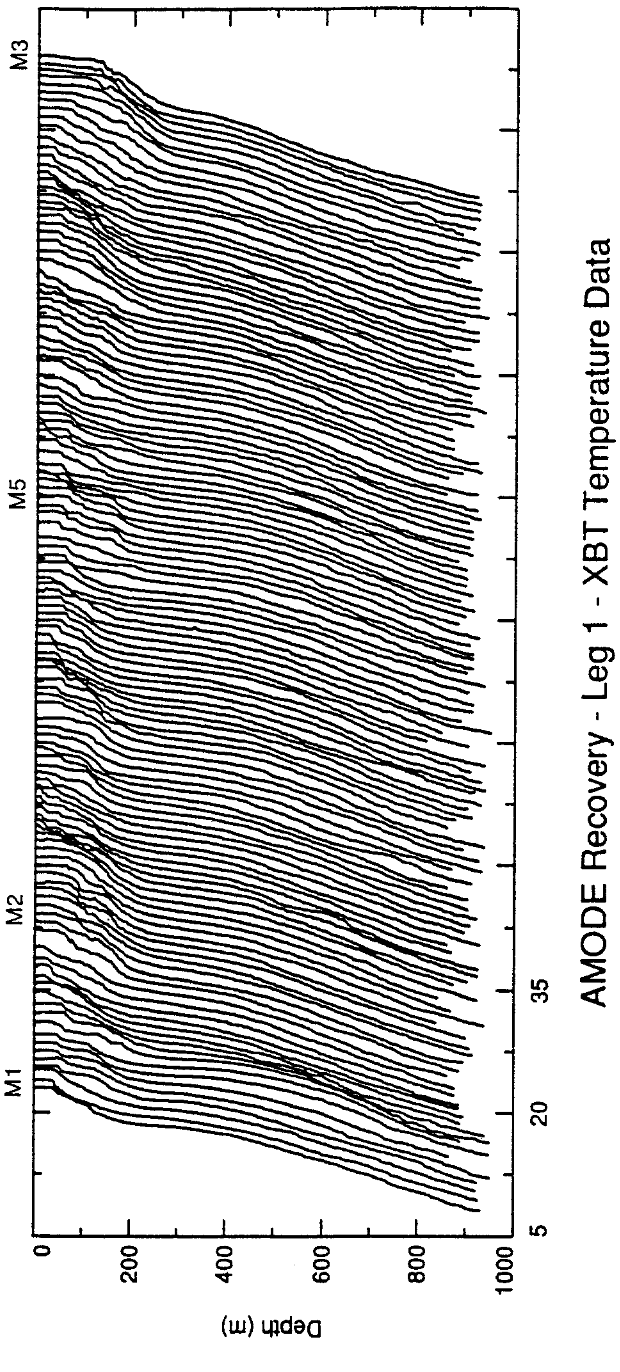


Figure G46


AMODE Recovery - Leg 1 - XBT Temperature Data
M1
M2
M5
M3
Depth (m)
0
200
400
600
800
1000
5
20
35

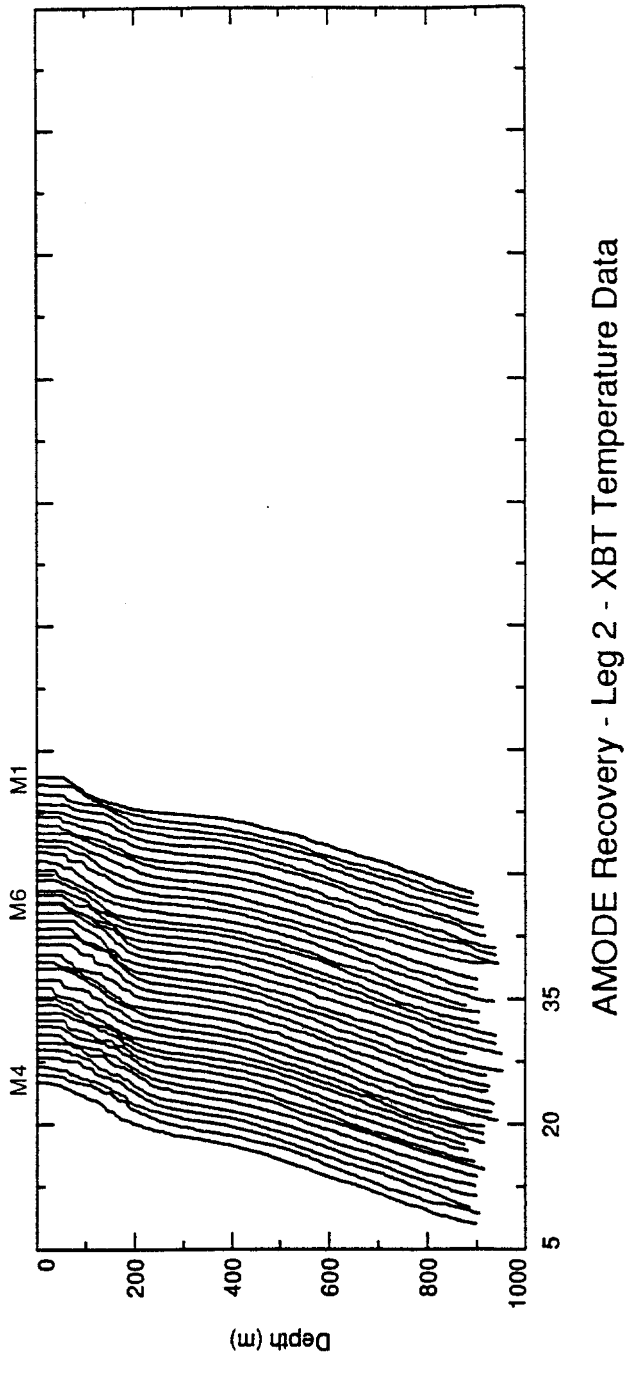

AMODE Recovery - Leg 2 - XBT Temperature Data
M4
M6
M1
Depth (m)
0
200
400
600
800
1000
5
20
35

Figure G47

M2-M5

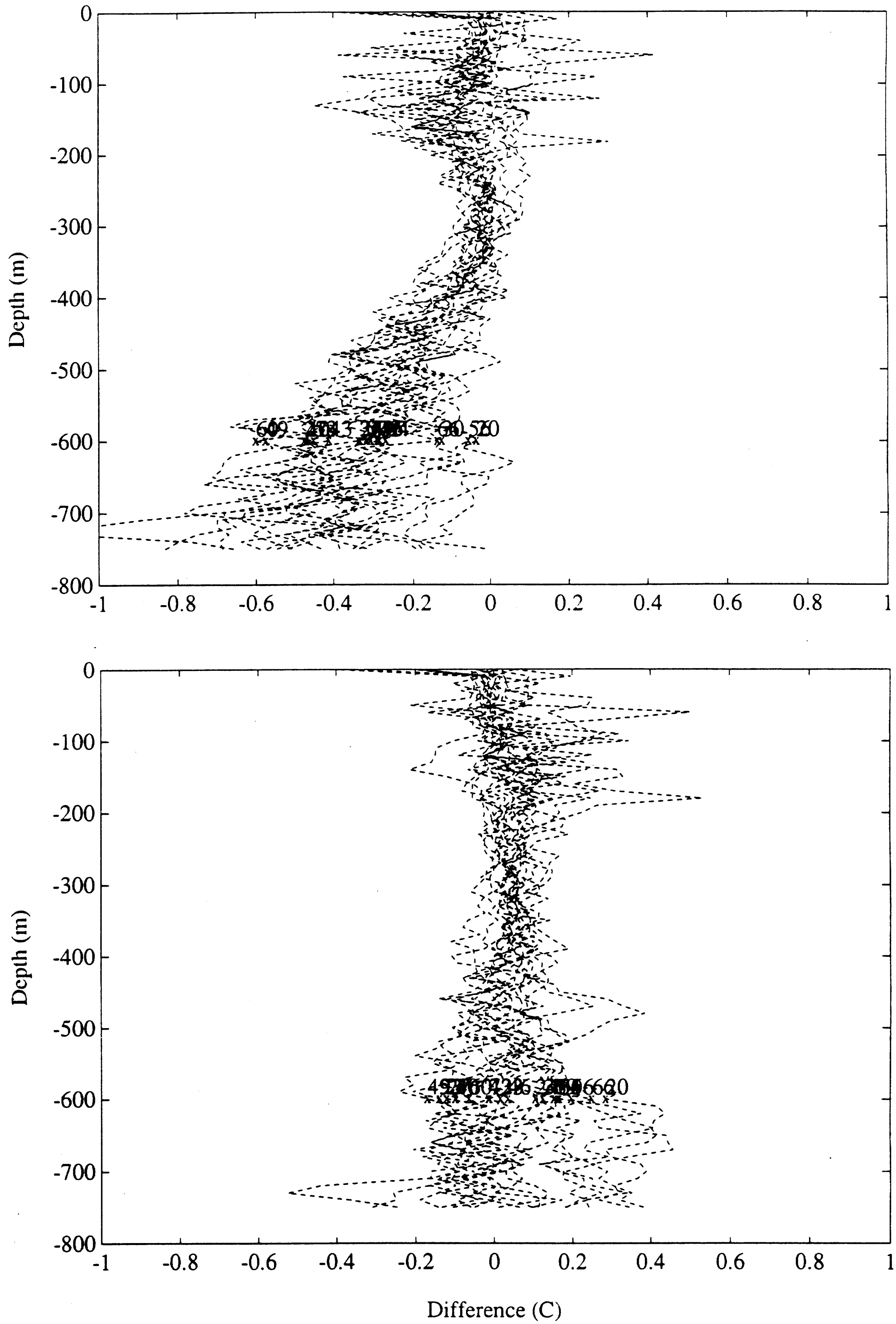


Figure G48

M5-M3

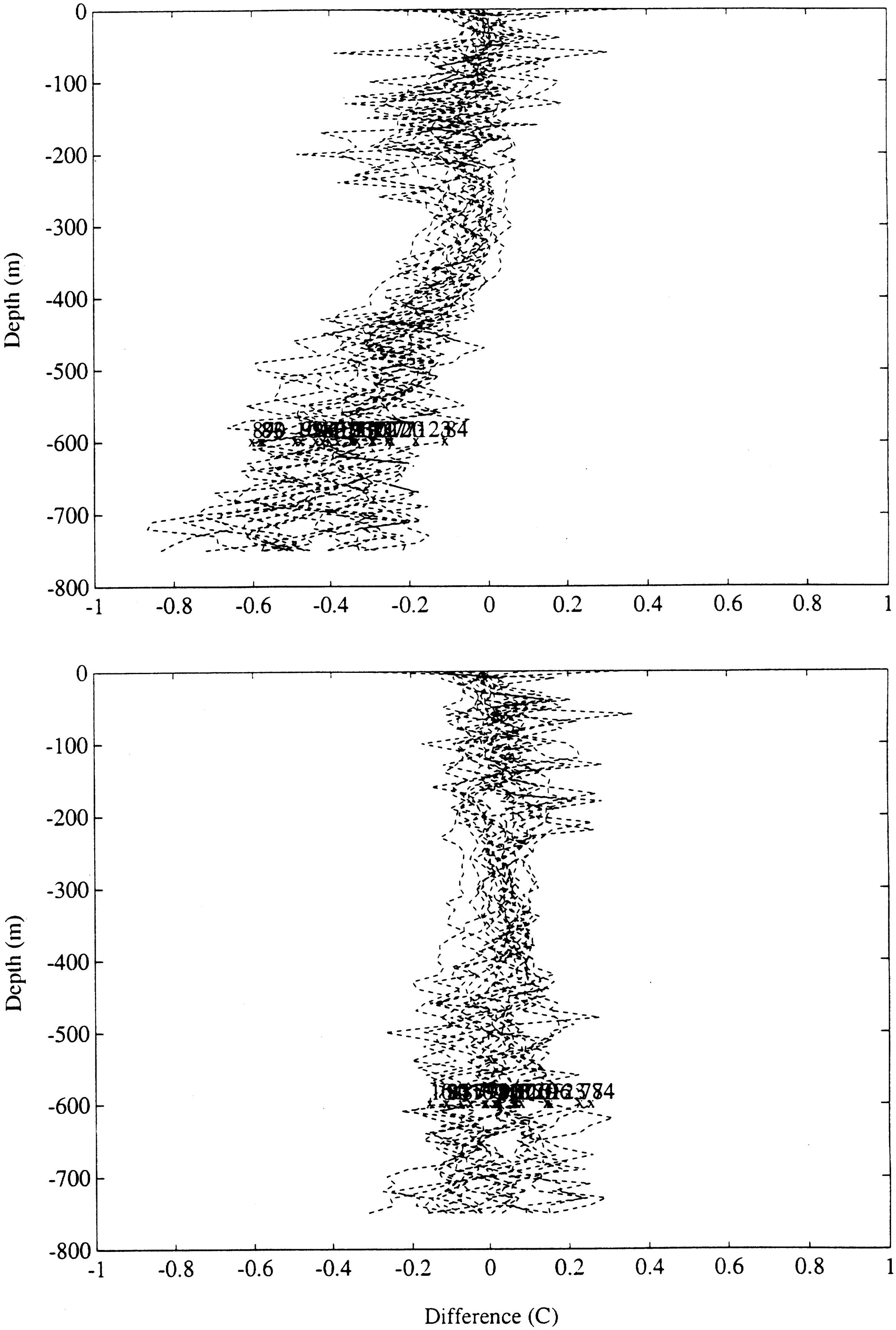


Figure G49

Second Leg

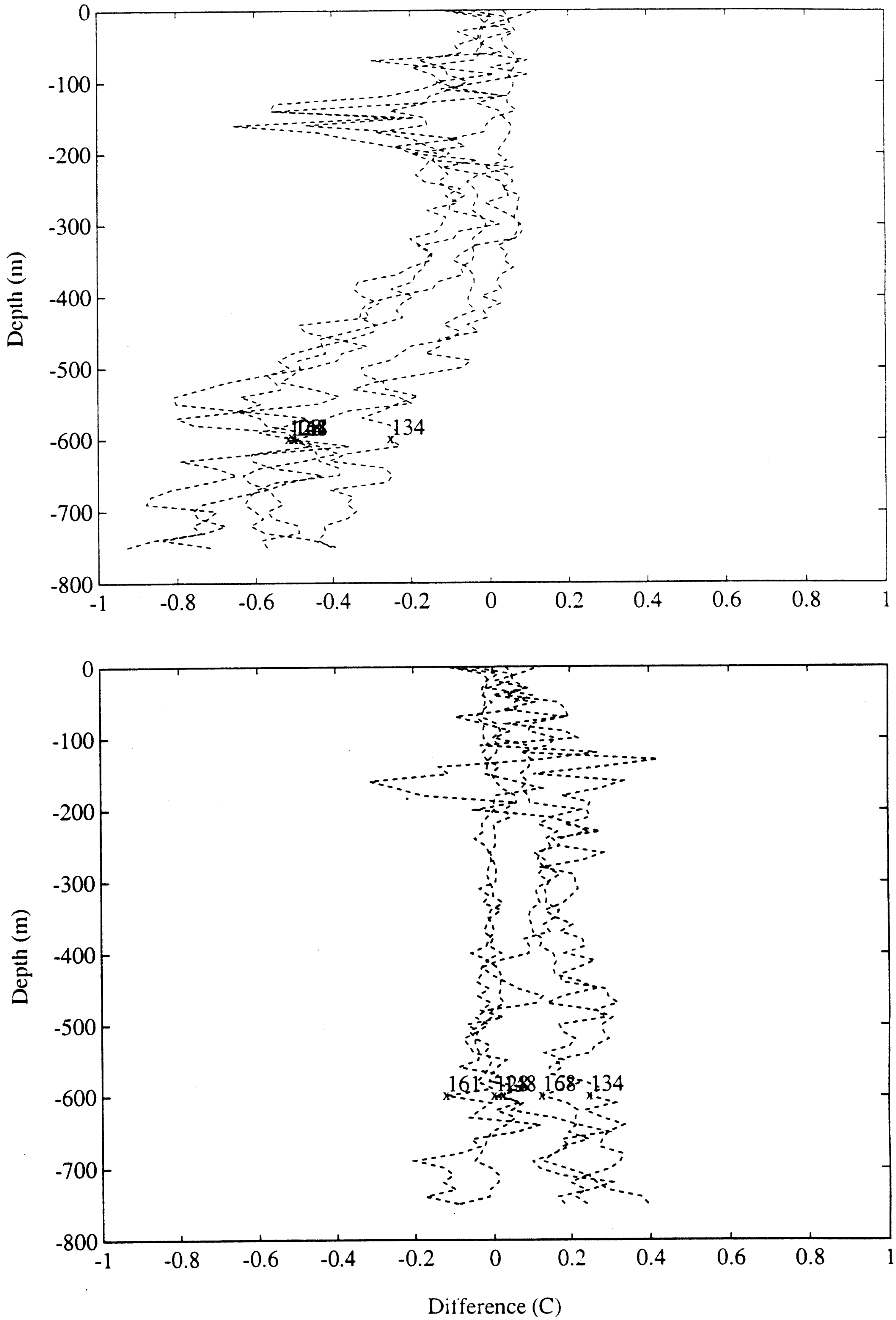


Figure G50