Cruise Report

Shatsky Rise Expedition: R/V *Thomas G. Thompson* Cruise TN037

23 July to 4 September 1994

Sponsored by:

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Technical Report 95-5-T
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EQUIPMENT & OPERATION

Navigation

Positioning was accomplished entirely by GPS satellite navigation. The output of several different GPS receivers were recorded, smoothed, and displayed by a computer program named "Phrognav", written by Pelagos, Inc. Navigation fixes were recorded in different files at different rates. One file, the 'DAS' file, contained fixes at 1 minute intervals, whereas the Hydrosweep system recorded a navigation fix for every ping, at approximately 10-15 second intervals. These positions correspond to the GPS receiver, located on the mast, just aft of the bridge and 37.2 m forward of the stern (Fig. 5).

Bathymetry

Bathymetry data were recorded by two systems, the Hydrosweep multibeam echo sounder and an automatic depth-recording, 3.5 kHz echo-sounder. The primary data set is that derived from the Hydrosweep, which reads depth with 59 individual beams that form a fan-shaped sounding array athwartship. Each beam insonifies an area of approximately 2° x 2° and the entire electronic array covers a swath with a width of approximately twice the water depth.

Data were recorded at a rate proportional to water depth. For deep water in the study area, the ping rate was about once per 14 seconds. Hydrosweep depth data recorded on ship received no corrections for water velocity variations; a constant sonic velocity 1500 m/s sonic velocity was used for the entire water column.

Seismic Reflection Profiling

Seismic reflection data were collected with a system provided by Scripps Institution of Oceanography and the Hawaii Institute of Geophysics and assembled by Perry Crampton, seismic engineer from Scripps. The system consisted of a six-channel hydrophone array (streamer) consisting of a 70 m leader, 5 m weighted section, 25 m stretch section, six 25 m active sections, and two extra, non-active 25 m sections at the tail (Fig. 5). This streamer had no depth sensor nor active depth positioning system, so its depth was determined by water drag and vessel speed. Thus, we had no way of accurately determining the streamer tow depth.

Two airgun seismic sources were used during the cruise. One was a two-chambered "GI-airgun". The two chambers (105 and 45 cubic inches) were triggered with a slight delay so that one bubble would damp the other, reducing the bubble pulse signature. It was towed approximately 18 m behind the stern at a depth of 9 m (Fig. 5). The other source was a four airgun array, consisting of Bolt/Par air chambers with volumes of 80, 108, 150, and 200 cubic inches (Fig. 5). The four airguns were towed at about the same depth and at distances ranging from 20.7 to 22.9 m astern.

For both sources, a ten-second repetition rate was used. Lines with the GI-airgun were run at 7.3 knots, to give a 2-fold coverage. Lines with the airgun array were run at 4.86 knots to give a 3-fold coverage and because of speed limitations of the airgun flotation system.

Seismic signals were amplified and sent through band-pass filters, which rejected frequencies below 15 Hz and above 3 kHz. The signal was split, with channel 1 being output to two analog EPC chart recorders, with sweep widths of 2 and 4 seconds. All six channel signals were digitized at a 1 ms rate, displayed in real time on the screen of a Sun Sparc10 workstation, and written to DAT and Exabyte tapes in SEG-Y format using a program, named "A2D", written by Mike Simpson of the University of Hawaii.

Seismic "lines" were numbered 1 to 17, the numbers corresponding to one block of data collected with the same set up. In some instances, this may have been a single line with a constant course; however, in others, this may have been a grid of continuous seismic lines collected with the same source at the same speed. Seismic line information is given in Table 1.

Magnetics

A Geometrics G-801 magnetic gradiometer was leased for the cruise from Harvey-Lynch, Inc., of Stafford, TX. Within hours of initial deployment, the gradiometer cable failed, with the loss of both sensors and the intervening 500 feet of cable. The option that minimized our loss of ship-time was to return to Hawaii and borrow a Geometrics single-sensor cable to be used with the gradiometer electronics.

The Hawaii sensor cable was only 600 feet (183 m) in length because it was designed for the R/V *Moana Wave*. On our cruise, it was towed 178 m astern. This distance is less than three ship lengths from the stern of the *Thompson*, so there was a 'ship-effect' which changed with heading. So that we could remove the ship-effect in post-cruise processing, the ship was sailed in a circle in a magnetically 'quiet' location near the study area with the magnetometer in operation. This gave the change in magnetic anomaly seen by the sensor at different headings (Fig. 6; Table 2).

Total field magnetic data were recorded at intervals of 5 seconds using a PC and digitizing program. The raw data were somewhat noisy, with random variations of typically 5-20 nT, perhaps a result of using a sensor cable not matched to the electronics package. In addition, on occasions the magnetometer produced spurious values. To address both of these problems, all magnetic data were filtered using a median filter with a width of 3 minutes. This filter ignored values greater than two standard deviations from the mean, which expunged the spurious data values. The filter length was chosen empirically to give a reasonable average of the data without smoothing out geologically-significant features.

Because no backup magnetometer was available, magnetic data were collected sparingly on the transit to Shatsky Rise. Consequently, the data are not continuous before about 4 August 1994. After that, magnetic data were acquired whenever practical on seismic lines and between stations until it was necessary to terminate data collection, on 31 August, so that the magnetometer could be packed away for shipment. Table 3 gives the dates and times on which magnetic data were collected.

Gravity

Gravity data were collected with a LaCoste & Romberg "S-type" marine gravimeter on a gyro-stabilized platform located in the aft-starboard corner of the computer lab. Although this was not the optimal location (the ship's center of mass would be best, but this is located in the engine room) it appeared to be the best compromise environment for the system. Nevertheless, the stability of the R/V *Thompson* and the low sea state weather encountered during the Shatsky expedition more than made up for the slightly off-center instrument location.

The gravimeter electronics filter the gravity data and logs them on a PC computer. Gravity values were recorded every 10 seconds. The gravimeter filter is symmetric and has a width of 10 minutes; thus, raw gravity values were recorded five minutes late. During processing, the times were shifted back to correct for this offset.

Gravity values were recorded during the entire cruise, from the dock at Honolulu to the dock at Guam. The Honolulu dock reading was made from 1650-2000Z on 23 July, whereas the Guam dock reading was made from 2200Z on 3 September to 0100Z on 4 September.

The Honolulu dock tie was from next to the ship at Pier 1A to the marker outside Room 108 of the HIG building on the University of Hawaii campus. We measured a gravity difference of 21.69 mGal from the reference datum of 978958.90 mGal. The height difference of 1.83 m between dock and meter induced a correction of 0.56 mGal. Thus, we calculated the expected gravity value at the meter to be 978936.65 mGal.

In Guam, the tie was to a reference station located on the porch of building 1716 at the Naval Fuel Depot, several hundred meters south of the ship's location. We determined a difference of 0.52 mGal between dockside and the reference location, which has a gravity value of 978519.61 mGal. The height correction between dock and the sensor, 1.39 m, gave a correction of 0.43 mGal. Thus the calculated gravity value at the sensor was 978519.71 mGal.

Dredges

To collect rock samples from the seafloor, dredges from the Scripps Institution of Oceanography were used under the direction of Seth Mogk, resident technician at Scripps. These dredges have a rectangular mouth measuring approximately 50 x 100 cm. To this is attached a chain link bag approximately 1.8 m in length, with openings about 10 cm in diameter. A net bag with a mesh about 2 cm in diameter was used within the chain link bag to keep small samples from falling out. A 12 kHz pinger was used to locate the dredge during sampling and it was attached to the wire approximately 150 m above the dredge.

Because of the R/V *Thompson*'s remarkable station-keeping ability, it was possible to sail to the desired location for the beginning of the dredge drag path and to lower the dredge to the bottom. This helped to minimize the effect of water drag, so that the dredge and wire hung nearly directly below the ship. Having Hydrosweep bathymetry was also very useful because it was possible to map the dredge targets in three dimensions. Using Hydrosweep during dredge stations also made it easier to figure the ship's location relative to the target.

During cruise TN037 a total of 14 dredge stations were run (Table 4). Two of these were in the Ojin Rise Seamounts, five on the North High, three on the Central High, one on a seamount between the Central and South highs, and three on the South High. Appendix 1 describes samples recovered by dredging. Approximately half of the dredge samples were sent to Scripps Institution of Oceanography for archival. The others, including most of the geologically important samples, were sent to Texas A&M for the first year post-cruise. Eventually, all samples will be archived at Scripps.

Cores

Piston cores were taken using the University of Washington/Oregon State University 9-cm diameter piston core apparatus. The core barrel length used was 20 feet, but because we attempted to core indurated sediments, we never recovered more than 2.5 meters of sediment. The coring system used a 4-cm diameter trigger core to retrieve an additional sample of the surficial sediments. A 12 kHz pinger was also used to locate the core relative to the seafloor and this was attached to the winch wire approximately 150 m above the corer. Core locations and descriptions are given in Table 5. These cores will be archived at the core repository at Oregon State University.

CRUISE NARRATIVE

R/V *Thomas G. Thompson* departed Pier 1A in Honolulu at 2000Z on 23 July 1994 to begin the Shatsky Rise Expedition, cruise TN037 (Fig. 4). The cruise ended 42.1 days later at 2200Z on 3 September 1994 when the *Thompson* tied up at the commercial pier in Apra Harbor, Guam. Of the intervening time, the ship spent approximately 16.3 days in transit to Shatsky Rise from Honolulu and from the rise to Guam (Fig. 7). The 24.8 days of Shatsky Rise surveying consisted of about 19.5 days of underway profiling and 6.3 days on dredge and core stations.

Transit to Shatsky

The *Thompson* began cruise TN037 on 23 July within an hour of schedule, despite a port call abbreviated owing to the close pass of a hurricane. On 21 July, the hurricane passed a few hundred miles south of Oahu, raising the specter that it could turn northward and within a day hit the islands or cause a high southern swell into Honolulu harbor. Consequently, the Coast Guard ordered the harbor evacuated and the *Thompson* put to sea to wait out the storm. By the next day, the storm threat was over and the harbor was reopened. The ship returned to Pier 1A to gather a few last minute supplies and the remainder of the crew and scientific party.

The *Thompson* sailed west along the leeward coast of Oahu, through the channel between Oahu and Kauai, and began a long transit to Shatsky on the north side of the Hawaiian Chain. Soon after leaving port, the Hydrosweep multibeam echo sounder, 3.5 kHz echo sounder, and LaCoste & Romberg marine gravimeter were all confirmed to be operational. However, because of the lost time in port, it was not possible to test the seismic system and magnetic gradiometer immediately upon leaving Honolulu, as was desired. Instead, tests on those systems did not begin until 2230Z on 24 July, when the *Thompson* was northwest of Kauai. Neither system worked at first, apparently owing to pervasive 60-Hertz contamination in the onboard electronics. After working for hours to correct this problem failed, it was decided to move the electronics from the computer lab to the hydro lab, but the hour being late, this was postponed until the following day.

TN037 (July 23 - September 4, 1994)

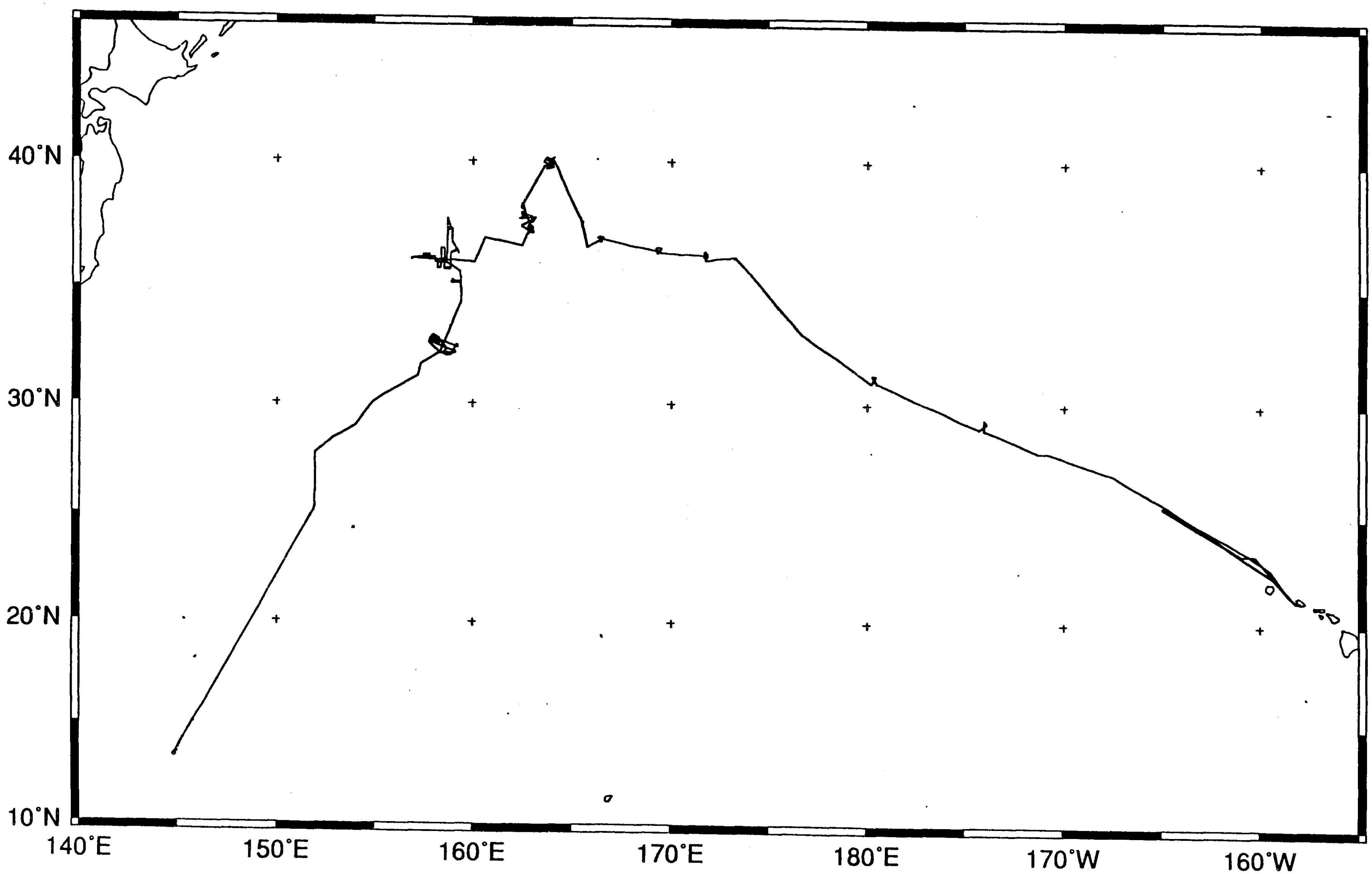

Figure 4. Overview of cruise TN037 track.

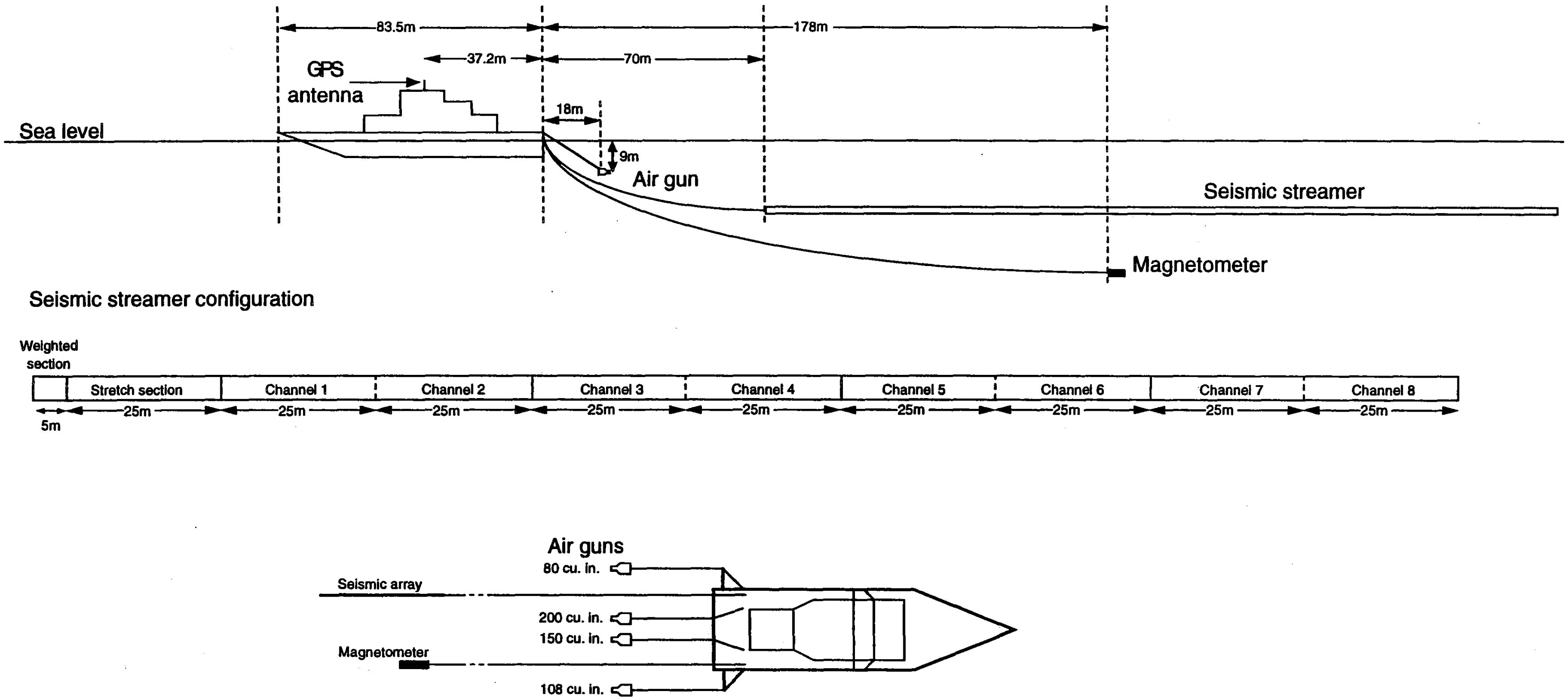

Figure 5. Cartoon showing configuration of seismic, navigation, and magnetic equipment used on cruise TN037.

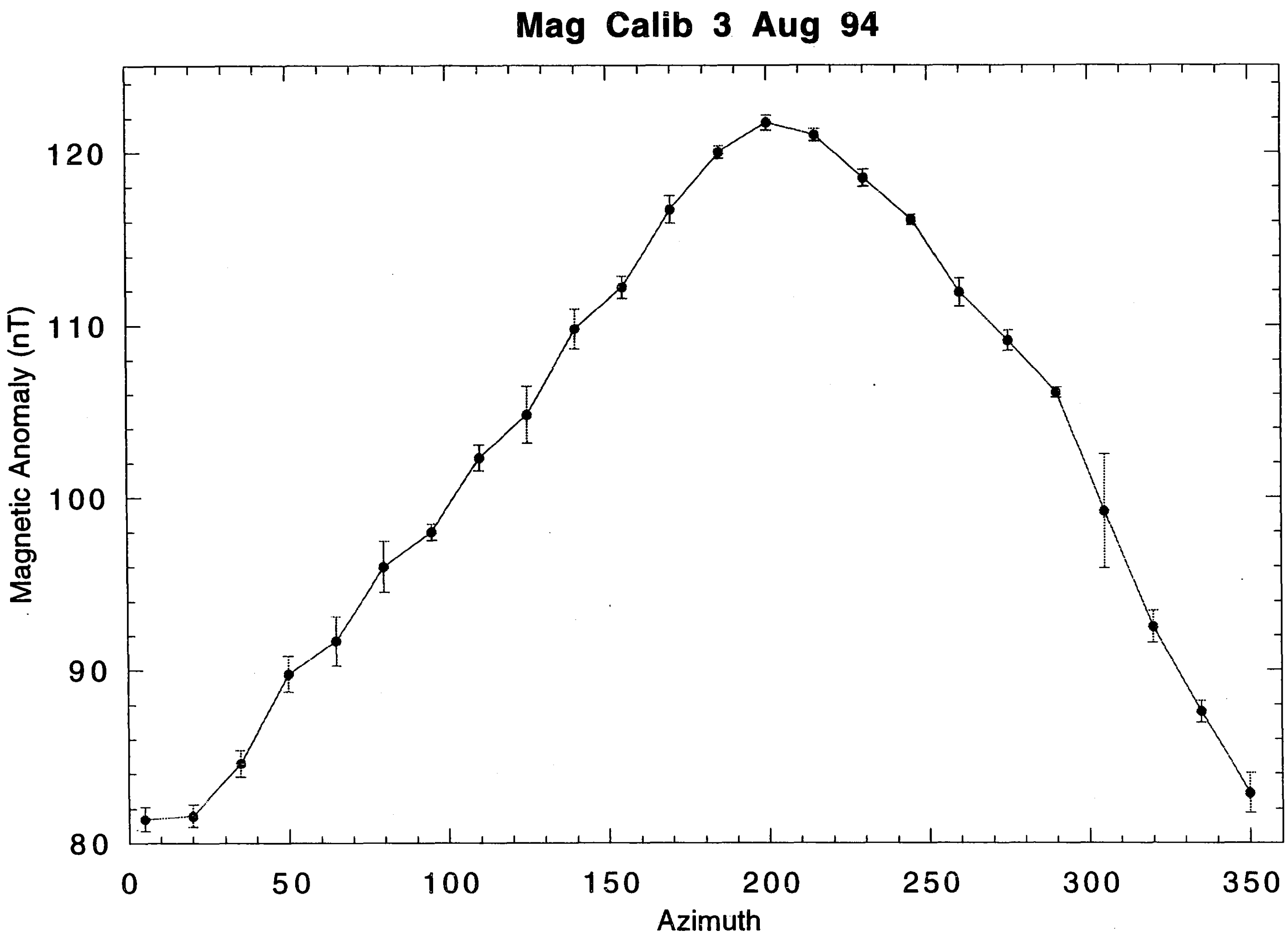

Figure 6. Variation in magnetic field with ship's heading, measured while sailing the Thompson in a circle to quantify the "ship effect" caused by using a short magnetometer sensor cable. A value of 39800 nT has been subtracted from the anomaly

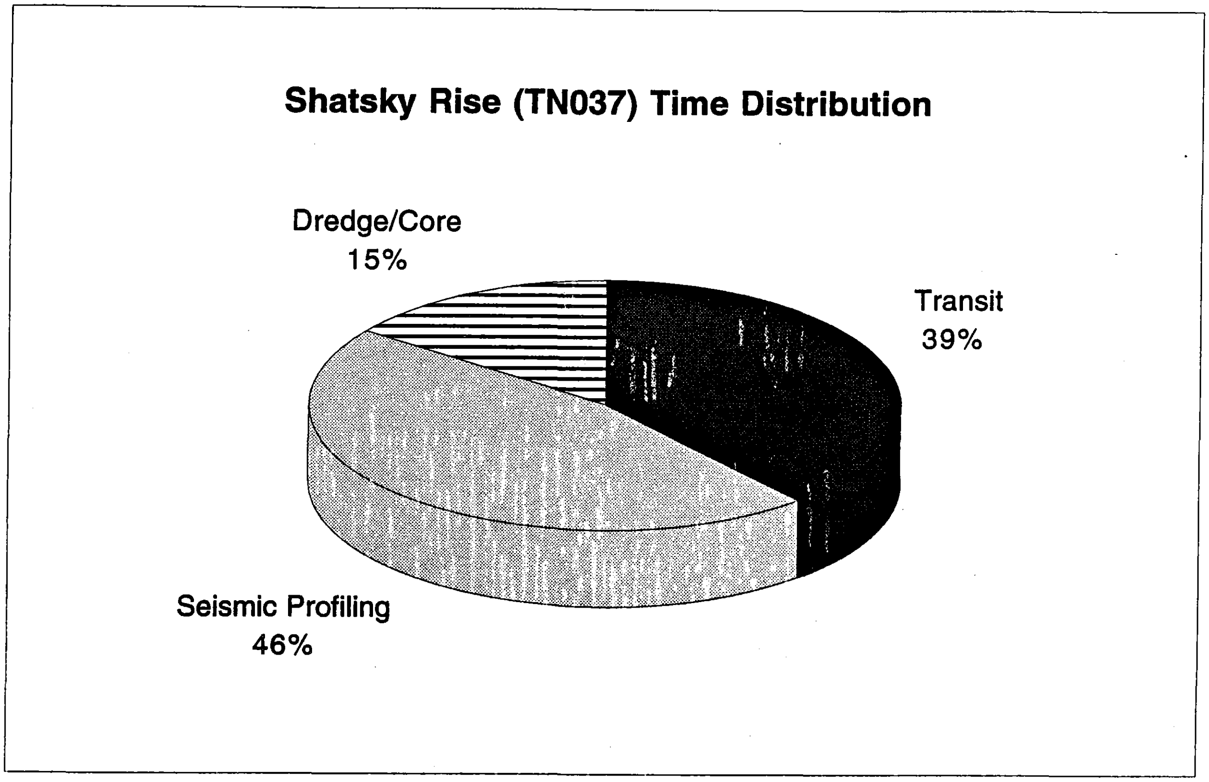

Figure 7. Pie chart showing distribution of time use on cruise TN037.

Moving the electronics lessened, but did not completely eliminate the 60-Hertz problem. The main source of the signal contamination seemed to be the computers in the computer lab. After relocation, the seismic system proved usable, the contamination signal having been reduced by a factor of ten. Problems continued with the magnetic gradiometer. Tests revealed the problem to be a short in the towed sensor cable, so the cable was brought in. It was discovered that a catastrophic failure of the cable had occurred and both sensors and 500 feet of cable connecting them had disappeared sometime during the deployment. The cause of the failure is still unknown.

After deliberation, it was decided that the most time efficient course of action that would restore the capability to collect magnetic data was to return to Honolulu to borrow a sensor cable from the University of Hawaii. Thus, at 2140Z on 25 July (2.1 days after leaving Honolulu), the ship was turned around to go back to Honolulu (Fig. 8). On the return to port and the subsequent transit back, an effort was made to parallel the previous tracks at a distance slightly greater than the width of the Hydrosweep swath so that these bathymetry data would give a useful image of the north side of the Hawaiian Ridge.

The *Thompson* approached Honolulu Harbor on 27 July, but did not dock to save time with customs. A launch brought the spare magnetometer cable, which was loaded aboard at 1900Z. The ship retraced its path along the leeward coast of Oahu and along the Hawaiian chain. By 0815Z on 29 July, the Thompson passed the point at which it had previously turned (Fig. 8). The total time lost in returning to port was 3.4 days.

Table 1. Seismic Lines, Cruise TN037, R/V *Thomas G. Thompson*

Line #1A - Test, North of Kauai
Date/Time (UT): 23 July 2354 - 24 July 0637
Start: 24° 20.3'N, 162° 41.0'W | End: 24° 37.3'N, 163° 15.8'W
Duration: 6.7 hr | Length: 66.6 km | Source: GI airgun | Fold: N/A

Line #1B - Test, Northwest of Kauai
Date/Time (UT): 24 July 2336 - 24 July 1215
Start: 25° 26.9'N, 164° 55.1'W | End: 25° 19.0'N, 164° 40.2'W
Duration: 2.7 hr | Length: 28.9 km | Source: GI airgun | Fold: N/A

Line #2 - Ojin Rise transect
Date/Time (UT): 06 August 0306 - 06 August 1144
Start: 36° 39.9'N, 165° 46.7'E | End: 37° 39.9'N, 165° 28.0'E
Duration: 8.6 hr | Length: 114.6 km | Source: GI airgun | Fold: 2

Line #3 - North flank of North High survey
Date/Time (UT): 07 August 1050 - 08 August 0300
Start: 39° 47.2'N, 164° 13.9'E | End: 40° 07.5'N, 164° 04.6'E
Duration: 16.2 hr | Length: 218.8 km | Source: GI airgun | Fold: 2

Line #4 - Transit from north flank to summit of North High
Date/Time (UT): 09 August 0049 - 09 August 1532
Start: 39° 43.6'N, 163° 32.6'E | End: 38° 10.5'N, 162° 33.5'E
Duration: 14.7 hr | Length: 198.5 km | Source: GI airgun | Fold: 2

Line #5 - North High summit survey with array
Date/Time (UT): 09 August 1829 - 11 August 0605
Start: 38° 14.3'N, 162° 31.7'E | End: 37° 46.0'N, 162° 25.4'E
Duration: 34.7 hr | Length: 223.9 km | Source: 4-airgun array | Fold: 3

Line #6 - Seismic line between dredges, North High summit
Date/Time (UT): 11 August 2016 - 12 August 0049
Start: 37° 56.8'N, 162° 33.2'E | End: 37° 38.6'N, 162° 58.1'E
Duration: 4.6 hr | Length: 62.1 km | Source: GI airgun | Fold: 2

Line #7 - Transit from North High to Central High
Date/Time (UT): 13 August 0339 - 14 August 0802
Start: 37° 23.1'N, 162° 53.7'E | End: 36° 02.5'N, 160° 03.3'E
Duration: 28.4 hr | Length: 383.5 km | Source: GI airgun | Fold: 2

Line #8 - E-W transect across Central High
Date/Time (UT): 14 August 0834 - 15 August 1539
Start: 36° 02.4'N, 159° 58.1'E | End: 36° 10.2'N, 156° 54.9'E
Duration: 31.1 hr | Length: 279.6 km | Source: 4-airgun array | Fold: 3

Line #9A - Central High, partial line back to summit
Date/Time (UT): 15 August 2022 - 15 August 2139
Start: 36° 14.5'N, 157° 39.1'E | End: 36° 14.6'N, 157° 47.7'E
Duration: 1.3 hr | Length: 17.6 km | Source: GI airgun | Fold: 2

Table 1. Seismic Lines, (Continued)

Line #9B - Central High, line back to summit and to north flank
Date/Time (UT): 16 August 0156 - 16 August 2351
Start: 36° 14.6'N, 157° 39.2'E End: 37° 46.5'N, 158° 42.2'E
Duration: 21.9 hr Length: 295.8 km Source: GI airgun Fold: 2

Line #10 - Transit between dredges, Central High summit
Date/Time (UT): 17 August 1322 - 17 August 2151
Start: 37° 20.5'N, 158° 56.3'E End: 36° 24.0'N, 159° 15.5'E
Duration: 8.5 hr Length: 114.8 km Source: GI airgun Fold: 2

Line #11 - Central High summit survey with array
Date/Time (UT): 18 August 0816 - 20 August 0530
Start: 36° 28.6'N, 159° 06.3'E End: 36° 10.1'N, 158° 32.3'E
Duration: 45.2 hr Length: 406.4 km Source: 4-airgun array Fold: 3

Line #12 - Exit from Central High
Date/Time (UT): 20 August 2358 - 21 August 0735
Start: 35° 53.1'N, 158° 53.6'E End: 35° 10.4'N, 159° 22.0'E
Duration: 7.6 hr Length: 102.9 km Source: GI airgun Fold: 2

Line #13 - North Flank of South High
Date/Time (UT): 21 August 1957 - 22 August 1144
Start: 35° 11.4'N, 159° 21.9'E End: 33° 21.0'N, 158° 51.3'E
Duration: 15.8 hr Length: 213.2 km Source: GI airgun Fold: 2

Line #14 - Array survey of South High summit
Date/Time (UT): 22 August 1313 - 25 August 0503
Start: 33° 21.3'N, 158° 51.4'E End: 32° 16.2'N, 158° 32.8'E
Duration: 39.8 hr Length: 358.1 km Source: 4-airgun array Fold: 3

Line #15 - Transit between dredge sites, South High summit
Date/Time (UT): 25 August 1243 - 25 August 2334
Start: 32° 16.0'N, 158° 35.3'E End: 32° 46.0'N, 157° 50.6'E
Duration: 10.9 hr Length: 146.5 km Source: GI airgun Fold: 2

Line #16 - Transit from Toronto Ridge to start of array line
Date/Time (UT): 27 August 0817 - 27 August 1919
Start: 32° 40.3'N, 158° 04.3'E End: 32° 14.3'N, 158° 18.1'E
Duration: 11.0 hr Length: 148.6 km Source: GI airgun Fold: 2

Line #17 - South Flank of South High
Date/Time (UT): 27 August 2039 - 29 August 1049
Start: 32° 14.9'N, 158° 18.5'E End: 30° 25.9'N, 155° 34.8'E
Duration: 38.2 hr Length: 343.2 km Source: 4-airgun array Fold: 3

Totals:		
GI airgun	158.9 hours	2112.4 km
4-airgun array	189.0 hours	1311.4 km

Table 2. Magnetic heading effect.

Azimuth (degrees)	Magnetic Field (nT)*	Std. Dev. (nT)	Azimuth (degrees)	Magnetic Field (nT)*	Std. Dev. (nT)
5	81.4	0.7	185	120.0	0.4
20	81.6	0.7	200	121.7	0.5
35	84.6	0.8	215	121.0	0.4
50	89.8	1.0	230	118.5	0.5
65	91.7	1.4	245	116.1	0.3
80	96.0	1.5	260	111.9	0.8
95	98.0	0.5	275	109.1	0.6
110	102.3	0.8	290	106.1	0.3
125	104.8	1.7	305	99.2	3.3
140	109.8	1.2	320	92.5	0.9
155	112.2	0.7	335	87.6	0.6
170	116.7	0.8	350	82.9	1.2

*Constant, 39800 nT, subtracted from all values.

Table 3. Magnetic Line Times*

Line	Begin Time	Begin Day	Julian Day	End Time	End Day	Julian Day	Description
1	1021	30-Jul-94	211	1539	30-Jul-94	211	Seamount 1
2	311	31-Jul-94	212	1052	31-Jul-94	212	Seamount 2
3	1028	1-Aug-94	213	1831	1-Aug-94	213	Seamount 3
4	905	3-Aug-94	215	1632	4-Aug-94	216	Calibration circle + Seamount 4, Seamount 5 + Eastern Ojin Rise
5	232	5-Aug-94	217	1207	6-Aug-94	218	Western Ojin Rise
6	2115	6-Aug-94	218	821	8-Aug-94	220	Transit to north flank of North High + NF survey
7	2357	8-Aug-94	220	1021	11-Aug-94	223	North High
8	2009	11-Aug-94	223	113	12-Aug-94	224	North High
9	1415	12-Aug-94	224	1640	12-Aug-94	224	North High
10	318	13-Aug-94	225	2154	13-Aug-94	225	Transit; end at power outage
11	2210	13-Aug-94	225	2128	15-Aug-94	227	Central High; end at drive outage
12	2209	15-Aug-94	227	440	17-Aug-94	229	Central High
13	1319	17-Aug-94	229	2150	17-Aug-94	229	Central High
14	751	18-Aug-94	230	529	20-Aug	232	Central High
15	2347	20-Aug	232	735	21-Aug	233	Central High Exit
16	1749	21-Aug	233	505	25-Aug-94	237	South High
17	1244	25-Aug-94	237	2331	25-Aug-94	237	South High
18	808	27-Aug-94	239	2330	31-Aug-94	243	South High Exit

* Times in GMT.

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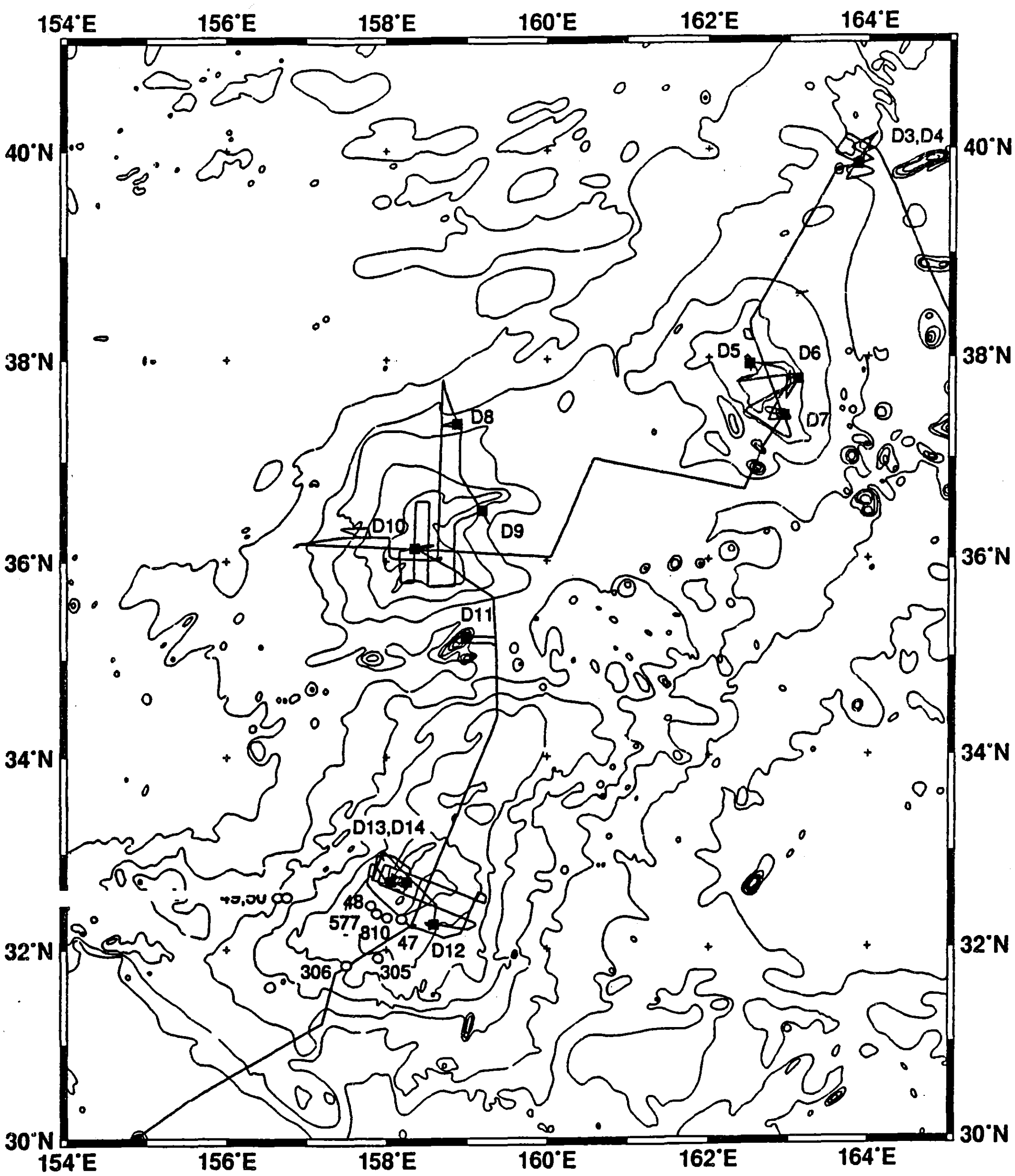


SUMMARY

Cruise TN037 of the R/V *Thomas G. Thompson*, was a marine geological and geophysical survey of Shatsky Rise, in the northwest Pacific Ocean. The primary goals of the cruise were to collect geologic and geophysical data to understand the formation and evolution of the rise as well as seismic data for Ocean Drilling Program site surveys. The cruise began at Honolulu on 23 July 1994 and ended at Guam on 3 September 1994. The 42.1 days of the cruise, consisted of 16.3 days of transit, 19.5 days of underway surveying, and 6.3 days on dredge or coring stations. Hydrosweep bathymetry and gravity data were collected during the entire cruise and magnetic data were collected over the study area and across four seamounts located north of the Hawaiian Seamount Chain. A total of 3423.8 km of digital seismic data were collected using a six-channel streamer and airgun sources. Of this, 2112.4 km were shot using a two-chambered, GI-airgun at a speed which gave two-fold coverage and 1311.4 km were shot using a 4-airgun array at a speed suitable for three-fold coverage. Fourteen dredges were attempted and all recovered samples. Five cores were taken, one from the North High, two from the Central High, and two from the South High.

Seismic data from the rise show thick sediment caps, greater than 1.0 sec two-way travel time, atop all three of the main uplifts. Seismic layering suggests the sediments are mainly pelagic carbonates, but reflector geometries imply a complex pattern of erosion and redeposition. Basement is seen in most places, and is often thought to represent the top of the volcanic pedestal; however, smooth basement in some areas may be a layer of volcaniclastic sediments. At a few locations, notably the sedimented rise flanks, basement identification is more problematic. Basement depths between uplifts is typically at the depth of the surrounding abyssal seafloor, suggesting that the rise topography in these regions is mainly sedimentary apron. Hydrosweep bathymetry data showed that the morphology of the main uplifts is more complex than shown on pre-existing charts, owing to the paucity of pre-existing data. What have been shown on bathymetry charts as smooth flanks are in places crenulated, incised by channels, and sometimes have cone-like features. Furthermore, seamounts within the rise have lineated shapes trending either E-W or WSW-ENE, contrasting with the larger rise features and suggesting a different origin. Hydrosweep data also showed that the Ojin Rise Seamounts, to the east of the North High, have different morphologies from those within Shatsky Rise, implying a different origin. They are also not well represented on existing charts owing to the sparse data in the region.

Dredging produced usable samples of altered basalts from the Ojin Rise Seamounts, a seamount on the north flank of the North High, the Central High, a seamount between the Central and South highs (Cooperation Seamount), and from the South High. The chief problem with dredging was finding an outcrop with a sufficiently steep slope and which was not mantled by thick layers of manganese, manganese nodules, and pumice dropstones. Although the TN037 dredges will go a long way towards giving constraints on the age and geochemistry of the rise, it is clear that only drilling will provide adequate geologic constraints. Dredging also produced fossils of what appear to be rudists and corals from the summit of the South High, indicating that the summit was in shallow water early in its history.

INTRODUCTION

Background

Shatsky Rise is an oceanic plateau, about the size of the state of California, located approximately 1600 km east of Japan (Fig. 1). It consists of three main uplifts, the South, Central, and North highs, which have a southwest-northeast trend (Fig. 2). The largest of these is the South High, and volume decreases towards the NE. At the latitude of the North High, the rise appears to bifurcate. To the east, towards the Emperor Seamounts, stretches a slight rise, called the Ojin Rise, capped by clumps of small seamounts. To the northeast of the North High extends a another low rise. This northern arm is more prominent and continuous than the Ojin Rise, but has fewer associated seamounts.

Shatsky Rise sits at the confluence of two prominent sets of magnetic lineations (Fig. 3), the NE-trending Japanese lineations and the SE-trending Hawaiian lineations (Larson and Chase, 1972). Studies of these magnetic lineations indicate that this intersection is the trace of the Pacific-Izanagi-Farallon triple junction during the late Jurassic and Early Cretaceous (Sager et al., 1988; Nakanishi et al., 1989). Evidently the triple junction became unstable or quasi-stable from about M21 to M12 time (149-137 Ma; all anomaly ages given herein are from the Harland et al., 1989 time scale) when its drift relative to the Pacific plate changed from NW to NE (Sager et al., 1988). Probably not coincidentally, Shatsky Rise lies along the trace of the triple junction during the quasi-stable period.

Although the South High of the rise was drilled during three DSDP legs (7, 32, and 86) and one ODP leg (132), volcanic basement was not reached and thus only minimum and maximum ages for the plateau are known. The oldest sediments, at DSDP Site 306, are Berriasian (earliest Cretaceous) in age (Larson, Moberly, et al., 1975) and place a lower limit on the edifice age. Magnetic lineations M21-M16 (149-142 Ma) in the lithosphere around the South High constrain the age of that feature to be Late Jurassic or younger. Sager and Han (1993) noted that the positive magnetic anomaly of the South High implies a reversed magnetic polarity and suggested that the South High formed during the longest late Jurassic reversed polarity chron, M17 (144.8-143.6 Ma). Age constraints on the other uplifts are poorer. The lithosphere beneath the Central and North highs is Early Cretaceous (M17-M10; 144-133 Ma), indicating these features must be younger than the South High; thus, Shatsky Rise becomes younger to the NE. Prominent Aptian-Albian reflectors in the sediment cap of the South High have been tentatively traced to the more northerly uplifts (Sliter and Brown, 1993), giving rough lower limits on their age.

Recent research on large igneous provinces has lead to the idea that oceanic plateaus and continental flood basalts are closely related. They are thought to be the continental and oceanic manifestations of incipient mantle plumes (Richards et al., 1989; Duncan and Richards, 1991). According to this hypothesis, a mantle plume originates at the core-mantle boundary and rises with a large bubble of magma at its head. When the plume head impacts the base of the lithosphere, rapid and voluminous volcanism is the product. The magnetic anomaly of Shatsky Rise is consistent with this hypothesis. Sager and Han (1993) noted the relatively coherent anomaly of the South High and concluded that it indicates this 2×10^6 km^3 feature mostly erupted during a single reversed chron. Assuming this chron was M17, the longest late Jurassic chron (duration 1.2 Ma), they calculated a minimum eruption rate of 1.75 km^3/yr, a value similar to continental flood basalts, such as the Deccan Traps (Duncan and Richards, 1991; Coffin and Eldholm, 1994).

Although not related to the plume-head hypothesis, sediments on Shatsky Rise have an interesting story of their own to tell. All three highs have thick caps of siliceous pelagic carbonate sediments, about 1.0 sec twtt or more thick. Khankishieva (1989) and Sliter and Brown (1993) divide the sedimentary section into three packets of mainly Early Cretaceous pelagic carbonates which make up most of the cap, topped by a thin layer of mainly Cenozoic pelagic sediments. The older three units, primarily consisting of chalk and limestone, were deposited when the rise was near the equator, soon after its formation, and are separated by two prominent reflectors that may represent unconformities (Sliter and Brown, 1993). Abundant silica deposited in these layers has recrystallized into chert and porcellanite nodules which hampered drilling of the older layers during DSDP legs 6 and 32. The later sediments are typically foraminifer nannofossil oozes deposited

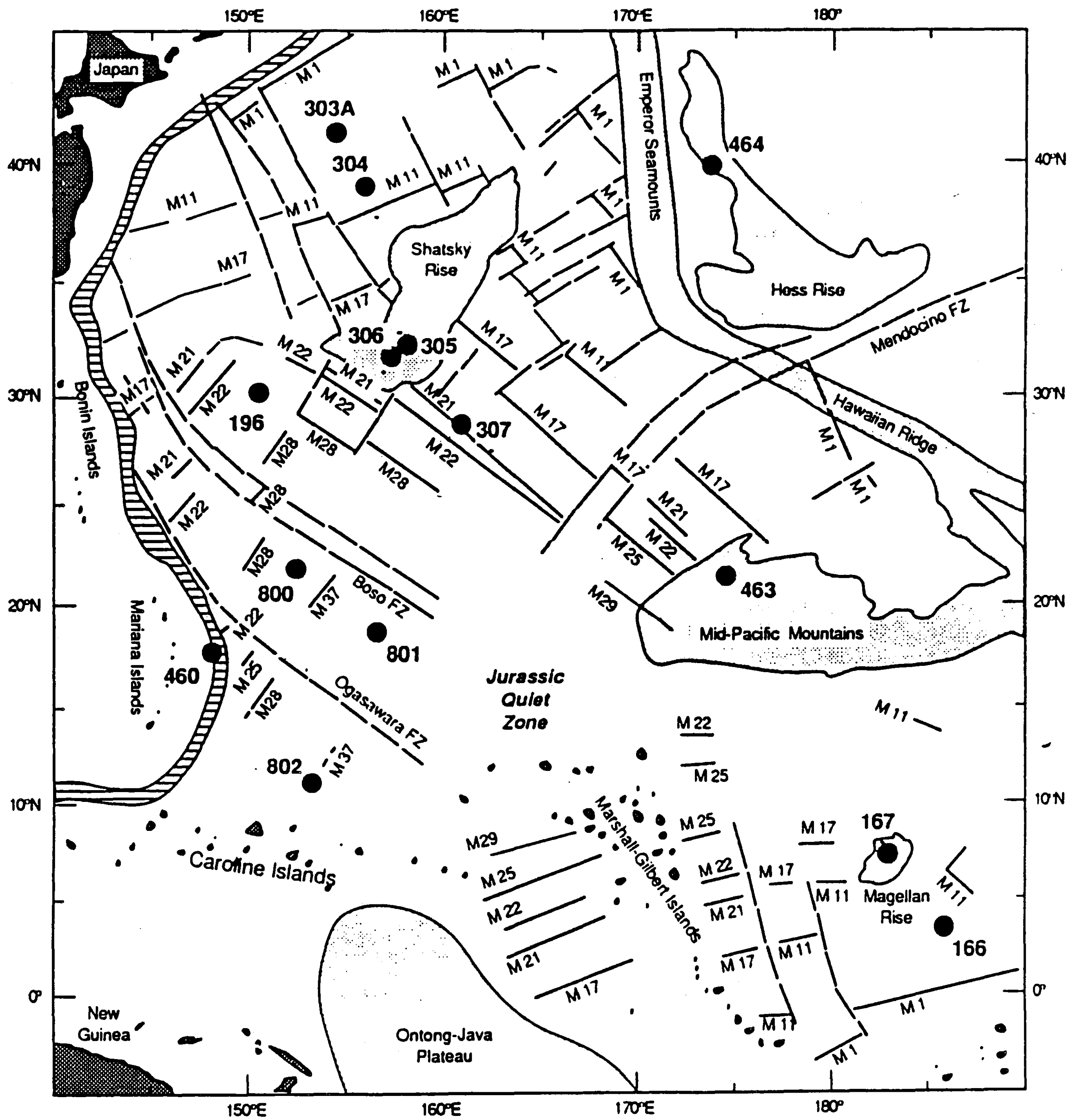


Figure 1. Location of Shatsky Rise, western Pacific Ocean. Major bathymetric features are outlined. Selected magnetic lineations are shown by straight solid lines; fracture zones, by dashed lines. Numbered filled circles denote DSDP and ODP drill sites. (from Ogg et al., 1992)

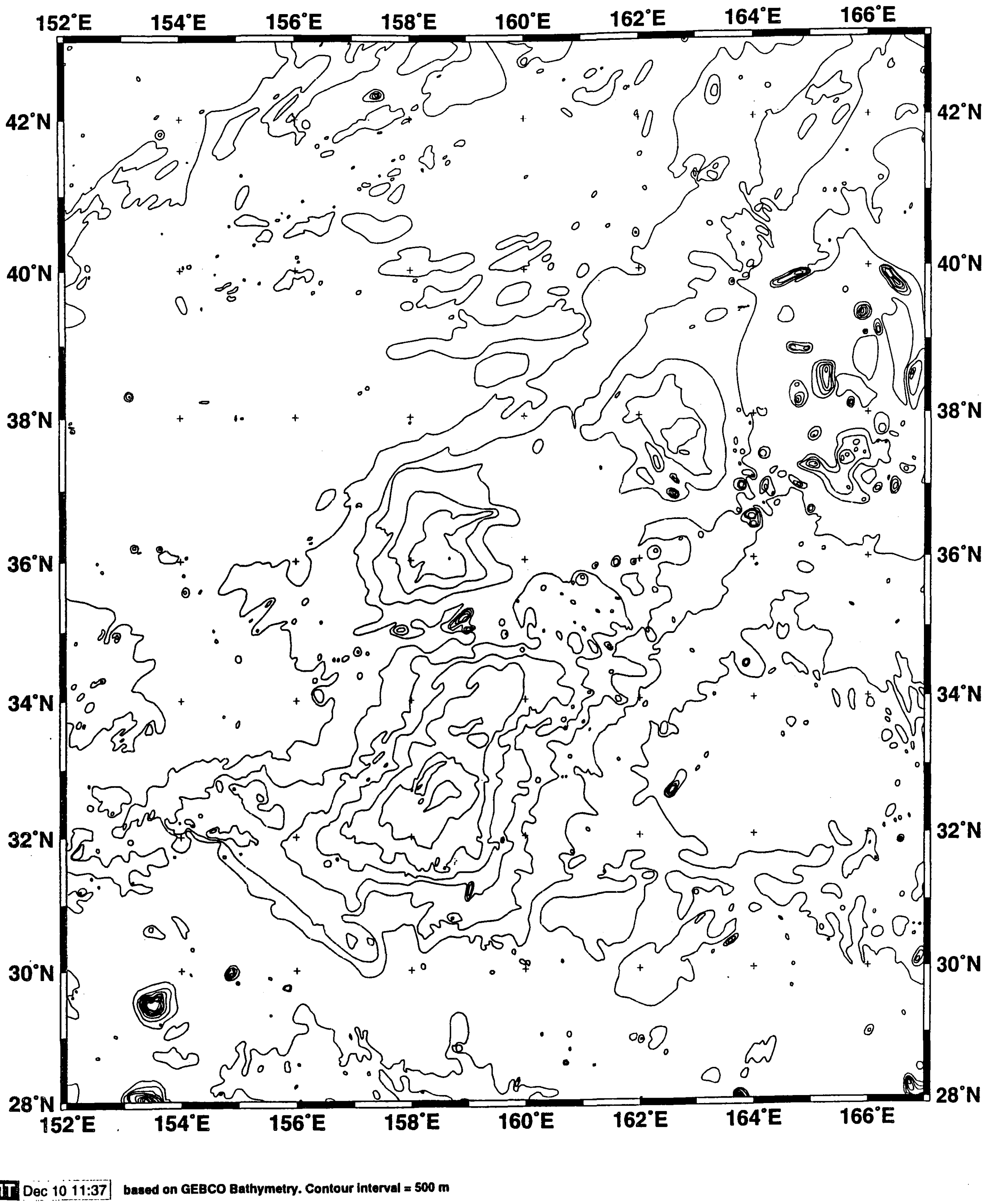


Figure 2. Bathymetry of Shatsky Rise. Contours are from the regional GEBCO chart and are shown at 500-m intervals.

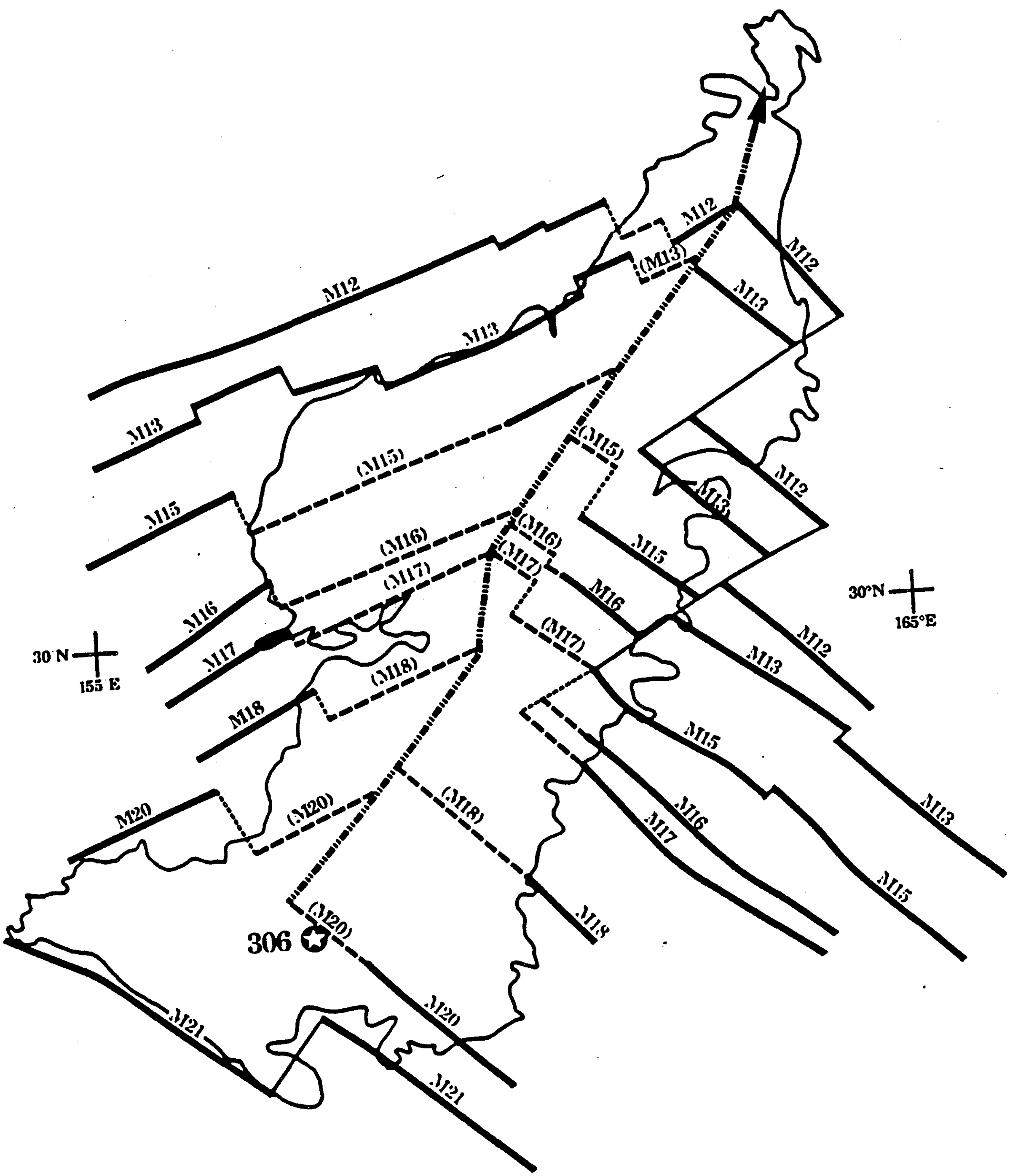


Figure 3. Magnetic lineations around Shatsky Rise. The lineations have been extrapolated beneath the rise to show possible locations of the Pacific-Izanagi-Farallon triple junction in time. (from Nakanishi et al., 1989)

foraminifer nannofossil oozes deposited atop the rise once it moved into higher latitudes (Sliter and Brown, 1993).

Cruise Philosophy

The Shatsky Rise expedition, cruise TN037 of the R/V *Thomas G. Thompson* (Fig. 4), was funded by the Ocean Drilling Program (ODP) Office of the National Science Foundation as a site survey to pave the way for possible future drilling of the rise. Earthwatch provided volunteer scientific personnel who helped the cruise effort with their labor and monetary contributions, which supported the travel of non-U.S. scientists to participate in the cruise. In addition, the International Programs Office of NSF supported collaboration with Russian scientists, who contributed Russian geophysical data from Shatsky Rise as well as their expertise.

The primary scientific justification for the study was to provide better constraints and understanding of the origin and geologic evolution of this plateau, so a multi-purpose geological/geophysical cruise was designed to study the rise. A primary objective was to obtain high-quality, digital seismic reflection data that could be used for constraining the locations of ODP drill sites. For this purpose, we used airgun sources and a 6-channel hydrophone streamer with a unix-based digital data acquisition system. Because of the large distances to be covered and the multi-purpose nature of the cruise, a true multichannel survey was considered impractical. Nevertheless, the digital recording and low-fold coverage give us the ability to make significant improvements in image enhancement compared to existing standard single-channel data.

Seismic surveys concentrated on the summits of the three large topographic highs for several reasons: (1) the summits are likely drill targets because of their shallow depths, (2) sedimentary layering is more easily imaged on the summit owing to the thicker sediments and shallower depth, and (3) on the summits it was possible to shoot grids of intersecting lines with crossings in deep sediments (for sediment cap drilling) and thin sediments (for igneous basement drilling), and (4) the summits are where the effects and interplay of igneous construction, erosion, sedimentary deposition, uplift, and subsidence can be examined. Seismic lines were also shot on the flanks and in between the main highs, where volcaniclastic sediments record the volcanic history of the rise. These were usually limited to lines approaching and leaving the highs and it was not possible to shoot intersecting lines for these profiles because of time constraints.

To understand the origin and evolution of Shatsky Rise, it is important to determine the structure and age of the igneous basement. Hydrosweep multibeam bathymetry was used to give a clearer representation of the morphology of the rise and the seismic data are to be used to delineate basement structures. Underway magnetic and gravity data were collected to give additional structural control because both of these types of data can be used to map changes in basement shape, composition, and age. Magnetic data can also be used to constrain the age of the underlying lithosphere via mapping of magnetic lineations as well as deciphering the interactions of rise, ridge systems, and triple junction.

Geological samples were collected for age constraints. Cores were taken on the Central and North Highs to check suggested correlations among sedimentary layers (Sliter and Brown, 1993). On the South High, cores were taken in a deep erosional channel to obtain the age of the oldest exposed sediments, near the base of the sedimentary column.

Dredge samples were collected from apparent igneous basement outcrops in an effort to obtain basalts that could be dated using radiometric techniques and which would give geochemical clues to the origin of the rise and the relationships among different parts of the rise. Important goals were to determine the ages of plateau features, the age ranges of these features, and decipher any age progression. With geochemical studies of tracer isotopes and rock chemistry, as mantle source tracers, we hoped to find relations with other igneous provinces in the Pacific.

Table 4. Dredge Information.

Dredge	Date GMT	Water Depth (m)	Start Location (on bottom) (Lat N)	(Lon E)
D1	4 Aug 94	4267	36° 27.02'	169° 18.13'

Seamount, East Ojin Rise:

The dredge recovered mostly manganese nodules, about 15% volcanic fragments, and 1% loose sediments. Volcanic fragments consist of massive, vesicular, and amygdaloidal basalts with pillow structures. Some samples have both tiny vesicles and a few amygdules in them. Significant amount of pumice was also recovered. Both basalts and pumice are weakly to highly altered by submarine weathering.

D2	6 Aug 94	4833	37° 37.58'	165°27.52'

Seamount, West Ojin Rise:

A very large manganese pavement and some manganese nodules were recovered. Fragments of highly weathered basalt in the core of some manganese nodule fragments, few fragments of lithified fossiliferous sediments. The large manganese pavement contains fragments of highly altered basalts, green alteration products and fossiliferous sediments.

D3	8 Aug 94	4227	39° 51.91'	163° 53.66'

Seamount on north flank of North High:

The dredge recovered manganese nodules and crusts, some with tubular and cylindrical forms plus a few pebbles of highly weathered pumice.

D4	8 Aug 94	4000	39° 50.26'	163° 54.79'

Seamount on north flank of North High (same as D3):

The dredge recovered mostly manganese nodules, some moderate to highly altered basalt fragments, and siliceous and calcareous sediments.

D5	11 Aug 94	3345	37° 57.11'	165°29.67'

Protrusion of basement from NW flank of North High:

Three buckets of manganese nodules with pebble to boulder-sized pumice fragments were recovered. A green highly altered basalt fragment was found in the core of a nodule.

D6	12 Aug 94	3835	37° 48.29'	163°07.52'

Basement outcrop, east flank of North High:

The samples included mostly big spherical manganese nodules and one boulder-sized manganese pavement. Some small fragments of basalt, pumice, green alteration product, and siliceous fragments in core of the nodules.

D7	12 Aug 94	3759	37° 23.50'	162°54.91'

Seamount, south of North High summit:

The suite consists of highly altered basalt fragments in the core of nodules, silicified mudstone, carbonate, pumice, manganese nodules and crusts with some fossil fragments.

D8	17 Aug 94	4806	37° 23.60'	158°50.29'E

Basement outcrop, scarp on north flank of Central High:

The suite consists of highly altered basalts in varying stages in the cores of manganese nodules, pumice, some mud, and mostly manganese nodules and pavement.

Table 4. Dredge Information (continued).

Dredge	Date GMT	Water Depth (m)	Start Location (on bottom) (Lat N)	(Lon E)
D9	17 Aug 94	3900	36° 31.15'	159°11.62'

Basement outcrop, scarp on east flank of Central High:
The suite consists mostly of boulder-sized basalts that are unusually dense despite the vesicularity of some of them, a few pumice, chert, and siliceous sediments, and the ever present manganese nodules.

Dredge	Date GMT	Water Depth (m)	Lat N	Lon E
D10	20 Aug 94	3474	36° 08.07'	158°22.45'

Basement outcrop, summit of Central High:
The samples consist of vesicular to amygdaloidal basalts mostly encrusted by manganese, some pumice, and sediments formed by basalt alteration. Also included are manganese nodules and manganese-encrusted fossil fragments.

Dredge	Date GMT	Water Depth (m)	Lat N	Lon E
D11	21 Aug 94	3760	35° 15.70'N	158°57.05'E

Cooperation Seamount, between Central and South highs:
The samples consist of basalt fragments that are mostly fresh or weakly altered and a few altered ones, some benthic organic molds and manganese nodules.

Dredge	Date GMT	Water Depth (m)	Lat N	Lon E
D12	25 Aug 94	3016	32° 12.93'	158°36.21'

Conical basement pinnacle, SE summit of South High:
The suite consists mostly of reefal sedimentary rocks, some fossils and fossiliferous sediments that are either with or without manganese encrustations.

Dredge	Date GMT	Water Depth (m)	Lat N	Lon E
D13	26 Aug 94	2357	32° 43.09'	158°15.07'

East flank of ridge on west side of summit, South High:
The samples consist of moderate to highly altered basalts, breccia, pumice, silicified and fossiliferous sediments. Also included are sponge fragments that are mostly manganese stained or encrusted, and some manganese nodules.

Dredge	Date GMT	Water Depth (m)	Lat N	Lon E
D14	27 Aug 94	2155	32° 39.97'	158°03.79'

Cone on west flank of ridge on west side of summit, South High:
The dredge recovered few boulders of dense basalt (some altered and silicified), some pumice, fossil fragments, and manganese nodules.

Table 5. Piston Cores.

Core	Date	Time GMT	Water Depth	Location (Lat N)	Location (Lon E)	Description and samples
PC-1	12 Aug 94	1140	3447	37° 48.36'	163° 00.01'	North High; core did not trigger; trigger core: 119 cm of stiff brown ooze + core catcher; piston core: 40 cm of stiff brown ooze + core catcher
PC-2	20 Aug 94	1649	3242	35° 54.41'	158° 50.95'	Central High SE summit; trigger core: 15 cm of fine-gr carbonate ooze + core catcher; piston core: 36 cm of white to buff chalk and brown carbonate ooze + core catcher
PC-3	20 Aug 94	2112	3262	35° 53.45'	158° 51.30;	Central High SE summit; trigger core: 14 cm white/buff soupy carbonate ooze (some redeposited) + core catcher; piston core: 127 cm mixed chalk and carbonate ooze; 63 cm of carbonate silt settled from suspension in core + core catcher
PC-4	26 Aug 94	0435	3552	32° 58.83'	157° 56.79'	South High; erosional channel west of ridge; trigger core: 58 cm of tan carbonate ooze + core catcher; piston core: 168 cm of buff to dark brown carbonate ooze + core catcher
PC-5	26 Aug 94	1035	3630	32° 59.84'	157° 56.44'	South High; erosional channel west of ridge; trigger core: 18 cm of light brown, soupy carbonate ooze + core catcher; piston core: 254 cm of light brown carbonate ooze, compact at bottom and soupy at top + core catcher

During the long transit along the northern side of the Hawaiian Ridge, we conducted short surveys across four seamounts to collect Hydrosweep, magnetic, and gravity data (Fig. 8). At each seamount, the magnetometer was deployed to gather data for seamount magnetic anomaly inversions. Three of these seamounts have radiometric age control, making such inversions valuable data for constraining Pacific plate motion. The magnetometer was not deployed during most other parts of the transit to minimize the risk of losing the only sensor cable and thus being unable to collect magnetic data over Shatsky Rise.

The first seamount crossing was a simple east-west transect, from 1021Z to 1538Z on 30 July, over a seamount located at 27° 55.5'N, 170° 59.3'W. The age of this seamount is unknown. The second crossing was over a seamount located at 29° 04.2'N, 174° 03.0'W. Because this seamount has a radiometric age of 82 Ma (Pringle and Dalrymple, 1993), but has few survey tracks, we conducted a "bowtie" survey over it (two crossings), from 0311Z to 1036Z on 31 July, to map its shape and magnetic anomaly. A similar "bowtie" was made over the third seamount, which has been radiometrically dated at 94 Ma, from 1028Z to 1831Z on 1 August (Pringle and Dalrymple, 1993). The location of this seamount is 31° 11.8'N, 179° 40.0'W, south of Hess Rise.

Between the third and fourth seamounts, we conducted a calibration circle for the magnetometer. Because the magnetometer sensor cable was designed for the R/V *Moana Wave*, it was too short for the longer *Thompson*. Thus, it was necessary to measure the "ship effect" on the sensor at different headings. Based on an examination of existing magnetic data, we located a spot northwest of Hess Rise, near the desired transit path, where the magnetic field variation appeared to be small. We sailed over the summit of Hess Rise at 1600Z on 2 August and made a calibration circle from 0905Z to 1100Z on 3 August at 36° 12.2'N, 173° 15.1'E (Fig. 9).

The fourth seamount surveyed is a small edifice in the southern Emperor Seamounts, located at 36° 26.5'N, 171° 43.0'E. Because this seamount is also aligned with the trend of the Ojin Rise Seamounts, we wished to discover to which group it belongs. Three passes over this seamount were made between 1830Z on 3 August and 0130Z on 4 August (Fig. 9). The large size and magnetic anomaly of this seamount is quite different from those found in the Ojin Rise group and leads us to conclude that it is a younger seamount and a member of the Emperor chain.

From the Emperor seamount it was a short transit to the easternmost Ojin Rise seamounts. At 1240Z on 4 August, we crossed the first of these seamounts, marking the end of the long transit and the beginning of the Shatsky Rise survey (Fig. 9).

Ojin Rise Survey

The Ojin Rise is a low swell that extends eastward from the North High of Shatsky Rise to near the Emperor Seamounts. Numerous small to medium seamounts are located atop the swell. Because these seamounts could be the trace of a hotspot related to Shatsky Rise, we conducted a short program of surveying and dredging in this region (Fig. 9). Two dredges were collected from the area: D1 from a small seamount in the eastern Ojin seamounts, on 4 August at 36° 27.0'N, 169° 18.1'E , and D2 from one of a cluster of seamounts in the western part of the chain, on 6 August at 37° 37.4'N, 165° 27.1'E. D1 recovered a good haul including basalt (see Appendix 1). D2 yielded mostly manganese crusts and nodules, some of which contained highly weathered basaltic fragments.

Between dredge sites, we shot a seismic line over the western seamount cluster using the GI-airgun, from 0300Z to 1200Z on 6 August. In addition, we surveyed a small seamount between 1600Z and 2300Z on 5 August with the magnetometer. This seamount produced a positive magnetic anomaly that indicates its polarity to be reversed. Because the Ojin Rise Seamounts appear to be old (judging by the thick manganese crusts brought back by dredges) the reversed polarity constrains the age of this seamount to the period between about M7 (132 Ma; the age of the underlying lithosphere; Nakanishi et al., 1989) and M0 (124 Ma). Having thus reasoned a date for this seamount, we did not dredge it.

After finishing the seismic transect, the ship proceeded directly to the northern flank of the North High. Although this path took the ship over the abyssal seafloor east of Shatsky Rise (Fig. 10), this course saved a half day over proceeding straight to the North High and thence to the north flank.

North High Survey

The hydrophone array and GI-airgun were deployed at 1025Z on 7 August to begin shooting seismics for the north flank survey. Two parallel lines were shot, trending ESE-WNW, over two small seamounts located at the junction between the north flank of the North High and the northern extension of Shatsky Rise (Figs. 11, 12). Subsequent lines partially filled the gap between lines and completed Hydrosweep coverage of the two seamounts. The seismic data suggest that the seamounts flank an ESE-WNW trending graben separating the North High from the northern extension.

Two dredges, D3 and D4 were made on the southern of the two seamounts (Fig. 12). The first of these, attempted at 39° 52.0'N, 163° 54.0'E on 8 August, recovered mostly manganese nodules and crusts. Thus, it was decided to dredge the seamount once more. D4 was made at 39° 50.3'N, 153° 52.8'E, also on 8 August. It recovered a substantial amount of basalt.

Having made the successful dredge, the magnetometer, seismic array and GI-airgun were redeployed at 2349Z on 8 August to gather data on a line up the north flank of the North High. A thick pile of sediments, including a thick, lower turbid layer, were seen in the seismic data on this line. At 1526Z on 9 August, the ship circled for the first deployment of the 4-airgun array in order to obtain a 3-fold seismic line across the summit of the North High.

Surveying of the North High continued until 13 August, alternating between the GI-airgun and 4-airgun array sources and interspersed with three dredge stations and one core station (Fig. 13). The initial 4-airgun array survey consisted of a line, nearly north to south over the summit, crossed by two nearly east to west lines, one through the thickest sediments and one at the southern edge of the summit platform where sediments are thin. This set of seismic lines ended at 0610Z on 11 August.

Shortly thereafter, dredge D5 was made on a promontory on the NW side of the summit at 37° 57.1'N, 162° 29.5'E. The dredge became stuck on the bottom and the recovery was low. Mostly manganese nodules, crusts, and pumice dropstones were recovered. The GI-airgun was deployed for a seismic line across the summit to the east side of the North High, where another dredge was attempted. Beginning at 0303Z on 12 August, dredge D6 was made at 37° 48.3'N, 163° 07.5'E. Like the previous dredge, this one recovered mostly manganese nodules and crusts as well as pumice dropstones.

After the dredge, the ship moved a few miles west, to the southeast edge of the summit platform to take a core. Core station C1 is located at 37° 48.5'N, 163° 00.1'E at a place where some of the upper Cretaceous sediment layers are missing. When the core resurfaced at 1330Z on 12 August, it was found that it had not tripped. Approximately 40 cm of brown ooze was recovered in the core (Table 5).

From the core station, the ship proceeded southwest to dredge a satellite seamount located due south of the North High summit. Dredge site D7, located at 37° 23.5'N, 162° 54.9'E, was reached at 2117Z on 12 August. As did other dredges on the North High, D7 was disappointing in that it recovered manganese nodules, crusts, and pumice dropstones. Although we found highly altered basalt fragments inside manganese nodules from the North High dredges, it is doubtful that any are useful for radiometric dating. This was disappointing and a significant gap in our sample set, but having passed the halfway point in the cruise, the decision was made to sail south to the Central and Southern highs.

At 0318Z on 13 August, the GI-airgun, hydrophone array, and magnetometer were deployed to run a line between the North and Central highs. Rather than make a direct line between features, a "zig-zag" track was made to help in recognition of magnetic anomaly trends in this poorly mapped region (Fig. 11). The seismic data showed a thick pile of sediments with basement at about the same depth as expected in abyssal regions outside the rise.

Central High Survey

The Central High survey proper began at 0840Z on 14 August when the ship commenced at 36° 02.3'N, 159° 59.6'E an east to west transect across the entire Central High using the 4-airgun array (Fig. 14). Line showed apparent dipping reflectors on the east flank and a fascinating seismic stratigraphy of summit sediments. Sediment thicknesses at the summit are extremely variable,
from less than 0.2 s twtt to more than 1.0 sec twtt. Furthermore, the layers are not usually horizontal, but show evidence of erosion, unconformities, and sediment drifts. The airgun array transect ended at 1530Z, 36° 10.5'N, 156° 56.6'E, at the foot of the western flank. The seismic gear was pulled in and the ship retraced its track to the potential dredge location, where a scarp was thought to exist. The scarp was not found, so the dredging was canceled. The GI-airgun was deployed to shoot a seismic line back to the summit, but at 2128Z on 15 August, the ship's drive went out, forcing the recovery of all gear and delaying operations by several hours. The seismic line was recommenced and a parallel line with crossings was run to the summit and thence to the northern flank (Fig. 14), where the seismic line was terminated at 2347Z on 17 August.

The first Central High dredge (D8) was attempted at 37° 23.6'N, 158° 50.3'E, on an apparent volcanic cone atop a scarp at the base of the north flank. At 1245Z on 18 August, the dredge was recovered. It contained mostly manganese nodules and pumice dropstones. After the dredge, the GI-airgun was deployed to shoot a seismic line en route to a dredge site at the east edge of the summit. On this line, the ship crossed a flat-topped, ridge feature trending NE from summit (later we would recognize its similarity to the ridge atop the South High) and found a 45° scarp on the east side. Dredge D9 was made on the southeast side of this ridge, along the scarp, at 2334Z on 17 August at 36° 30.2'N, 159° 12.0'E. Problems with positioning and currents lead to restarting the dredge at 36° 31.2'N, 159° 11.6'E at 0230Z on 19 August. The dredge was recovered at 0712Z and it was found to contain many samples of moderately to severely weathered basalt, including one manganese nodule containing a fragment of apparent cumulate rock.

After the dredge, a set of three north-south oriented lines was begun with the 4-airgun array in order to make a grid of crossing lines at the Central High summit (Fig. 14). This line began at 0815Z on 19 August, near 36° 28.1'N, 159° 05.1'E, and ended at 0530Z on 20 August, near 36° 10.0'N, 158° 32.3'E. The line was terminated near a small scarp at the summit that was thought suitable for dredging. Dredge D10 was deployed at 0800Z at 36° 08.0'N, 158° 21.7'E. Recovered at 1230Z, the dredge contained mostly manganese nodules and pumice dropstones, but some nodules were found to contain reasonably good pieces of basalt.

Following the dredging, the ship proceeded to the southeast side of the summit for core stations where apparent Early Cretaceous sediment layers were observed to outcrop on the previous seismic lines. As the distance from the preceding dredge station is small, the seismic gear and magnetometer were not deployed. Core C2 was taken at 1649Z at 35° 54.4'N, 158° 50.9'E, whereas core C3 was taken at 2112Z at 35° 53.4'N, 158° 51.4'E. Both cores struck consolidated sediments, so the penetration was small. The former recovered about 36 cm of sediments and appeared to contain chalk, which is characteristic of Cretaceous sediments. The latter retrieved about 2 m of sediment, mostly brown ooze, much of it watery and redeposited within the core liner during handling (Table 5).

With the coring finished, the GI-airgun was deployed to run a line between the Central and South Highs (Fig. 15). We decided to pass 20 nm east of Cooperation Seamount, located approximately halfway between the two highs. This line was begun at 0004Z on 21 August. When east of Cooperation Seamount, at 0800Z, the ship broke off the line to run west for a dredge of the seamount. Dredge D11 was begun at 1221Z, along the rough summit of Cooperation Seamount, at 35° 15.7'N, 158° 57.1'E. The dredge was recovered at 1721Z. It contained many pieces of basalt as well as the ubiquitous manganese nodules and pumice dropstones. After securing the dredge, the ship proceeded east to rejoin the seismic line.

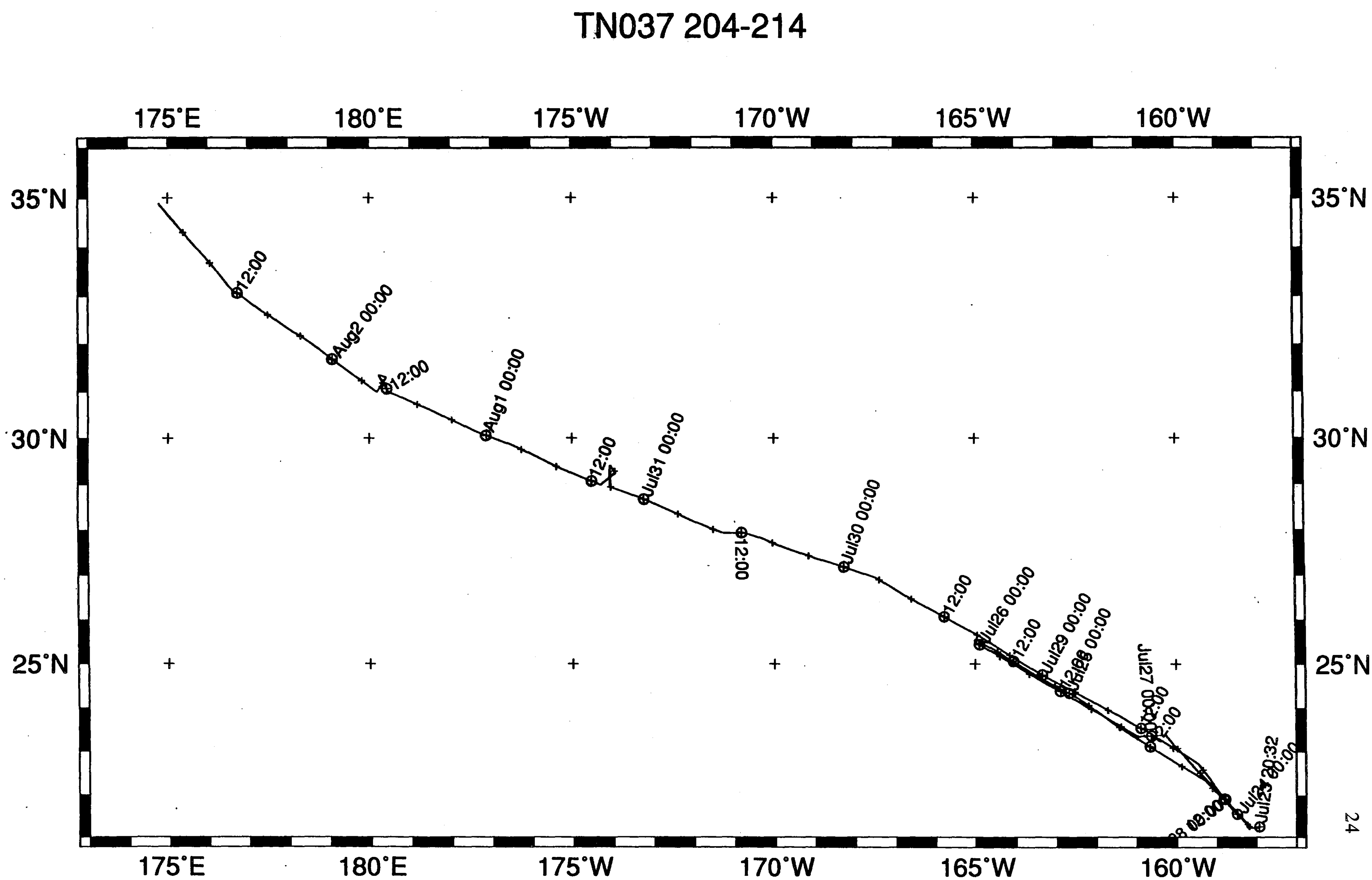


Figure 8. Ship track chart of the TN037 transit north of the Hawaiian chain, including the return to Honolulu at the beginning of the cruise. Tick marks are at 4-hour intervals.

Figure 9. Map of ship tracks in the Ojin Rise Seamounts region. Tick marks are at 1-hour intervals. D1 and D2 denote dredge locations. Bathymetry contours at 500-m intervals from GEBCO charts.

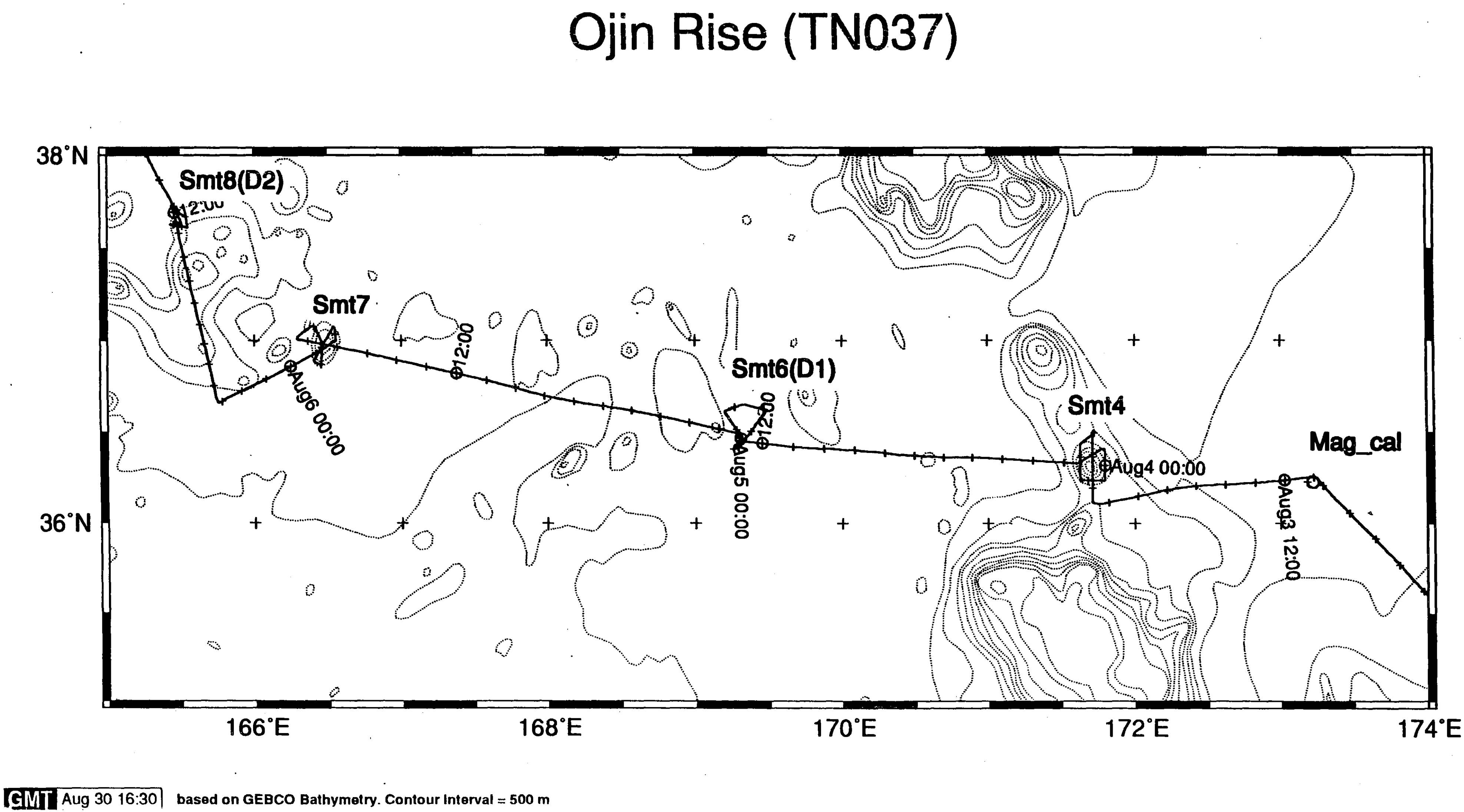


Figure 10. Overview of ships tracks over Shatsky Rise. Dashed boxes denote areas shown in Figures 12, 13, 14, and 15. Bathymetry contours at 500-m intervals from GEBCO charts.

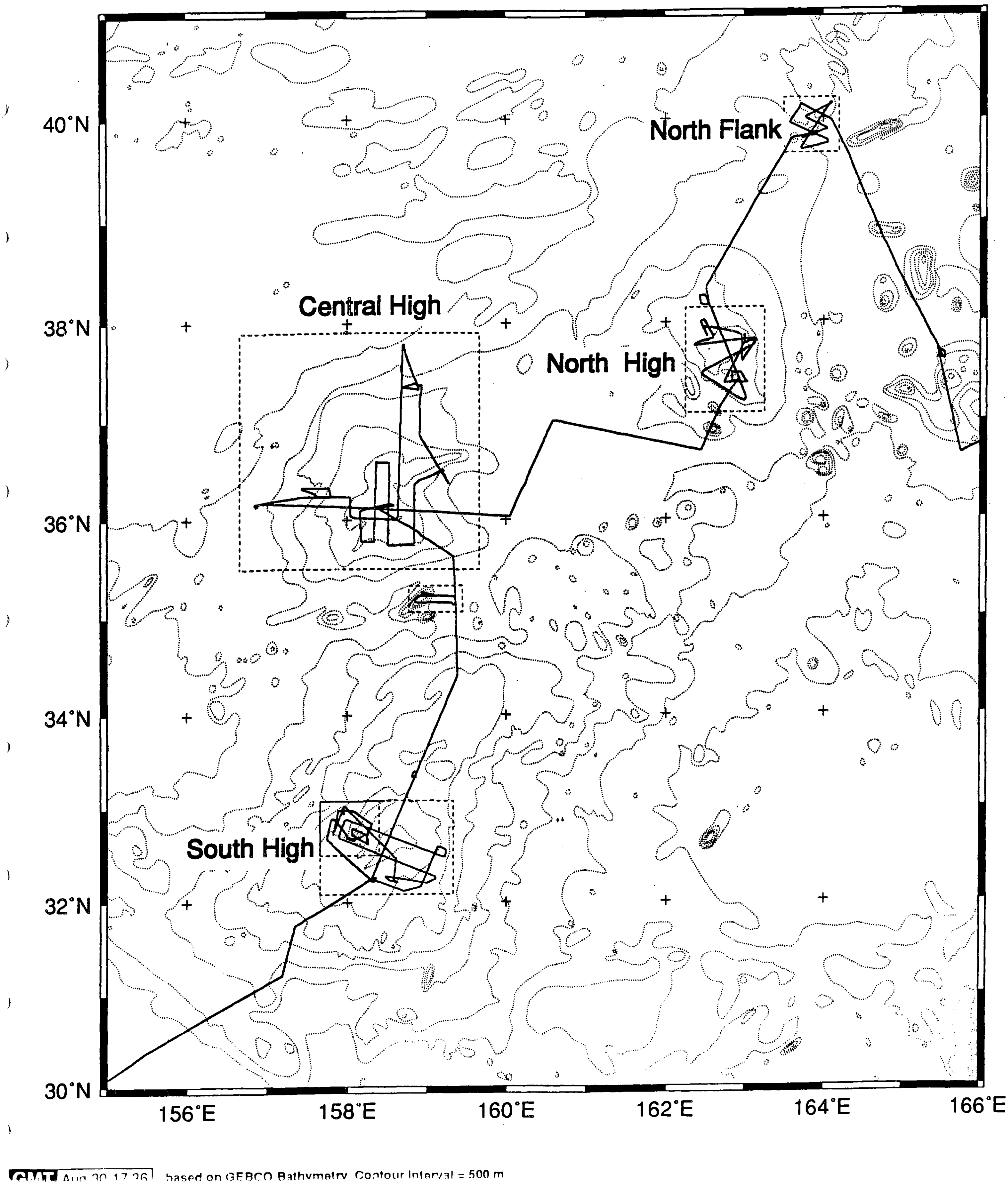


Figure 11. Ship tracks in the northern Shatsky Rise survey area. Tick marks are at 1-hour intervals. Dashed boxes show the areas covered in Figures 11, 12, and 13. Bathymetry contours at 500-m intervals from GEBCO charts.

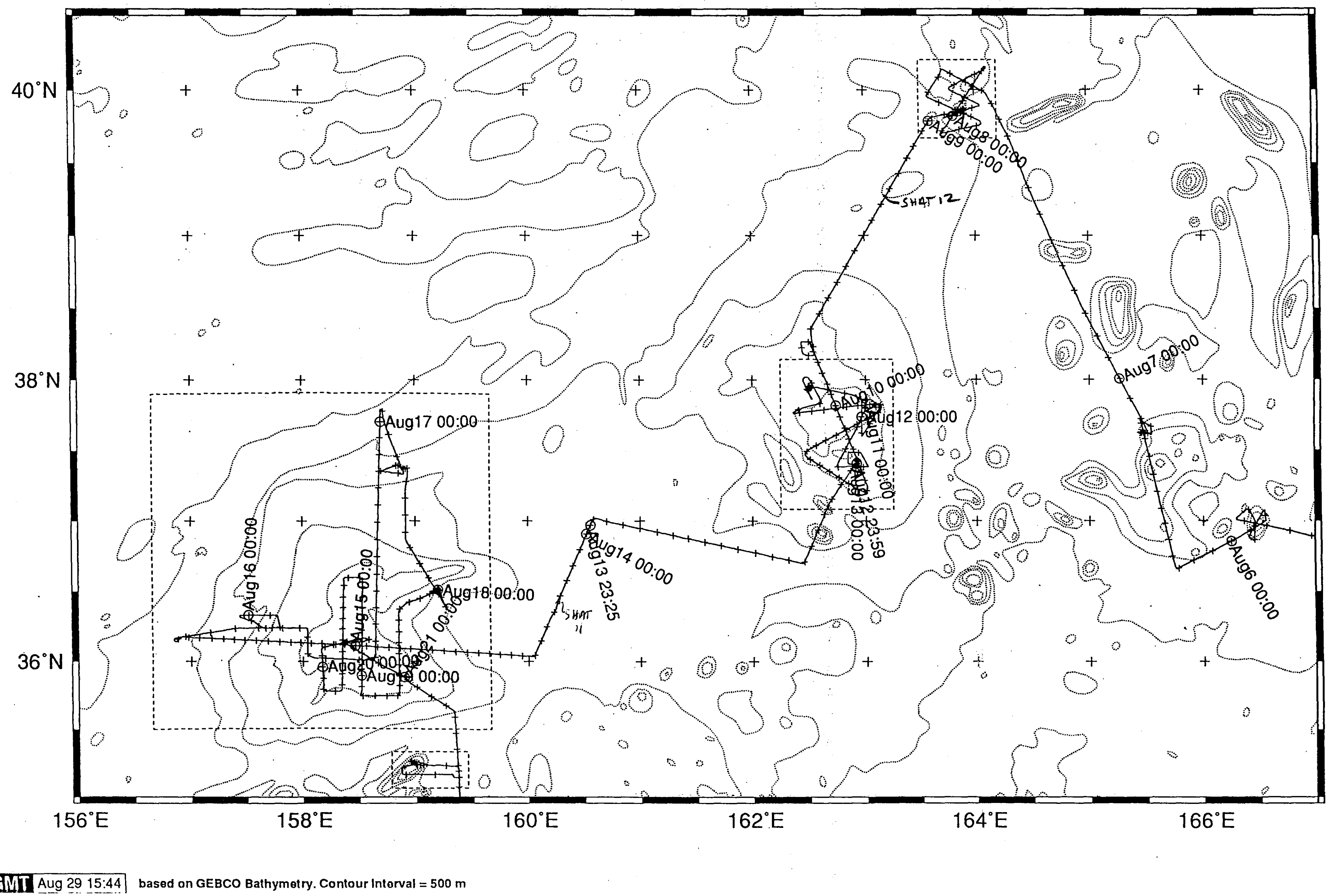


Figure 12. Ship tracks in the North High northern flank survey area. Dotted lines show hydrosweep bathymetry, at 100-m intervals. Tick marks are at 15-minute intervals. D3 and D4 denote dredge locations.

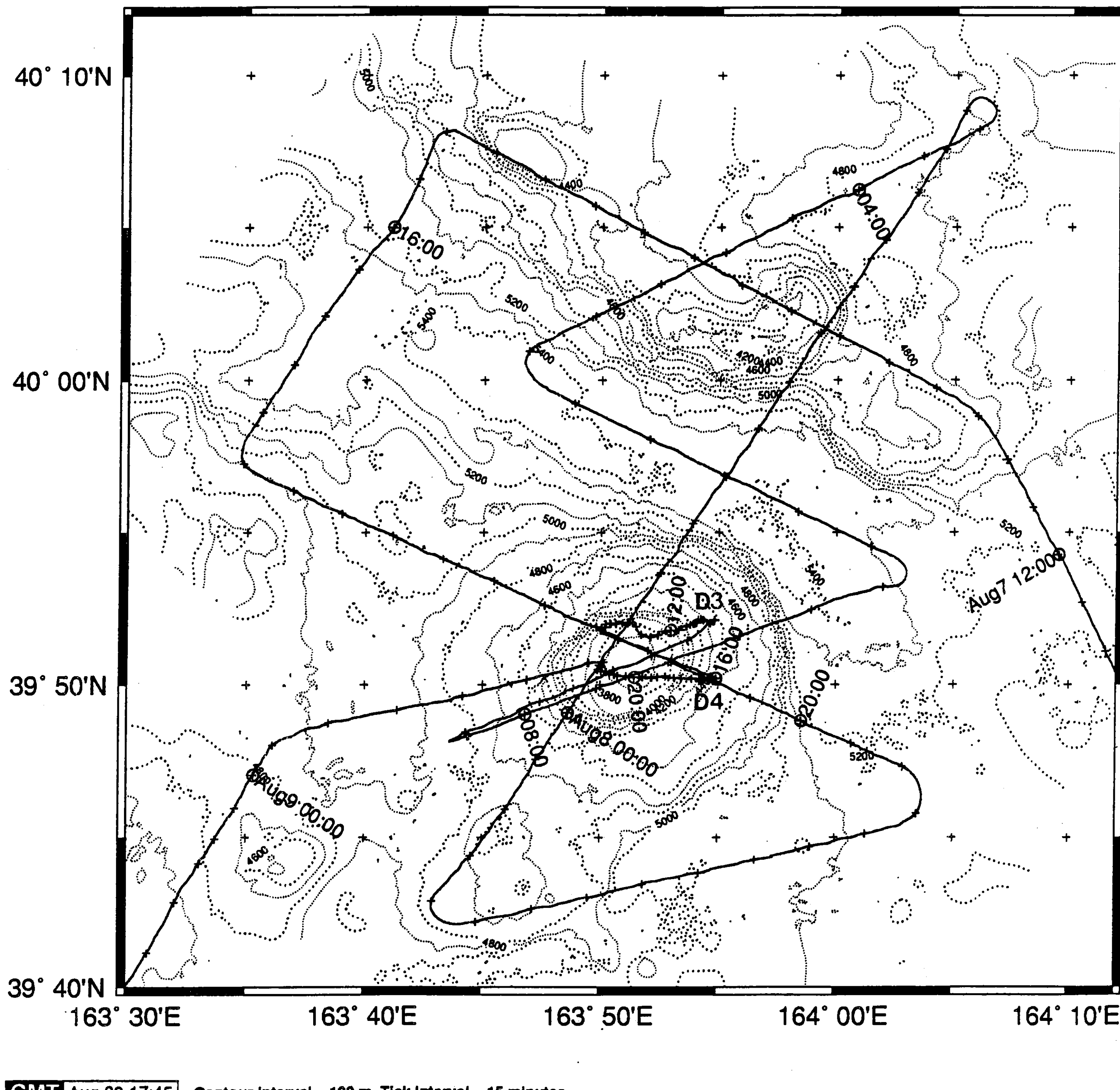
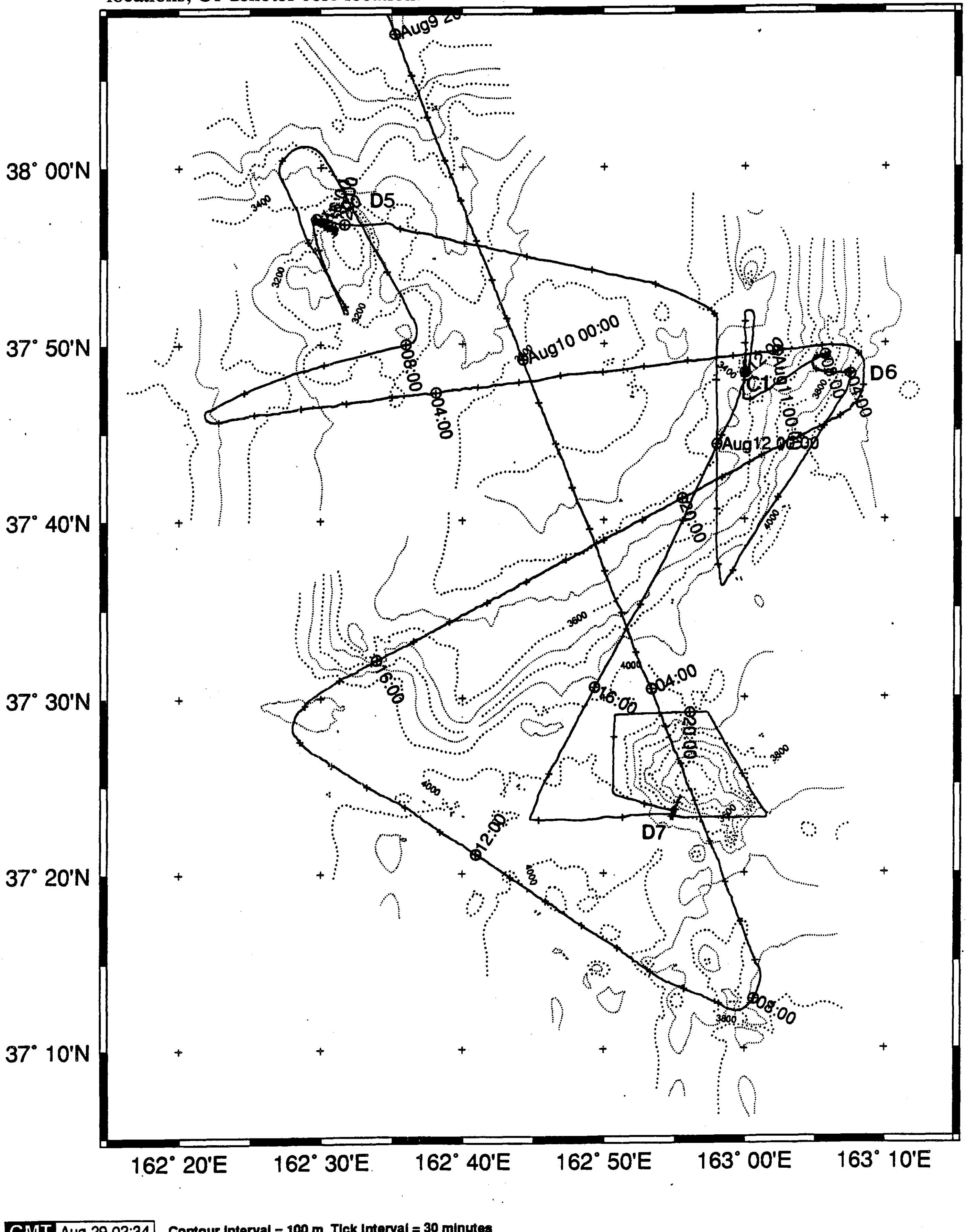


Figure 13. Ship tracks in the North High summit survey area. Dotted lines show Hydrosweep bathymetry, at 100-m intervals. Tick marks are at 30-minute intervals. D5-D7 denote dredge locations; C1 denotes core location.



South High Survey

The seismic line to the South High was recommenced at 1958Z on 21 August using the GI-airgun. By the beginning of 22 August, the ship was climbing the north flank of the South High. Our line took us to the NE-trending axis of the high, where the course was changed to south-southwest towards the summit.

At 1142Z on 22 August, the ship slowed and circled to deploy the 4-airgun array for a line over the summit. The line was rejoined with this source near 33° 22.3'N, 158° 51.8'E. The line was continued towards the south-southwest, over the top of the summit sediment pile. At 0353Z on 23 August, at 32° 14.8'N, 158° 18.4'E, the ship turned to the east to run a line over the east side of the summit, where the sediments are thinner. After making the line along the east side of the summit, two E-W lines were shot across the summit, from the shallow sediments on the east side across the ridge at the west side of the summit (Fig. 16). Airgun array line ended at 0505Z on 25 August near pinnacle on southeast side of summit platform. Because the pinnacle appears to be a basement outcrop, we decided to dredge it.

Dredge D12 was taken on the south side of the pinnacle (Fig. 16), at about 32° 12.9'N, 158° 36.3'E, where some sediments seem to have been eroded from its base, giving a larger dredge target. The dredge was deployed at 0712Z and recovered at 1128Z on 15 August. It contained mainly silica nodules and chert, but also some very interesting fossils. A number of club urchin spines were recovered as well as fragments of rudists and what appear to be corals.

The GI-airgun was deployed to shoot a seismic line across the previous lines en route to dredge and core stations on the west side of the summit. After crossing the western summit ridge, a north to south line was shot across two erosional channels trending westward from the summit. The channels proved deep, the northern one seemingly cutting down to near basement. The ship retraced its track to the northern channel and took two cores, C4 and C5, at 32° 58.8'N, 157° 56.8'E and 32° 59.8'N and 157° 56.5'E, respectively (Fig. 16). The first core was tripped at 0436Z and the second at 1035Z on 16 August. The former had recovery of 2.26 m whereas the latter retrieved 2.56 m; both contained some indurated sediments and also soupy carbonate oozes (Table 5).

After the coring, several lines were run across the western ridge to fill in bathymetry gaps with the Hydrosweep and to find a suitable location for dredging. At 1800Z on 26 August, the ship slowed to take a dredge on the east side of the ridge at 32° 43.0'N, 158° 15.0'E. The dredge became hung on the bottom, but was worked free. Upon recovery at 0052Z on 27 August, it was found to contain mostly manganese nodules, so a second dredge on the ridge was planned. Later, some rocks, coated with manganese, were found to contain basalt.

The ship moved to the southwest side of the ridge, where a volcanic cone approximately 500 m tall was dredged. The dredge station was located at 32° 40.5'N, 158° 05.0'E and commenced at 0251Z. On deck at 0734Z, the dredge contained basalt fragments as well as the ubiquitous manganese nodules and pumice. The GI-airgun was deployed and a seismic line was run to the southernmost point of the SSW-trending airgun array line. At 2040Z, the ship was circled to deploy the airgun array for an exiting seismic line down the southwest flank of the South High.

Before leaving the subject of the South High summit, it is worthwhile noting that operations in this area were hampered by strong currents with variable directions. On the east side of the summit, we found a 2-3 kt current behind the ship as it proceeded north. This made it impossible to maintain the 4.86 kt speed necessary for obtaining 3-fold coverage. Conversely, on the west side of the summit, we had to fight a southward-moving current of similar magnitude when he ship was turned north to go back to the core station. Current maps from the weather service showed that at the time of our survey, the Kuroshio current was passing over the northern part of Shatsky Rise and we were probably experiencing the effects of current eddies.

On the seismic line down the southwest flank of the South High, we tried to take a path more-or-less towards Guam, our final destination, to save time. However, we knew from existing seismic lines that part of the south flank is barren of sediments, whereas the west flank has sediments. We tried to go between these areas, hoping to take a shorter path, but one with flank sediments. Our method did not produce the desired effect as we passed over an erosional channel that gave way to barren basement. Evidently most of the south side of the South High has been stripped of sediments. The seismic line was continued to the bottom of the flank, at a depth of about 5000 m. At 1047Z on 29 August, the seismic line was terminated at 30° 25.4'N, 155° 33.8'E.

Transit to Guam

Although the exit line had been designed with about a half to full day of extra time to survey at the base of the southwest flank, the ship's captain decided that the transit to Guam should begin early, at 1230Z on 29 August. The problem was that Tropical Storm Ivy was located south of Shatsky Rise and Hurricane John, to the southeast. The captain feared that one or both storms could get between the ship and Guam, making it impossible to head directly to port to arrive on time. Although we outflanked Ivy within an additional day, we still continued to Guam, but at reduced speed. We sought to use the extra time to make Hydrosweep surveys of the Marianas Trench or Mariana Trough; however, the captain informed us that such surveys were impossible without prior permission from the Coast Guard to operate in fisheries areas within 200 nm of land. Unfortunately, there was no time to obtain such permission.

During the initial portion of the transit, we towed the magnetometer over the magnetic lineations near the Jurassic magnetic bight between Shatsky and Guam. The magnetometer was retired at 2030Z on 31 August.

Although the Hydrosweep and gravity meter were run all the way to Guam, it was impossible to collect data with the seismic system and magnetometer during most of the transit. The hydrophone streamer was designed for speeds less than 8 kt, and the transit speed was at times 12-13 kt. Furthermore, it was necessary to have all of the equipment ready to be shipped when the *Thompson* reached the dock owing to daily leasing charges and the amount of time in port. Thus, much of the transit time was spent demobilizing and packing equipment for shipping.

The Thompson arrived at the sea bouy at Apra Harbor at daybreak on 4 September (local). By 2200 Z on 3 September, the ship was tied up at the commercial pier and cruise TN037 was over.

PRELIMINARY RESULTS

Bathymetry

The Hydrosweep system allowed us to map make detailed bathymetry maps of most of the areas of the seamounts crossed on the transit north of the Hawaiian Chain. The 82-Ma (29° 10'N, 174° 00'W) and 94-Ma (31° 10'N, 179° 40'W) seamounts (Figs. 17, 18) show relatively classic guyot structures with flat tops and radial ridges representing rift zones (e.g., Vogt and Smoot, 1984). This morphology suggests seamounts formed in a relatively isotropic stress field. Rift zones are not as prominent in the morphology of the guyot surveyed in the southern Emperor Seamounts (Fig. 19). Despite the fact that this seamount is aligned with the Ojin Rise Seamounts, its morphology is distinctly different, implying that it is was either formed by the Hawaiian hotspot as part of the Emperor Chain or is a Cretaceous seamount like the 82 and 94 Ma seamounts.

Ojin Rise Seamounts

Because we had little time to spend in the Ojin Rise Seamount province, it was only possible to map small edifices in limited areas. We found the bathymetry to be quite different from representations on published bathymetric charts owing to the paucity of geophysical ship tracks in the area. Not only are the shapes of seamounts in the chain misrepresented, because each edifice is inadequately sampled, but also the morphology of the seamount chain itself is misrepresented. From our limited sampling of the area and observations that many of the Ojin Rise seamounts are small edifices, we suspect there are many small undiscovered seamounts in the chain.

Figures 20-22 show three small seamounts from the Ojin Rise chain. Two of these were dredged (see Table 3). In morphology, they are very different from the seamounts surveyed near the Hawaiian chain. All are subcircular and have nearly flat, rounded summits. Furthermore, none show evidence of rift zones. These differences imply that their eruption mechanisms are different than those of the other seamounts.

One seamount, from the middle of the Ojin Rise chain (Fig. 21), showed a positive magnetic anomaly which indicates a reversed polarity. This seamount sits nearly atop seafloor magnetic lineation M7, so it must be younger than this (about 132 Ma). Conversely, because it is reversed in polarity, it either formed between M7 and M0 (about 124 Ma) or after anomaly 34 (the Cretaceous Long Normal Superchron) which ended at about 83 Ma. The latter seems unlikely, since thick manganese nodules and crusts were dredged in the Ojin Rise Seamounts. These observations imply that this particular seamount was formed within a short interval of time after the formation of the lithosphere.

North High

At the northern tip of the North High, we surveyed two small seamounts and an intervening trough (Fig. 23). The trough appears to be a graben trending northwest-southeast, approximately parallel to the strike of the Hawaiian magnetic lineations and perpendicular to the Japanese lineations. These lineations are not well defined at this location and the trough is near their intersection, so the graben may be related to rifting at the Pacific-Farallon ridge crest or it may be a fracture zone trough related to spreading on the Pacific-Izanagi ridge. The seamounts that bound the trough appear much different than those in the Ojin Rise Seamounts. These have steeper flanks near their summits and lower slopes on their deeper flanks. One of these seamounts is sub-circular in plan view, whereas the other is elongated parallel to the edge of the trough.

The North High itself has a more complex shape than that shown on current bathymetric charts (compare Figures 24 and 11). Existing representations show the North High summit region as being sub-circular, with one or more smaller peaks nearby to the south. Our initial track across the summit happened to parallel a canyon in the north flank. The summit itself is rounded owing to the presence of a thick pelagic sediment cap which rises to a depth less than 3200 m. The edges are crenulated with reentrants and indentations are seen on the north, east, and west flanks (Fig. 24). The main edifice itself is elongated southwest-northeast and has conical volcanoes on the northwest and south sides (Fig. 24). The southern cone rises to less than 3400 m depth, which is higher than the basement beneath the pelagic cap on the main edifice. Thus, if the flat basement beneath the cap is an effect of sea level erosion, the rounded south cone must have formed later because it does not appear to be eroded.

As the ship sailed southward from the North High towards the Central High, it passed over the seamount shown nearby to the south on some bathymetry charts. The Hydrosweep showed that this seamount is highly elongated with a nearly E-W trend. Later we would find a similar trend to Cooperation Seamount, located between the Central and South highs. These seamounts appear very different than other volcanic features associated with Shatsky Rise.

Central High

Unlike the North and South Highs, the Central High is sub-circular in plan view. However, like the other highs, it also has a thick pelagic sediment cap that rises to a depth slightly less than 3200 m (Fig. 25), like that on the North High. Although most of its flanks are smooth, scarps are seen in places near the base of the flank. We crossed such scarps on the north and west flanks (Fig. 24) and made dredge D8 on a conical feature atop the north scarp. Another scarp, at the edge of what appears to be a basement ridge that protrudes to the NE from the summit, is remarkable in that is has slopes that are locally in excess of 45° on its east side. We made dredge D9 on this scarp.

The summit of the Central high has some small local relief owing to a basement high that outcrops on the summit. We dredged this ridge at the summit, with dredge D10, where there is about 400 m of apparent basement exposed.

On our transit from Central to South high, we crossed and dredged Cooperation Seamount (Fig. 26). This seamount is elongated E-W, has steep slopes, and displays a number of small cones on its flanks. Sedimentary cover atop this seamount is appears negligible. Thus, this seamount is very different in its morphology from other features within Shatsky Rise. Indeed, dredge D11, from this edifice, gave basalts that look much fresher than those from other locales on the rise and with thinner manganese coatings. These clues suggest that this seamount, and perhaps

Figure 14. Ship tracks in the Central High survey area. Dotted lines show hydrosweep bathymetry, at 100-m intervals. Tick marks are at 30-minute intervals. D8-D10 denote dredge locations; C2-C3 denote core locations.

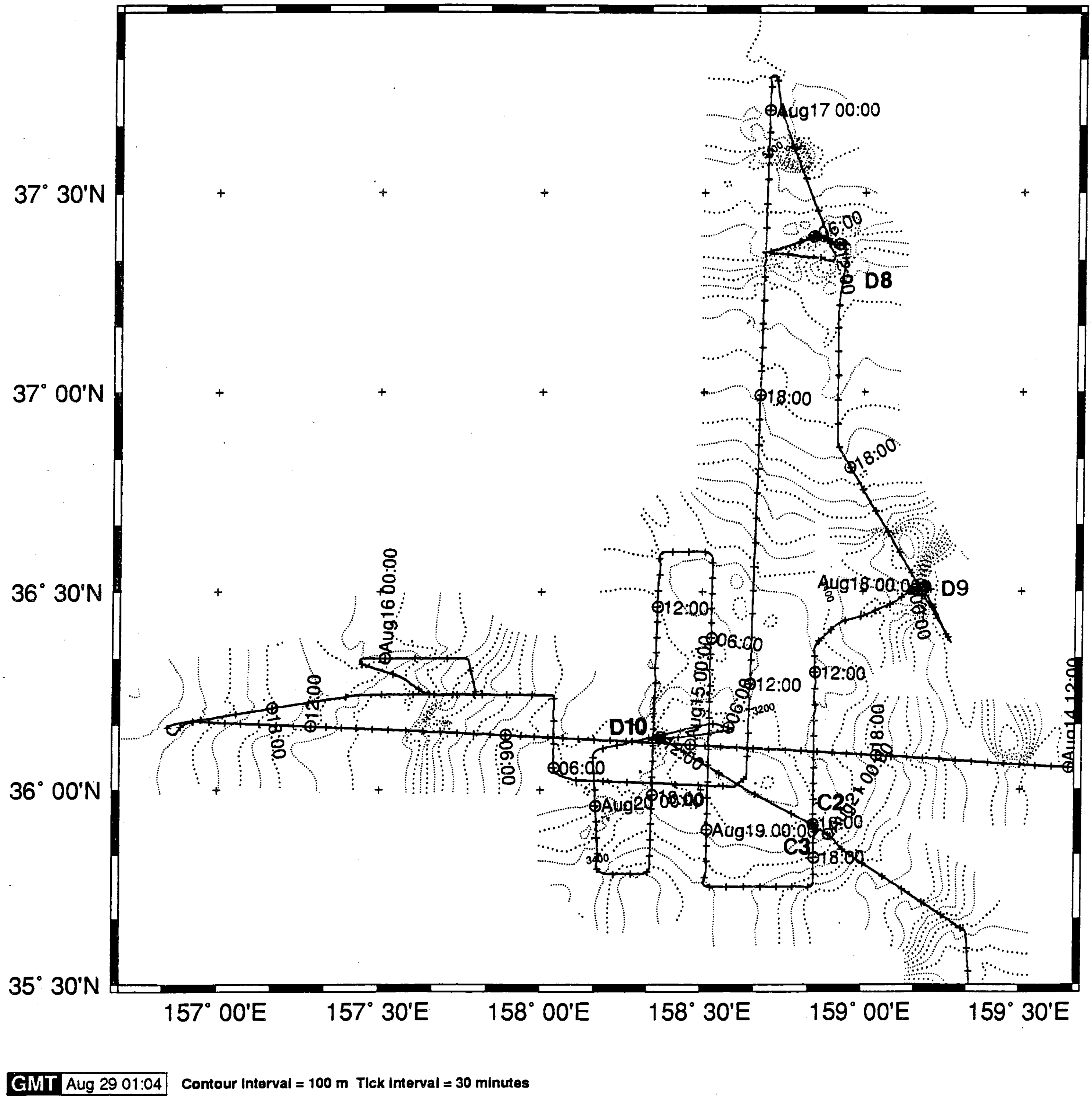


Figure 15. Ship tracks in the southern Shatsky Rise survey area. Tick marks are at 1-hour intervals. Dashed boxes show the areas covered in Figures 11, 12, and 13. Bathymetry contours at 500-m intervals from GEBCO charts. D11 shows dredge location.

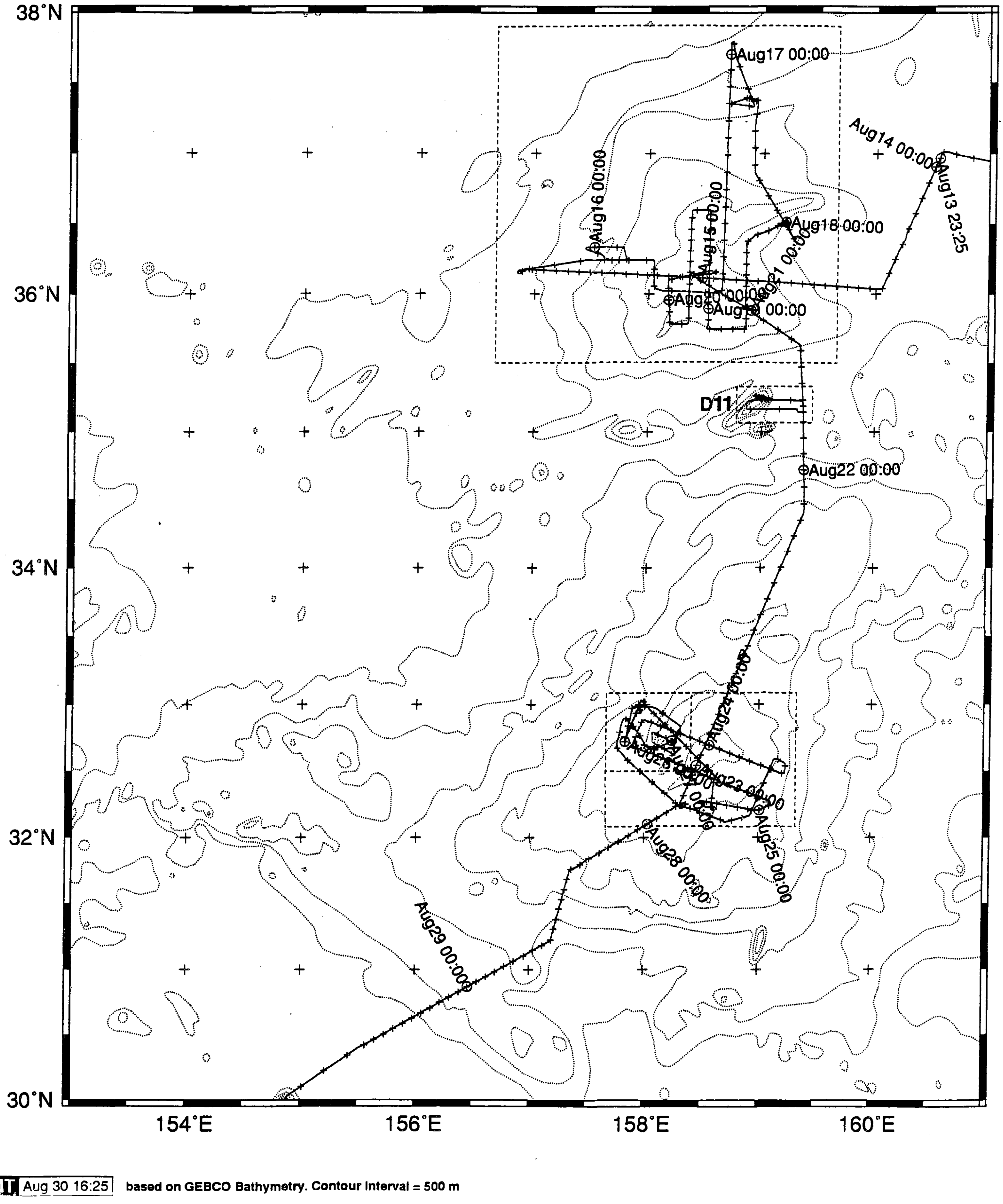
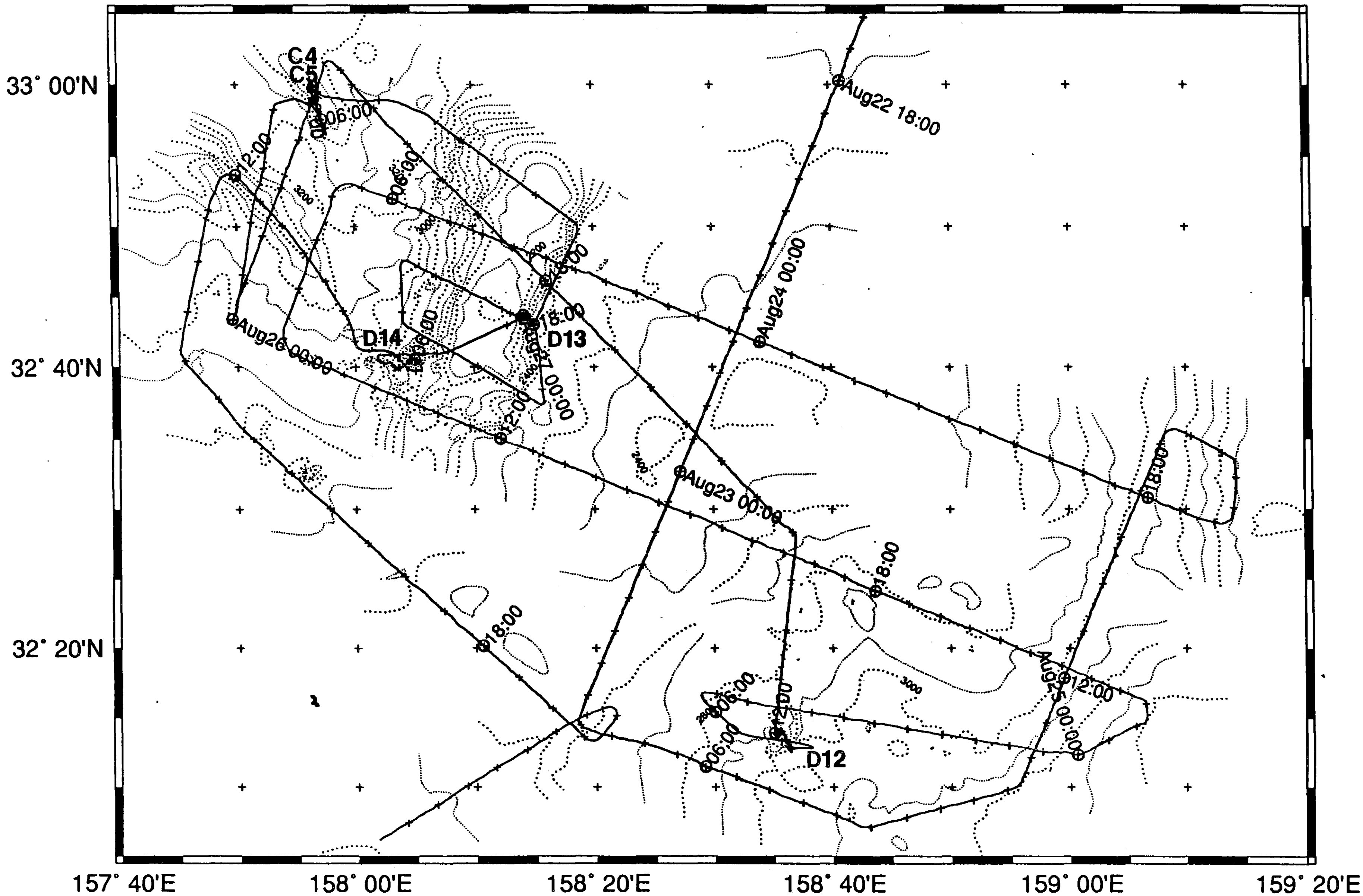


Figure 16. Ship tracks in the South High summit survey area. Dotted lines show hydrosweep bathymetry, at 100-m intervals. Tick marks are at 30-minute intervals. D12-D14 denote dredge locations; C4-C5 denote core locations.



GMT Aug 29 01:06 Contour Interval = 100 m Tick Interval = 30 minutes others, such as the one we crossed near the North High, may have a different origin and may be much younger than the main plateau features.

South High

The South High is elongated southwest-northeast with the summit nearer to the SW end than the other. The ship climbed the north flank to the northeast protruding ridge and then followed it to the summit. The South High summit also has a thick pelagic cap that makes a rounded dome that reaches slightly less than 2400 m depth (Fig. 27). On the east side of the summit, the slope towards the flank is gradual, giving the plateau a rounded shape. Punctuating this slope is a small conical basement pinnacle at about 158° 35'E (Fig. 27). Dredge D12 was taken from the south side of this feature. Around this pinnacle, the contours show a reentrant character, the result of erosion of the some of the upper sediment layers at the edge of the summit.

The west side of the summit has several interesting features. A basement ridge trends nearly N-S on at the west edge of the summit (Fig. 28). At its south end, this ridge dives beneath the sedimentary cover and the northern end was not mapped. In between, the ridge has a flat top and nearly parallel sides. In several locations, small cones are seen on its flanks. Dredges D13 and D14 were taken from this ridge (Table 3). Farther west, two prominent canyons cut through the sediments, trending NW (Fig. 28). Because these canyons begin near the base of the ridge, it appears that they were formed by flows, probably turbidites, emanating from the ridge flank.

After surveying the South High summit, the ship sailed down the southwest flank of the high. Midway down the flank, the sedimentary cover was interrupted by another erosional channel, trending SE. Farther downslope, the rise continued to near abyssal seafloor depths until a low ridge was crossed near 30° 42.5'N, 156° 08.2'E. Southwest of the ridge was apparent abyssal seafloor and undisturbed lithosphere.

During the transit to Guam, we crossed a small seamount southwest of the South High, at 27° 21.4'N, 151° 57.6'E. After that, we steered clear of other seamounts for the next two days to get magnetic anomaly data suitable for tracing the magnetic lineations in the area. We crossed the Mariana Trench at about 0100Z on 2 September, near 18° 45'N, 148° 06'E, where the depth was about 7900 m. After that the ship proceeded up the trench inner wall towards the Mariana Islands.

Seismic Reflection Data

Seismic line times and locations are given in Table 1.

Line 1

North of Hawaiian Ridge; 25-26 July

Line 1 was a short test line to evaluate the performance of the streamer and GI-airgun. The system produced usable data up to 10 kt, but the data at the faster speed was clearly of lesser quality than those taken at slower speeds.

Line 2

Ojin Rise Seamounts; 6 August

Line 2 was an 8-hour transect across a cluster of seamounts in the western Ojin Rise Seamounts province. It was shot with the GI-airgun at a speed of 7.3 knots, the speed necessary to achieve 2-fold coverage. This was the target speed for all lines on the cruise shot with this source. The profile shows the summit of Victoria Seamount (Russian name), which appears to have a domal pelagic sediment pile and has a morphology similar to carbonate guyots. Most of the rest of the line shows slumped sediments on the platform upon which the seamounts rest. A small seamount rises from the north side of the platform.

Line 3

Shatsky Rise Northern Arm; 7-8 August

The junction of the Northern Arm and northern flank of the North High is the location of the survey contained in Line 3. This line was shot with the GI-gun as the ship made a zig-zag pattern back and forth across the Northern Arm and the trough between it and the North High (see Fig. 23). On the approach, about 0.4 sec of sediments were seen; the sequence appears to be a relatively transparent layer overlying an acoustically reflective layer with one prominent reflector within. It is not clear whether this reflector is real or an artifact of the seismic system (some sort of short-path multiple). With a turn to the NW, the line runs across the Northern Arm, showing a platform rising approximately 1 sec above surrounding basement, surmounted by two small seamounts 0.5-0.8 sec in height (Fig. 29).

After crossing the Northern Arm, the line turns to the SW, crossing the trough at 1630Z on 7 August. Sediments fill the trough and the diffraction of seismic energy from its walls suggests normal faults, so the trough appears to be a graben. This graben is parallel to the Hawaiian magnetic lineations and nearly perpendicular to the Japanese lineations, so it is probably related to the formation of the lithosphere via seafloor spreading. On the south side of the trough, the track returns to the SE, crossing Earthwatch Seamount, which rises to approximately 4.8 sec TWTT at 1915 Z on 7 August. At the base of the seamount's flanks, tilted fault blocks are observed, buried beneath a thin layer of sediments. Sediment thickness atop this part of the volcanic ridge is thin and variable. After doubling back over Earthwatch Seamount, the track crosses the trough again and the seismic line ends on the north side of the easternmost seamount on the North Arm, crossed on the first pass across the ridge. About 0.4 sec of sediments are observed atop this ridge.

Line 4
Northern Shatsky Rise North High; 9 August

Line 4 is the transit from the northern flank of the North High to the vicinity of the North High summit, shot using the GI-airgun. The beginning of the line shows a typical lower slope stratigraphy, with an upper transparent layer containing sparse internal reflectors, and a lower, acoustically reflective layer overlying basement. Usually a strong reflector is seen within this layer, approximately 100 msec above the terminal reflector. The similarity of the two reflectors suggests that the upper one is probably volcanic basement and the lower may be an artifact. The upper transparent layer and the lower reflective layers both display variable thicknesses; the upper layer appears to have responded to currents, whereas the bottom layer seems to have filled depressions or collected at the flanks of topographic highs. Within the upper transparent layer, two main reflectors are observed; these may be correlated to similar mid-Cretaceous layers seen at the summit of the South High, denoted R1 and R2 (Sliter and Brown, 1993).

Although it has a number of basement irregularities, the northern flank of the North High is relatively flat-lying from the beginning of the line to 0830Z on 9 August. After that, there is a significant increase in slope, with the flank rising toward the summit. At 1030Z on 9 August, the sedimentary section is about 0.8 sec thick and apparent reflectors are observed within basement, dipping outward from the summit. The lower, acoustically reflective layer is well-developed at this location on the flank, exceeding 0.5 sec in thickness and containing internal reflectors. Two types of basement high are seen on this line: (1) a conical feature, about 0.8 sec high, extends through the sediments at 1210Z on 9 August and (2) a broad dome covered with sediments, about 8 km across and 0.2 sec high observed at 1400Z on 9 August. Interestingly, the lower reflective layer stays nearly the same thickness and is arched over the dome, whereas the overlying transparent pelagic sediments onlap the dome and are thin atop it.

Line 5
Summit of North High; 9-11 August

Line 4 was terminated as the summit of the North High was approached so that the summit seismics could be shot with the 4-airgun array. After the GI-airgun was turned off, the ship sailed in a circle while deploying the array, so that the next line would begin overlapping the old line. This was the deployment routine for switching seismic sources during the cruise.

Line 5 was the first on the cruise shot with the 4-airgun array. The target speed used for this line was 4.9 knots, the speed which would give 3-fold seismic coverage. We attempted to use this same speed for all lines shot with the same source.

Smt 2

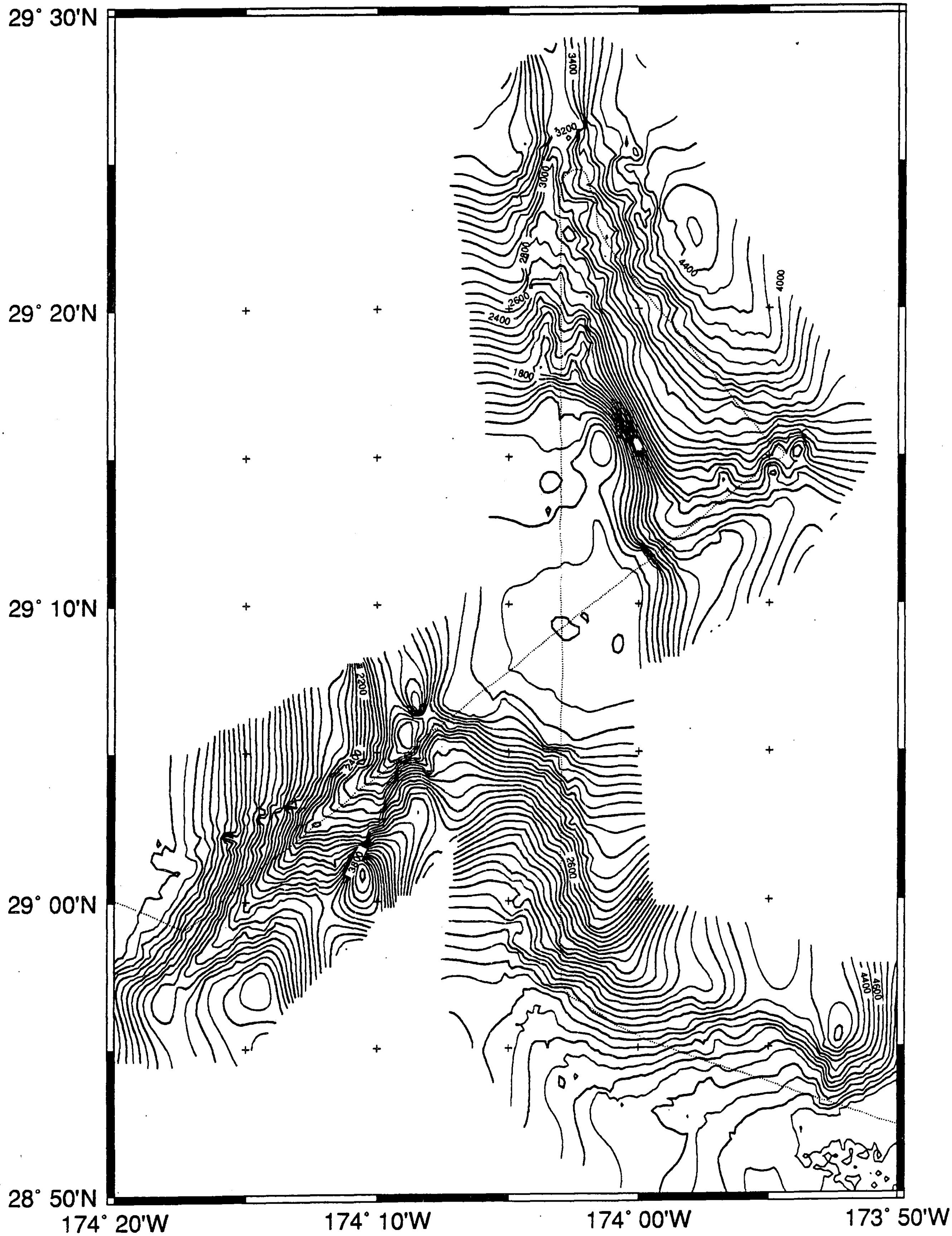


Figure 17. Hydrosweep bathymetry of 82-Ma guyot north of the Hawaiian Chain. Contour interval is 100 m. Light gray line shows ship track.

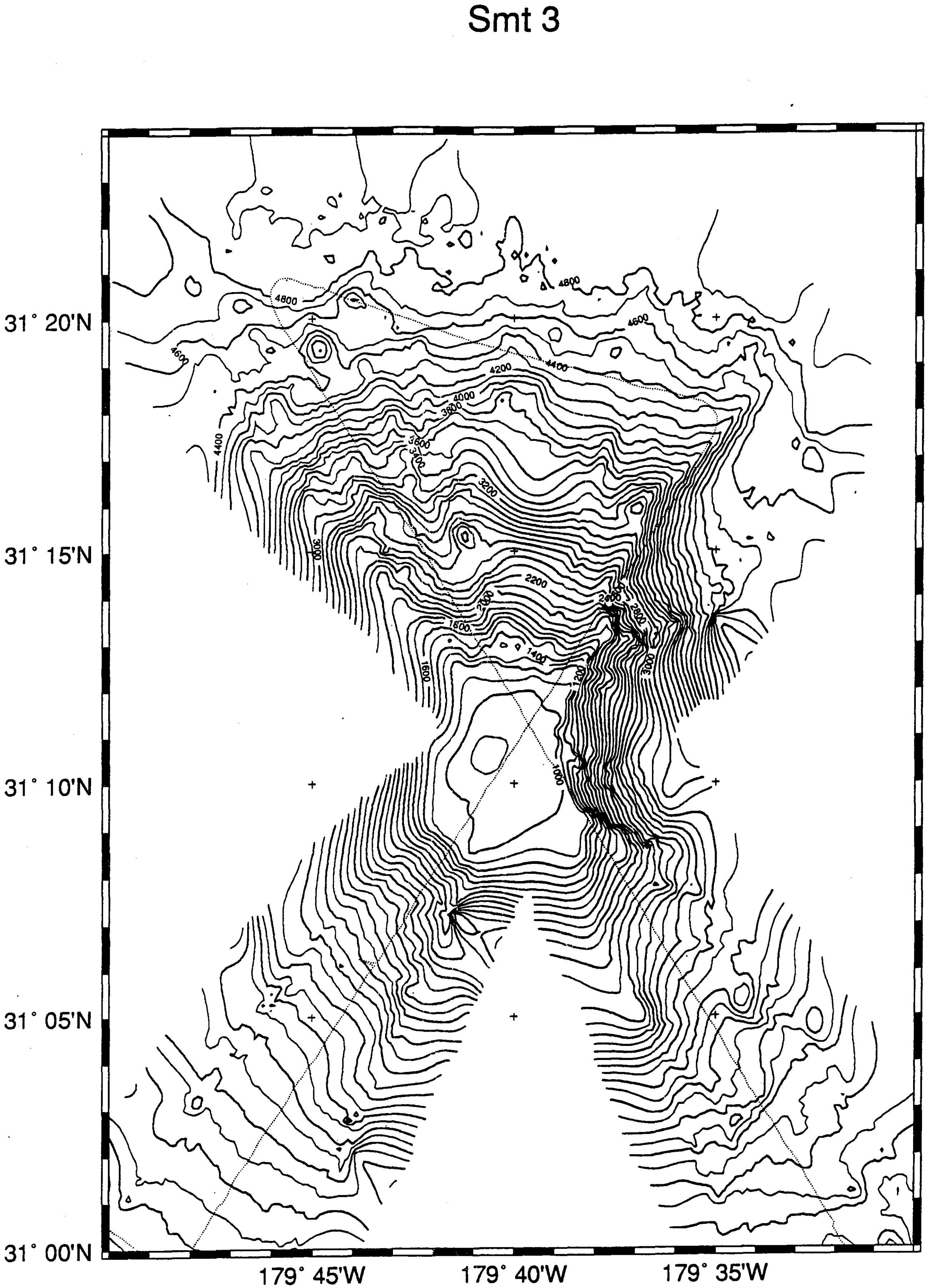


Figure 18. Hydrosweep bathymetry of 94-Ma guyot north of the Hawaiian Chain. Contour interval is 100 m. Light gray line shows ship track.

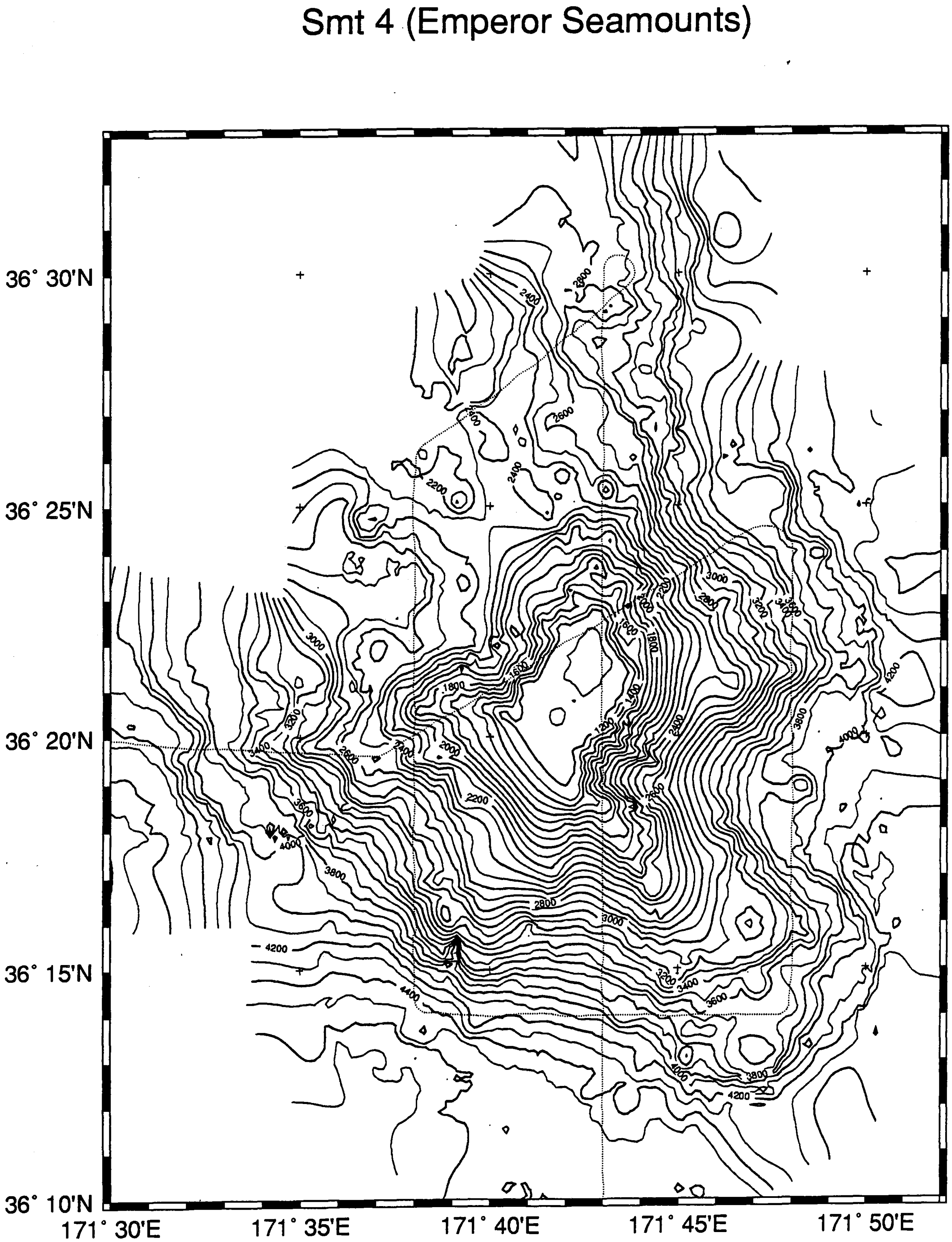


Figure 19. Hydrosweep bathymetry of small guyot in the southern Emperor Chain. Contour interval is 100 m. Light gray line shows ship track.

Figure 20. Hydrosweep bathymetry of a small seamount in the eastern Ojin Rise Seamounts. Contour interval is 100 m and light gray line shows ship track. Dredge D1 was obtained from this seamount (Table 3).

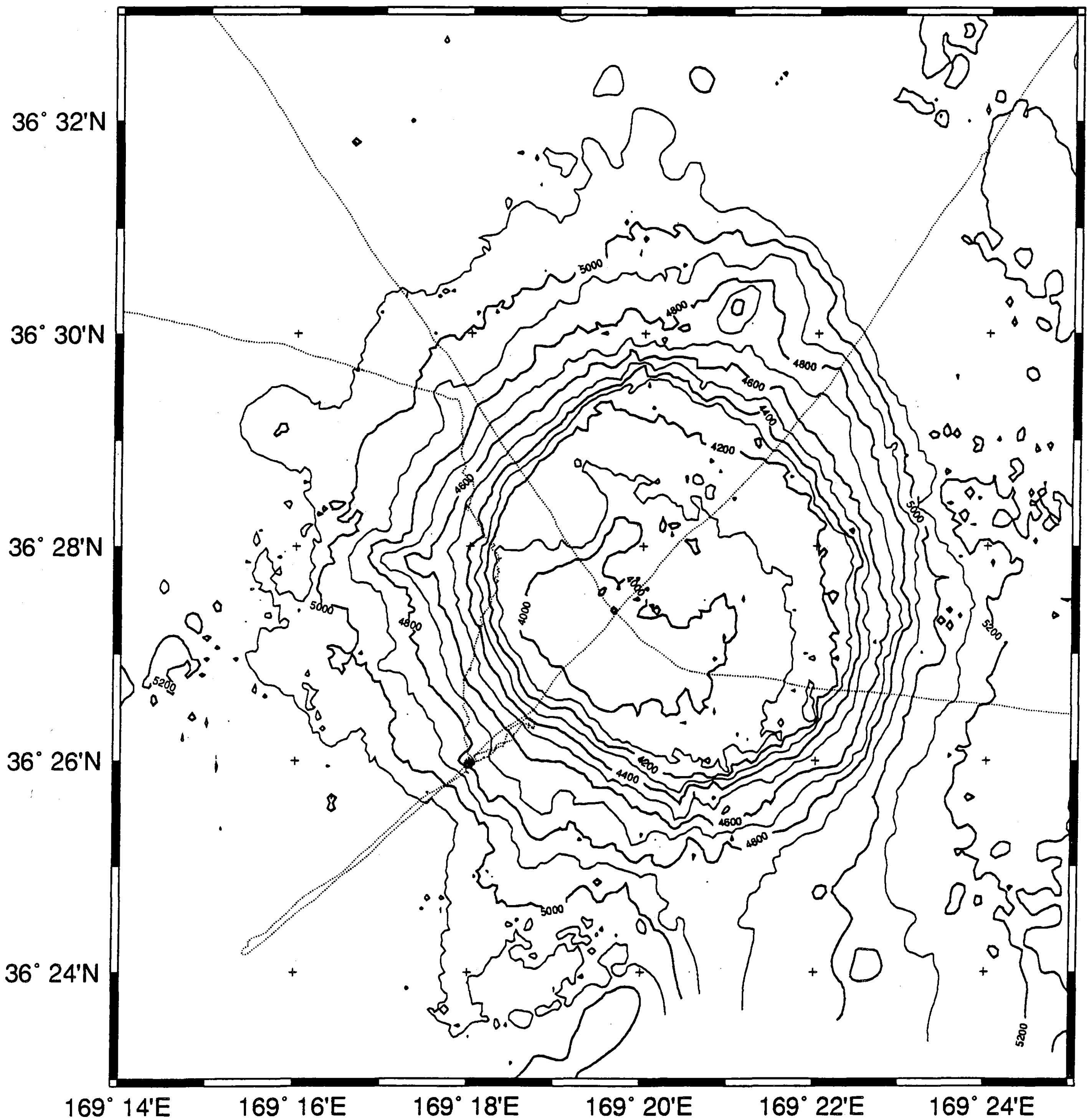


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Figure 21. Hydrosweep bathymetry of a small seamount in the central Ojin Rise Seamounts. Contour interval is 100 m and light gray line shows ship track.

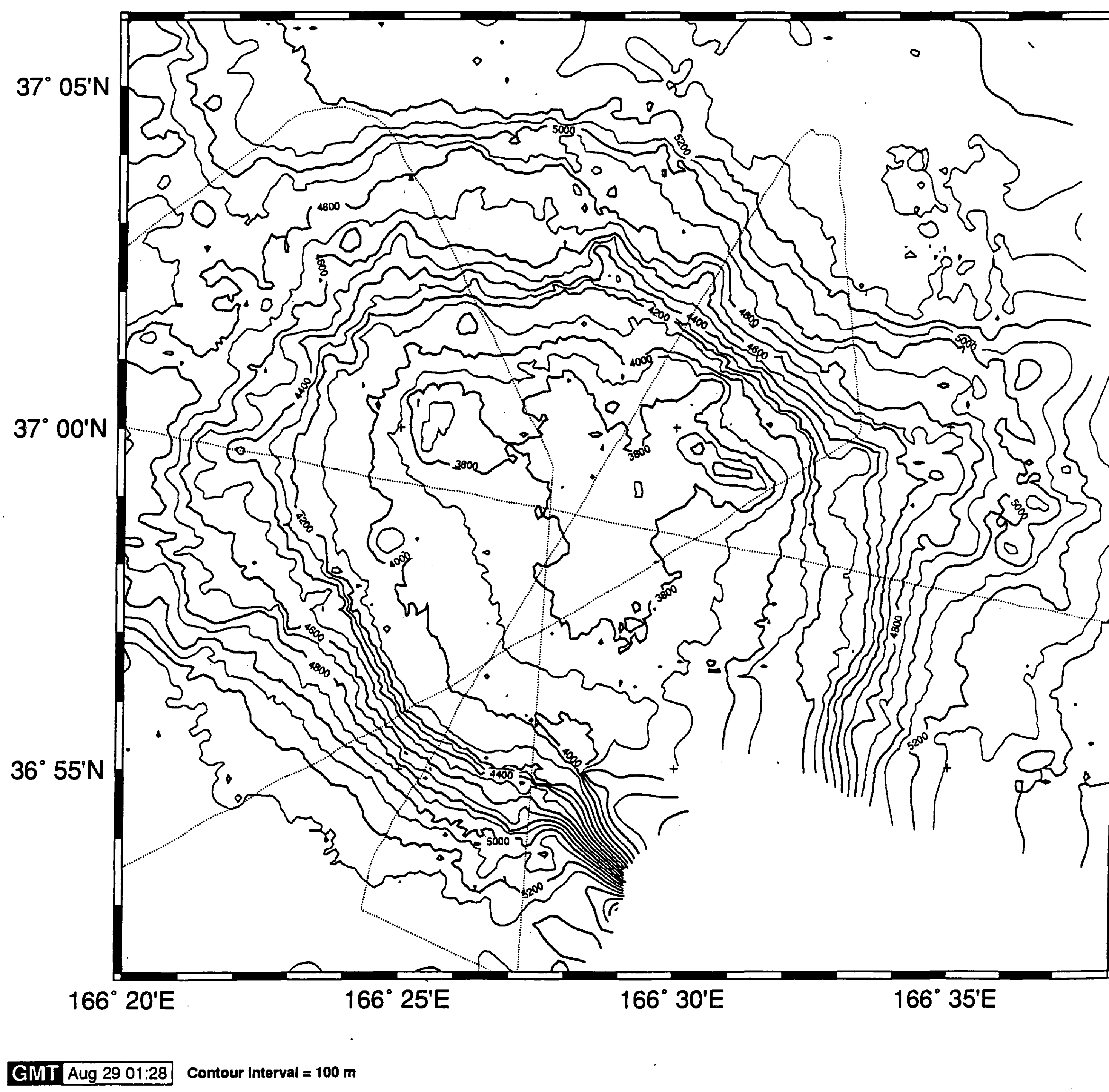

Figure 22. Hydrosweep bathymetry of a small seamount in the eastern Ojin Rise Seamounts. Contour interval is 100 m and light gray line shows ship track. Dredge D2 was obtained from this seamount (Table 3).

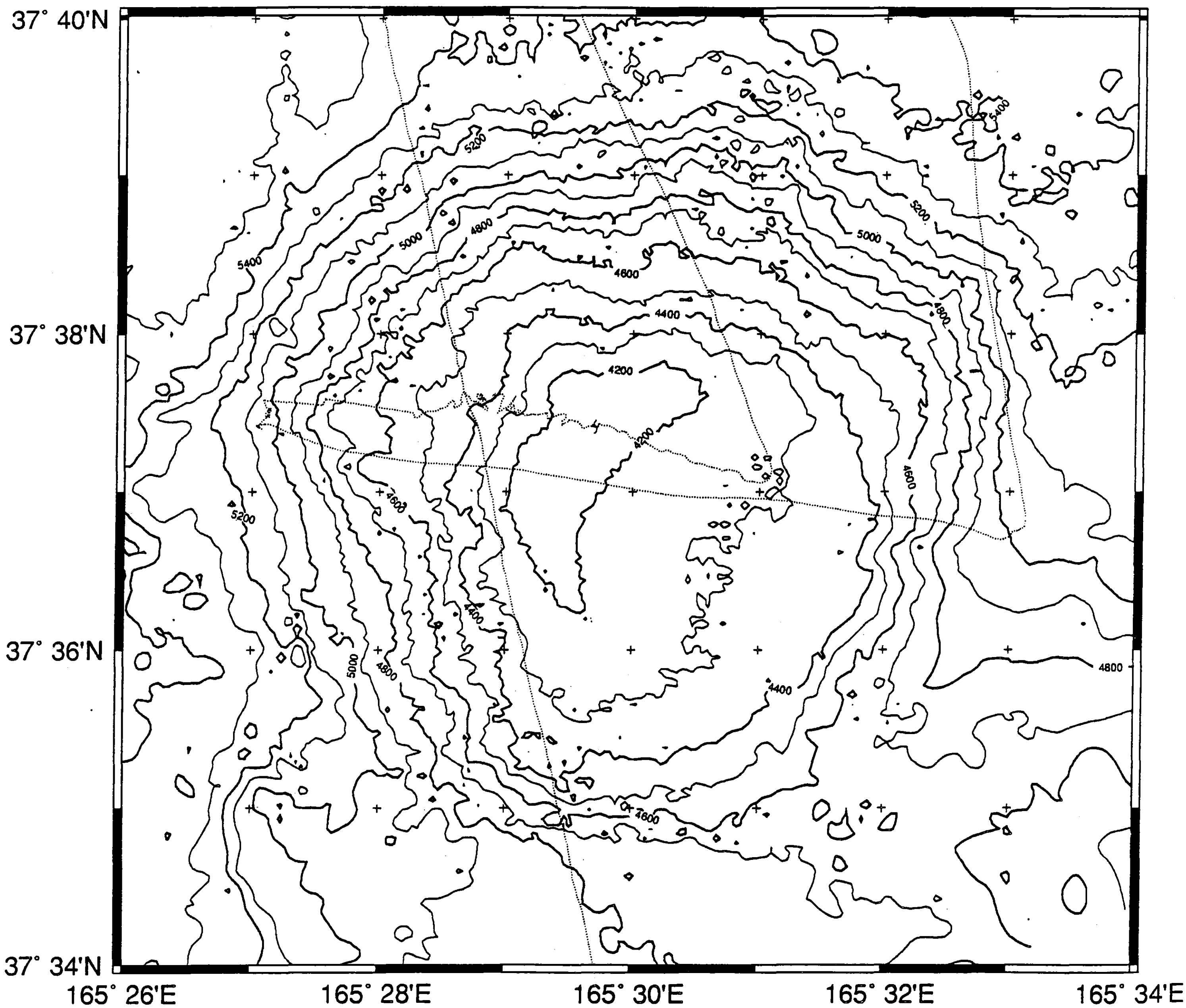

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Figure 23. Hydrosweep bathymetry of the northern tip of the North High, showing two seamounts and an intervening graben. Contour interval is 100 m and light gray lines show ship tracks.

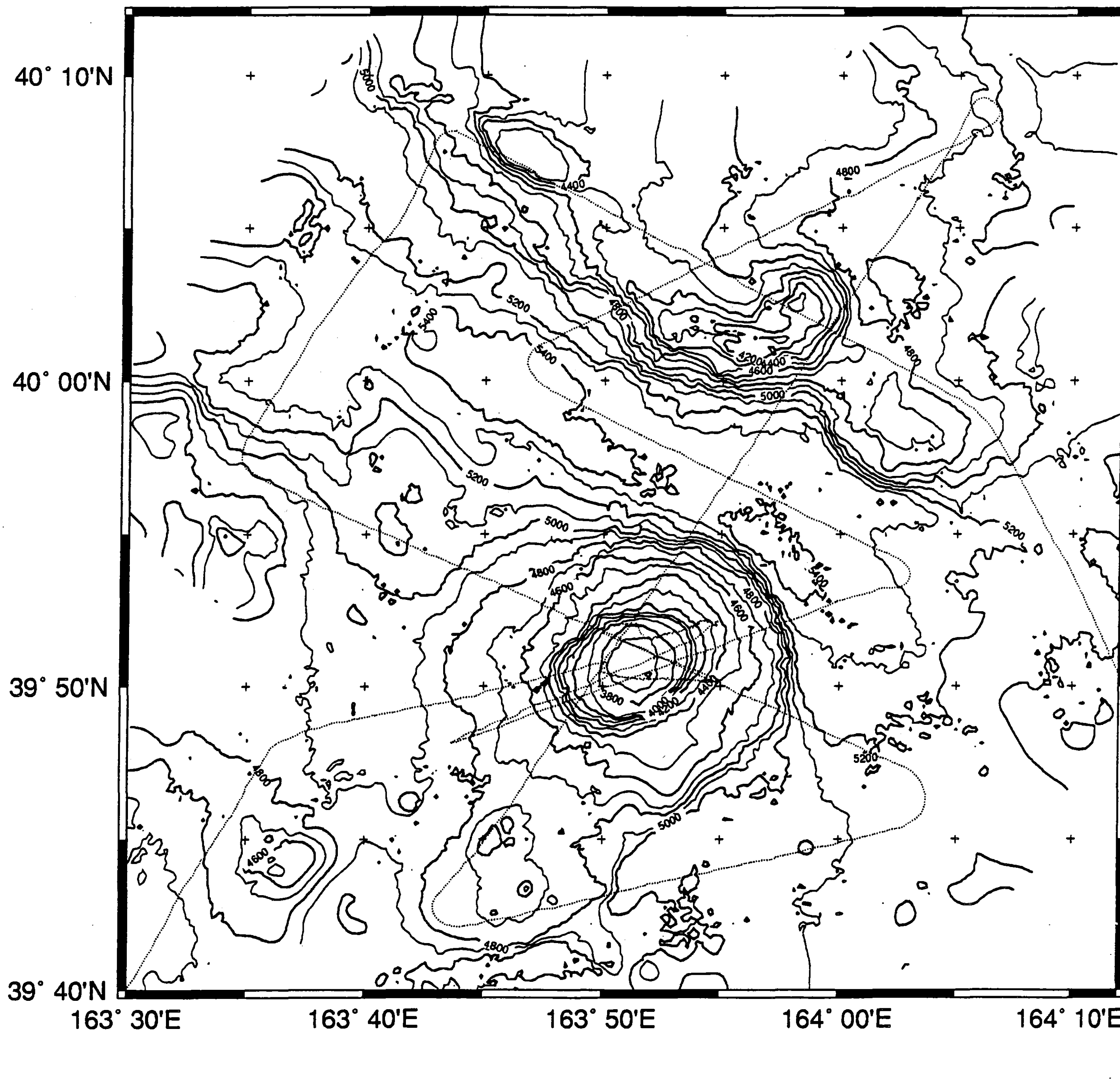


Figure 24. Hydrosweep bathymetry of the North High summit region. Contour interval is 100 m and light gray lines show ship tracks.

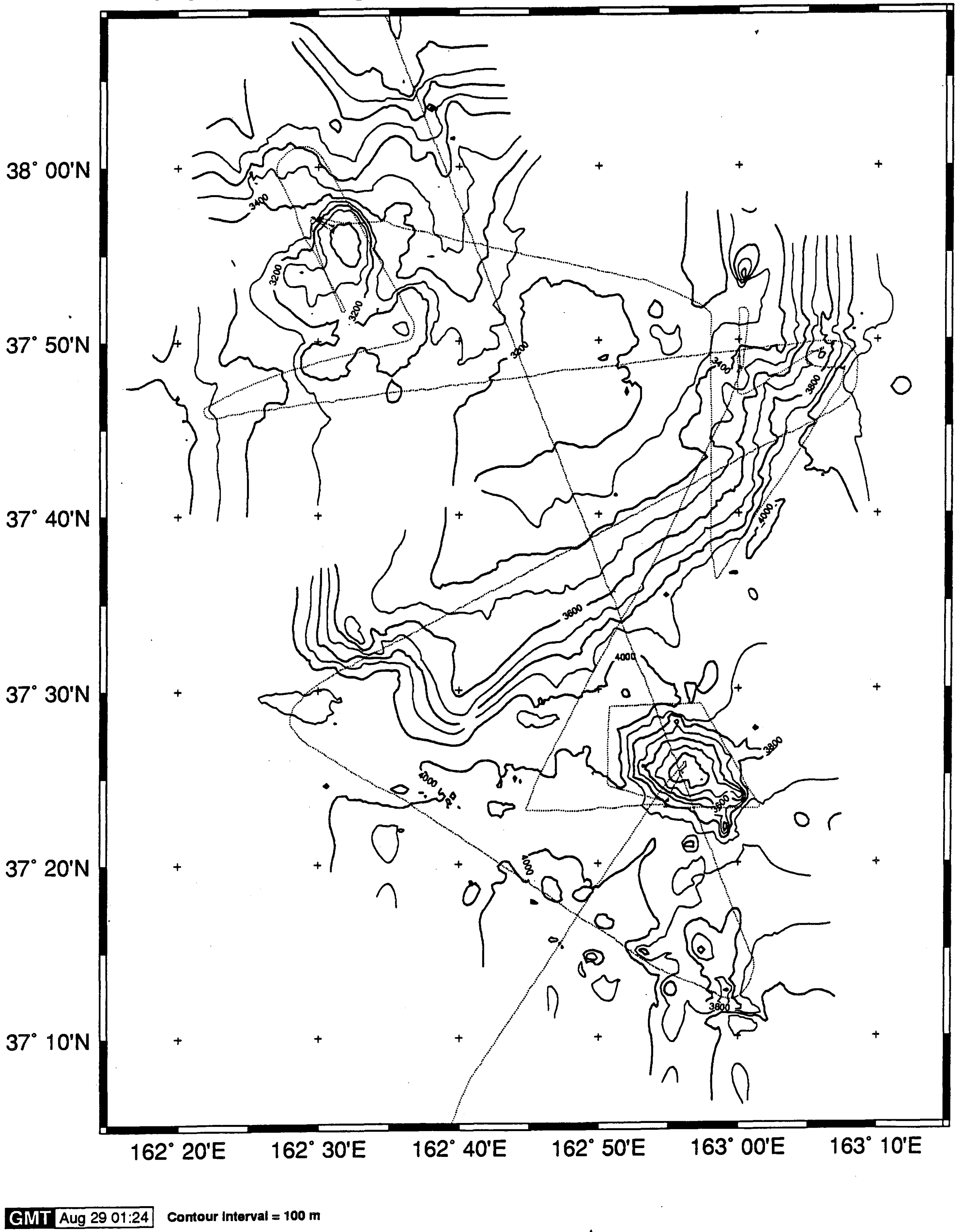


Figure 25. Hydrosweep bathymetry of the Central High summit region. Contour interval is 100 m and light gray lines show ship tracks.

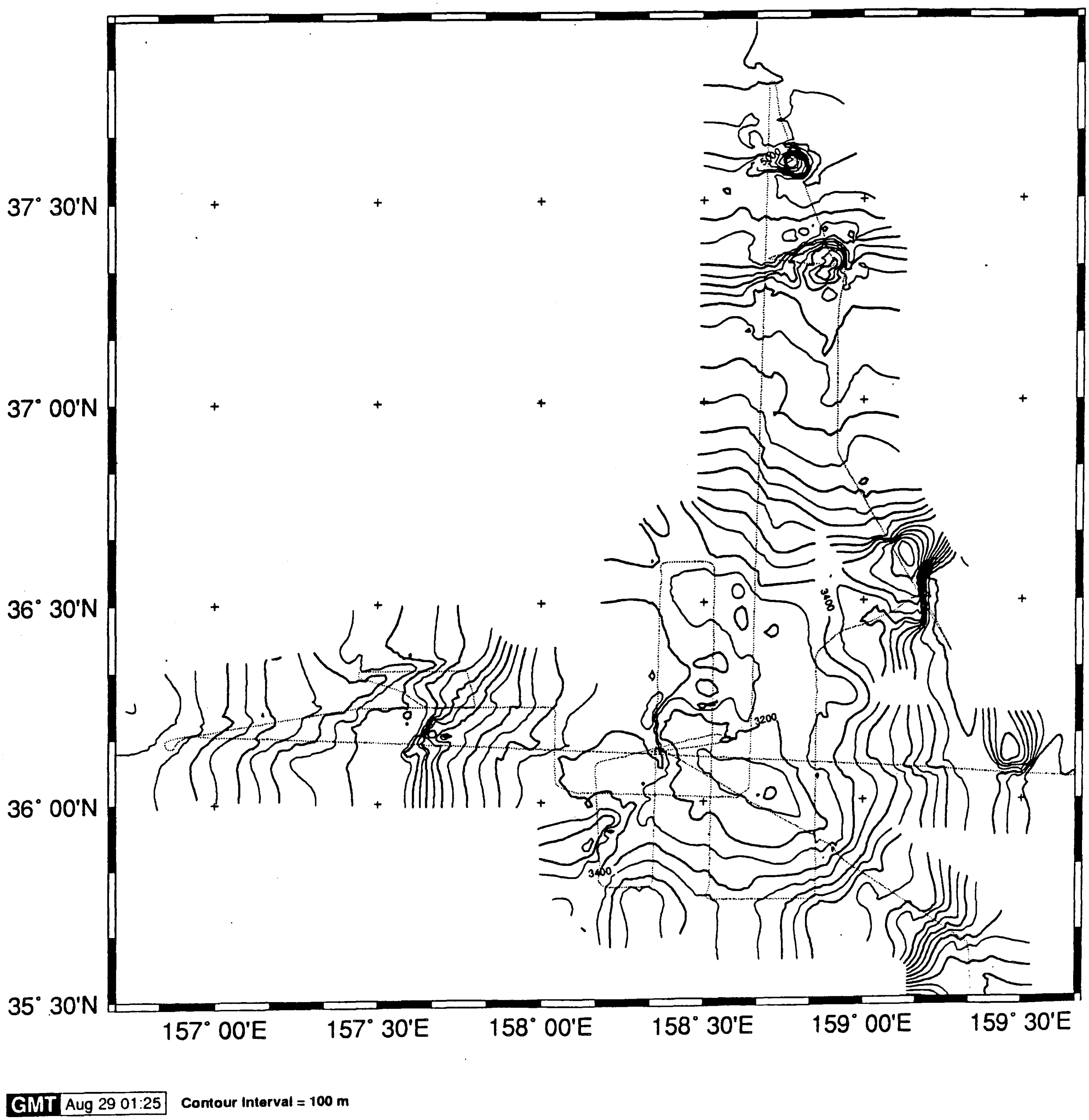


Figure 26. Hydrosweep bathymetry of Cooperation Seamount, located between the Central and South highs. Contour interval is 100 m and light gray lines show ship tracks.

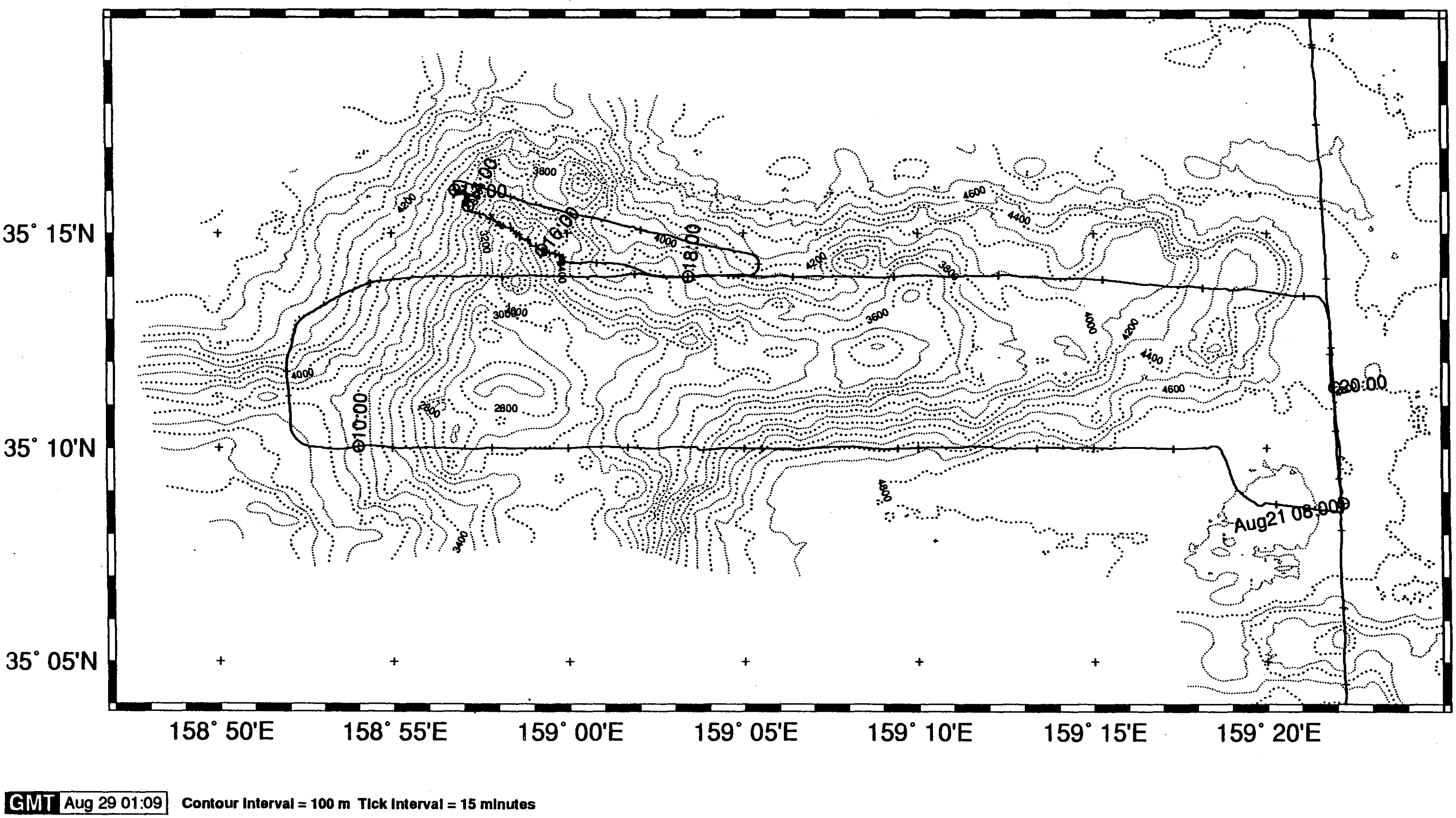


Figure 27. Hydrosweep bathymetry of the South High summit region. Contour interval is 100 m and light gray lines show ship tracks.

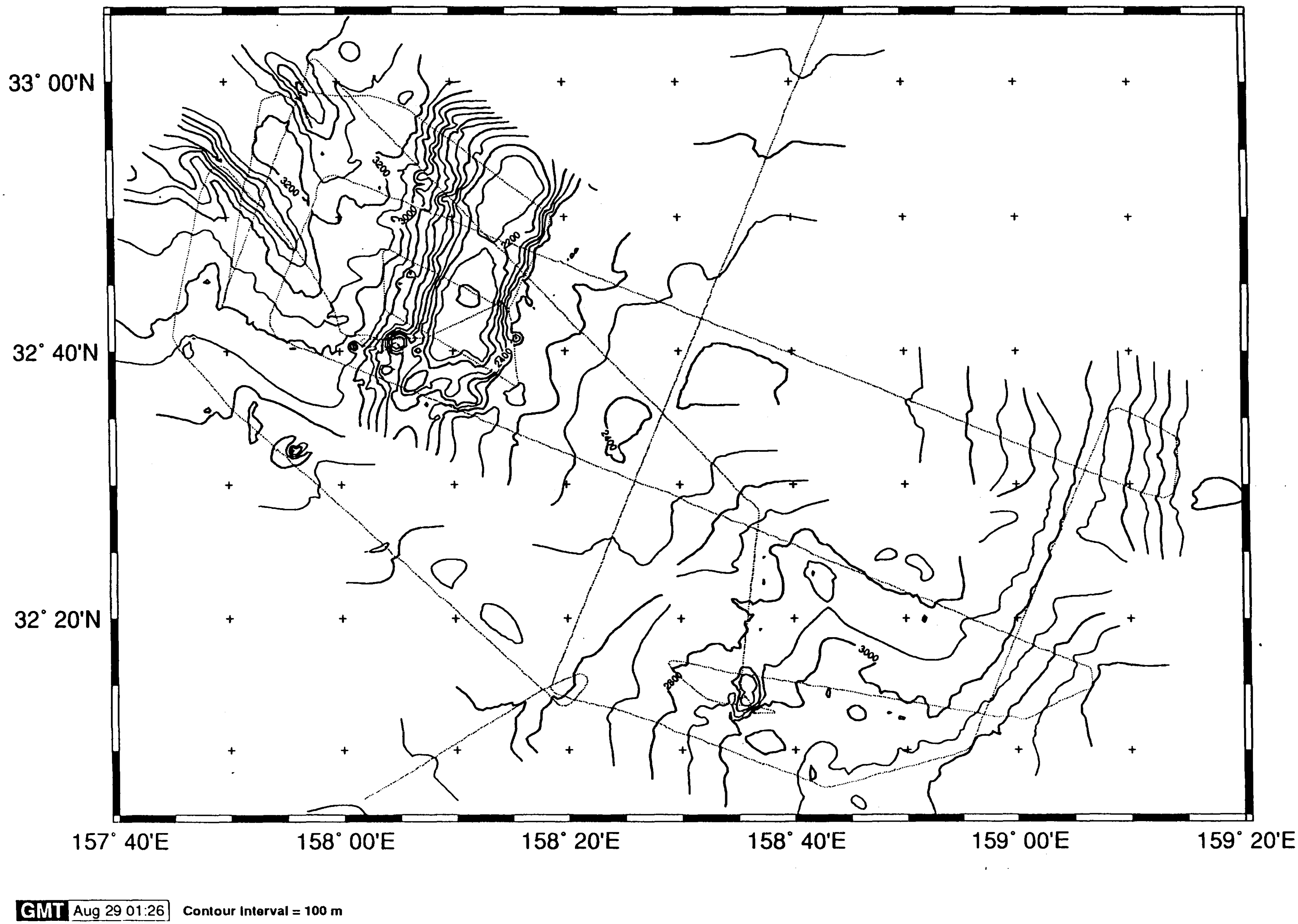
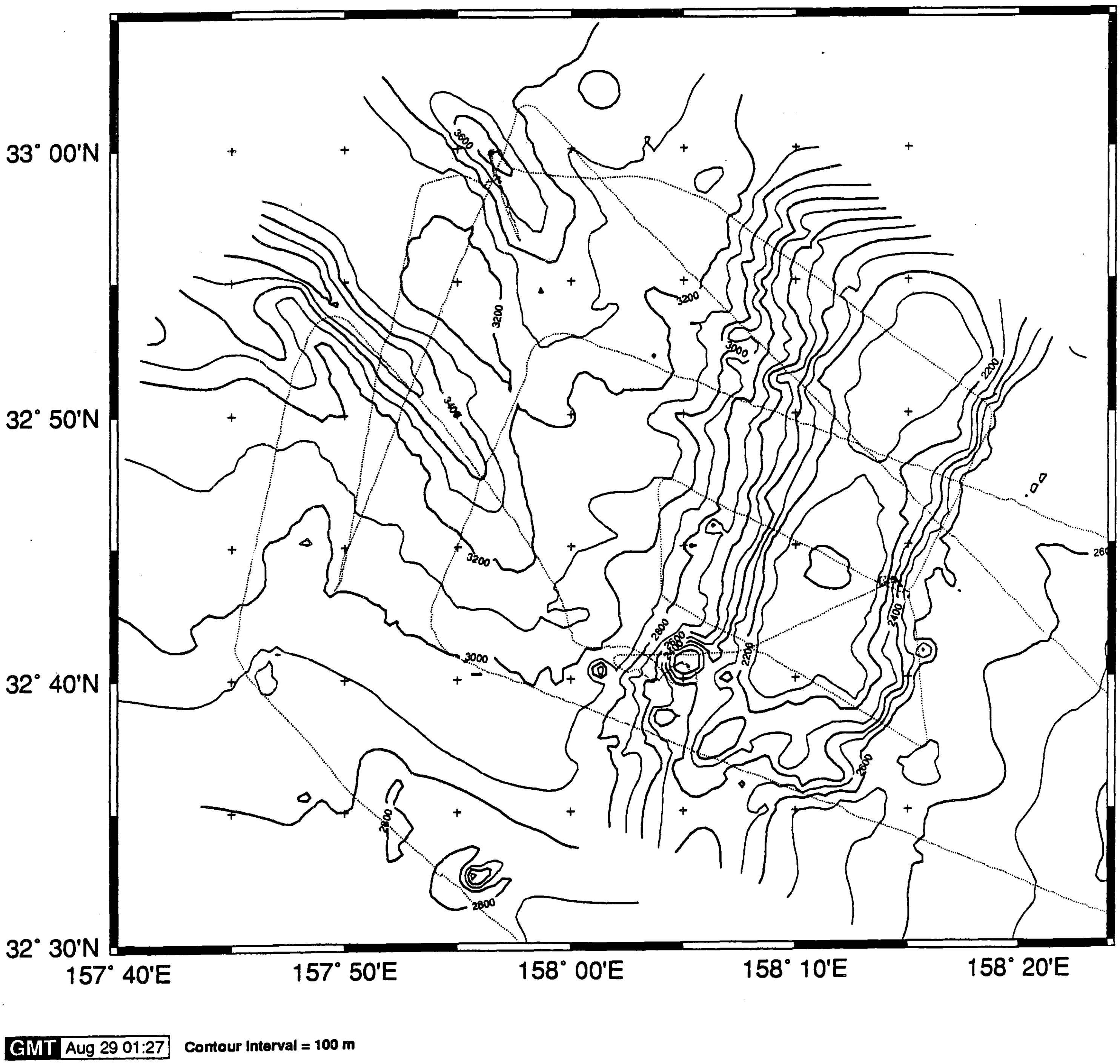


Figure 28. Hydrosweep bathymetry of the western part of the South High summit region, showing the western ridge and erosional canyons. Contour interval is 100 m and light gray lines show ship tracks.



The line runs south-southeast up the north flank of the North High, passes over the North High summit, extends to the south of the summit, and then doubles back with two lines trending more-or-less east-west over the south edge of the summit and the center of the summit. This survey was designed to obtain two crossing lines across the summit where sediments are thickest and also where relatively thin (see Figs. 10 and 13).

At the beginning of the line, basement rises and the upper transparent and lower reflective layers both thin up to a scarp at 2035Z on 9 August. The Hydrosweep swath bathymetry showed that the ship accidentally ran up a channel on the north side of the summit. The apparent scarp is likely seismic energy returned from the conical feature protruding from the north flank about 8 km west of the shiptrack (Fig. 24). This patently demonstrates a problem with seismic data: the seismic waves cover a large area and local topography offline can cause misinterpretations of the topography beneath the ship.

Crossing the summit, a broad dome of relatively transparent sediments is seen, with a thickness up to 0.8 sec at 0030Z on 10 August (Fig. 30). No lower reflective layer is observed atop the North High. The basement on this crossing is remarkably flat, as if it had been eroded at this level by subaerial exposure. Within the transparent sediments, many internal reflectors are observed (Fig. 30). A general five-layer seismic stratigraphy was observed: (1) a lower transparent layer about 0.08 sec thick, restricted to the center of the summit; (2) a layer with internal nearly flat-lying reflectors, about 0.20 sec thick, (3) a thin upper transparent layer about 0.10 sec thick, (4) an upper layer with internal reflectors, about 0.25 sec thick, and (5) an upper layer with reflectors draped over topography. The upper transparent and reflective layers both appear eroded on the edges of the summit and overlain by the upper drape layer, which shows some evidence of slumping or reworking by currents.

To the south of the North High summit, the line crossed a seamount (0515Z 10 August) with little sediment cover that rises about 0.6 sec above the level of the buried flat surface of the North High summit. This suggests either that the flat surface was not formed by subaerial erosion or that the seamount post-dates the subsidence of the North High.

On the southwest side of the North High summit, the profile probes deeper sediments on the flanks of the edifice. Here penetration is about 0.5 sec (1200Z 10 August), and a five-layer stratigraphy is also seen, albeit with somewhat different characteristics than on the summit. The reflective layers do not have internal reflectors with the same degree of continuity; the upper transparent layer is not clear, and the upper reflective layer is more irregular and gives stronger reflections. It is unclear whether this stratigraphy is the same as that of the summit or whether the similarity is a coincidence.

The second pass over the summit is at the south edge of the sediment pile, so the same summit stratigraphy is observed, but condensed from that of the first pass. At the beginning of the third pass over the summit, an erosional scarp was noted (0040Z 11 August). The scarp is about 0.15 sec tall and is a result of the upper layers being removed by channel erosion. A potentially good drill site is located about 4 km east of this scarp, where basement rises at the edge of the summit platform and only thin sediments onlap basement (0010Z 11 August). At 0430Z 11 August, the profile crosses a large basement high that protrudes through the thick pelagic cap. This basement feature may be related to the conical construct located on the north flank of the North High edifice (see Fig. 24). Line 5 ends approximately 8 km after crossing this feature.

Line 6

Summit of North High; 11-12 August

Line 6 was a short (4.5 hour) line shot in transit from the dredge site on the north flank of the North High summit to the dredge site on the southeast side of the summit. The line was shot with the GI-airgun. It shows the same sediment layers observed previously on the summit, with notable irregularities in the upper two layers. On this line, the lower reflective layer and the bottom of the upper reflective layer look like single, diffuse reflectors, which may be correlatable to the R1 and R2 reflectors mapped on the South High summit (Sliter and Brown, 1993). At 2230Z on 11 August, the track crosses a basement pinnacle that barely protrudes through the sediment cap. At the end of the line, the erosional scarp is profiled once again.

Line 7

Transit from North High to Central High; 13-14 August

After completing dredge D7 on the seamount south of the North High summit, the GI-gun was deployed to shoot a transit seismic line between the North and Central highs. Leaving the North High, 0.4 sec of sediments were observed overlying basement. At 0630Z on 13 August, the ship crossed another seamount, this one uncharted, which has a distinct E-W trend, similar to Cooperation Seamount (located between the Central and South highs). Between this seamount and a smaller seamount feature at 1430Z 13 August, about 80 km to the southwest, basement is rough and overlying sediments are variable in thickness. After crossing the 1430Z seamount, basement becomes nearly flat lying again, with 0.4 sec of sediments. At 1800Z 13 August, for example, the sedimentary section consists of a relatively transparent lower layer of about 0.2 sec thickness overlain by a reflective layer of about 0.12 sec thickness and an upper transparent layer of 0.08 sec thickness. The bottom of the reflective layer appears as a strong reflector itself.

Progressing toward the Central High, basement gradually becomes deeper and the sediments thicker. Basement is generally flat, but a few small basement highs are observed. By 0000Z on 14 August, the seafloor is at 6.45 sec and basement is 0.6 sec beneath that. Although the seismic layering is the same, except that the reflector at the bottom of the reflective layer has disappeared, all layers have increased in thickness. At 0400Z on 14 August, just before the edge of the Central High was reached, the sediments are 0.8 sec thick, with a 0.3 sec lower transparent layer, a 0.2 sec reflective layer, and a 0.3 sec upper transparent layer (Fig. 31).

At 0545Z 14 August, a basement high at the edge of the Central High was crossed. Basement rises towards the high and the lower transparent layer pinches out. Over and around the basement high, the upper transparent layer is thinned as well. At the end of the line, 0730Z-0800Z 14 August, seaward-dipping reflectors are observed within basement, probably showing lava flows on the flank of the high.

Line 8

Transect across Central High; 14-15 August

Line 8 is an east to west transect across the Central High shot with the 4-airgun array. Seaward dipping reflectors within basement are noted at the beginning of the line. At 1330Z 14 August, the Central High slope begins in earnest with a scarp about 0.4 sec high. Behind the scarp, basement is shallow with variable thickness sediments. From 1430Z to 1700Z, the sediments are only about 0.2 sec or less in thickness and show an undulating surface that more or less follows basement. After 1730Z on 14 August, the pelagic cap thickens. The entire cap on this part of the Central High is relatively transparent with many internal reflectors. Notable among them is a strong set of reflectors about 0.05 sec in thickness that seems to divide the cap into lower and upper layers. Whereas the upper layer thickens and then thins toward the summit in a regular way, the lower layer is much more variable; it fills depressions, pinches out against basement, and may be truncated at the strong reflector between layers, as if there were erosion between the deposition of the two.

The profile reached the shallowest point on this line at 2335Z 14 August. Beneath the sediments at this location, a basement high rises toward the surface and outcrops at 0055Z (Fig. 32). At the shallowest point, the upper sediment layer shows structure that appears like a sediment drift (Fig. 32). To the west of the shallowest point is a channel, bounded partly by the basement high, where the uppermost sediments have been removed by erosion.

To the west of the summit, the line shows sediment layers much like those on the east side. A thick package of sediments is observed from 0130Z to 0330Z 15 August. At this location a lower layer hugs the basement, which is bowl-shaped, and an expanded upper layer is almost flat-lying. A restricted layer of transparent sediments is noted in between from 0235Z to 0305Z. The bottom of the upper layer is more reflective than the other layers, similar to the situation seen elsewhere on Shatsky Rise and its flanks. Farther to the west, the upper layer is variable in thickness, as if it has been modified by currents. It eventually disappears by 0640Z 15 August, leaving the lower layer outcropping. This layer thins until 0845Z 15 August, where the edge of the upper Central High edifice is marked by a scarp about 0.6 sec high. Farther west, basement still deepens by more than 0.8 sec from 0845Z to 1530Z 15 August (a distance of about 60 km), but the sedimentary sequence atop basement is resembles that on the deep eastern flank. This sedimentary sequence is about 0.5 sec thick and consists of a thin lower transparent layer, a middle reflective layer, and an upper transparent layer.

Line 9

Central High west flank, summit and north flank; 15-17 August

After recovering the 4-airgun array at the end of Line 8, the ship was turned about and the GI-airgun deployed for Line 9, a profile back to the summit and thence to the north flank (Fig. 14). A drive failure at 2128Z 15 August caused the line to be stopped for several hours. At 0150Z on 16 August, the ship began the seismic line again, overlapping the short previous segment. Line 9 initially runs to the north of and parallel to Line 8 (Fig. 14), but to make a grid of summit seismic lines and to provide crossings of Line 8, the profile was run to the south of Line 8 for about 20 km. This yielded two intersections of lines 8 and 9 (Line 9: 0525Z and 1040Z 16 August; Line 8: 2210Z 14 August and 0420Z 15 August).

Proceeding toward the summit, similar sediment packages are observed as on Line 8. Between 0330Z and 1000Z on 15 August, the profile shows a series of four basement highs. Between the highs the sediment layers are expanded in the lows. Typically this occurs by the thickening of the lower layers. As before, the section consists of a lower transparent layer, a middle reflective layer, an upper transparent layer, and an uppermost layer with many reflectors which seem to show uneven sedimentation. On this line the lower transparent layer seems to contain a reflective layer, particularly notable within the lows. The rough surfaces of some of the basement highs suggests faulting, such as might occur on a rift zone.

Just after turning north, about 1000Z on 16 August, the profile crossed the shallowest point on the summit, a ridge of pelagic sediments that has the appearance of a sediment drift (see Line 8). By 1200Z, basement is observed to slope towards the north flank, but from 1240Z to 1500Z, a large basement high was crossed. This basement high is particularly interesting because one side is stepped and the other falls off abruptly, both characteristics suggesting faults.

Proceeding downslope to the north, Line 9 shows a transition between summit sediment layering and flank layering. The lower transparent layer and middle reflective layers thin and eventually offlap basement, the latter butting into a ridge above a scarp at the lower edge of the flank. The middle reflective layer is about 0.4 sec thick at 1500Z 16 August and shows much internal layering, including a relatively transparent middle. Downslope, this package thins to a single layer, a little over 0.1 sec thick, with more homogeneous character.

At the north edge of the Central High is a common flank-bounding structure on Shatsky Rise. A scarp, approximately 1.2 sec high occurs at the bottom of the flank. The top of the scarp is an asymmetric basement high that dams flank sediments. To the east of the location of this profile, the basement high atop the scarp becomes a small seamount, which was dredged at station D8. Seaward of the scarp, sediments approximately 0.55 sec thick surround a small seamount whose relation to the Central High is unclear (Fig. 25).

Line 10

Central High north flank, 17 August

Line 10 was an eight-hour profile shot with the GI-gun between the location of dredge D8 at the edge of the north flank and the location of dredge D9 on the ridge protruding from the northeast flank of the Central High. The profile shows similar, but much thinner sediment layers on the lower and middle flank. Much thinner middle and lower sediment layers is the cause of the thinner sediment cover. Basement rises towards the Central High summit and the sediments become thinner along the line until a tall basement ridge outcrops from 1930Z to 2120Z on 17 August. The basement ridge is 1.3 sec tall on the eastern side where the slope is as great as 45° (measured by hydrosweep contours). The ridge also has a flat top and appears to be mostly clear of sediments except for a small mound of pelagic sediments at 1955Z 17 August (Fig. 33). What appears to be a strong reflector at 0.1 sec below the summit is probably a multiple owing to the source-receiver geometry. Dredge D9 was taken along the east side of this ridge.

Line 11

Central High summit seismic grid,18-20 August

Line 11 was a 42-hour seismic line shot with the 4-airgun array to provide a high-quality seismic grid on the Central High summit. The ship proceeded southwest from the dredge D9 site to a longitude of 158° 50'E and then turned south to shoot a north-south line. After imaging the southern part of the summit, the profile turned west and shot two additional north-south lines across the summit before finishing at a dredge station near an outcrop at the summit center (Fig. 14). North-south segments of Line 11 cross Line 8 in three places (Line 8: 2002Z and 2328Z 14 August and 0105Z 15 August; Line 11: 1430Z 18 August, 0235Z and 1625Z 19 August).

Leaving the flat-topped ridge, the profile crossed a thick sediment pond on the northeast side of the summit, approximately 0.65 sec thick at 1200Z 18 August. At this location, the sediments seem to consist mainly of two layers, a lower more transparent layer separated by an unconformity from an upper layer with many reflectors. From 1400Z to 1830Z 18 August, a broad basement high was observed that nearly outcrops on the south side of the summit. Offsets of basement on this high suggest faulting. After turning to the west, the more typical summit sedimentary layering was observed. Sediments thicken towards the center of the summit after the profile turned north. The maximum sediment thickness, 0.8 sec, was crossed at 02330Z 18 August, approximately 27 km south of the shallowest point on this profile, at 0230Z on 19 August. This shallowest point occurs on what appears to be a sediment drift atop a basement high (this is the same high shown in Figure 32). The basement high is bounded by steps on the south side, implying faults, and has a flat top from 0230Z to 0410Z 19 August. At the latter point, the high outcrops.

Farther north, sediments are ponded between the edge of the flat-topped basement high and a basement pinnacle that barely outcrops at 0530Z 19 August. On the north side of this feature, another thick sediment mound is imaged. Its thickest point is 0.7 sec at 0730Z on 19 August. Upon its return to the south, similar sediment layers were crossed, with a 0.75 sec-thick section in a basement low centered at 1330Z 19 August. From 1400Z to 1900Z on 19 August, the basement high at the center of the summit was crossed again. This high has a peak which outcrops from 1450Z to 1610Z 19 August and another to the south which is buried by sediments. The sediment cover thickens to the south until the line turns back to the north. From 2200Z to 2300Z, basement rises to an outcrop from 2310Z to 2330Z on 19 August. Just to the north of the outcrop, a channel has been cut in the sediments, 0.25 sec deep and 6.6 km across. As the profile approaches the center of the summit for the final time, a thick sediment package is again seen, pinching out against the side of the central basement high. The outcropping scarp of this high was dredged at station D10.

Line 12

Central High south flank 20-21 August

After coring the southeast side of the Central High summit, the GI-airgun was rigged and the ship departed for the South High by shooting a line southward from the southeast side of the summit. The profile shows the south flank to descend rapidly, with a graben from 0100Z to 0215Z on 20 August, partly filled with sediments. On the lower flank, sediments are thin, but thicken toward the bottom to about 0.6 sec near the edge of Cooperation seamount. On the flat seafloor seen around 0600Z, a lens-shaped pile of pelagic sediments is observed, implying current modified sedimentation.

Near the end of the line, a basement scarp was crossed at the edge of Cooperation Seamount. Sediments from the north appear to abut the scarp with no deformation.

Line 13

South High north flank, 22-22 August

After dredging Cooperation Seamount, the ship returned to the east side of the seamount where the GI-airgun was deployed to run Line 13 up the north flank of the South High. A small east-west trending ridge, the same orientation as elongated Cooperation Seamount (Fig. 26), was crossed about 22 km north of the South High flank (2050Z 21 August). This ridge protrudes through a sedimentary column about 0.5 sec thick that displays the usual layering: lower transparent layer, middle reflective layer, and upper transparent layer.

As seen elsewhere, the South High flank is bounded by a large scarp, at 2230Z on 21 August, approximately 0.7 sec high. Furthermore, as is also seen elsewhere, small volcanic cones occur at the top of the scarp. Although sediments near the scarp are thin, they thicken rapidly upslope. Between 0110Z and 0400Z, the flank is interrupted by a large basement high, approximately 0.8 sec higher than the flank slope. Downslope from the high, the sediments have the characteristics of lower flank sediment layers seen on the Central High; upslope, the characteristics are similar to other upper flank sedimentary sequences, although, it is unclear how to relate the layering to the five-layer sequence described by Sliter and Brown (1993). The sediments seem to pond upslope of the basement high, attaining a thickness of 0.6 sec in the low immediately north of the basement structure. Reflectors within these sediments show complex relationships. The lower layers onlap the basement upslope, suggesting the basement low collected sediments in an expanding pile. The upper layers downlap downslope and also form a drift near the basement high, implying movements of sediments by currents.

At 0730Z on 22 August, the profile shows that basement levels off at a summit plateau. The sediment cover is variable, but greater than 0.3 sec, in thickness. The internal structure of these sediment packages suggests that the lower layers have been partly removed by erosion and the upper layers have formed large wave-like drifts with wavelengths of 20-30 km.

Line 14

South High summit, 22-25 August

Before reaching the summit, the ship was turned in a circle to allow the GI-airgun to be recovered and the 4-airgun array to be deployed. At 1600Z on 22 August, the profile crosses a transition between the current-modified sedimentary cover and a thick cover of nearly flat-lying sediments. The transition is marked by a scarp, 0.18 sec tall, that truncates the upper sediment layer. The sediment pile is 0.75 sec thick just past the scarp and it thickens toward the summit as the basement rises slowly (Fig. 34). From about 1800Z to 2200Z 22 August, the sediments reach a maximum thickness of about 0.95 sec.

As the highest point on the pelagic sediment dome is reached, at about 2300Z on 22 August, the sediment thin slightly owing to rising basement. Several basement highs that look like buried cones are seen along the transect. One of these, at 0200Z on 23 August, nearly reaches through the sedimentary column.

On the south side of the summit, around 0300Z, the two reflectors R1 and R2, noted by Sliter and Brown (1993) become prominent. In this area most of the sediments have similar reflection characters, except for R1, R2, and the uppermost draped reflective layer. A turn of the profile takes the ship toward the east side of the summit platform (Fig. 16). Downslope, the upper Cretaceous pelagic layers pinch out and the sediment column thins. At 0700Z on 23 August, the upper transparent layer pinches out and by 1045Z, the middle layers are also gone, leaving only the lowermost pelagic layer. This lower layer is only 0.23 sec thick, drapes the basement, and appears to have a relatively constant-thickness.

At 1300Z on 23 August, the profile crosses a broad basement high on the east side of the summit. At the turnaround on the northeast side of the survey (Fig. 16) the thinnest sediment cover is found, at a thickness of only 0.08 sec at 1700Z on 23 August. Between 1830Z to 2000Z on 23 August, on the east side of the basement ridge, just west of the track intersection (Fig. 16), terrace-like offsets are observed on the basement surface. These offsets imply small normal faults, such as those often found on the flanks of volcanic rift zones.

The profile next turns west, crossing the thick sediments at the summit again. As basement falls away, all sediment layers expand and a maximum thickness of 0.95 sec is observed at 0030Z on 24 August. Toward the west side of the basin, the layers thin again, onlapping the flanks of the basement ridge at the west side of the summit (Figs. 27 and 28). On this profile, the lowermost pelagic sediments seem thickest near the ridge and thin eastward (Fig. 35). The top of the lower sediment packet is nearly horizontal and seems to correspond to R1 of Sliter and Brown (1993). Younger sediments atop this surface form a lens which is thickest in the center of the basin.

At the location of the first crossing, the western summit ridge appears free of sediment at its top. To the west of the ridge, the sediments are not well-layered, suggesting that many of the sediments may have slumped to their current location. A channel cut into the sediments is observed at 0745Z on 24 August.

Doubling back across the western summit ridge (Fig. 16), the next crossing shows the ridge to be about the same width as the crossing to the north, but lower in height (1030Z to 1200Z 24 August). The southern east-west crossing of the summit sediment basin shows a thinner sediment pile, with a maximum thickness of 0.87 sec at 1415Z on 24 August. Similar to the northern east-west profile, this one shows a lower sediment layer that thins slightly eastward, a transition to more transparent upper sediments that form a pelagic dome, and a surface drape layer containing many reflections. On the east side of the summit, the upper layers again disappear, leaving the lower layers exposed or near the surface. At 1730Z on 24 August, basement rises over the eastern summit basement high, which is shallowest at 1945Z on 24 August. By the beginning of the course change at the end of this transect, at 2223Z on 24 August, the sediment layers have thinned to only 0.08 sec.

Line 14 ends with a short east-west line to the location of a basement pinnacle that protrudes through the sediment layers on the southeast side of the summit. The profile shows a wedge of sediments, thickening westward and onlapping the flanks of the basement high, which protrudes 0.25 sec above the sediments and is buried by 0.65 sec of sediments (0430Z on 25 August). This basement high was sampled by dredge D12 which recovered shallow-water fossils.

Line 15

South High summit, 25 August

Line 15 was an 11 hour transit line between dredge and core stations shot with the GI-airgun. It begins from near dredge station D12, heads north to cross the southern of the two east-west profiles, turns northwest to cross the western ridge, and runs south to cross the two erosional canyons to the west of the ridge (Fig. 16). The stratigraphic section appears similar to the southern east-west transect. Several small, buried basement pinnacles are observed on the east side of the ridge. As on other transects, the lower sedimentary layers are nearly flat-lying and constant in thickness whereas the upper layers form a dome in the center of the sedimentary basin.

On this crossing, the west summit ridge is more symmetrical than on other crossings and has a more nearly flat summit. Downslope on the west of the ridge, the profile shows that the two erosional canyons (at 2200Z and 2345Z on 25 August) cut deeply through the sediment layers. The northern of the two canyons seems to cut down nearly to basement, so it was the one cored at stations C4 and C5.

Line 16

South High summit, Transit to south edge of summit, 27 August

Line 16 was an 11 hour transit , shot with the GI-airgun, from the last dredge station (D14) on the west side of the summit ridge, to the southernmost point of the north-south line shot with the airgun array (Fig. 16). Leaving the west side of the ridge, the line proceeds down the southern erosional canyon, so the sediments on the profile are thin and poorly layered. At 1220Z on 27 August, the track climbs the side of the canyon and about 0.45 sec of layered sediments are observed on the South High flank. After turning easterly, the line crosses a basement high whose shallowest part is at about 1700Z on 27 August. From the location, this appears to be a buried extension of the western summit ridge. Pinnacles protrude from basement at 1535Z, 1725Z, and 1755Z 27 August. Furthermore, offsets in basement suggest normal faults. At 1630Z to 1650Z and 1702Z to 1714Z 27 August, low spots bounded by steep walls look like grabens. This morphology is suggestive of a rift zone.

Line 17

South High summit and southwest flank, 27-29 August

Line 17, shot with the 4-airgun array, links up with the north-south array line to make a continuous line from the summit to the south flank (Fig. 16). At the beginning of the line, the thick summit sediment package is observed, with a thin lower layer and thick upper transparent layer.

The summit sediment section thins slightly southward until 0530Z to 0730Z 28 August where the upper layers thin abruptly. The hydrosweep bathymetry shows that the thinning results from an erosional canyon. Seismic lines from other cruises show that the south flank to the east of this location is free of sediments, whereas farther west, sediments sit atop the flank. This indicates that erosion, perhaps owing to swift currents, has stripped the southeast flank of sediments.

From 0730Z to 1800Z on 28 August, sediment layers are thin and variable. In several areas it appears that basement outcrops, but others are covered with thin layers of sediments left as erosional remnants. After 1800Z on 28 August, a continuous lower flank sediment section, about 0.4 sec thick, is observed. This section consists of thin upper and lower transparent layers with a thick reflective layer in the middle.

From 0115Z to 0430Z on 29 August, the now familiar scarp is observed at the bottom of the South High flank. The scarp, at 0430Z 29 August, is about 0.5 sec high and has an associated volcanic cone about 18 km upslope. Lower flank sediments are dammed by the cone. Seaward of the scarp, a thin layer of deep ocean sediments, approximately 0.4 sec thick, is found. The layering of these sediments is similar to that on the lower flank. Basement beneath these sediments is suspiciously flat, implying that acoustic basement may not be the top of the oceanic crust.

Gravity and Magnetic Data

Collection of gravity and magnetic data is described above. Profiles of these data are shown with bathymetry in Appendix 2.

The first several days of profile plots show gravity and bathymetry data from the Hawaiian ridge near Oahu and Kauai; the ship departed Honolulu and then returned on 27 July to pick up a new magnetometer cable and then departed once again. Gravity values of up to and over 200 mgal are seen over the Hawaiian ridge, declining to values near zero in deep water to the north of the ridge. Magnetic data were not routinely collected during the transit to Shatsky Rise owing to the loss of the gradiometer cable and the lack of an additional back-up cable, so the first weeks of profiles show only occasional magnetic data collected over seamounts.

During 30 July to 1 August, the ship crossed four seamounts to the north of the Hawaiian ridge. The last three (labeled "Seamount-1", "-2", and "-3"), were targeted to provide bathymetry and magnetic data for magnetic anomaly inversions. Gravity values over these seamounts are in excess of 200 mgal, indicating that they formed off-ridge and are regionally compensated. Magnetic anomalies are also large. Seamount 1 has a <500 nT low over its summit with a short wavelength high at its center. This implies that the seamount is predominantly normally polarized, but possibly has some reversed polarity lavas at its center. Seamount 2 has an anomaly, with an amplitude >1000 nT, that appears to have several peaks and troughs over the seamount. This may denote a complex magnetization structure. Seamount 3 also has an anomaly with an amplitude >1000 nT and it too has a magnetic low over its summit indicating normal polarity.

On 2-3 August, the ship sailed over Hess Rise and the profile shows its characteristic, asymmetric shape. Gravity anomalies over the rise are low, less than 100 mgal, implying that the feature is isostatically compensated. On 3 August, the magnetometer was deployed for a survey over Seamount-4, also known as the south peak of Annei Seamount in the Emperor Chain (Fig. 9). This seamount displays a large gravity anomaly, with a peak over 150 mgal, indicating that the volcano formed off-ridge. The magnetic anomaly has an amplitude over 800 nT and shows a low over the seamount, indicating normal polarity.

Profiles from 4-6 August show anomalies over the Ojin Rise seamounts. The gravity anomalies over the eastern seamounts are barely evident in the profile plots and those in the western part of the chain are only slightly larger (about 50 mgal). Such small gravity anomalies imply that these seamounts were formed near-ridge and are isostatically compensated. Magnetic anomalies over these seamounts are moderate in size, but on the profiles they cannot easily be distinguished from M-series seafloor magnetic lineations in the region. From about 0000-1200Z on 7 August, the ship sailed over seafloor east of the Shatsky Rise North High on its way to the North Arm. In this zone, the profiles show negligible gravity anomalies and magnetic anomalies with amplitudes of around 500 nT. Most of the seafloor in this area is flat, so these anomalies are probably the Hawaiian magnetic lineations known to be in the region (Sager et al., 1988; Nakanishi et al., 1989).

From 1200Z 7 August to about 0000Z on 9 August, the ship surveyed and dredged the North Arm of Shatsky Rise and several small seamounts located there. The gravity anomalies over this feature are small and the magnetic anomalies are about the same amplitude as those over seafloor to the southeast, but have shorter wavelengths as they are associated with the topography.

Data from 10-13 August were collected over the North High. Once again, the gravity anomalies are quite small, less than 30 mgal, and are barely noticeable on the profile plots. Magnetic anomalies have amplitudes of about 250-300 nT and have wavelengths shorter than the bathymetry, a sign that the North High has a complex magnetic structure.

On 13-14 August, the ship transited between the North and Central highs. Gravity anomalies in this region are low, as might be expected. Magnetic anomalies show a transition to longer wavelength and higher amplitudes--characteristics associated with seafloor magnetic lineations. This supports our previous conclusions that the ocean crust between the rise highs is relatively undisturbed.

Long wavelength topographic highs show passes over the Central High on 14 to 20 August. Low amplitude gravity anomalies are seen (<25 mgal) and those anomalies have wavelengths similar to the topography. Magnetic anomalies have amplitudes of about 250-300 nT and wavelengths much shorter than the topography, once again suggesting a complex magnetic structure.

The ship crossed over and dredged Cooperation Seamount, between the Central and South Highs on 21 August. Few magnetic anomaly data were collected because previous studies have shown the anomaly to be complex. Gravity anomalies are small, indicating the seamount is isostatically compensated and implying it formed near the same time as the rise. This is somewhat surprising because the basalts dredged from the seamount appeared to be significantly fresher and covered with less manganese than typical Shatsky Rise rocks.

From 22 to 28 August, the South High was surveyed. Gravity anomalies over this feature are also small and have wavelengths consistent with the topography. The most notable anomaly is over the western summit ridge, as seen at about 0400Z 24 August, 1800Z 25 August, and 0400Z 26 August to 0800Z 27 August on the profiles. This feature has an anomaly of about 30 mgal. Magnetic anomalies over the South High are subdued, with typical amplitudes of only about 100-150 nT, smaller than those observed over the other highs. Nevertheless, these anomalies have short wavelengths that suggest a complex magnetic structure. This may be at odds with conclusions by Sager and Han (1993) that the South High magnetic anomaly is simple.

At about 0000Z on 29 August, the ship passed over the scarp marking the lower flank of the South High. At this location is a large magnetic anomaly, with an amplitude of over 800 nT, which is usually identified as M21 (Sager et al., 1988; Nakanishi et al., 1989). Magnetic anomalies after that time are the Hawaiian seafloor lineations southwest of Shatsky Rise.

On the transit to Guam, the ship passed over several seamounts. These generally have large gravity and magnetic anomalies typical of Cretaceous seamounts formed off-ridge. At 0200Z on 2 September, the ship passed over the Mariana Trench, where a low is seen in the gravity.

Dredges

Dredge locations and brief descriptions are given in Table 4. Hauls generally consisted of large amounts of manganese nodules and crusts with variable amounts of basalt, sedimentary rocks, and pumice dropstones. Manganese nodules frequently had cores containing basalt or other rock types. For the purpose of description, basalts and other rock types were grouped by similar characteristics and given sample numbers. Descriptions of these rocks are given in Appendix 1. Manganese nodules and crusts were generally not described because they were not of primary interest and there was no experienced scientist on board to make such descriptions.

In all, dredges were taken at 14 stations. Two stations (D1 and D2) are in the Ojin Rise Seamounts to the east of the North High. Two stations (D3 and D4) are on the flanks of Earthwatch Seamount, a small seamount on the Northern Arm. At the North High, three stations were dredged (D5-D7). One is located on the north rim of the North High summit, one is on the east side of the summit, and the third is on the seamount adjacent to the south side of the summit. Three stations are on the Central High (D8-D10). D8 is located on the northern lower-flank scarp, D9 on the steep scarp making up the east side of the flat-topped ridge on the northeast side of the high, and D10 is on an exposed scarp of a basement high at the summit. D11 is located on Cooperation Seamount, between the Central and South Highs. The final three stations are located on the South High. D12 is on a pinnacle on the southeast side of the summit, whereas D13 and D14 are on the western summit ridge.

The main target for dredging were basement outcrops because we hoped to recover basalt amenable to radiometric dating. Also of interest were shallow water fossils, although no obvious shallow-water targets, such as relict reefs, were found. Basalt fragments were recovered in dredges D1, D4, D9, D10, D11, D13, and D14. Small, highly altered basalt fragments or were also found within nodules in dredges D2, D5, D6, D7, and D8. These latter samples will be of no value for radiometric analysis and are of uncertain value for geochemical analysis.

Sediments or sedimentary rocks were recovered in a number of dredges (see Appendix 1). These generally consisted of chert, limestone, or carbonate mudstone. Fossils were found occasionally in some dredges, except for D12 which recovered mostly fossils and fossil sediments. Possible bryzoans were found in dredge D7 (sample D7-09). Gastropod shells were recovered from dredge D8 (samples D8-13 and D8-14). Also, dredge D10 may have produced mollusc fragments (sample D10-12). It was dredge D12, from the pinnacle at the southeast edge of the South High summit, that gave the most fossils. It contained many examples of spines from "club urchins". In addition, it contained examples of fossil corals and molds or fragments of rudists. These latter fossils indicate that the dredge site, at a depth of about 2900 m, was in shallow water during the late Jurassic or Early Cretaceous. Since the western summit ridge is several hundred meters shallower, this implies that Shatsky Rise had islands. Dredge D12 also produced many kilograms of silicified limestone and sedimentary rocks that have the appearance of carbonate breccias. Whether they contain diagnostic fossils is uncertain.

Cores

Five cores were taken during the cruise. The targets were places where older sediments appeared to outcrop on seismic records, our goal being to date older sedimentary layers. Because the targets were indurated sediments, the cores typically had only shallow penetration. The longest core was PC-5, which had a length of 2.54 m.

Only one core was attempted on the summit of the North High because suitable targets were lacking. PC-1 was taken on the east side of the summit where some of the upper sediment layers have been eroded away. The core trigger malfunctioned and only 40 cm of stiff brown ooze was recovered (Table 5). Two cores were taken from the southeast side of the Central High summit. Both were targeted at an outcrop where Lower Cretaceous layers appear to outcrop. The two cores are located approximately 1800 m apart. PC-2 recovered about 36 cm of chalk and ooze whereas PC-3 returned 190 cm of similar lithology. The upper 63 cm of this core consisted of carbonate silt that was in suspension within the core and settled out when drained on deck. Two more cores were taken on the South High. Both were targeted at sediments in the bottom of the northern of the two erosional channels located to the west of the basement ridge at the summit. PC-4 recovered 168 cm of dark brown carbonate ooze, whereas PC-5 yielded 254 cm of light brown carbonate ooze. Like PC-3, the upper part of PC-5 was suspended in water when recovered and necessitated draining.

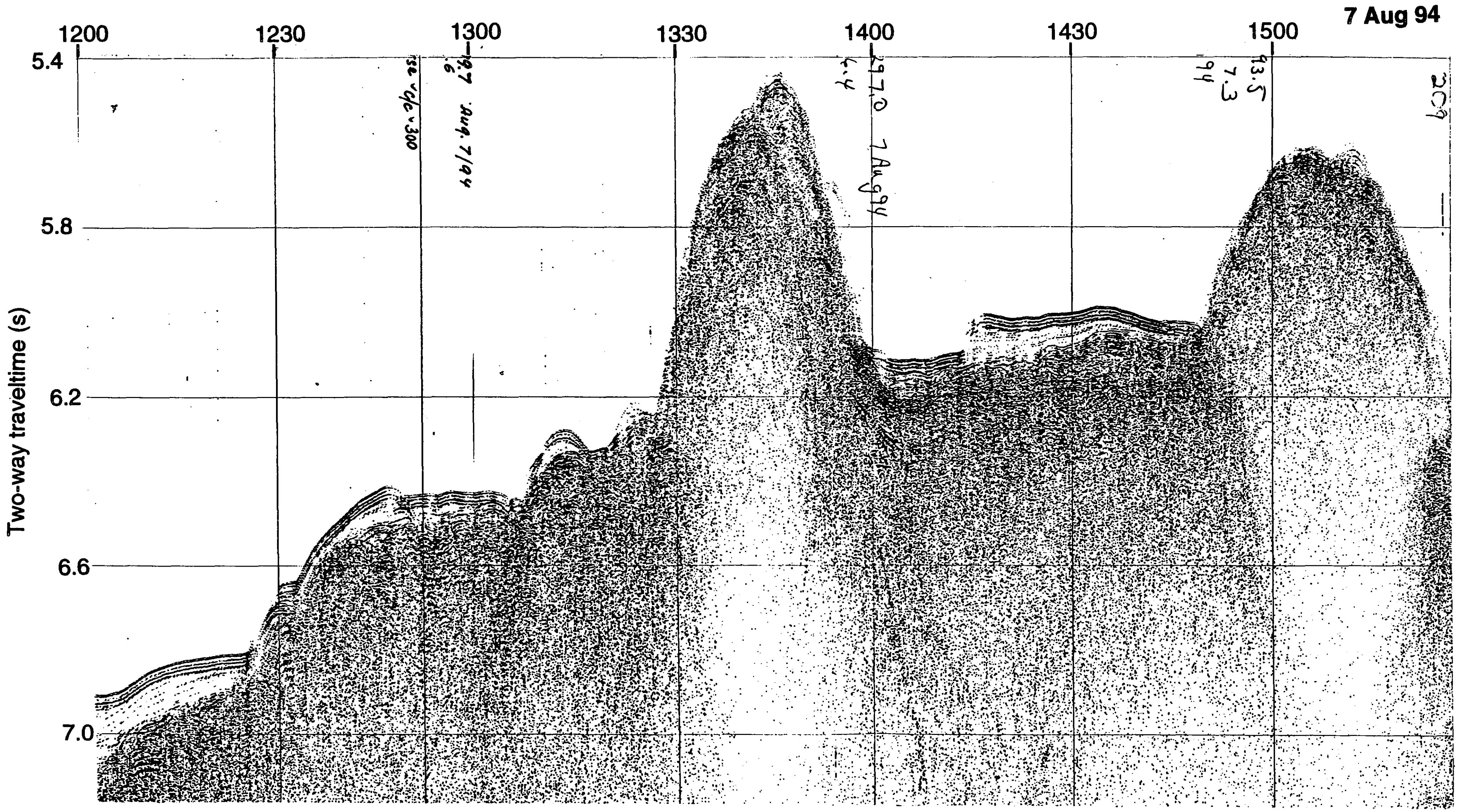


Figure 29. Section of seismic line 3 across the North Arm of Shatsky Rise. Profile shows igneous ridge of North Arm, two small seamounts on top, and thin sediments. The record was made using a GI-airgun at a speed of 7.3 kt. Figure is from a single-channel analog monitor record; vertical exaggeration is 17:1, east is at left, west at right.

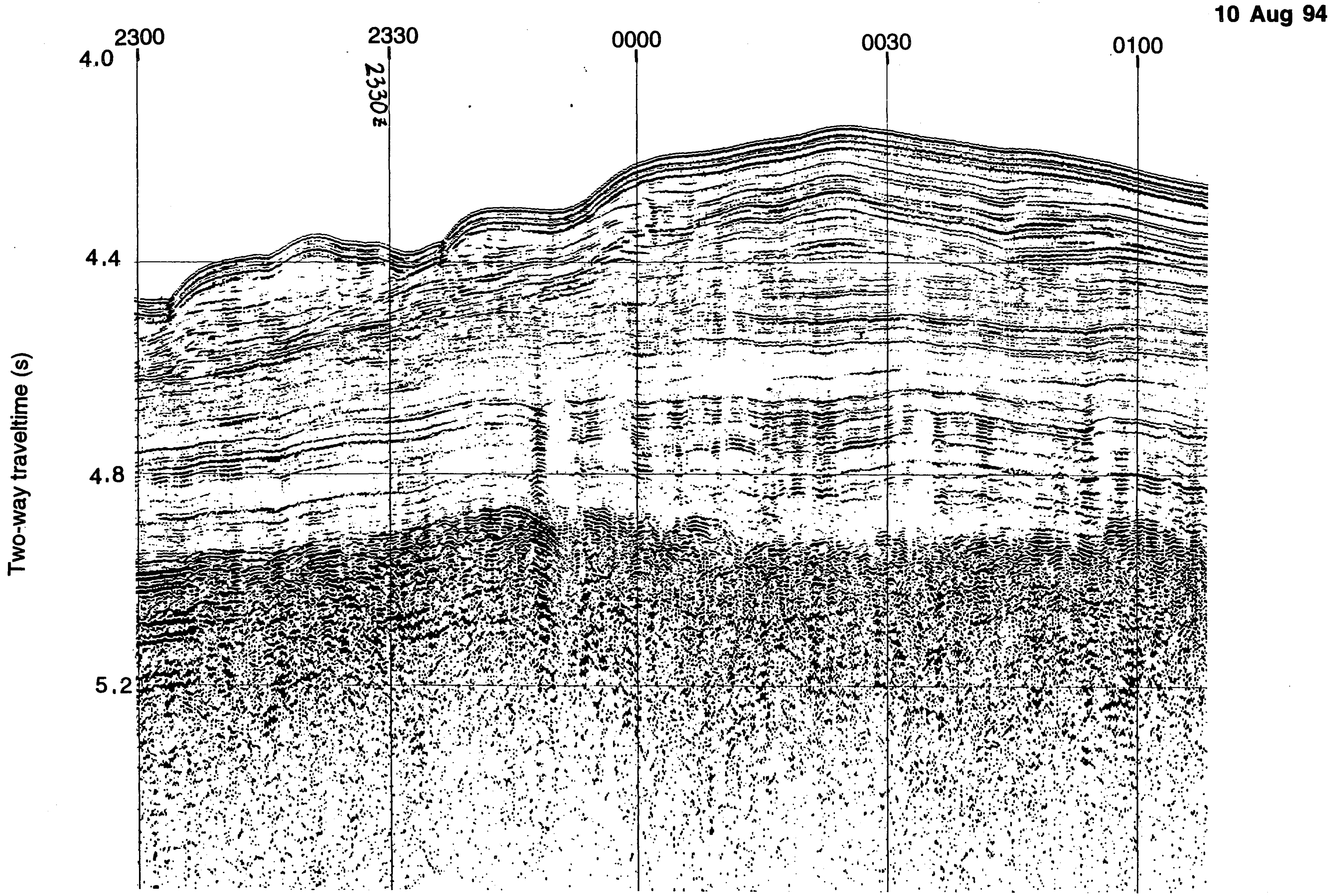


Figure 30. Section of seismic line 5 showing sediment cap of the North High. Flat-lying basement of the North High summit is seen to be overlain with as much as 0.8 sec of sediments. Profile was shot with a 4-airgun array at a speed of 4.9 kt. Figure shows analog single-channel monitor record, vertical exaggeration is 13:1. North is at right; south at left.

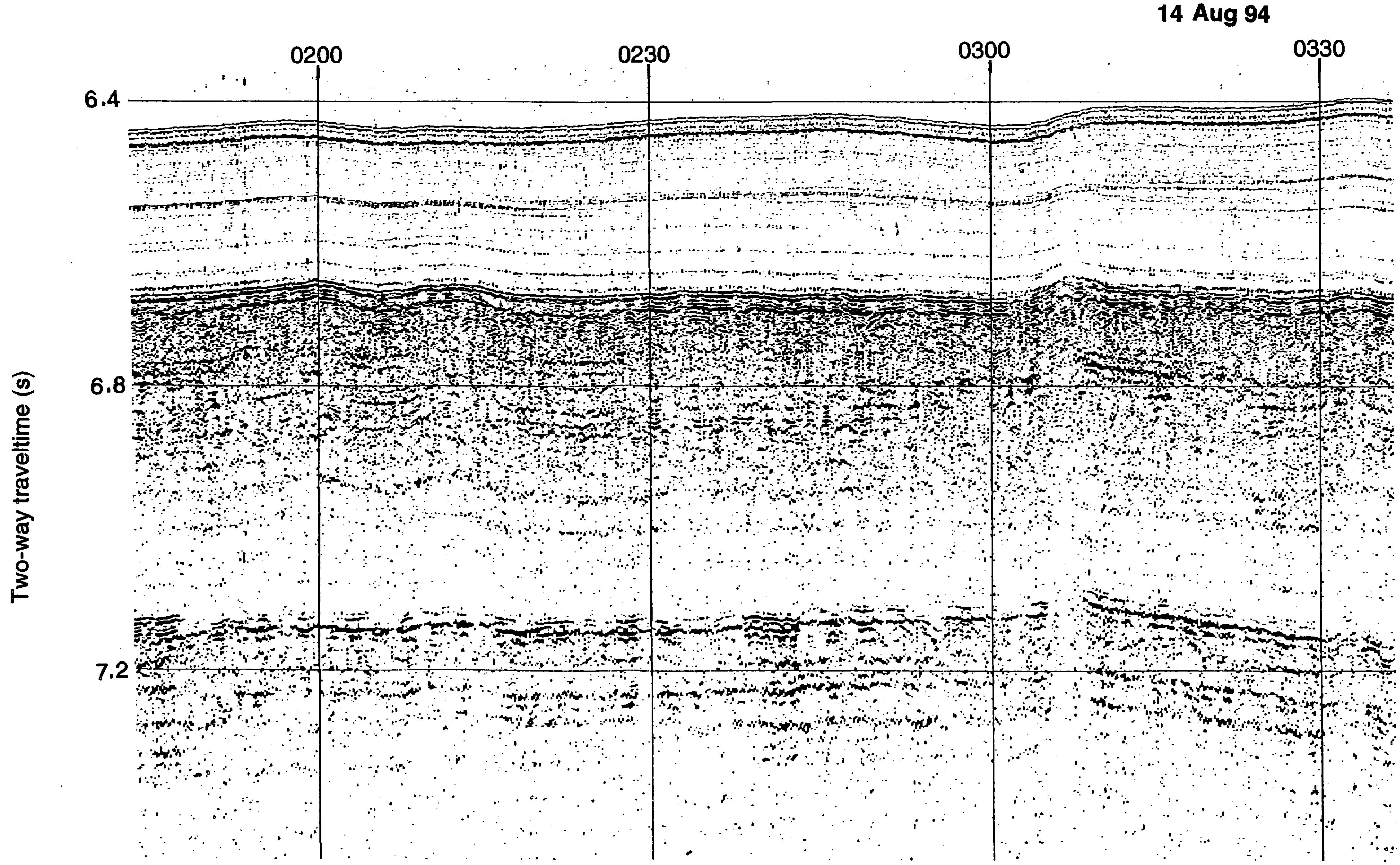


Figure 31. Section of seismic line 7 showing sedimentary layers within Shatsky Rise between the North and Central highs. Layering is typical of sediments on deeper parts of rise, showing a lower transparent layer above acoustic basement (at 7.15 sec), a middle reflective layer with a sharp upper boundary, and an upper transparent layer beneath the seafloor (just below 6.4 sec). Profile was shot with a GI-airgun at a speed of 7.3 kt. Figure reproduces an analog, single-channel monitor record. Vertical exaggeration is 17:1; northeast is to the left, southwest to the right.

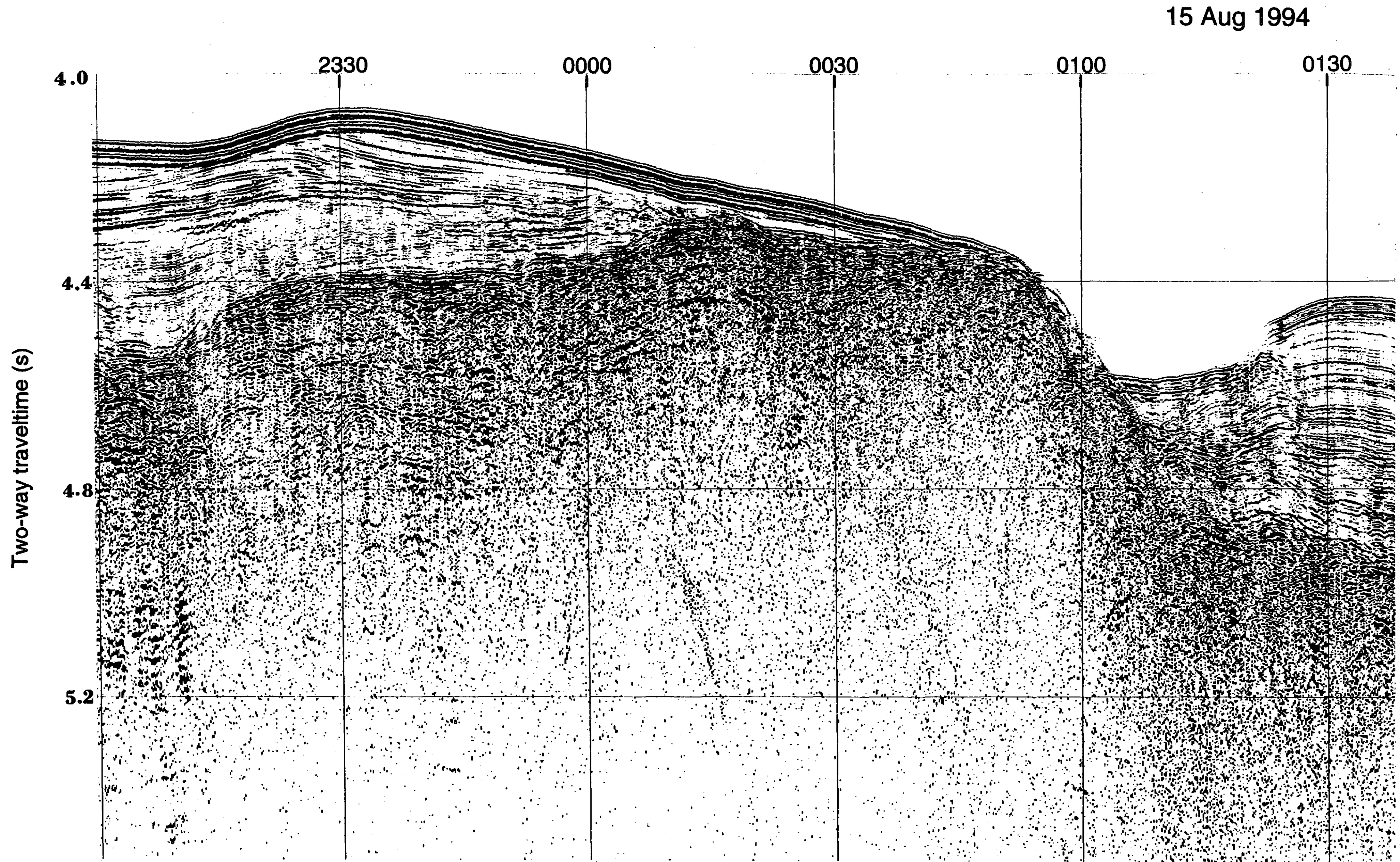


Figure 32. Section of seismic line 8 showing basement structure and sediments near the summit of the Central High. The record shows a basement high with a scarp on one side. Pelagic sediments mostly cover the high and show evidence of modifications by currents. An erosional channel is cut into the sediments on the flank of the basement high. The profile was shot with a 4-airgun array at a speed of 4.9 kt. Figure reproduces an analog single-channel monitor record. Vertical exaggeration is 13:1; east is to the left and west to the right.

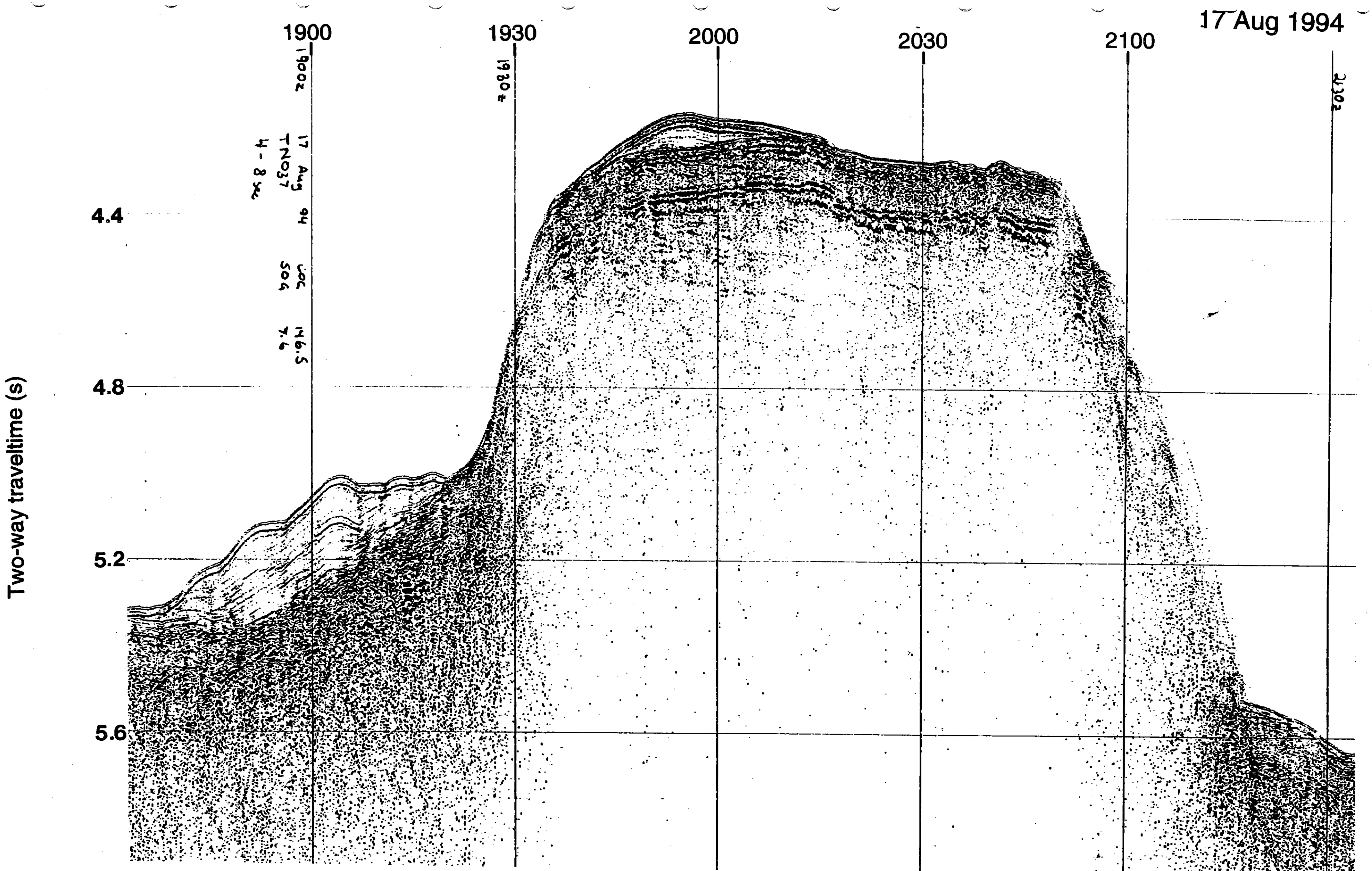


Figure 33. Section of seismic line 9 showing the flat top ridge on the northeast side of the Central High summit. Sediments are thin around and atop the basement ridge. The scarp on the right has slopes locally as high as 45° and was successfully dredged (Station D9). Profile was shot with a GI-airgun at a speed of 7.3 kt. Figure reproduces an analog, single-channel monitor record. Vertical exaggeration is 17:1; northwest is to the left, southeast to the right. Strong reflector at 0.1 sec below the top of the ridge is probably an artifact of the seismic system source-receiver geometry.

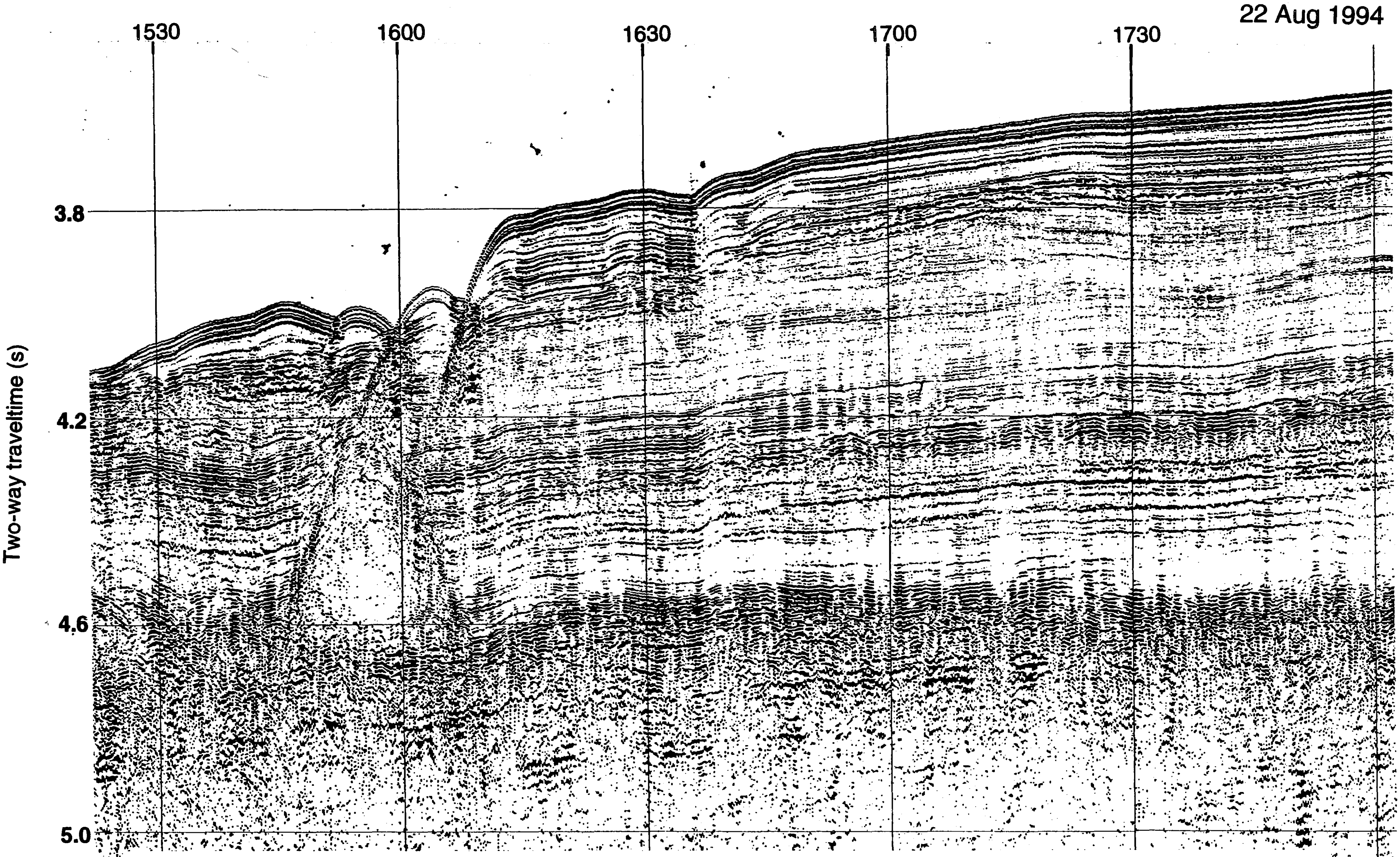


Figure 34. Section of seismic line 14 showing the north edge of thick sediment cap atop the South High. Record shows scarp eroded in upper sediment layers which marks the transition from mounded and current-modified sediments to thicker, relatively flat lying layers that are typical of the summit. Profile was shot with a 4-airgun array at a speed of 4.9 kt. Figure reproduces an analog, single-channel monitor record. Vertical exaggeration is 13:1; north is to the left, south to the right.

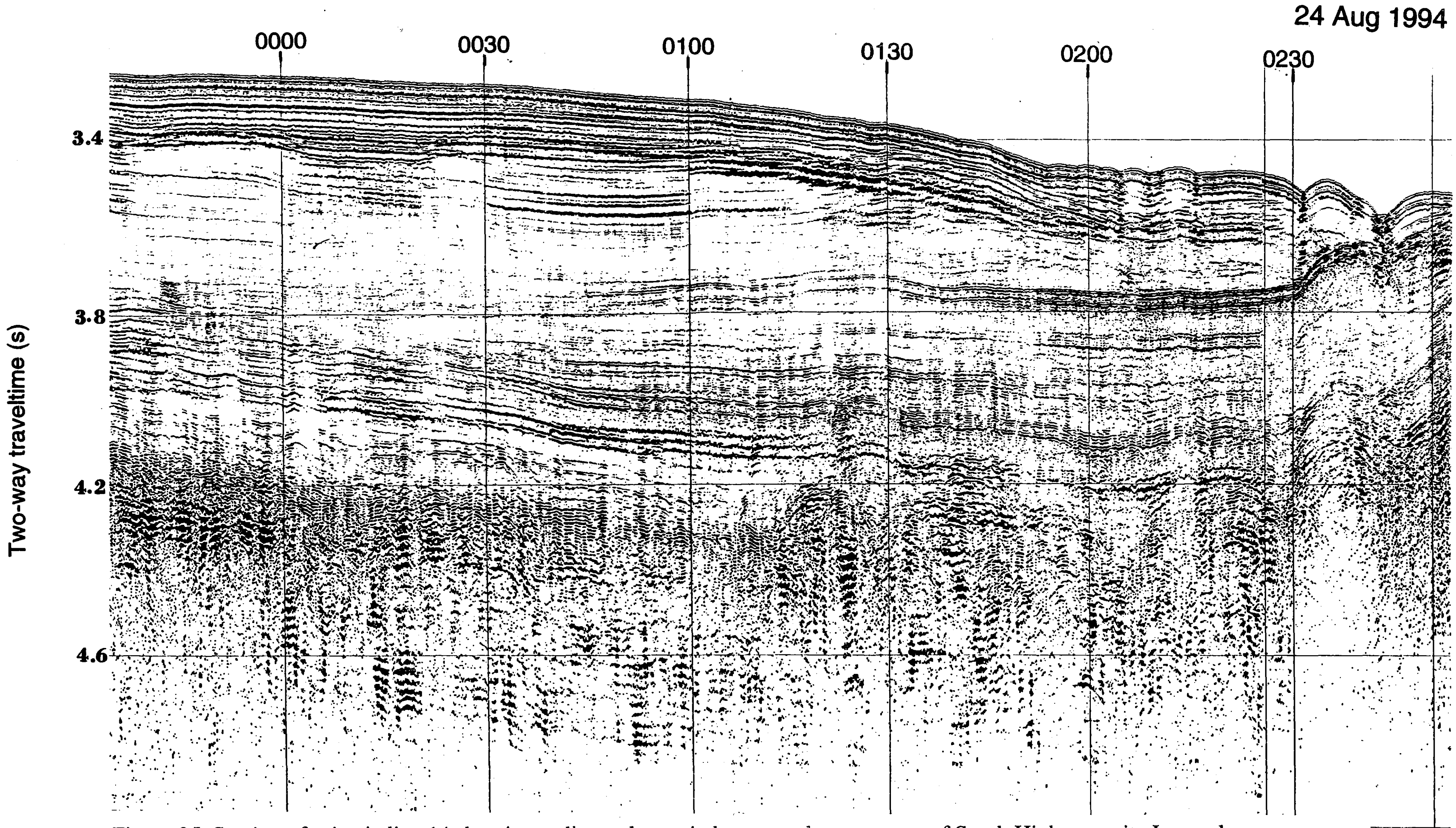


Figure 35. Section of seismic line 14 showing sediment layers in basement low at center of South High summit. Lower layers are seen to be thicker on flanks of western summit basement ridge (just past right side of figure) and thin towards left. Upper layers form pelagic mound thickest near left side of figure. Profile was shot with a 4-airgun array at a speed of 4.9 kt. Figure reproduces an analog, single-channel monitor record. Vertical exaggeration is 13:1; east is to the left, west to the right.

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Geological Samples

Maria Luisa Tejada and Glenn Brown

All geological samples obtained during the survey are described in the attached EXCEL database (SHATRX.xls). A sample number was assigned to either suites of samples or to unique individual specimens. As a rule, descriptions were kept to under 255 characters. A guide to this spreadsheet follows.

Sample No.
TN=R/V Thompson, D=Dredge, C=Core, represents sample or suite of samples
Location
description of geographic location
Latitude/Longitude
for touch-down location or during site
Depth
mbsl for site
Date
start of site
Rock Type
general lithology
Size (cm)
# of pieces, dimensions in cm, length for cores, d=diameter
General Description
# of pieces, dimensions in cm, length for cores, d=diameter; color; texture; grain size; alteration; distinct minerals; other comments, structure. d=diameter, Mn refers to manganese oxy-hydroxide mineralization, sed=sediment, ol=ol, gmass=groundmass.
Photography
P=print, S=slide
Distribution
A=Allan, B=Brown, S=Sager, K=Klaus, Te=Tejada, P=Pringle, Ta=Tatsumi, Sl=Sliter, Br=Bralower, Bo=Boyer.

Piston/Gravity Cores

The *Thompson* piston-corer and associated gravity corer in the trigger were used to sample the sediment layers of Shatsky Rise. Cores were cut from the base up. Cautions should be taken in some sections, as the sampled material was soupy mud. Refer to descriptions for items with this problem. Samples were taken of ooze samples for Bill Sliter (USGS) and Tim Bralower (UNC) to determine ages using foraminifera and nanofossils respectively.

Core 1	N. Shatsky, East Terrace	37° 48.35.60'N, 163°08.20'E	3450 (mbsl)
Core 2	Central Shatsky, SE Terrace (upper)	36° 07.999'N, 158°21.660'E	3242
Core 3	Central Shatsky, SE Terrace (lower)	35° 53.447'N, 158°51.298'E	3262
Core 4	Valley West of Toronto Ridge (thalweg)	32° 59.731'N, 157°56.466'E	3630
Core 5	Valley West of Toronto Ridge (thalweg)	32° 59.731'N, 157°56.466'E	3630

Shatsky Rise 1994 Survey **Geological Sample Descriptions** ***R/V Thompson (TN037)***

Prepared by Maria Luisa Tejada (University of Hawaii), Glenn Brown (University of Toronto), and Atsushi Horio (University of Shizuoka)

Sample No.	Location	Latitude Longitude	Depth	Date	Rock Type	Size (cm)	General Description	Photography	Distribution
TN=R/V Thompson, D=Dredge, C=Core, represents sample or suite of samples	description of geographic location	for touch-down location or during site.	mbsl for site	start of site	general lithology	# of pieces, dimensions in cm, length for cores, d=diameter	color; texture; grain size; alteration; distinct minerals; other comments. d=diameter, Mn refers to manganese oxy-hydroxide mineralization, sed=sediment, ol=ol	P=print, S=slide	A=Allen, B=Brown, S=Sager, K=Klaus, Ts=Tejada, P=Pringle, Ta=Tatsumi, Si=Sliter, Br=Bralower, Bo=Boyer.
TN037-D1-01	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	basalt-amygdaloidal	15x7x10	dark gray; amygdaloidal (~7% amygdules) and aphyric; moderately altered with ~1 cm alteration rind.	P	Ta
TN037-D1-02	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	basalt-amygdaloidal	4 pcs; d=5	dark gray; aphyric; with ~10% amygdules; fresh to weakly altered.	P	Ta
TN037-D1-03	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	basalt-amygdaloidal	12x10x5	aphyric; with 1% amygdules and 5% vesicles (d<1mm); moderately altered.	P	Ta
TN037-D1-04	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	basalt-massive	12 X10X5	green-gray with rusty discoloration; massive basalt with Mn encrustation; highly altered.	P	
TN037-D1-05	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	basalt-massive		green - gray; massive with ~1% <1mm vesicles and 2% amygdules; and aphyric; thin Mn coating and ~ 1 cm alteration rind.	P	Ta,P,Te
TN037-D1-06	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	basalt-amygdaloidal		dark gray; massive; 3% amygdules and 7% vesicles (d<1mm) and thin Mn coating; aphyric with one ol. phenocryst observed.	P	Ta,P,Te
TN037-D1-07	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	pumice	1 boulder; 5 pebbles	light to brown - gray; striated; porous and very light; occasional to 2% quartz phenocrysts; weakly to highly altered.	P	Ta,P,Te
TN037-D1-08	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	basalt-amygdaloidal		dark to brown - gray; aphyric; and vesicular with ~5% amygdules and 10% vesicles; moderately altered.	P	Ta,P,Te
TN037-D1-09	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	basalt-pillow		light gray; aphyric; vesicular to amygdaloidal with up to 1 cm long elongated vesicles along the margins; highly altered with up to 3 cm wide alteration rind.	P	Ta
TN037-D1-10A	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	basalt-massive		green - gray; massive; and aphyric with asymmetric Mn encrustation and occasional amygdules; moderately altered; similar to TN037-D1-05.	P	Ta,P,Te
TN037-D1-10B	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	sediment		well-defined laminations of Mn with inclusions of siliceous and clay fragments encrusting TN037-D1-10A.	P	
TN037-D1-11	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	basalt-pillow		mottled brown-gray to gray; aphyric; vesicular with 1-2 mm vesicles and ~2% amygdules; highly altered with brown weathering rim; secondary vesicles filled with green clay; Mn; in addition to carbonate and zeolite.	P	Ta
TN037-D1-12	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	basalt-amygdaloidal		dark gray with brown-gray rim; amygdaloidal; weakly altered interior grading to highly altered margins; secondary vesicle fillings of zeolite (?).	P	Ta,P,Te
TN037-D1-13A	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	basalt-amygdaloidal		dark gray; amygdaloidal (~10% amygdules) with thin coating of Mn and some calcareous sediments; weakly altered with zeolites filling the vesicles.	P,S	Ta,P,Te
TN037-D1-13B	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	sediment		overlies the thin coating of Mn on TN037-D1-13A; pumiceous (?) sediments with chert and mud fragments.	P	B
TN037-D1-14	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	basalt-amygdaloidal	15x15x5	mottled purple - to light gray; aphyric and vesicular with 2% amygdules; moderately altered with calcite and zeolite filling the vesicles.	P	Ta
TN037-D1-14B	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	sediment		white; chalky; calcareous and clay sediments coating TN037-D1-14A.	P	B
TN037-D1-15	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	basalt-pillow	20x20x15	mottled colors of green - to purple - to brown - gray; massive grading to vesicular towards the margins; aphyric; with few elongated vesicles of up to 5 mm wide; <2.5cm weathering rind with oxidized fractures and dendritic Mn radiating from cracks.	P	Ta
TN037-D1-16	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	basalt-massive	15x10x5; 8x10x3; 10x5x5; 5x7x10 (2)	green-gray; massive and aphyric with ~1% amygdules and thin Mn coating; moderate to highly altered.	P	Ta,Te,P
TN037-D1-17	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	basalt-amygdaloidal	18x12x7; 10x5x5	green to light gray; aphyric; and vesicular with up to 1.5 mm size vesicles; up to 1 cm weathering rind; siliceous sediments and Mn coating filling the vesicles.	P	Ta
TN037-D1-18	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	basalt-pillow	5x10x3	purple grading to brown-gray; massive; and aphyric; with 1% vesicles (d=1mm) and 1% amygdules; moderately to highly altered; chalky sediment infills vesicles, dendritic Mn along cracks.	P	

TN037-D1-19	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	basalt-amygdaloidal	7x5x7; 10x5x3; 7x2x2	purple- to light gray; massive and aphyric with 1% vesicles (d=1mm) and 1% amygdules; moderately to highly altered with chalky sediment infill vesicles, dendritic Mn along cracks.	P	Ta
TN037-D1-20	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	manganese nodules	2pcs, d=~10 cm	black, spherical; with colloform texture; with single core; appears to record several sedimentation events and hiatus; a layer with brecciated chert and sediment fragments prominent.	P,S	All
TN037-D1-21	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	manganese nodules	2 pcs	black, spherical; colloform texture; with two or more cores.	P,S	
TN037-D1-22	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	manganese nodules	3pcs	black, spherical; colloform texture; with basaltic core.	P	
TN037-D1-23	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	manganese nodules	1 pc	black spherical; colloform texture; with one core and prominent brown layer.	P,S	
TN037-D1-24	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	basalt-silicified	1 pc	mottled purple to brown color; aphyric with few amygdules; highly altered; with fossil belemnite and sediment encrustation.	P,S	B
TN037-D1-25	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	sediment	many pcs	lime green colored with Mn coating and speckle; many nodules have same material in core. Soft with soapy feel; commonly brecciated.	P	B
TN037-D1-26	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	chert	many pcs (>1cm)	buff-colored chert fragments; serve as nucleus for Mn nodules; color resembles D1-24.	P	B
TN037-D1-27	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	sediment	many pcs	originally a hard-ball sized piece of pink-cream ooze with some sand/gravel breccia fragments. Same sediment coats other samples (e.g. D1-13).	P	B
TN037-D1-28	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	sediment	1 pc	sediment ball surrounded by laminated Mn of <1 cm thick.	P	B
TN037-D1-29	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	sediment	many pcs	mix-bag of chert and green clay fragments and Mn-crusts.	P	B
TN037-D1-30	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	manganese nodules	1 pc	black spherical; colloform texture; with a core of clustered green fragments of altered pumice(?).	P	All
TN037-D1-31	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	manganese nodules	1 pc	black spherical; colloform texture; with a core of Mn crust.	P	
TN037-D1-32	Seamount-East Ojin Rise	36° 27.022'N; 169° 18.130'E	4267	5-Aug-94	manganese nodules	2 pcs	black spherical; colloform texture; with a core of pumice and pumiceous sediment.	P	
TN037-D2-01	North Victoria Seamount	37° 37.578'N; 165°27.519'E	4833	8-Aug-94	basalt	many pcs	fragments of massive basalts in cores of manganese nodules; green-gray mottled with brown-gray discoloration; aphyric; 1% 1mm-size vesicles with occasional carbonate infilling; moderate to highly altered.	P,S	Ta,P,Te
TN037-D2-02	North Victoria Seamount	37° 37.578'N; 165°27.519'E	4833	8-Aug-94	sediments	cobble to pebble	creamy white (with light green and white streaks) poorly consolidated pumiceous (?) or volcaniclastic sediments with very fine to fine grain size; of some volcanic; probable foraminiferal tests (?); and manganese oxide particles.	P	B
TN037-D2-03	North Victoria Seamount	37° 37.578'N; 165°27.519'E	4833	8-Aug-94	manganese crust	boulder	black; with thick layering; enclosing fragments of highly weathered basalts; and calcareous and green clay sediments.	P	B
TN037-D2-04	North Victoria Seamount	37° 37.578'N; 165°27.519'E	4833	8-Aug-94	basalt	1 pc	brown; vesicular aphyric basalt that is highly oxidized; encrusted with Mn crust.	P,S	B
TN037-D2-05	North Victoria Seamount	37° 37.578'N; 165°27.519'E	4833	8-Aug-94	sediments	pebble-size	olive- to apple-green; friable; fine-grained; Mn specks present, could be an alteration product of volcanic rocks.	P	B
TN037-D3-01	North Arm VolcanoShatsky Rise	39° 51.914'N; 163° 53.66'E	4227	8-Aug-94	pumice	5pcs cobble; 8pcs pebble	creamy white; vesicular and frothy; 1% quartz phenocrysts; some with black stains.	P	Ta,Te
TN037-D3-02	North Arm Shatsky Rise - Earthwatch Seamount	39° 51.914'N; 163° 53.66'E	4227	8-Aug-94	manganese accretion	many pcs	manganese encrusted fragments of benthic biota; cylindrical and fan shaped; some with remnant structure.	S,P	B
TN037-D4-01	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	basalt-massive		green-gray with brown mottling; massive with occasional big cavities & minute (<1mm) vesicles with light green clay material; moderate to highly altered with some dendrites of Mn; chloritized matrix; aphyric.	P	Ta,P,Te
TN037-D4-02	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	basalt	18x15x10; 8x3x5; 10x5x5; 12x5x5	green- to purple-gray; vesicular with 10-30% vesicles of d=5mm; partial palagonitization and chloritization of matrix; fractured; aphyric.	P	Ta
TN037-D4-03	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	basalt-pillow	15x12x10; 20x12x10; 12x10x10	gray to brown-gray; grading to brown toward the margin; up to 20% vesicles (pipe vesicles); vesicles elongated up to 1cm; increasing toward the margins; highly altered; vesicles sometimes filled with sediments; fractures filled with Mn.	P	Ta
TN037-D4-04	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	basalt	12x7x5; 7x7x3; 7x5x4; 15x7x7; 15x12x7	light green to brown-gray; vesicular with up to 30% vesicles; d=3-8mm; moderate to highly altered with Mn dendrites and sediments filling vesicles; fractured; aphyric.	P	

TN037-D4-05	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	basalt	18x12x7; 10x5x5; 15x7x5; 7x5x5; 10x7x5; 7x5x4; 12x8x5; 7x6x5; 5x5x3; 8x6x4	light green-gray with brown stains; vesicular 20-30%; ~ 1mm size vesicles; Mn stains/dendrites; chloritized (?) matrix; aphyric.	P	Ta,Te,P
TN037-D4-06	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	basalt	18x10x10; 15x10x5	gray to brown-gray; occasional to 2% vesicles; generally massive; chloritized matrix; Mn staining and dendrites; aphyric.	P	
TN037-D4-07	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	basalt	12x10x5;15x12x5	streaked light and brown-gray; flow structure but generally massive; Mn dendrites surrounding flow structure; oxidation; aphyric.	P	Ta,P,Te
TN037-D4-08	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	basalt-pillow	12x10x5; 7x7x5; 15x10x7; 10x5x5; 12x12x7 - 5 pcs; 7x5x5 - 1 piece	dark gray grading to brown towards margin; pipe vesicles pointing outwards toward the margins; 7% vesicles; encrusted with Mn; fractured; vesicles filled with sediments; oxidized and chloritized; solution cavities filled with sec. minerals; aphyric.	P	
TN037-D4-09	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	basalt-pillow	15x7x6; 10x5x3 - 2 pcs	dark gray with brown rim; vesicular margins; (pipe vesicles); massive center; some vesicles filled with siliceous sediments; moderately chloritized matrix; aphyric.	P	Ta
TN037-D4-10	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	basalt-pillow	10x7x7; 10x7x3 - 2 pcs	dark gray; vesicles increasing in size towards margin; sediment filling some vesicles; alteration by chloritization & oxidation; aphyric.	P	Ta,Te
TN037-D4-11	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	basalt	18x15x10	dark gray; vesicular with few big vesicles; fractured; vesicles filled with sediments; aphyric	P	Ta,Te
TN037-D4-12	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	basalt	18x10x10; 18x15x10 - 2 pcs	gray with brown stains; vesicles with altered glass up to 10mm diameter; up to 2cm Mn crust; moderately altered by chloritization & oxidation; aphyric.	P	Ta,P,Te
TN037-D4-13	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	basalt	20x15x12	light to brown- gray margin; vesicular with large vesicles up to 7mm wide; oxidation; chloritization; palagonitized glass in some vesicles; aphyric.	P	Ta,P,Te
TN037-D4-14	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	basalt-pillow	18x15x12; 8x5x5; 5x6x5 - 3 pcs	dark to brown-gray; fractured towards the margin; vesicular (pipe vesicles) up to 2cm long; oxidized margin; sediment filling vesicles; moderate chloritization; aphyric.	P	Ta,P,Te
TN037-D4-15	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	basalt-pillow	18x15x12; 5x5x3; 10x7x5 - 3 pcs	dark to brown- gray; fractured towards the margin with pipe (x-section) vesicles; about 2cm thick Mn; oxidized along cracks; oxidized margins; sediment filled vesicles; aphyric.	P	
TN037-D4-16	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	basalt	12x7x7	green-gray; vesicular with Mn crust (~1.5cm); 5% vesicles; sediment filling of vesicles; moderately altered; aphyric.	P	
TN037-D4-17	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	basalt	12x7x9, 5x4x5, 5x5x4, 7x5x5, 5x4x3, 4x5x4, 5x4x3 - 7 pcs	dark gray mottled with oxide stains; vesicular; fractured; sediments fill vesicles; pervasive oxidation; aphyric.	P	
TN037-D4-18	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	basalt	10x5x7, 10x5x5, 7x5x3, 15x5x5, 7x5x3 - 5 pcs	light gray with brown stains; vesicular; Mn dendrites in matrix and vesicles; clay material filling vesicles; aphyric.	P	
TN037-D4-19	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	basalt-massive	12x10x5, 10x5x4, 7x5x5, - 3 pcs, 7x5x3, 7x5x3 - 2 pcs.	green-gray; massive with some patches of palagonitized glass; oxidized & chloritized; Mn dendrite patches; aphyric.	P	Ta
TN037-D4-20	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	basalt	15x7x5, 7x5x5, 12x5x5 - 3 pcs	dark gray with brown stains; massive to slightly vesicular along margin; fractured; chloritized & oxidized matrix; sediment & altered glass in some vesicles; aphyric.	P	
TN037-D4-21	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	basalt	3x3x2x, 7x5x5, 5x4x3, 8x5x2, 5x4x2 - 5 pcs	light gray with rusty stains; 2% vesicles; chloritized & oxidized; Mn dendrite patches; aphyric.	P	
TN037-D4-22	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	basalt-pillow	10x7x4, 7x5x3 - 2 pcs	dark to brown-gray margin; pipe vesicles along margin; chloritized & oxidized matrix; altered glass in some vesicles; aphyric.	P	
TN037-D4-23	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	basalt-massive	7x5x4, 5x5x5, 15x10x7 - 3 pcs	dark gray mottled with brown coloring; massive except for few vesicles; fractured; with Mn along fractures and matrix.	P	
TN037-D4-24	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	basalt-massive	4x3x4, 3x2x1, 4x2x2 - 3 pcs	light gray with brown stains; massive to slightly vesicular; chloritized, limonite stains present; aphyric.	P	

TN037-D4-25	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	flintstone (chert)	5x2x3	light gray; smooth, glassy abraded surface; non-clastic, homogeneous texture; curved fractures; very hard.	P	
TN037-D4-26	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	siliceous mudstone	12x5x5	light gray with purple-brown streaks; very fine clastic mixture with purple-brown fragments of chert(?); elongated and deformed parallel to poorly defined layering in the rock; soft sediment deformation structure; some volcanic fragments & Mn particles.		
TN037-D4-27	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	pumice	7x5x4, 5x4x2, 7x4x5 - 3 pcs	light beige to light gray; black stains; very porous; light; frothy & vesicular with 5mm coating of Mn crust; 1% quartz phenocryst.	P	
TN037-D4-28	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	coralline (?) limestone	15x5x5, 12x5x3 - 2 pcs	white to creamy white; non-clastic but porous.	P	B
TN037-D4-29	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	hemipelagic mud	half bucket	poorly cemented calcareous; clay-like and siliceous with some green fragments.	P	
TN037-D4-30	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	manganese nodule	many pcs	black; spherical; max d=80mm; some laminae include calcareous particles about 1cm from nucleus, some sandy layers; cores are buff chert, altered basalt and volcaniclastic seds, hemipelagic ooze (d<1.5cm); some Mn laminae encrust sandy pieces.	P	B
TN037-D4-31	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	manganese crust	many pcs	3cm of black Mn laminae encrusting altered basalt; poorly cemented hemipelagic seds with carbonate and rusty volcanic fragments sandwiched between Mn layers.	P	B
TN037-D4-32	North Arm Shatsky Rise - Earthwatch Seamount	39° 50.264'N; 163° 54.789'E	4000	9-Aug-94	carbonate mud	many pcs	dirty white sediment patches 1cm thick; smooth perimeter; surrounded in a matrix of Mn.		B
TN037-D5-01	N. Shatsky, North Terrace Seamount	37° 57.107'N, 165°29.672'E	3345	11-Aug-94	basalt-altered	7x5x3	apple green with brown specks; quartzite-like texture; apparent elongation of brown mineral; fractured; epidote, chlorite, silica and Mn in fractures; green-brown clay mineral; resembles greenstone; dense/hard; encrusted with 8cm of Mn.	P	Te
TN037-D5-02	N. Shatsky, North Terrace Seamount	37° 57.107'N, 165°29.672'E	3345	11-Aug-94	pumice	32x18x12	light brown, rusty stains; frothy vesiculation; clay filling margin vesicles; highly weathered; quartz (2%).	P	Ta
TN037-D5-03	N. Shatsky, North Terrace Seamount	37° 57.107'N, 165°29.672'E	3345	11-Aug-94	manganese nodule	15x12x10	jet black with gray & white specks; colloform; core surrounded with volcanoclastic material and laminated with Mn oxides.	P	
TN037-D5-04	N. Shatsky, North Terrace Seamount	37° 57.107'N, 165°29.672'E	3345	11-Aug-94	manganese nodule	d=7-8	jet black; colloform; core surrounded with volcanoclastic material and laminated with Mn oxides; nuclei are gray and white grains; nuclei are 0.5 to 1cm fragments of altered basalt and pumice.	P	
TN037-D5-05	N. Shatsky, North Terrace Seamount	37° 57.107'N, 165°29.672'E	3345	11-Aug-94	manganese crust	0.5 cm	Mn encrusted volcanoclastic and hemipelagic sands.	P	B
TN037-D6-01	N. Shatsky, East Flank	37° 48.292'N, 163°07.521'E	3835	12-Aug-94	volcanic breccia (?	7x5x3, 5x3x3, 5x4x3, 4x2x2, 3x3x2	light yellow-brown to brown; coarse angular fragment of volcanic, silicic, and calcareous rocks, Mn, green-silica/clay, and clayey-mud in silicified matrix; calcareous sediments in cavities.	P	
TN037-D6-02	N. Shatsky, East Flank	37° 48.292'N, 163°07.521'E	3835	12-Aug-94	pumice	5x5x4	yellow-brown center with black exterior; highly vesicular; vesicles infilled with calcareous material; quartz 1-2%; coated with Mn.	P	
TN037-D6-03	N. Shatsky, East Flank	37° 48.292'N, 163°07.521'E	3835	12-Aug-94	pumice	18x12x7, 10x5x4, 15x12x7, 12x5x5	dirty white to light brown; frothy; highly weathered; quartz 5-10%; coated with Mn.	P	Ta
TN037-D6-04	N. Shatsky, East Flank	37° 48.292'N, 163°07.521'E	3835	12-Aug-94	manganese nodule	8x5x3	brown-black; outer Mn laminae are porous and friable; weak reaction to HCl; probably Mn-replaced coral(?).	P	
TN037-D6-05	N. Shatsky, East Flank	37° 48.292'N, 163°07.521'E	3835	12-Aug-94	manganese nodule	variable size, many pcs	black; colloform texture; single or multiple nucleus of basalt, chert and pumice; most are near spheres.	P	
TN037-D6-06	N. Shatsky, East Flank	37° 48.292'N, 163°07.521'E	3835	12-Aug-94	manganese nodule	d=8	similar to TN037-D6-04; this sample contains a fragment of chalk in core (1x0.5cm).	P	B
TN037-D6-07	N. Shatsky, East Flank	37° 48.292'N, 163°07.521'E	3835	12-Aug-94	manganese encrusted mud	7x5x3	oval nodule, broken on one end; exposed core is dirty beige hemipelagic mud; Mn shell is 2-3 mm	P	B
TN037-D6-08	N. Shatsky, East Flank	37° 48.292'N, 163°07.521'E	3835	12-Aug-94	manganese encrusted pumice	12x6x8	similar to TN037-D6-03,04; oval shaped nodule with 5-10mm of laminated Mn crust; margin vesicles infilled with clay; foreign particles in Mn at 2mm from core.	P	B
TN037-D6-09	N. Shatsky, East Flank	37° 48.292'N, 163°07.521'E	3835	12-Aug-94	mixed bag of seds	many pcs	yellow-brown, buff colored pcs of chert and hemipelagic sediments; bag of light brown recent mud.	P	B
TN037-D7-01	N. Shatsky, South Flank Seamount	37° 23.50'N, 162°54.906'E	3759	12-Aug-94	basalt-altered	13x5x5	yellow-orange-brown with yellow-green to gray bands; fractured and massive; palagonite (?)/chlorite alteration; clay and Mn in fractures; encrusted with Mn rind (~1 cm thick), hardness ~6.	P	
TN037-D7-02	N. Shatsky, South Flank Seamount	37° 23.50'N, 162°54.906'E	3759	12-Aug-94	basalt-altered/Mn encrusted	15x12x10, 15x15x10	black with brown fragment inside; palagonite; colloform and layered ~2cm crust on massive brown core.	P	

TN037-D7-03	N. Shatsky, South Flank Seamount	37° 23.50'N, 162°54.906'E	3759	12-Aug-94	basalt-altered	7x5x5, 3x3x2	brown mottled with black and yellow-green; massive; smaller piece has crack filled with creamy white sec. silica(?); bigger piece has a crack filled with Mn; basalt(?) completely replaced by palagonite; palagonite altered into chlorite and clay mineral.	P	
TN037-D7-04	N. Shatsky, South Flank Seamount	37° 23.50'N, 162°54.906'E	3759	12-Aug-94	mudstone-silicified	7x4x3	dark gray-black with oxidation stains on surface; piece is rounded and nodular, part coarse-grained and partly fine-grained clastics, bedded, soft-sediment deformation; fragments of basalt and white mineral.	P	
TN037-D7-05	N. Shatsky, South Flank Seamount	37° 23.50'N, 162°54.906'E	3759	12-Aug-94	spilite(?)	12x10x7	olive-green with brown stains surrounded by black rind; massive; highly fractured; replaced with chlorite; clay; originally basalt(?).	P	Ta
TN037-D7-06	N. Shatsky, South Flank Seamount	37° 23.50'N, 162°54.906'E	3759	12-Aug-94	carbonate	7x7x5	black with brown stains; spongy; sediments filling cavities; carbonate & Mn; Mn replaced coral(?); weak reaction to HCl.	P	
TN037-D7-07	N. Shatsky, South Flank Seamount	37° 23.50'N, 162°54.906'E	3759	12-Aug-94	pumice	15x12x8, 5x5x3, 10x4x3x, 10x7x5	white to light gray with brown stains; frothy vesicles; Mn and clay fill some vesicles, variable weathering (weak to high); 10% quartz phenocrysts 1-3mm, thin Mn coating.	P	Ta
TN037-D7-08	N. Shatsky, South Flank Seamount	37° 23.50'N, 162°54.906'E	3759	12-Aug-94	manganese nodules	many pcs	spherical to elongate; irregular shapes with cores of altered basalt, pumice, chert, calcareous fragments, and Mn nodules; some carbonate particles added later to Mn laminae.	P	B
TN037-D7-09	N. Shatsky, South Flank Seamount	37° 23.50'N, 162°54.906'E	3759	12-Aug-94	fossil fragments	4x1x0.5	light brown to creamy white; porous; striated; carbonatized; bryozoan(?) or bryozoan replaced by carbonate.	P	
TN037-D7-10	N. Shatsky, South Flank Seamount	37° 23.50'N, 162°54.906'E	3759	12-Aug-94	manganese crust	5x2x1	black; Mn encrusted coral(?) or other organism(?).	P	
TN037-D7-11	N. Shatsky, South Flank Seamount	37° 23.50'N, 162°54.906'E	3759	12-Aug-94	manganese encrusted sediment	5x4x14	black interior with several beds of laminae separated by other mineral grains; layers may be Mn crust; interior is encased in 4mm of Mn.	P	B
TN037-D8-01	Central Shatsky, North Flank	37° 23.604'N, 158°50.294'E	4806	17-Aug-94	basalt-altered	11x5x5, 5x2x3	brown-green; vesicles d<1mm, some amygdules; hard, dense.	S,P	Te,La
TN037-D8-02	Central Shatsky, North Flank	37° 23.604'N, 158°50.294'E	4806	17-Aug-94	basalt-altered	65x50x5x	light green with gray streaks, minor fractures with Mn infilling; max thickness of Mn crust is 22mm; outer rim on ones side has been altered to green clay- looks devitrification of glassy margin; 1mm vesicles.	S,P	La
TN037-D8-03	Central Shatsky, North Flank	37° 23.604'N, 158°50.294'E	4806	17-Aug-94	basalt-altered	2 pcs	highly altered basalt with crossing Mn fractures, almost friable, red-brown clay interior; 1cm crust.	S,P	
TN037-D8-04	Central Shatsky, North Flank	37° 23.604'N, 158°50.294'E	4806	17-Aug-94	basalt-altered		light green with white specks; porous texture becciated by Mn penetration into criss-crossing fractures; 1-1.5cm Mn crust; assimilated fragments of red-brown clay in Mn.	S,P	
TN037-D8-05	Central Shatsky, North Flank	37° 23.604'N, 158°50.294'E	4806	17-Aug-94	basalt-altered	18x15x8	light green with white specks; completely brecciated, pcs floating in Mn; remnant vesicles; 1.5-3cm thick Mn crust.	S,P	La
TN037-D8-06	Central Shatsky, North Flank	37° 23.604'N, 158°50.294'E	4806	17-Aug-94	basalt-altered	16x11x11	light brown with brecciated and exfoliated margin; dense, massive, hard; red clay around perimeter; banding in Mn crust (3-4cm thick).	S,P	La
TN037-D8-07	Central Shatsky, North Flank	37° 23.604'N, 158°50.294'E	4806	17-Aug-94	pumice	11x6x6, 20x14x13	gray-black, one pc contains 2cm-wide mud-filled cavities; Mn thickness 1mm on one pc, negl. on other; one pc has 2% quartz phenocrysts with open vesicles.	P	La
TN037-D8-08	Central Shatsky, North Flank	37° 23.604'N, 158°50.294'E	4806	17-Aug-94	manganese encrusted sediment	many pcs	black; elongate shapes common (e.g. 13x5x5); thickness of crust averages 3cm, some 1.5cm; interior various shapes and contorted but commonly linear. Mn has consumed perimeter of core clast. Core has clay matrix, resembles sediment layer.	P	La
TN037-D8-09	Central Shatsky, North Flank	37° 23.604'N, 158°50.294'E	4806	17-Aug-94	manganese nodules	d=5.5 to 9, many pieces	black to dark brown; multiple core of small fragments of pumice, clay beds, colloform Mn, altered basalts, and bioclasts (burrows, spicules, organic struct.); accreted bioclast has sandy material in core; some nodules incl. older cores of dense Mn.	P	All
TN037-D8-10	Central Shatsky, North Flank	37° 23.604'N, 158°50.294'E	4806	17-Aug-94	manganese pavement	24x12x14	jet-black; sandy sediments cover brittley-deformed Mn pavement ; accreted to spherical nodule; entire sample is well-cemented; Mn pavement is interbedded with sand/silt layers; Mn coated seabed surface contains encrusted bioclasts and pumice.	P	B
TN037-D8-11	Central Shatsky, North Flank	37° 23.604'N, 158°50.294'E	4806	17-Aug-94	mud	28x18x12	light red; clay-silt sized, with fragments of volcanic rock, poorly cemented; Mn covering on surface <3mm, streaks of Mn throughout; mineralized burrows (5.5cm long, 1cm wide), some infilled with brown mud.	P	B

TN037-D8-12	Central Shatsky, North Flank	37° 23.604'N, 158°50.294'E	4806	17-Aug-94	bone ?	4x1x1 (2pcs)	buff color; porous; fibrous interior with clear and black crystals; one end is knobby and bone-shaped; sample maybe pumice imitation.	P	
TN037-D8-13	Central Shatsky, North Flank	37° 23.604'N, 158°50.294'E	4806	17-Aug-94	encrusted fossils	2 pcs	encrusted shell of gastropod and ?; the former is identical to silicified specimen found in earlier dredge.	P,S	
TN037-D8-14	Central Shatsky, North Flank	37° 23.604'N, 158°50.294'E	4806	17-Aug-94	encrusted fossils	2 pcs	Mn-coated gastropod (?)	P,S	
TN037-D9-01	Central Shatsky, East Flank	36° 31.15'N, 159°11.619'E	3900	17-Aug-94	basalt	boulder, broken into many pcs	gray with brown streaks; porphyritic 30% .5mm plagioclase phenocrysts some converted to clay, fine-grained gmass, occasional vesicles; 1-.5 cm Mn crust, Mn in fractures, matrix converted to brown clay; dense.	P,S	Ta,Te,P,A,La
TN037-D9-02	Central Shatsky, East Flank	36° 31.15'N, 159°11.619'E	3900	17-Aug-94	basalt-vesicular	boulder, broken into many pcs	red-gray (almost purple) to brown-gray; plagioclase phenocrysts 5%; amygdaloidal; weathering, oxidized, Mn ranges from 1mm to 4cm; 20% vesicles, some filled with Mn.	P	Ta,Te,P,A,La
TN037-D9-03	Central Shatsky, East Flank	36° 31.15'N, 159°11.619'E	3900	17-Aug-94	basalt-vesicular	boulder size (broken into many pcs)	purple: no fractures, thin Mn, oxidized, clay minerals, line source vesicles; high density despite 20% vesicles.	P,S	Ta,Te,P,A,La
TN037-D9-04	Central Shatsky, East Flank	36° 31.15'N, 159°11.619'E	3900	17-Aug-94	basalt	boulder size (broken into many pcs)	brown-gray; massive, porphyritic with 3% 2mm long plagioclase in crystalline gmass, dense; brown clay in fractures, Mn speckles, similar to D9-01, but more weathered.	P	Ta,Te,P,A,La
TN037-D9-05	Central Shatsky, East Flank	36° 31.15'N, 159°11.619'E	3900	17-Aug-94	ol-phyric basalt	d<6, many pieces	brown-gray with rust and black stains; porphyritic; ol. (3-5%) altered to iddingsite in crystalline gmass; Mn streaks and 0.3 to 1.5 cm Mn crust.	P	Ta,Te,P,A,La
TN037-D9-06	Central Shatsky, East Flank	36° 31.15'N, 159°11.619'E	3900	17-Aug-94	basalt-cumulate	8x5x5	reddish-brown; 1% vesicles, plagioclase 50%, Fe-oxide ground mass, magnetic, cumulate texture.	P,S	Ta,Te,P,A
TN037-D9-07	Central Shatsky, East Flank	36° 31.15'N, 159°11.619'E	3900	17-Aug-94	basalt-altered	8x6x12	yellow-brown with rusty patches; alteration related alignment give mottled appearance, ol. to iddingsite, Mn 1-2cm thick, fractured	P	Ta,Te,P,A
TN037-D9-08	Central Shatsky, East Flank	36° 31.15'N, 159°11.619'E	3900	17-Aug-94	basalt-altered/vesicular	6x7x6	purple-brown (red); vesicles with secondary infilling by light colored clay minerals, altered ol. 5%.	P	
TN037-D9-09	Central Shatsky, East Flank	36° 31.15'N, 159°11.619'E	3900	17-Aug-94	basalt-altered	9x6x4	brown-gray, massive phaneritic; plagioclase phenocrysts 5-15%, ol. 3%; xtalline ground mass altered to clays and Fe oxides; parallel fractures.	P	Te
TN037-D9-10	Central Shatsky, East Flank	36° 31.15'N, 159°11.619'E	3900	17-Aug-94	pumice	10x8x6	white to gray; vesicular, frothy with black Mn stains on surface, 2% quartz phenocrysts; low density.	P	Ta,Te,La
TN037-D9-11	Central Shatsky, East Flank	36° 31.15'N, 159°11.619'E	3900	17-Aug-94	basalt-regolith	boulder size	red-orange; clay replaces basalt, encrusted with Mn, 2-4 cm Mn crust, fragmented.	P	B,La
TN037-D9-12	Central Shatsky, East Flank	36° 31.15'N, 159°11.619'E	3900	17-Aug-94	manganese crusts	16x14x13, 13x12x8, many pieces	max Mn thickness 5.5 cm; mix bag of basalt lithologies, sediments and Mn floating in Mn gmass; may be from talus pile.	P	
TN037-D9-13	Central Shatsky, East Flank	36° 31.15'N, 159°11.619'E	3900	17-Aug-94	manganese nodules	5<d<14	crust thickness 3-4 cm; cores of basalt, sediment, bioclasts; contamination event around nucleus.	P	
TN037-D9-14	Central Shatsky, East Flank	36° 31.15'N, 159°11.619'E	3900	17-Aug-94	olivine-phyric basalt	6x6x7	purple-gray, porphyritic with occasional cavities, red infill of cavities, oxidation, ol. partial to complete replacement by iddingsite, ol. (5-7%) up to 3mm size phenocrysts in aphanitic gmass, fractured, ~1cm wide Mn rim.	P	Ta,Te,La
TN037-D9-15	Central Shatsky, East Flank	36° 31.15'N, 159°11.619'E	3900	17-Aug-94	basalt (with layering)	11x5x6	brown to light brown; pophyritic; alternating ol-phyric and ol. +plag.-phyric bands 0.5-1.0cm thick, ol. d=3mm altered to iddingsite	P	Ta,Te,P, A
TN037-D9-16	Central Shatsky, East Flank	36° 31.15'N, 159°11.619'E	3900	17-Aug-94	altered ferro-basalt	9x6x8	red-gray w/ lt gray patches, granular, fine to coarse, hematite replacing ol. and gmass, clay replacing gmass and feldspar, ol. < 5%, magnetic, more weathered version of D9-06, occasional cavities, 1 cm Mn crust, at least 6 layers Mn ~2mm thick.	P	Ta,Te, P, A
TN037-D9-17	Central Shatsky, East Flank	36° 31.15'N, 159°11.619'E	3900	17-Aug-94	ferrugenous chert	8x7x7	red to creamy white, non-clastic, Mn along fractures, amorphous SiO2, highly fractured, very hard, 4-7, 1.5 cm Mn rim (at least 3 layers).	P	
TN037-D9-18	Central Shatsky, East Flank	36° 31.15'N, 159°11.619'E	3900	17-Aug-94	chert or siliceous mud	9x6x6	creamy white, non-clastic, but some spicules + rock fragments, poorly defined layers of light and dark shade, 1-2cm Mn rim, >5 layers of Mn w/ some layers containing basalt or chert fragments.	P	
TN037-D9-19	Central Shatsky, East Flank	36° 31.15'N, 159°11.619'E	3900	17-Aug-94	basalt-altered within nodule	d=6	spherical nodule; basaltic core altered to chlorite and Fe clay, Mn dendrites, remnants of basalt observed, prominent layer of cherty Mn.	P	B
TN037-D9-20	Central Shatsky, East Flank	36° 31.15'N, 159°11.619'E	3900	17-Aug-94	silicious mudstone	11x13x4	yellow-brown. mud-sized grain particles; w/ coarse inclusions of altered basalt fragments; silica+Mn along fractures curved to almost conchoidal fractures; very hard	P	B

TN037-D10-01	Central High (acoustic basement)	36° 08.070'N, 158°22.454'E	3474	20-Aug-94	**vesicular olivine-phyric basalt**	17x13x10,10x7x9	brown-gray to dark gray, vesicular to amygdaloidal, sediment filling cavities and vesicles, ol. altered to iddingsite (5%), oxidation, smaller pieces w/ limonite + chlorite reaction rims, moderate fracturing.	P	Ta, La
TN037-D10-02	Central High (acoustic basement)	36° 08.070'N, 158°22.454'E	3474	20-Aug-94	**vesicular olivine-phyric basalt**	12x13x10	gray w/ purple tint, vesicular, seds filling vesicles, cracks w/ silica infill, ol. altered to iddingsite, similar to D9-14, Mn crust 2cm thick, >6 layers.	P	Ta
TN037-D10-03	Central High (acoustic basement)	36° 08.070'N, 158°22.454'E	3474	20-Aug-94	**amygdaloidal basalt**	12x11x4,8x9x5,12x10x8,8x8x7,12x10x7	light to dark gray w/brown, white, green specks; chlorite, clay, zeolites in vesicles, Mn dendrites in cracks + gmass, ol. 5-7% altered to iddingsite, fractured with occasional cavities, Mn crust up to 3 cm, prominent cherty layer.	P	Ta,P,Te,A
TN037-D10-04	Central High (acoustic basement)	36° 08.070'N, 158°22.454'E	3474	20-Aug-94	**vesicular basalt**	9x8x6,12x8x5,7x7x4,7x7x6,	purple gray to brown gray, vesicular, oxidation, sed filling vesicles, Mn filling hair-fine cracks & vesicles, aphyric, similar to D9-03 but smaller vesicles, 2cm Mn crust with prominent cherty layer.	P	La
TN037-D10-05	Central High (acoustic basement)	36° 08.070'N, 158°22.454'E	3474	20-Aug-94	**massive basalt**	11x9x6,8x8x5,8x6x3,8x9x5	dark gray, massive, clay and Mn replacing gmass, aphyric, 3cm Mn crust w/ cherty layer.	P	
TN037-D10-06	Central High (acoustic basement)	36° 08.070'N, 158°22.454'E	3474	20-Aug-94	**breccia**	16x21x10,21x16x14,16x13x11,14x12x7	white, brown, lt gray, green enclosed in black matrix, fragmental, sand-boulder fragments, max 5 cm wide; altered basalt, silica, white clayey mineral, soft, brown mineral (siderite?), green clay, Mn nodules, white mineral has ghost textures of basalt.	P	
TN037-D10-07	Central High (acoustic basement)	36° 08.070'N, 158°22.454'E	3474	20-Aug-94	**altered basalt**	13x13x11	brown-gray vesicular basalt with well-defined weathering/alteration margins, oxidized w/ ferruginous chert replacing gmass & margins altered to green clay & Fe-oxide, enclosed in 1cm Mn coating.	P	
TN037-D10-08	Central High (acoustic basement)	36° 08.070'N, 158°22.454'E	3474	20-Aug-94	**manganese nodules**	many pieces	spherical to elongated (5-11 cm); single cores of rel. fresh basalt to completely altered basalt, chert (creamy white to dark gray) brown siderite (?); white chalky clay aggregate (phillipsite?), Mn nodules, bioclasts.	P	
TN037-D10-09	Central High (acoustic basement)	36° 08.070'N, 158°22.454'E	3474	20-Aug-94	**pumice**	many pieces	brown-gray, highly vesicular, frothy, light, highly weathered with Mn filling vesicles & coating surface.	P	
TN037-D10-10	Central High (acoustic basement)	36° 08.070'N, 158°22.454'E	3474	20-Aug-94	**manganese nodules**	many pieces	Mn coating cylindrical, fan-shaped benthic bioclasts.	P	
TN037-D10-11	Central High (acoustic basement)	36° 08.070'N, 158°22.454'E	3474	20-Aug-94	**white clay**	boulder, broken into pieces, 20 cm thick	altered basalt, changed completely to brown-white carbonate/clay, overlain by 4 cm-thick white chalky layer with fine horizontal veinlets and large fractures filled with Mn and other clay that also encrust other basalts of D6-06; 1-2 cm thick Mn crust.	P	B
TN037-D10-12	Central High (acoustic basement)	36° 08.070'N, 158°22.454'E	3474	20-Aug-94	**fossils, many pieces**	many pieces	Mn encrusted Cnidaria (?), sponge (?) and other tubular and cylindrical organic forms (possible Mollusca).	P	B
TN037-D10-13	Central High (acoustic basement)	36° 08.070'N, 158°22.454'E	3474	20-Aug-94	**altered basalt**	9x11x6;9x7x5	mottled color of yellow,yellow-orange+brown in a creamy white background;fragmental appearance;remnant igneous texture in fractured surfaces;limonite,chlorite+yellow to yellow-orange mineral alteration+cemented by silica;very hard+dense;thin Mn coating.	P	B
TN037-D11-01	Cooperation Seamount	35° 15.7'N, 158°57.05'E	3760	20-Aug-94	**basalt-vesicular**	17x9x7,9x5x6,10x7x7,13x8x8,14x8x9,16x15x10	light-gray; vesicles range from <1mm to 1cm, increase toward margin, largest piece has massive core; weakly altered to fresh; aphyric; weak oxide staining; crystalline calcite in some vesicles; very thin Mn coating.	P	Ta,La,Te,P,A
TN037-D11-02	Cooperation Seamount	35° 15.7'N, 158°57.05'E	3760	20-Aug-94	**basalt**	many pieces, 5cm to 2cm in diameter	light-gray; vesicular to amygdaloidal, vesicle size up to 7mm; weakly to moderately altered, rusty stain,some discoloration, sec. calcite and zeolite in vesicle; aphyric;similar to TN037-D11-01; very thin to 1cm Mn coating.	P	Ta, La
TN037-D11-03	Cooperation Seamount	35° 15.7'N, 158°57.05'E	3760	20-Aug-94	**basalt (altered)**	many pieces, 2 to 15cm in diameter	dark-gray with rusty brown-yellow discoloration; vesicular, amygdaloidal; feldspar to clay, zeolites, sec. calcite in vesicles, Fe-oxide stains, bleached margins, Mn in fractures, color bands related to stage of alteration; aphyric, patchy to 2 cm Mn.	P	
TN037-D11-04	Cooperation Seamount	35° 15.7'N, 158°57.05'E	3760	20-Aug-94	**basalt-amygdaloidal**	20x12x9,10x7x7,5x6x2,11x5x3	mottled light to dark gray; vesicle infilled with zeolite, sec. calcite; drusy calcite common in some vesicles; weak to moderately altered.	P	Ta,P,Te,A,La
TN037-D11-05	Cooperation Seamount	35° 15.7'N, 158°57.05'E	3760	20-Aug-94	**basalt (flow-banded)**	14x7x6,6x6x4,8x5x5,5x6x2	light-gray; alternating vesicle-free and vesicular bands, calcite fills vesicles; some vesicles flattened in one direction; biggest piece with bleached banded reaction rim containing drusy aragonite, earthy yellow-orange and yellow mineral (arsenides?).	P	Ta, Te

TN037-D11-06	Cooperation Seamount	35° 15.7'N, 158°57.05'E	3760	20-Aug-94	**basaltic breccia**	11x10x9	brown-, blue- and pink-gray with yellow brown-gray linings; fragmental; basaltic fragments amalgamated together by basaltic material; edges of fragments lined with partly oxidized basalt; variable vesicle size of fragments.	P	
TN037-D11-07	Cooperation Seamount	35° 15.7'N, 158°57.05'E	3760	20-Aug-94	**pumice**	10x9x7,5x2x2	gray-white; vesicular and frothy; 1-2% quartz; big piece is fresh but smaller piece is altered by Mn; flow band in the bigger piece.	P	Ta, Te
TN037-D11-08	Cooperation Seamount	35° 15.7'N, 158°57.05'E	3760	20-Aug-94	**breccia**	many pieces, 2 to 7cm width	fragmental; clast- to matrix-supported; highly to moderately altered basalt fragments enclosed by Mn.	P	
TN037-D11-09	Cooperation Seamount	35° 15.7'N, 158°57.05'E	3760	20-Aug-94	**basalt (altered)**	8x7x5	mixed colors of orange-brown, yellow, yellow-green and light-gray surrounded with black margin; highly fractured, vesicular texture preserved; basalt altered to arsenide and clay minerals, basalt remnants; partially brecciated; 0.5cm Mn coating.	P	
TN037-D11-10	Cooperation Seamount	35° 15.7'N, 158°57.05'E	3760	20-Aug-94	**organic remains / molds**	many pieces	mixed Mn-coated bioclasts (some buff-colored and not Mn-coated); cylindrical to fan-shaped; basket-shaped structures still preserved in some.	P	
TN037-D11-11	Cooperation Seamount	35° 15.7'N, 158°57.05'E	3760	20-Aug-94	**benthic biota (?)**	many pieces	mixed fibrous (sponge?) and skeletal leaf-like fragments.	P, S	
TN037-D12-01	S. Shatsky-Sponge (?) Mountain	32° 12.927'N, 158°36.21'E to 32° 14.068'N, 158°35.684'E	3016	25-Aug-94	**pumice**	d=13	gray-black; aphyric; Mn very thin; rounded pieces of mafic country rock, elongation of vesicles during cooling.	P, S	Ta
TN037-D12-02A	S. Shatsky-Sponge (?) Mountain	32° 12.927'N, 158°36.21'E to 32° 14.068'N, 158°35.684'E	3016	25-Aug-94	**carbonate sandstone breccia**	many pcs, boulder	white-buff-cream; silt-1.6mm, some large bioclasts (some round in cross-section); platey white crystals; friable-moderately cemented; silica replacement, chert piece and laminated silica, round fossils d=.5cm, many pcs brecciated.	P, S	
TN037-D12-02B	S. Shatsky-Sponge (?) Mountain	32° 12.927'N, 158°36.21'E to 32° 14.068'N, 158°35.684'E	3016	25-Aug-94	**carbonate sandstone breccia**	1pc	same as 12-02A with tubular bioclast 0.5cm long; Mn filled microfractures.	P, S	
TN037-D12-02C	S. Shatsky-Sponge (?) Mountain	32° 12.927'N, 158°36.21'E to 32° 14.068'N, 158°35.684'E	3016	25-Aug-94	**carbonate sandstone breccia**	1 cut pc	white; same as 12-02A with 3x2x2 pine-cone like bioclast; textured surface of fossil preserved (concentric circles at wide end, dotted on the other).	P, S	
TN037-D12-03	S. Shatsky-Sponge (?) Mountain	32° 12.927'N, 158°36.21'E to 32° 14.068'N, 158°35.684'E	3016	25-Aug-94	**fossil coral/sponge**	many pcs, e.g. 5.5x1x1.5	white-cream; sand to 3cm; fragmented coral matrix in some pcs; stratified coral growths resemble Agropora internal structure; with possible echinoderm fragment.	P, S	
TN037-D12-04	S. Shatsky-Sponge (?) Mountain	32° 12.927'N, 158°36.21'E to 32° 14.068'N, 158°35.684'E	3016	25-Aug-94	**fossil sponge/coral**	many pcs (2 doz.), 2-8x1.5-4	light brown; bulb shaped fossils with external incisions which criss-cross; bulb narrows to tube at one end, other end has radiating lines; inner cavity seen in some, but in most cases the interior is solid from replacement.	P, S	Bo (3 pcs)
TN037-D12-05	S. Shatsky-Sponge (?) Mountain	32° 12.927'N, 158°36.21'E to 32° 14.068'N, 158°35.684'E	3016	25-Aug-94	**fossil bivalve**	1 pc, 5.5cm	white; half shell of bivalve; replaced inner soft-parts or mud-filled; shell is laminated with some remnant mother-of-pearl on inner surface; very light Mn dusting on surface.	P, S	
TN037-D12-06	S. Shatsky-Sponge (?) Mountain	32° 12.927'N, 158°36.21'E to 32° 14.068'N, 158°35.684'E	3016	25-Aug-94	**fossil coral-partially altered**	many pcs, e.g. 5cm	rusty brown-black; coral resembles D12-05 except surface is coated/replaced by Fe/Mn oxides and coral has been heavily silicified; infilling mud between coral structure has been silicified.	P, S	B
TN037-D12-07	S. Shatsky-Sponge (?) Mountain	32° 12.927'N, 158°36.21'E to 32° 14.068'N, 158°35.684'E	3016	25-Aug-94	**silicified reef breccia**	many pcs	light green; coarse-grained fossil supported, mud matrix; porosity is high with many openings formed by leached bioclasts (secondary); many fragments are short "tubes" 1x.5mm in size; <1cm Mn, dolomite and silica replacement.	P, S	B
TN037-D12-08	S. Shatsky-Sponge (?) Mountain	32° 12.927'N, 158°36.21'E to 32° 14.068'N, 158°35.684'E	3016	25-Aug-94	**silicified carbonate mud**	21x16x17, 4x4x9	white-cream (similar to D12-09); fossils (same as D12-02C and coral) preserved in-growth position on ancient seafloor by 1.5cm Mn crust.	P, S	B
TN037-D12-09	S. Shatsky-Sponge (?) Mountain	32° 12.927'N, 158°36.21'E to 32° 14.068'N, 158°35.684'E	3016	25-Aug-94	**silicified carbonate mud and reef debris**	many pcs, largest 8x26x26	white-buff color; fine-silt sized grains, secondary porosity; <1.5cm Mn, buff areas are from silica replacement; fine grained samples resemble novaculite; pcs w/ 30% pores, pcs of granular sand, some w/ spicules and coral D12-03; most common rock in D12.	P	
TN037-D12-10	S. Shatsky-Sponge (?) Mountain	32° 12.927'N, 158°36.21'E to 32° 14.068'N, 158°35.684'E	3016	25-Aug-94	**silicified reef debris**	8x8x5	black-gray; silicified rocks described above; some have tubelets in interior; 1cm Mn.	P	
TN037-D12-11	S. Shatsky-Sponge (?) Mountain	32° 12.927'N, 158°36.21'E to 32° 14.068'N, 158°35.684'E	3016	25-Aug-94	**silicified diatomaceous earth (novaculite)**	15x12x15	two units with large cavities between; "lower" white unit has Mn along bedding laminae and 4mm of Mn, incl. burrows; upper material is altered carbonate sands with high porosity.	P, S	
TN037-D12-12	S. Shatsky-Sponge (?) Mountain	32° 12.927'N, 158°36.21'E to 32° 14.068'N, 158°35.684'E	3016	25-Aug-94	**silicified diatomaceous earth (novaculite)**	8x5x4	white w/black Mn between laminations; burrows; 4mm Mn; similar to lower unit of D12-11.	P	

TN037-D12-13	S. Shatsky-Sponge (?) Mountain	32° 12.927'N, 158°36.21'E to 32° 14.068'N, 158°35.684'E	3016	25-Aug-94	chert	many pcs, plates 3cm thick	buff color; many shapes but commonly platey, homogeneous fine-grained silica, classic flintstone.	P	
TN037-D12-14	S. Shatsky-Sponge (?) Mountain	32° 12.927'N, 158°36.21'E to 32° 14.068'N, 158°35.684'E	3016	25-Aug-94	silicified carbonate breccia	many pcs, one 23x12x15	light green-orange brown; fragments of diatomaceous earth in 1.5cm of Mn crust; contains green fragments of bioclastic and lithic breccia with some shell fragments.	P	
TN037-D12-15A	S. Shatsky-Sponge (?) Mountain	32° 12.927'N, 158°36.21'E to 32° 14.068'N, 158°35.684'E	3016	25-Aug-94	silicified reef debri	many pcs	red-purple-black-pink-white mottled; bioclasts and breccia from above with signif. replacement by silica; spicules and shells observed; many pcs have Mn in fractures; original sed burrowed and infilled with later clay-mud.	P	
TN037-D12-15B	S. Shatsky-Sponge (?) Mountain	32° 12.927'N, 158°36.21'E to 32° 14.068'N, 158°35.684'E	3016	25-Aug-94	brown clay	one sample	brown; fine-grained; sampled from vug in above.	P	B
TN037-D12-16	S. Shatsky-Sponge (?) Mountain	32° 12.927'N, 158°36.21'E to 32° 14.068'N, 158°35.684'E	3016	25-Aug-94	brecciated silicified carbonate mudstone	5x20x17	similar to 12-09; buff colored areas are brecciated in situ, some pieces are floating in silicified carbonate mud; one piece of chert (2cm) separated along bedding laminations space 0.5cm; Mn 1cm.	P	
TN037-D12-17	S. Shatsky-Sponge (?) Mountain	32° 12.927'N, 158°36.21'E to 32° 14.068'N, 158°35.684'E	3016	25-Aug-94	altered limestone	18x13x16	yellow-brown; soft with vugs and pores filled with brown clay; resembles hydrothermally altered carbonate, fossil fragments (vascular tubes) visible; Mn crust 0.5-1cm.	P	
TN037-D12-18	S. Shatsky-Sponge (?) Mountain	32° 12.927'N, 158°36.21'E to 32° 14.068'N, 158°35.684'E	3016	25-Aug-94	silicified carbonate	8x6x5	cream-white; silt to 1mm grains; moderate sorting; carbonate, but mostly altered to silica; coral and sponge remains, silica filled burrows; coquina.	P	
TN037-D12-19	S. Shatsky-Sponge (?) Mountain	32° 12.927'N, 158°36.21'E to 32° 14.068'N, 158°35.684'E	3016	25-Aug-94	silicified carbonate	boulder	medium brown; very fine-grained; pores 5%; more advanced silicification than D12-18; carbonate some pores; Mn coating.	P	
TN037-D12-20	S. Shatsky-Sponge (?) Mountain	32° 12.927'N, 158°36.21'E to 32° 14.068'N, 158°35.684'E	3016	25-Aug-94	corals, Mn-encrusted	many pcs	black, Mn encrusted coralline material; weak effervescence in acid when powdered; some still preserve the original network structure.	P	
TN037-D12-21	S. Shatsky-Sponge (?) Mountain	32° 12.927'N, 158°36.21'E to 32° 14.068'N, 158°35.684'E	3016	25-Aug-94	chert breccia	11x14x18	similar to D12-09; this sample has 4cm rip-up clasts of chert floating in poorly silicified carbonate mud; Mn 0.5cm.	P	
TN037-D12-22	S. Shatsky-Sponge (?) Mountain	32° 12.927'N, 158°36.21'E to 32° 14.068'N, 158°35.684'E	3016	25-Aug-94	silicified carbonate	8x9x9	dark brown; bioclasts of shells <1mm floating in carbonate mud, mud-filled pores; Mn thin <1mm.	P	
TN037-D12-23A	S. Shatsky-Sponge (?) Mountain	32° 12.927'N, 158°36.21'E to 32° 14.068'N, 158°35.684'E	3016	25-Aug-94	silicifed limestone reef	boulder size	white-brown-rust-black; silicified carbonate with many vugs and coral reef fragments; some openings to exterior filled with sand; bivalve bioclasts 3-4cm.	P	
TN037-D12-23B	S. Shatsky-Sponge (?) Mountain	32° 12.927'N, 158°36.21'E to 32° 14.068'N, 158°35.684'E	3016	25-Aug-94	light grey sand	one sample	silt-sand sample from opening in above; visible microfossils.	P	
TN037-D12-24	S. Shatsky-Sponge (?) Mountain	32° 12.927'N, 158°36.21'E to 32° 14.068'N, 158°35.684'E	3016	25-Aug-94	silicified carbonate sands	many pcs (orig. boulder)	pink-orange brown; sand; well-sorted, bioclast (shells and pellets-round and elongate) supported; silicified.	P	B
TN037-D13-01	S. Shatsky-Toronto Ridge	32° 43.093'N, 158°15.069'E to 32° 43.639'N, 158°14.261'E	2357	26-Aug-94	basalt-altered	many pcs, d=3-18	yellow-green-gray to brown-green at margin; porphyritic, 20-30% plag. pheno. in aphanitic gmass, plag. up to 2mm in length, moderate to highly fractured; chloritization and oxidation of gmass, plag. to white clay; Mn dendrites in fractures, Mn crust 1cm.	P	Ta, Te, La
TN037-D13-02	S. Shatsky-Toronto Ridge	32° 43.093'N, 158°15.069'E to 32° 43.639'N, 158°14.261'E	2357	26-Aug-94	basalt-altered	25x27x16	brown mottled with yellow-orange along fractured surface; similar to D13-01 except for different alteration by finely xtalline to earthy-yellow & yellow-orange minerals (AsS minerals?); moderately fractured but still compact & dense; Mn crust 0.7-1cm	P	Ta, Te, La
TN037-D13-03	S. Shatsky-Toronto Ridge	32° 43.093'N, 158°15.069'E to 32° 43.639'N, 158°14.261'E	2357	26-Aug-94	breccia	many pieces, d=6-16	Mn cemented fragments of altered basalt similar to D13-01, calcareous sed. similar to D13-13 & chert similar to D13-15; poorly sorted, angular fragments are either matrix to clast supported.	P	Ta, Te, P, A
TN037-D13-04	S. Shatsky-Toronto Ridge	32° 43.093'N, 158°15.069'E to 32° 43.639'N, 158°14.261'E	2357	26-Aug-94	pumice	14x12x8,7x6x5,6x4x3	white with gray to brown stains; frothy vesiculation; qtz phenocrysts(15%)=0.5-3mm; sed. fill vesicles.	P	Ta
TN037-D13-05	S. Shatsky-Toronto Ridge	32° 43.093'N, 158°15.069'E to 32° 43.639'N, 158°14.261'E	2357	26-Aug-94	frothy MnO (pumice?)	17x11x6	black; porous; marginal pores filled with mud; frothy; vesicles size 0.1-1 cm; big prismatic qtz. up to 0.7 cm long (2%).	P	Ta
TN037-D13-06	S. Shatsky-Toronto Ridge	32° 43.093'N, 158°15.069'E to 32° 43.639'N, 158°14.261'E	2357	26-Aug-94	basalt-silicified	13x9x4	greenish to brown gray with white shade; parallel fractures with Mn dendrites & silica; siliceous & hard; Mn crust very thin to 5mm	P	
TN037-D13-07	S. Shatsky-Toronto Ridge	32° 43.093'N, 158°15.069'E to 32° 43.639'N, 158°14.261'E	2357	26-Aug-94	silicified breccia	7x5x4	fragmental; angular fragments of basalt, brown-altered basalt, bioclast in creamy white siliceous matrix; porous margin sometimes filled with sed.	P	

TN037-D13-08	S. Shatsky-Toronto Ridge	32° 43.093'N, 158°15.069'E to 32° 43.639'N, 158°14.261'E	2357	26-Aug-94	breccia	12x8x5,13x9x6,10x9x4,8x7x6	yellow-brown to green-gray; fragmental; fragments are angular, consist of altered basalt, chert & porous sed.; similar to D13-07 but not silicified completely; SiO2 surrounds fragment Mn dendrites in fractures along solution channel.	P	
TN037-D13-09	S. Shatsky-Toronto Ridge	32° 43.093'N, 158°15.069'E to 32° 43.639'N, 158°14.261'E	2357	26-Aug-94	silicified calcareous deposit	4 pieces, d=8-16cm	travertine-like structure grading to fragmental texture; fine to coarse grained; fragments cemented by silica & sometimes surrounded by Mn; some pieces are highly brecciated & completely transformed to chert.	P	
TN037-D13-10	S. Shatsky-Toronto Ridge	32° 43.093'N, 158°15.069'E to 32° 43.639'N, 158°14.261'E	2357	26-Aug-94	silicified mudstone	10x7x5,11x9x8,7x6x5,8x6x3	light olive-green to brown-gray; very fine-grained; highly fragmental; full of cavities and some burrows; some cavities are filled with clay sediments and Mn; burrows are filled with Mn; Mn shell up to 1 cm thick and form dendrites in fractures.	P	
TN037-D13-11	S. Shatsky-Toronto Ridge	32° 43.093'N, 158°15.069'E to 32° 43.639'N, 158°14.261'E	2357	26-Aug-94	silicified fossiliferous sandstone	many pcs; D=5-15 cm	yellow to brown with white specks; porous; similar to TN037-D13-1 but higher degree of silicification such that original porosity is significantly reduced; Mn coating is 1-3 cm thick.	P	
TN037-D13-12	S. Shatsky-Toronto Ridge	32° 43.093'N, 158°15.069'E to 32° 43.639'N, 158°14.261'E	2357	26-Aug-94	breccia	20x14x12,7x7x1,19x11x11,10x6x5	yellow to cream-white; fragments of altered basalt, chert,Mn supported by silicified sand matrix d<2; similar to material observed on top of TN037-D13-02; Mn occurs as specks in matrix, dendrites along margins and as 0.5-1 cm coating.	P	
TN037-D13-13	S. Shatsky-Toronto Ridge	32° 43.093'N, 158°15.069'E to 32° 43.639'N, 158°14.261'E	2357	26-Aug-94	oolitic sandstone	13x15x5	gradational color from brown-gray to yellow to white; 0.5-3 mm well-sorted, elongated to circular shells or bioclasts; porous and poorly consolidated; poorly developed lamination; some lamina are silicified; 1 cm Mn crust.	P	
TN037-D13-14	S. Shatsky-Toronto Ridge	32° 43.093'N, 158°15.069'E to 32° 43.639'N, 158°14.261'E	2357	26-Aug-94	silicified brown rock	5 pcs; D=6-13 cm	brown, amorphous with finely-brecciated texture which gives granular appearance; very hard; smooth, curved fractures; pervasive Mn veining; some fractures contain white, clayey material; 1.5 Mn crust; original rock unidentifiable	P	
TN037-D13-15	S. Shatsky-Toronto Ridge	32° 43.093'N, 158°15.069'E to 32° 43.639'N, 158°14.261'E	2357	26-Aug-94	chert and cherty Mn	4 pcs; D=8-12 cm	pink to gray, non-clastic, and very hard; cherty Mn have interconnected veining and hair -fine lamination of chert	P	
TN037-D13-16	S. Shatsky-Toronto Ridge	32° 43.093'N, 158°15.069'E to 32° 43.639'N, 158°14.261'E	2357	26-Aug-94	sponge (?) fragments	many pcs;D=1.5-7cm	black to brownish-gray; white sponge(?) fragments, some coated with Mn	P	
TN037-D14-01A	S. Shatsky-Toronto Ridge	32° 39.97'N, 158°03.793'E to 32° 40.482'N, 158°05.94'E	2155	27-Aug-94	massive basalt	boulder(broken into fragments)	light brown-gray w/ white & orange specks; massive; dense;porphyritic; phenocrysts are plagioclase(~30%)+ol(~20%)in aphanitic gmass;0.5-1cm alteration rind w/ Mn dendrites; thin coating of Mn.	P	Ta
TN037-D14-01B	S. Shatsky-Toronto Ridge	32° 39.97'N, 158°03.793'E to 32° 40.482'N, 158°05.94'E	2155	27-Aug-94	massive basalt	boulder(broken into fragments)	similar to TN037-D14-01A but more altered; very dense; Mn negligible.	P	Ta
TN037-D14-02	S. Shatsky-Toronto Ridge	32° 39.97'N, 158°03.793'E to 32° 40.482'N, 158°05.94'E	2155	27-Aug-94	massive basalt (altered and silicified)	many pcs; D=3-25 cm	similar to D14-01B but Mn dendrites more pervasive; some pieces have elongated cavities (1%); fractured with Mn and SiO2 infill; slight silicification.	P	
TN037-D14-03	S. Shatsky-Toronto Ridge	32° 39.97'N, 158°03.793'E to 32° 40.482'N, 158°05.94'E	2155	27-Aug-94	massive basalt (weathered)	many pcs; D=5-10 cm	gray, similar to D14-01a but larger phenocrysts and slightly friable; Mn crust-basalt boundary not well-defined; porphyritic texture preserved but plag and ol. altered to clay and iddingsite respectively; gmass altered to clay and Mn; 0.2-1 cm Mn crust.	P	Ta
TN037-D14-04	S. Shatsky-Toronto Ridge	32° 39.97'N, 158°03.793'E to 32° 40.482'N, 158°05.94'E	2155	27-Aug-94	basalt (vesicular)	5x8x5; 17x11x7; 19x11x7	gradational from gray to brown to yellow; 3% vesicles (<1-3 cm) elongated in one direction subparallel to fractures; porphyritic; ol (5%) and plag (5%) phenocrysts; silicification partly obliterates texture; Mn as dendrites in fracture and <1mm-2 cm crust	P	Ta, Te, La
TN037-D14-05	S. Shatsky-Toronto Ridge	32° 39.97'N, 158°03.793'E to 32° 40.482'N, 158°05.94'E	2155	27-Aug-94	basalt (vesicular)	21x22x9; 7x6x4; 10x6x5	dark gray; some pcs pink-brown to white; 20% vesicles 0.5-2 mm; 20-25% plag phenocryst in aphanitic gmass; <1-2 mm Mn crust.	P	Ta, Te, P, A
TN037-D14-06	S. Shatsky-Toronto Ridge	32° 39.97'N, 158°03.793'E to 32° 40.482'N, 158°05.94'E	2155	27-Aug-94	pumice	many pcs; D=2-22 cm	white to gray with brownish white alteration rind; frothy vesiculation; vesicle 1-2 cm; qtz phenocrysts (5%); Mn stains along margins and filling some vesicles.	P	Ta, Te, La
TN037-D14-07	S. Shatsky-Toronto Ridge	32° 39.97'N, 158°03.793'E to 32° 40.482'N, 158°05.94'E	2155	27-Aug-94	silicified breccia	9x8x4	pink to gray with green fragments on one side; sand-sized Mn and sediments cemented by silica on one side grade to weakly cemented brown, gray, and green altered basalt fragments; similar to material on top of one of the D14-02 pcs.	P	

TN037-D14-08	S. Shatsky-Toronto Ridge	32° 39.97'N, 158°03.793'E to 32° 40.482'N, 158°05.94'E	2155	27-Aug-94	basalt (altered)	9x6x5; 11x7x8	cream-white with gray and brown patches; silica obliterates original texture but remnant porphyritic texture observed; original rock similar to D14-03.	P	
TN037-D14-09	S. Shatsky-Toronto Ridge	32° 39.97'N, 158°03.793'E to 32° 40.482'N, 158°05.94'E	2155	27-Aug-94	volcaniclastic breccia	17x17x8; 12x8x9	mixed colors of pink-brown, light-gray, and gray; clast supported sand-sized to 5 cm angular fragments weakly cemented by Mn and some clay; fragments consist of D14-05, D14-03, D14-08, and D14-02.	P	
TN037-D14-10	S. Shatsky-Toronto Ridge	32° 39.97'N, 158°03.793'E to 32° 40.482'N, 158°05.94'E	2155	27-Aug-94	chert (?)	7x4x2	banded structure; alternating gray-to cream-white; cream-white band is slightly porous; thin coating of Mn crust (~1 mm thick).	P	
TN037-D14-11	S. Shatsky-Toronto Ridge	32° 39.97'N, 158°03.793'E to 32° 40.482'N, 158°05.94'E	2155	27-Aug-94	altered rock(basalt?)	9x8x6;9x510x6;5x5x4	green-yellow center w/a shell of gray material w/ yellow specks; center is oblong w/ crystalline texture still preserved; surrounded by Fe-oxide+Mn; shell has remnant igneous texture similar to TN037-D14-03; exfoliation-like weathering pattern.	P	
TN037-D14-12	S. Shatsky-Toronto Ridge	32° 39.97'N, 158°03.793'E to 32° 40.482'N, 158°05.94'E	2155	27-Aug-94	fossil fragment	1pc, 4cm long	creamy-white to gray-white w/ incised criss-crossing pattern; similar to TN037-D12-04.	P	
TN037-D14-13	S. Shatsky-Toronto Ridge	32° 39.97'N, 158°03.793'E to 32° 40.482'N, 158°05.94'E	2155	27-Aug-94	fossil fragment(?)	4pcs,9x4x2;5x4x3	Mn coated, one piece is ear-shaped; other os elongated w/ some structures preserved; 2 pcs are slightly globular+ have silicified core inside.	P	
TN037-D14-14	S. Shatsky-Toronto Ridge	32° 39.97'N, 158°03.793'E to 32° 40.482'N, 158°05.94'E	2155	27-Aug-94	fossil fragments(?)	many pcs;D=2-4cm	white to brown-gray; some with network structure, others w/ spongy texture.	P	
TN037-D14-15	S. Shatsky-Toronto Ridge	32° 39.97'N, 158°03.793'E to 32° 40.482'N, 158°05.94'E	2155	27-Aug-94	pumice(Mn-replaced)	5 pcs	black, with some qtz crystals, similar to TN037-D13-05.	P	
TN037-D14-16	S. Shatsky-Basement High	32° 39.97'N, 158°03.793'E to 32° 40.482'N, 158°05.94'E	2155	27-Aug-94	manganese nodules	many pcs	black to brown-black; smooth-abraded surface; mostly round and single cored; cores consist of sediments,Mn,chert, and basalt fragments.	P	
TN037-C1-PCC1	N. Shatsky, East Terrace	37° 48.35.60'N, 163°08.20'E	3450	12-Aug-94	grey mud	1pc	core catcher (base).		
TN037-C1-PCC2	N. Shatsky, East Terrace	37° 48.35.60'N, 163°08.20'E	3450	12-Aug-94	grey mud	1pc	core catcher (top).		
TN037-C1-TRC1	N. Shatsky, East Terrace	37° 48.35.60'N, 163°08.20'E	3450	12-Aug-94	grey mud		trigger catcher (base).		
TN037-C1-TRC2	N. Shatsky, East Terrace	37° 48.35.60'N, 163°08.20'E	3450	12-Aug-94	grey mud		trigger catcher (top).		
TN037-C1-PC1	N. Shatsky, East Terrace	37° 48.35.60'N, 163°08.20'E	3450	12-Aug-94	grey mud	40cm	core barrel.		TAMUbox
TN037-C1-TR1	N. Shatsky, East Terrace	37° 48.35.60'N, 163°08.20'E	3450	12-Aug-94	grey mud	119cm	trigger gravity core.		TAMUbox
TN037-C2-PCC1	Central Shatsky, SE Terrace (upper unit)	36° 07.999'N, 158°21.660'E	3242	20-Aug-94	carbonate ooze	1 pc	white and light brown; fine grained, well-sorted; thin layer of foraminfera ooze.		Br,SI
TN037-C2-PC1	Central Shatsky, SE Terrace (upper unit)	36° 07.999'N, 158°21.660'E	3242	20-Aug-94	carbonate ooze	36cm	white and light brown; fine grained, well-sorted; white foraminfera ooze pieces surrounded by light brown mud.		TAMUbox
TN037-C2-TR1	Central Shatsky, SE Terrace (upper unit)	36° 07.999'N, 158°21.660'E	3242	20-Aug-94	carbonate ooze	15cm	light brown; fine grained, well-sorted; caution: mostly settled sediments from gravity core.		TAMUbox
TN037-C2-TRC1	Central Shatsky, SE Terrace (upper unit)	36° 07.999'N, 158°21.660'E	3242	20-Aug-94	carbonate ooze	1pc	white and light brown; fine grained, well-sorted; thin layer of foraminfera ooze.		Br, SI
TN037-C3-PC01	Central Shatsky, SE Terrace (lower unit)	35° 53.447'N, 158°51.298'E	3262	20-Aug-94	carbonate ooze	127cm	light brown with white areas with d=1; fine silt, well sorted, clumps of dense white carbonate ooze; dark brown mud in places, few .5cm rock fragments throughout.		TAMUbox
TN037-C3-PC02	Central Shatsky, SE Terrace (lower unit)	35° 53.447'N, 158°51.298'E	3262	20-Aug-94	carbonate ooze	45cm	light brown; fine silt, well sorted, caution: well disturbed by coring, sediments in upper core settled from soupy mix.		TAMUbox
TN037-C3-PC03	Central Shatsky, SE Terrace (lower unit)	35° 53.447'N, 158°51.298'E	3262	20-Aug-94	carbonate ooze	18cm	light brown; fine silt, well sorted, caution: well disturbed by coring, sediments in entire core settled from soupy mix.		
TN037-C3-TRC1	Central Shatsky, SE Terrace (lower unit)	35° 53.447'N, 158°51.298'E	3262	20-Aug-94	carbonate ooze	1pc	light brown; fine silt, well sorted.		Br, SI
TN037-C3-TR1	Central Shatsky, SE Terrace (lower unit)	35° 53.447'N, 158°51.298'E	3262	20-Aug-94	carbonate ooze	14cm	light brown with streaks of white/cream; fine silt, well-sorted; caution: partly disturbed by coring, sediments in upper part of core settled from soupy mix.		TAMUbox
TN037-C3-PCC1	Central Shatsky, SE Terrace (lower unit)	35° 53.447'N, 158°51.298'E	3262	20-Aug-94	carbonate ooze				Br, SI
TN037-C4-PCC1	S. Shatsky-Valley West of Toronto Ridge(lower wall)	32° 58.828'N, 157°56.796'E	3552	26-Aug-94	carbonate ooze		small pcs of chert and ooze collected from core.		
TN037-C4-TRC1	S. Shatsky-Valley West of Toronto Ridge(lower wall)	32° 58.828'N, 157°56.796'E	3552	26-Aug-94	carbonate ooze	fist-sized	white-light brown; hard/dry.		Br,SI
TN037-C4-PC01	S. Shatsky-Valley West of Toronto Ridge(lower wall)	32° 58.828'N, 157°56.796'E	3552	26-Aug-94	carbonate ooze	110cm	white patches with dark brown zones, but most light brown, 45cm from bottom has equal white/brown portions.		TAMUbox
TN037-C4-PC02	S. Shatsky-Valley West of Toronto Ridge(lower wall)	32° 58.828'N, 157°56.796'E	3552	26-Aug-94	carbonate ooze	58cm	light brown-cream with patches of foram ooze and dark brown mud; some rock fragments of sand+ size; soupy mud has lined outside of otherwise dense core.		TAMUbox
TNO37-C4-TR1	S. Shatsky-Valley West of Toronto Ridge (thalweg)	32° 59.731'N, 157°56.466'E	3630	26-Aug-94	carbonate ooze	58cm	light brown ooze.		TAMUbox

TNO37-C5-PCC1	S. Shatsky-Valley West of Toronto Ridge (thalweg)	32° 59.731'N, 157°56.466'E	3630	26-Aug-94	**carbonate ooze**	large pc	light brown-cream; fine grained; compact.		**Br,Sl**
TNO37-C5-TRC1	S. Shatsky-Valley West of Toronto Ridge (thalweg)	32° 59.731'N, 157°56.466'E	3630	26-Aug-94	**carbonate ooze**	small plug	same		**Br,Sl**
TNO37-C5-TR1	S. Shatsky-Valley West of Toronto Ridge (thalweg)	32° 59.731'N, 157°56.466'E	3630	26-Aug-94	**carbonate ooze**	18cm	light brown; soupy mix of suspended mud (this was later recut after settling).		**TAMUbox**
TNO37-C5-PC01	S. Shatsky-Valley West of Toronto Ridge (thalweg)	32° 59.731'N, 157°56.466'E	3630	26-Aug-94	**carbonate ooze**	144cm	light brown compacted ooze.		**TAMUbox**
TNO37-C5-PC02	S. Shatsky-Valley West of Toronto Ridge (thalweg)	32° 59.731'N, 157°56.466'E	3630	26-Aug-94	**carbonate ooze**	111cm	lower part Section 1; light cream color on top; soupy mud mix between core and liner.		**TAMUbox**

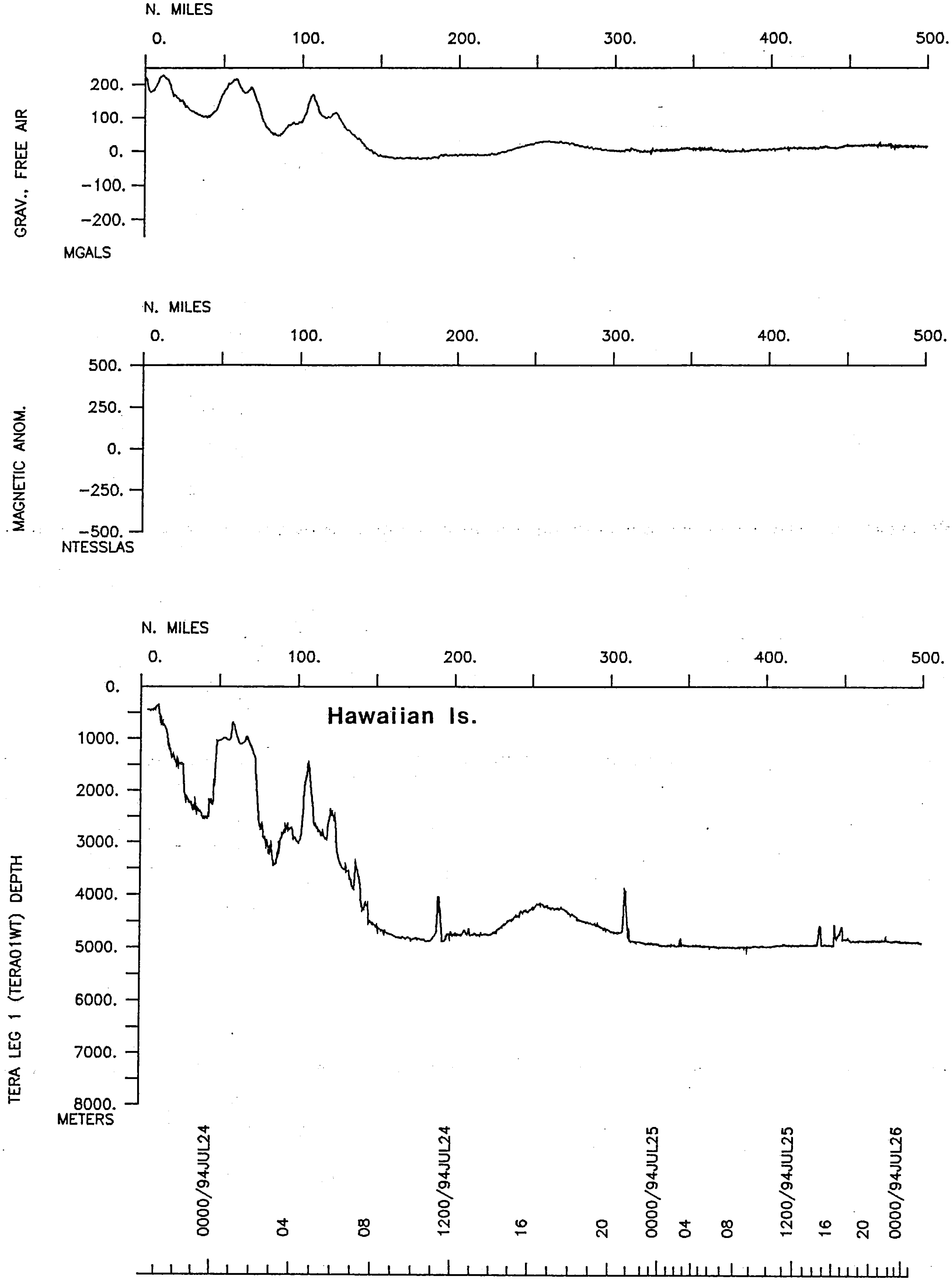
Appendix 2

Profiles of Digital Geophysical Data

Free Air Gravity Anomaly (Top)

Magnetic Anomaly (Middle)

Bathymetry (Bottom)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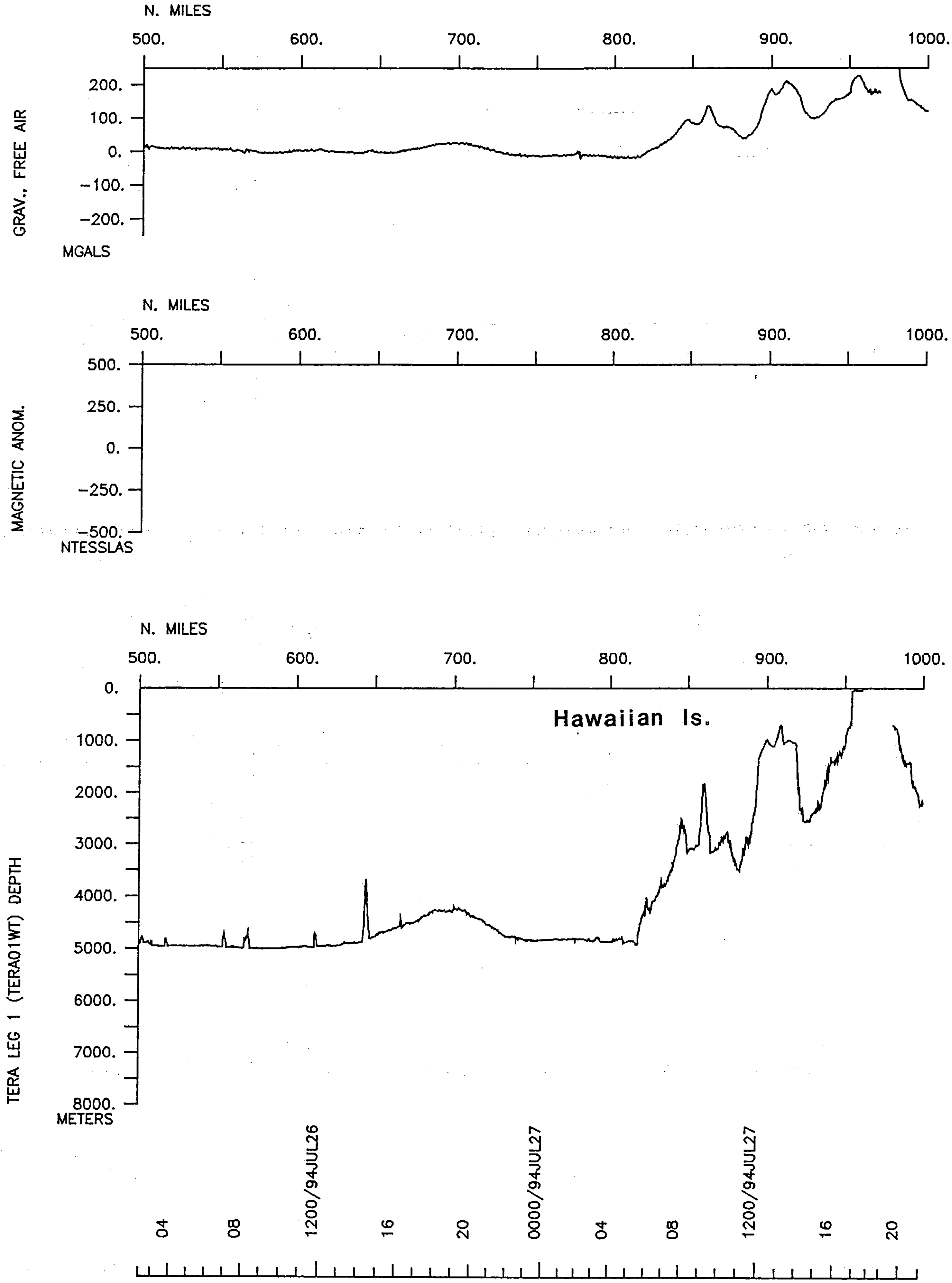
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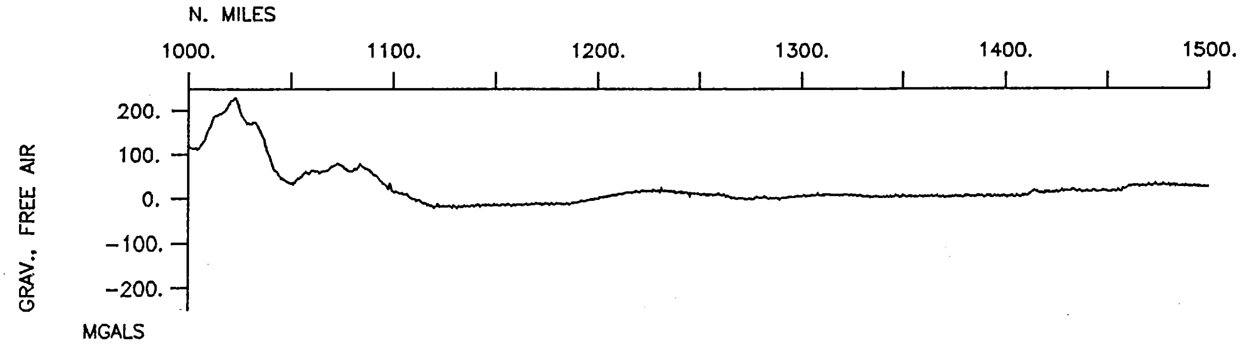
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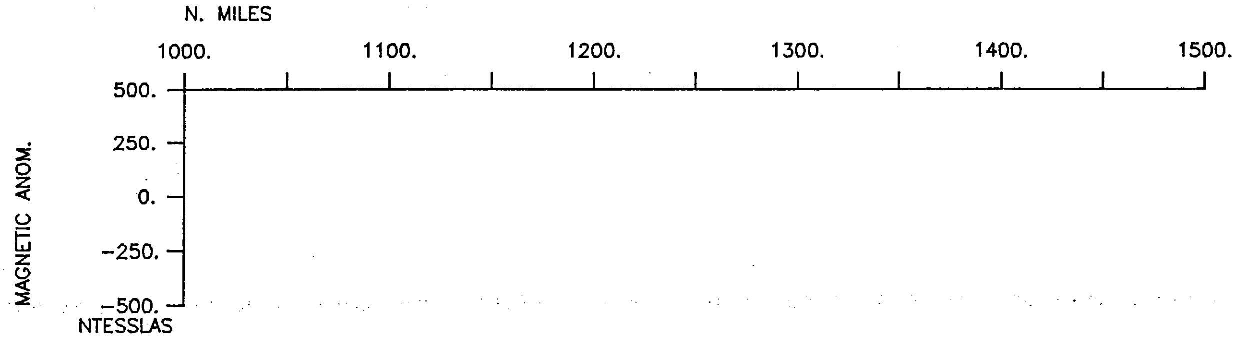
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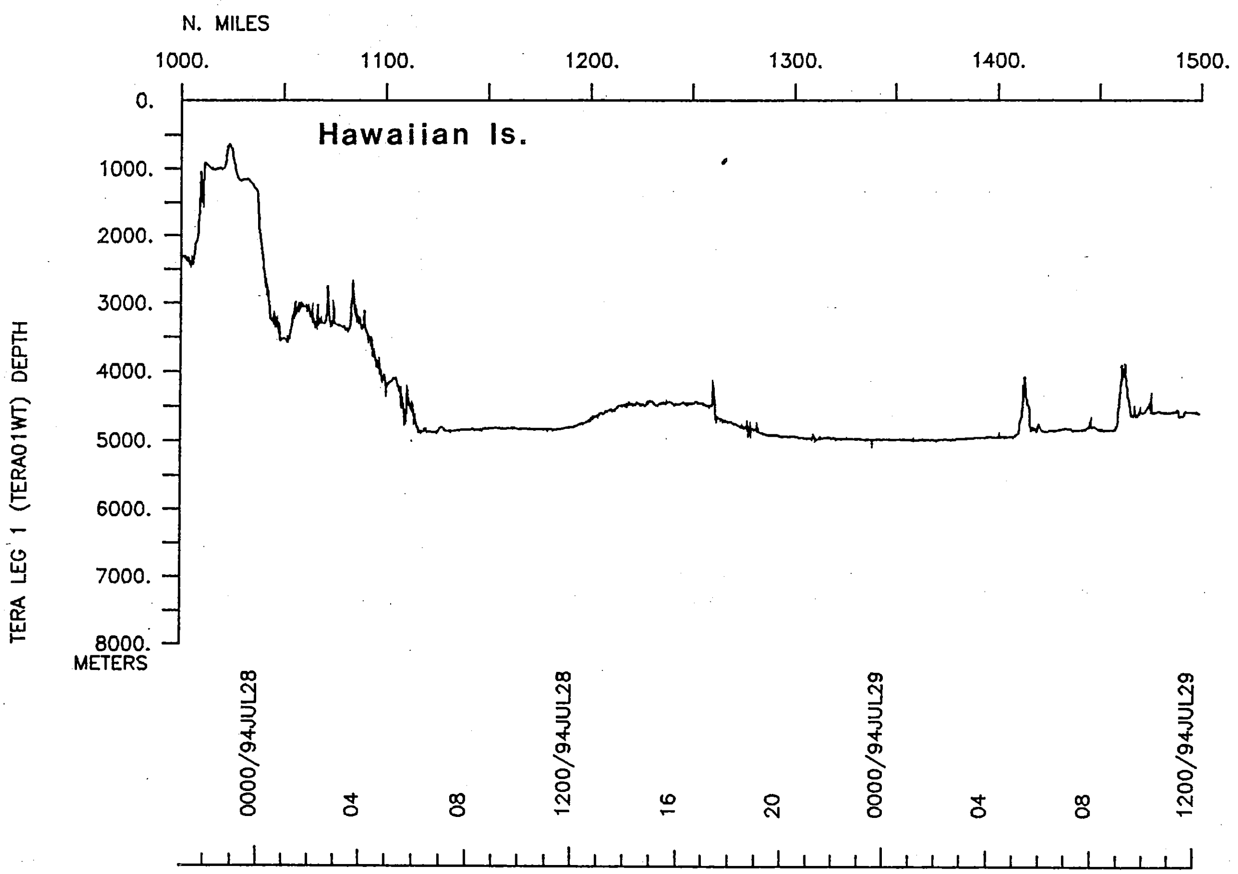
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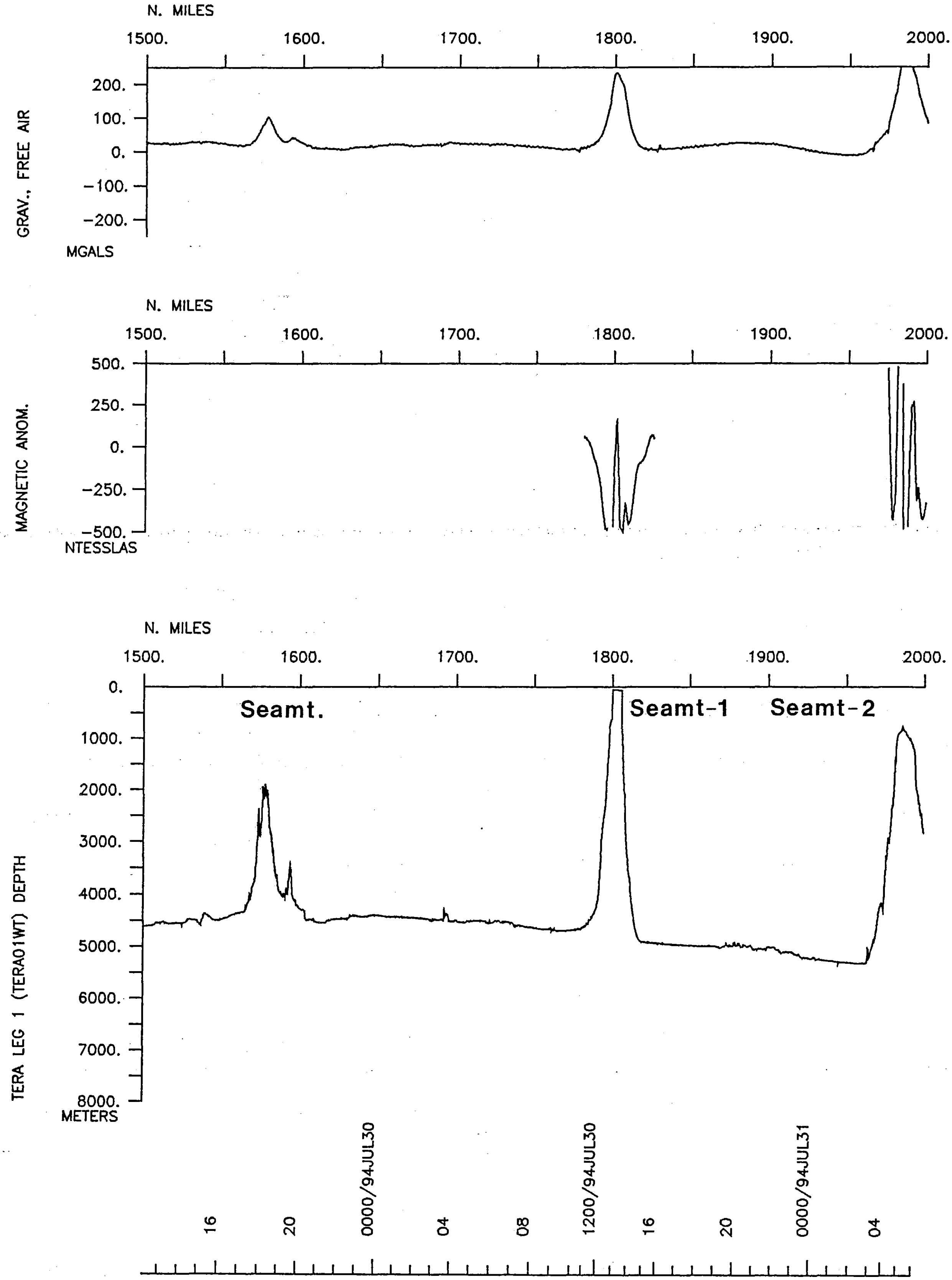
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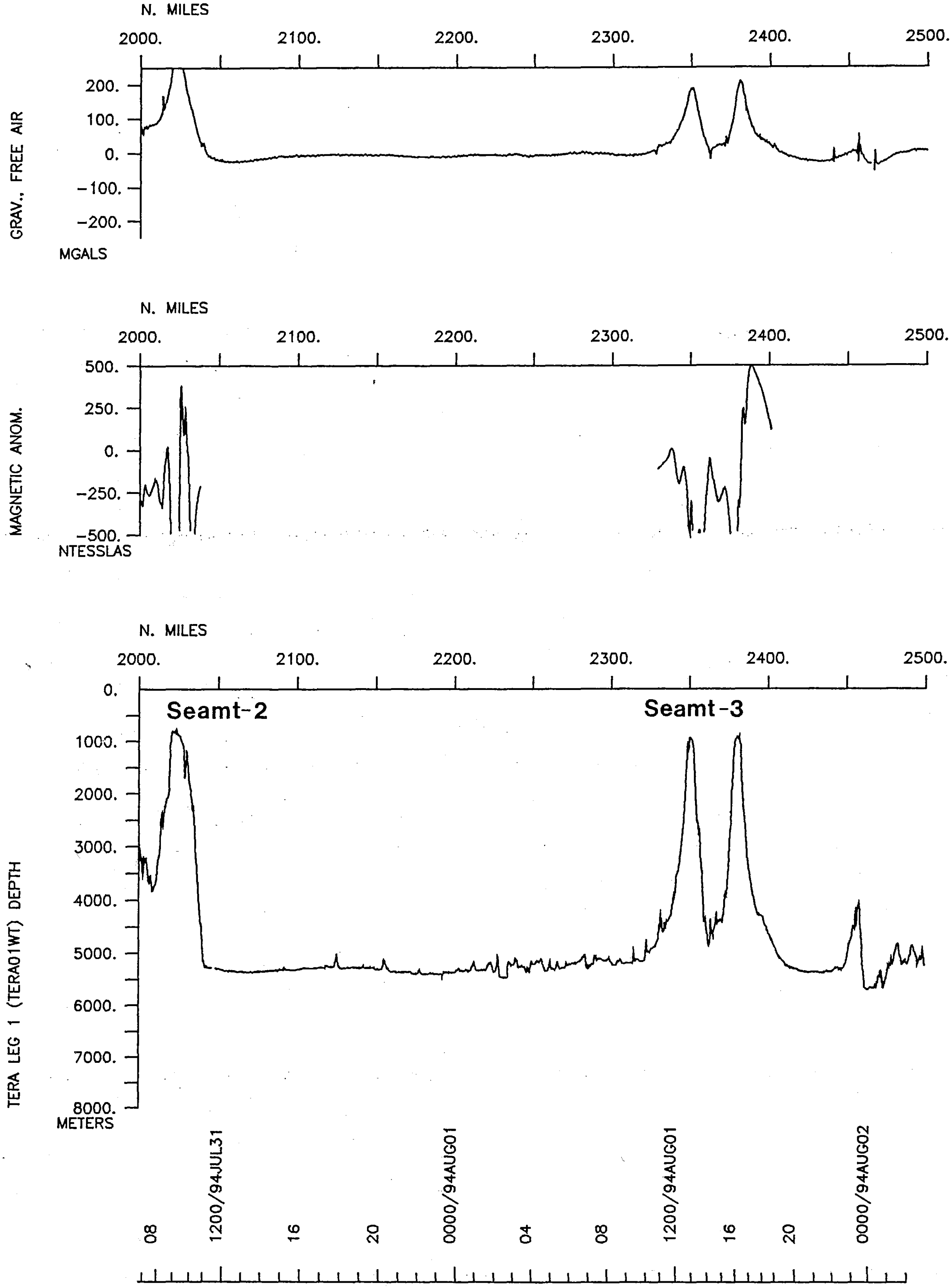
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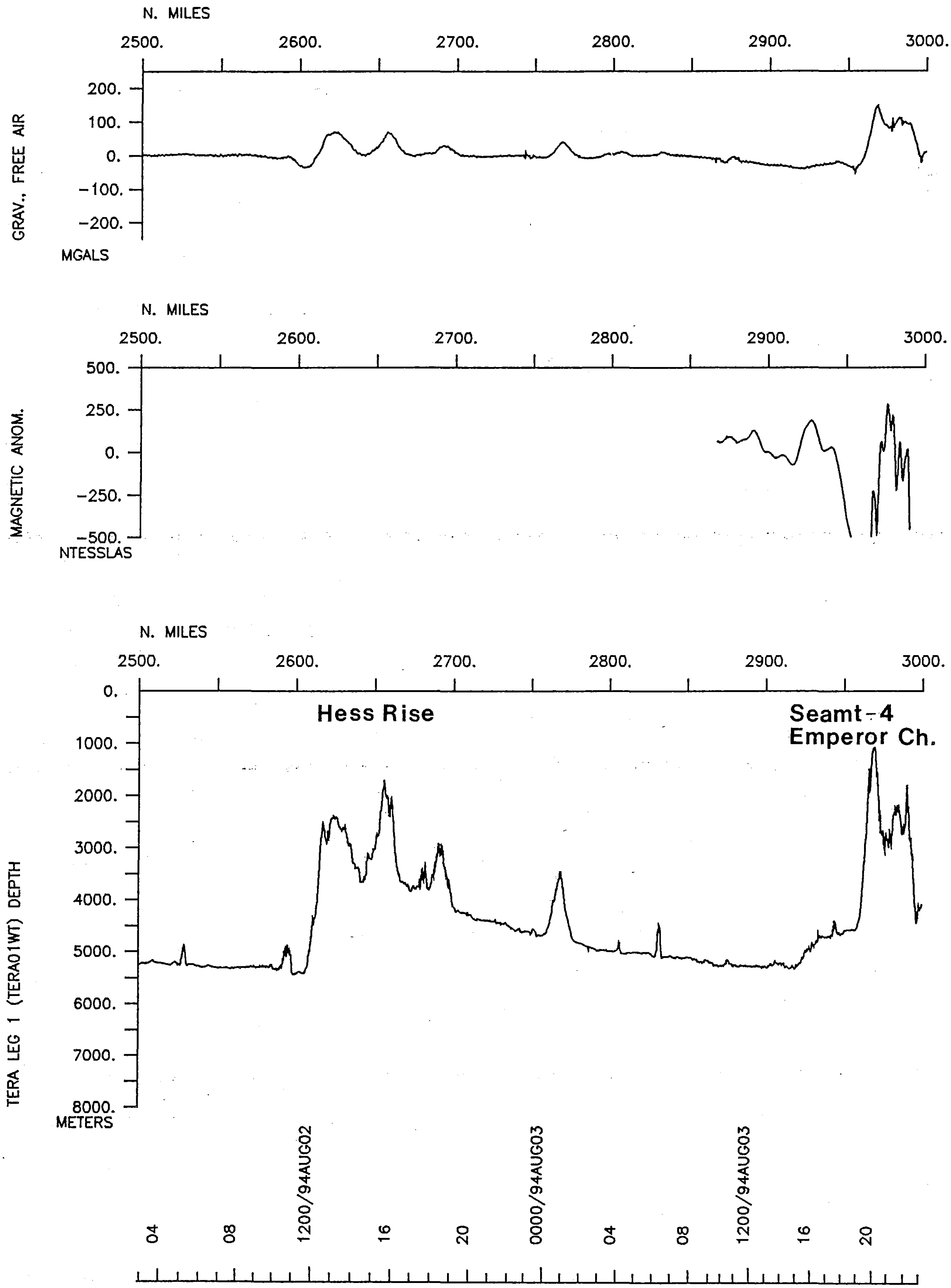
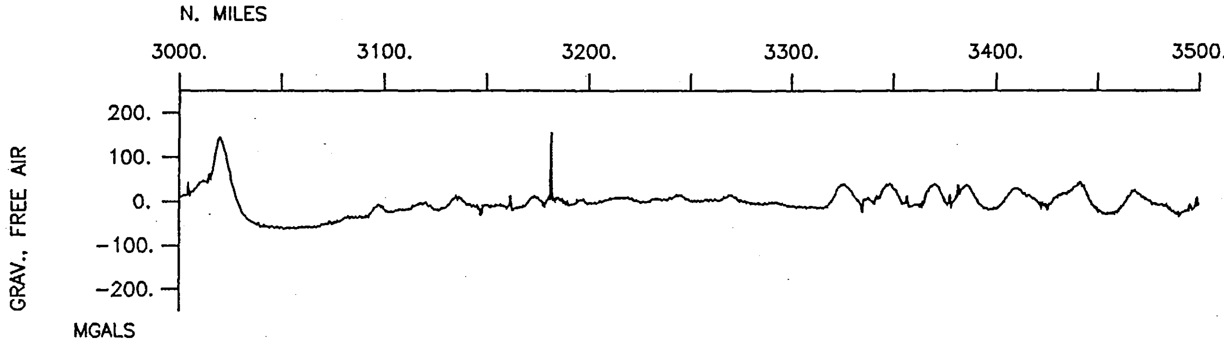
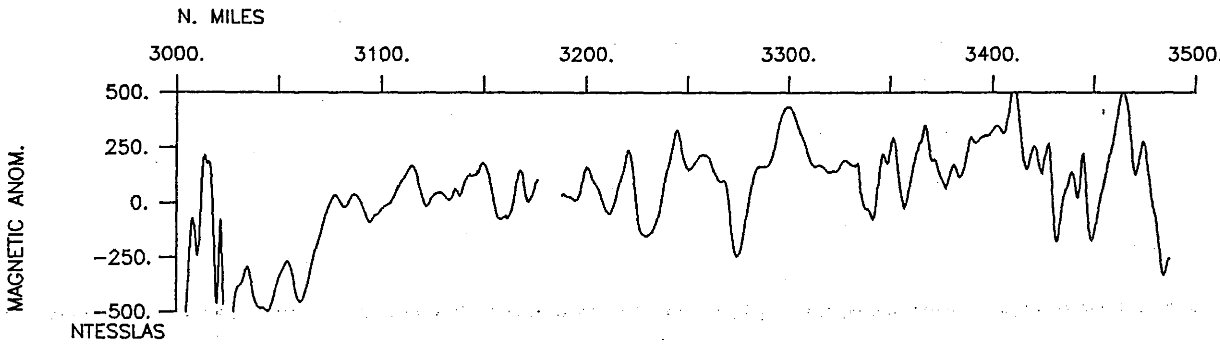
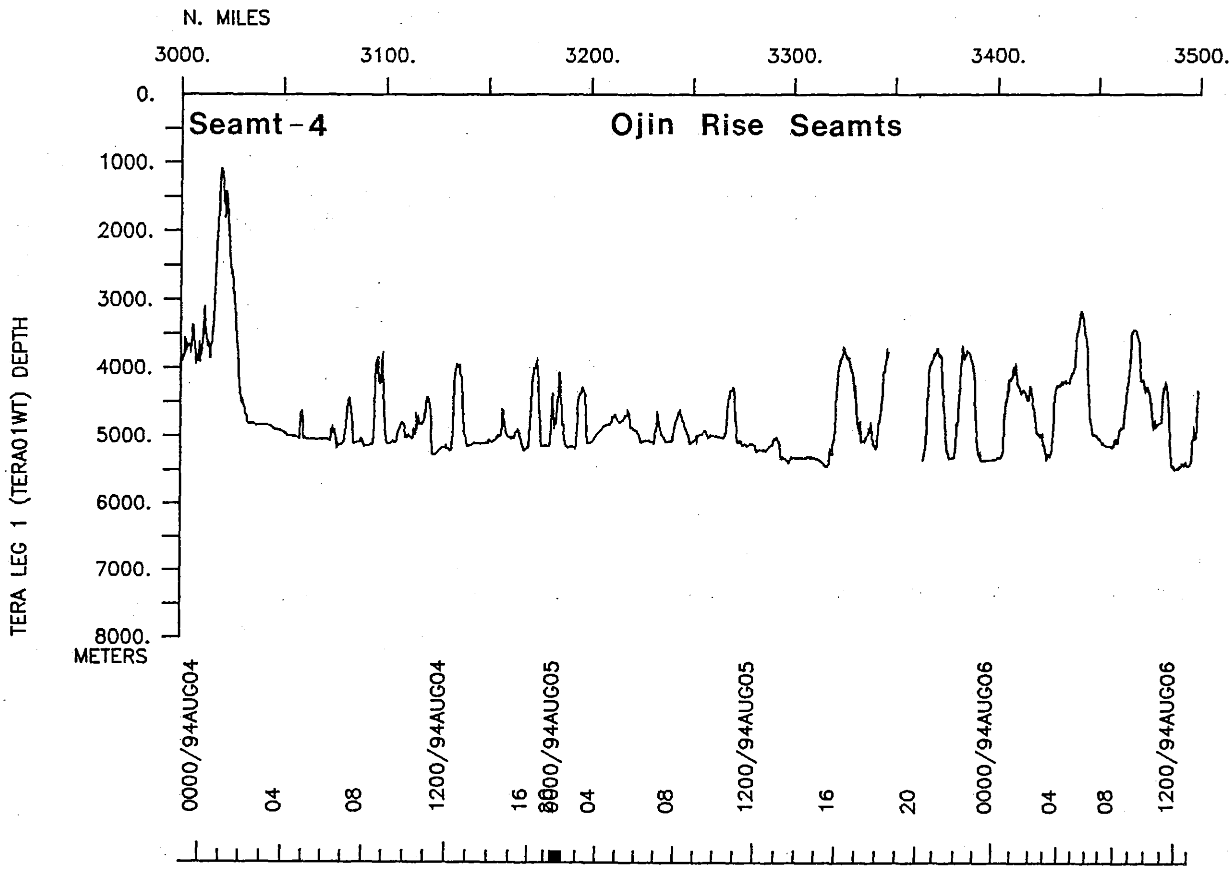

N. MILES
2500.
2600.
2700.
2800.
2900.
3000.
200.
100.
0.
-100.
-200.
GRAV., FREE AIR
MGALS
N. MILES
2500.
2600.
2700.
2800.
2900.
3000.
500.
250.
0.
-250.
-500.
MAGNETIC ANOM.
NTESSLAS
N. MILES
2500.
2600.
2700.
2800.
2900.
3000.
Hess Rise
Seamt-4
Emperor Ch.
0.
1000.
2000.
3000.
4000.
5000.
6000.
7000.
8000.
TERA LEG 1 (TERA01WT) DEPTH
METERS
04
08
1200/94AUG02
16
20
0000/94AUG03
04
08
1200/94AUG03
16
20



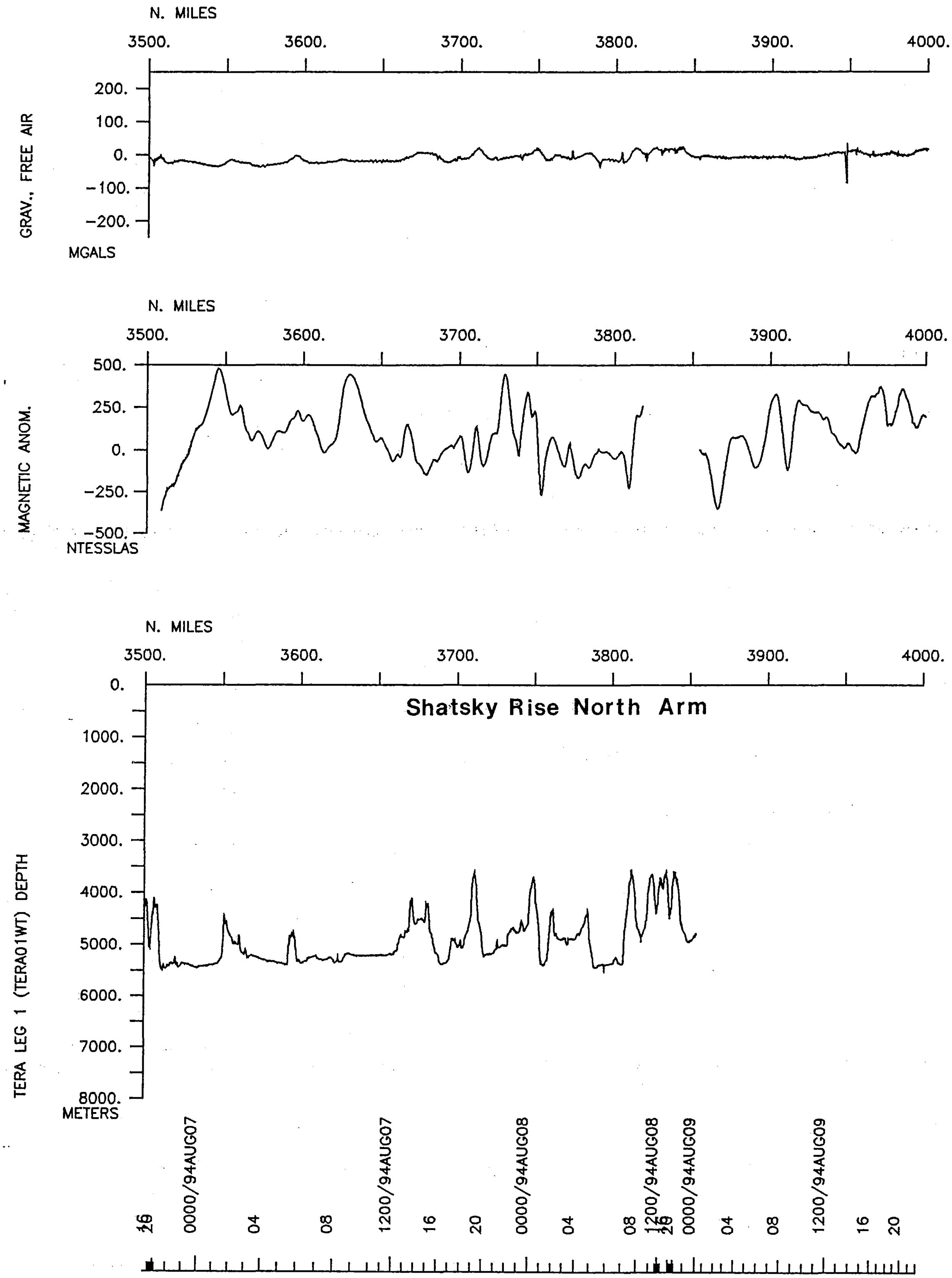
N. MILES
3000.
3100.
3200.
3300.
3400.
3500.
200.
100.
0.
-100.
-200.
GRAV., FREE AIR
MGALS

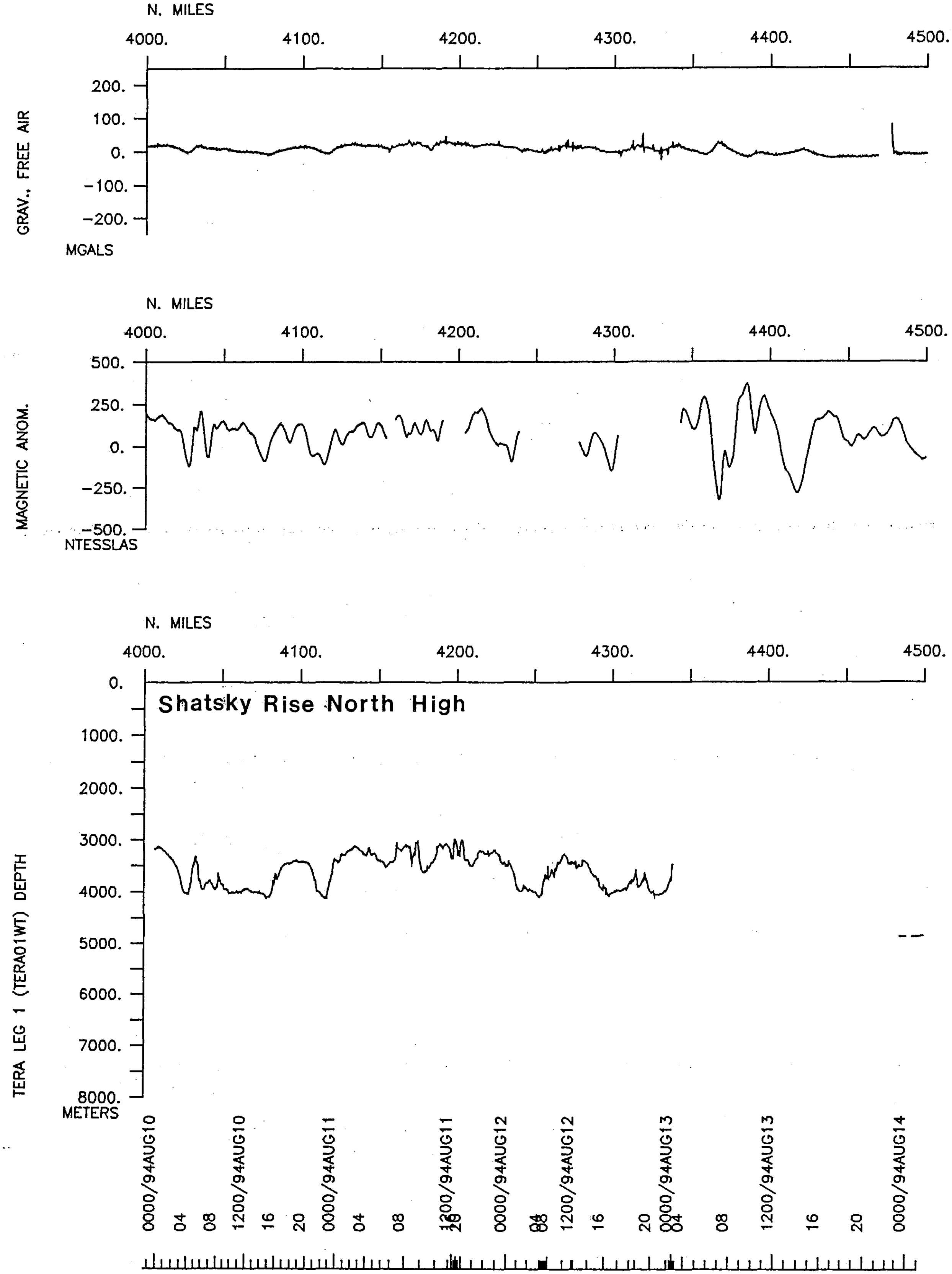


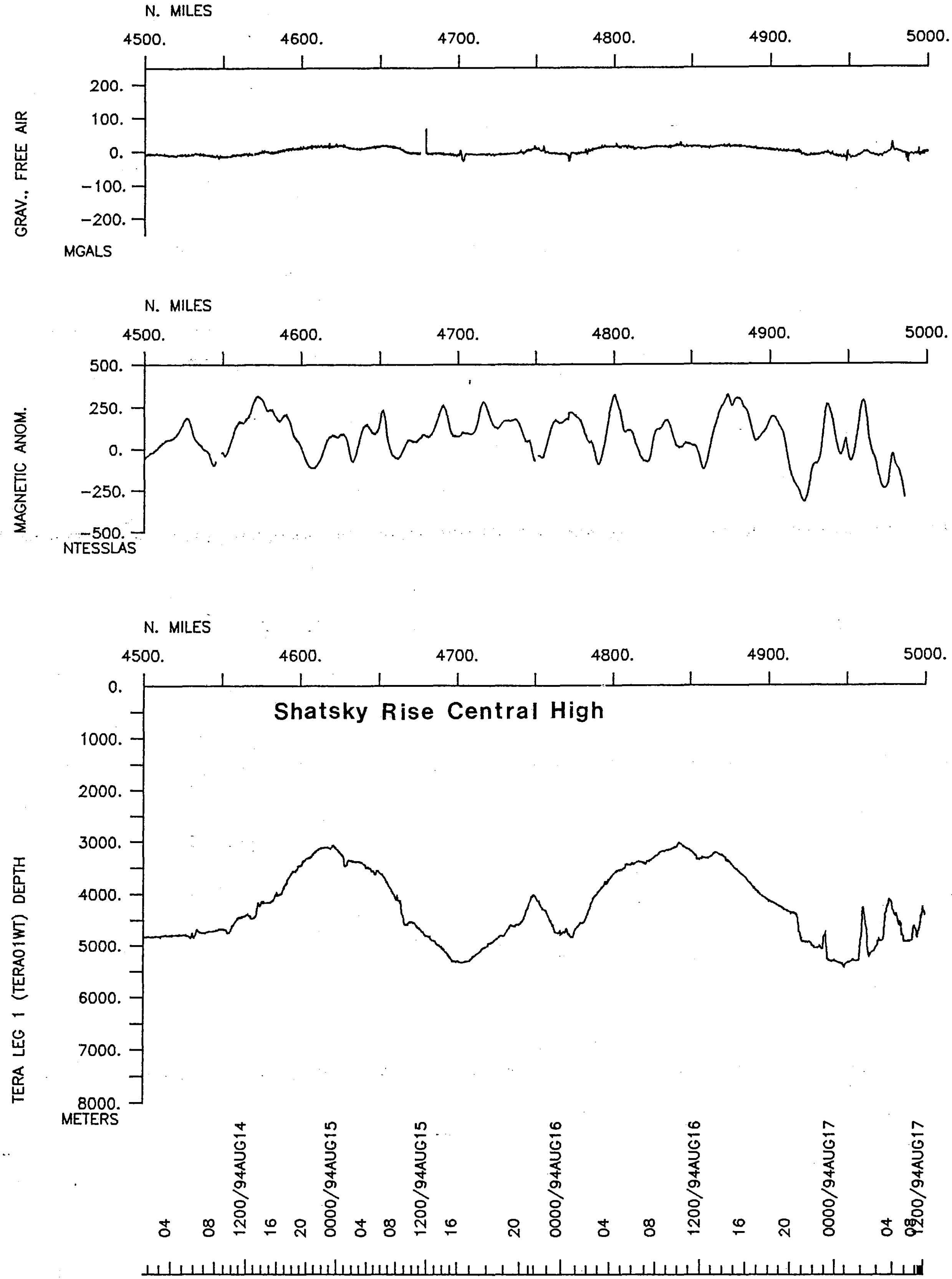
N. MILES
3000.
3100.
3200.
3300.
3400.
3500.
500.
250.
0.
-250.
-500.
MAGNETIC ANOM.
NTESSLAS



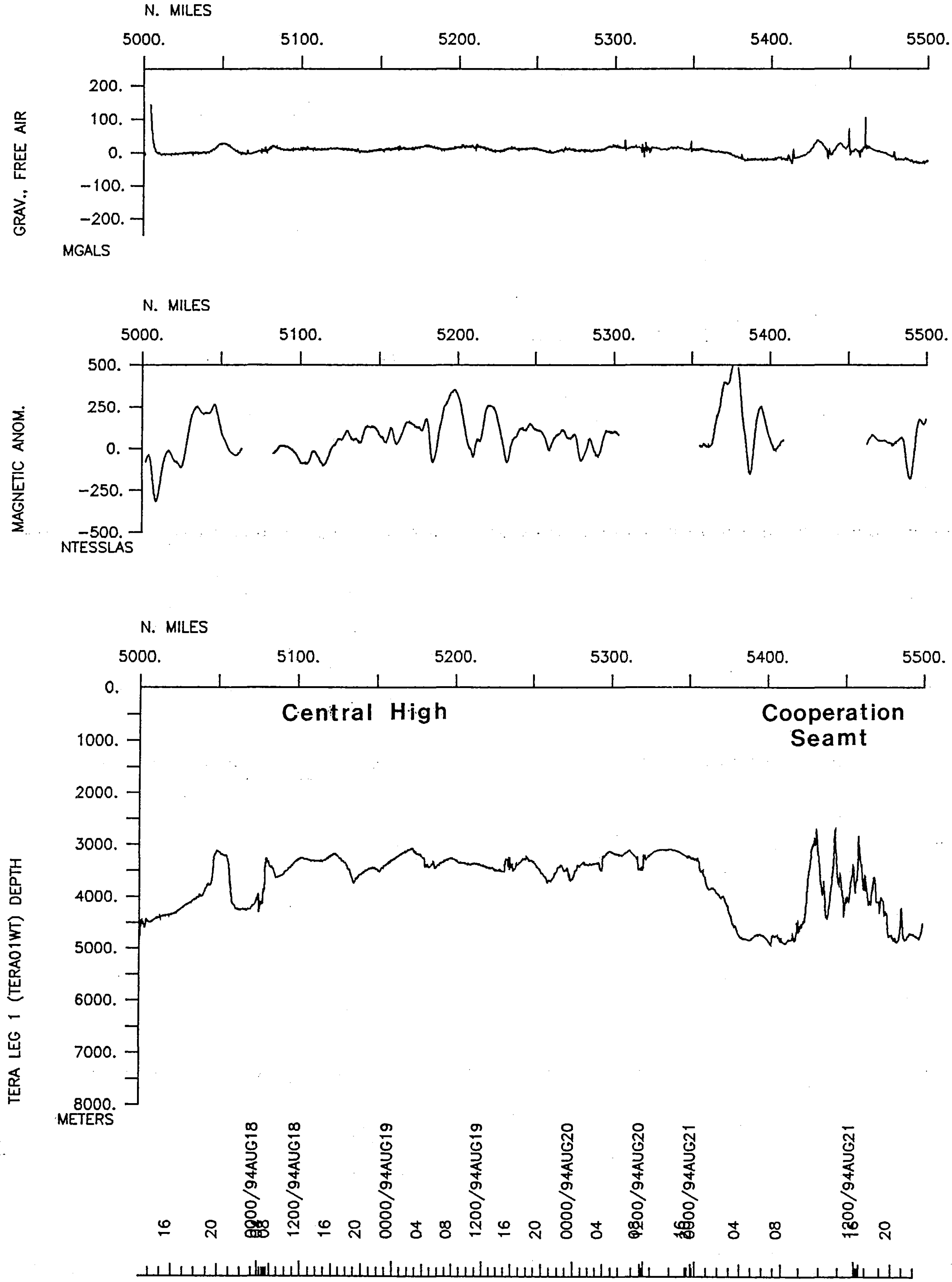
N. MILES
3000.
3100.
3200.
3300.
3400.
3500.
Seamt-4
Ojin Rise Seamts
0.
1000.
2000.
3000.
4000.
5000.
6000.
7000.
8000.
METERS
TERA LEG 1 (TERA01WT) DEPTH
0000/94AUG04
04
08
1200/94AUG04
16
0000/94AUG05
04
08
1200/94AUG05
16
20
0000/94AUG06
04
08
1200/94AUG06

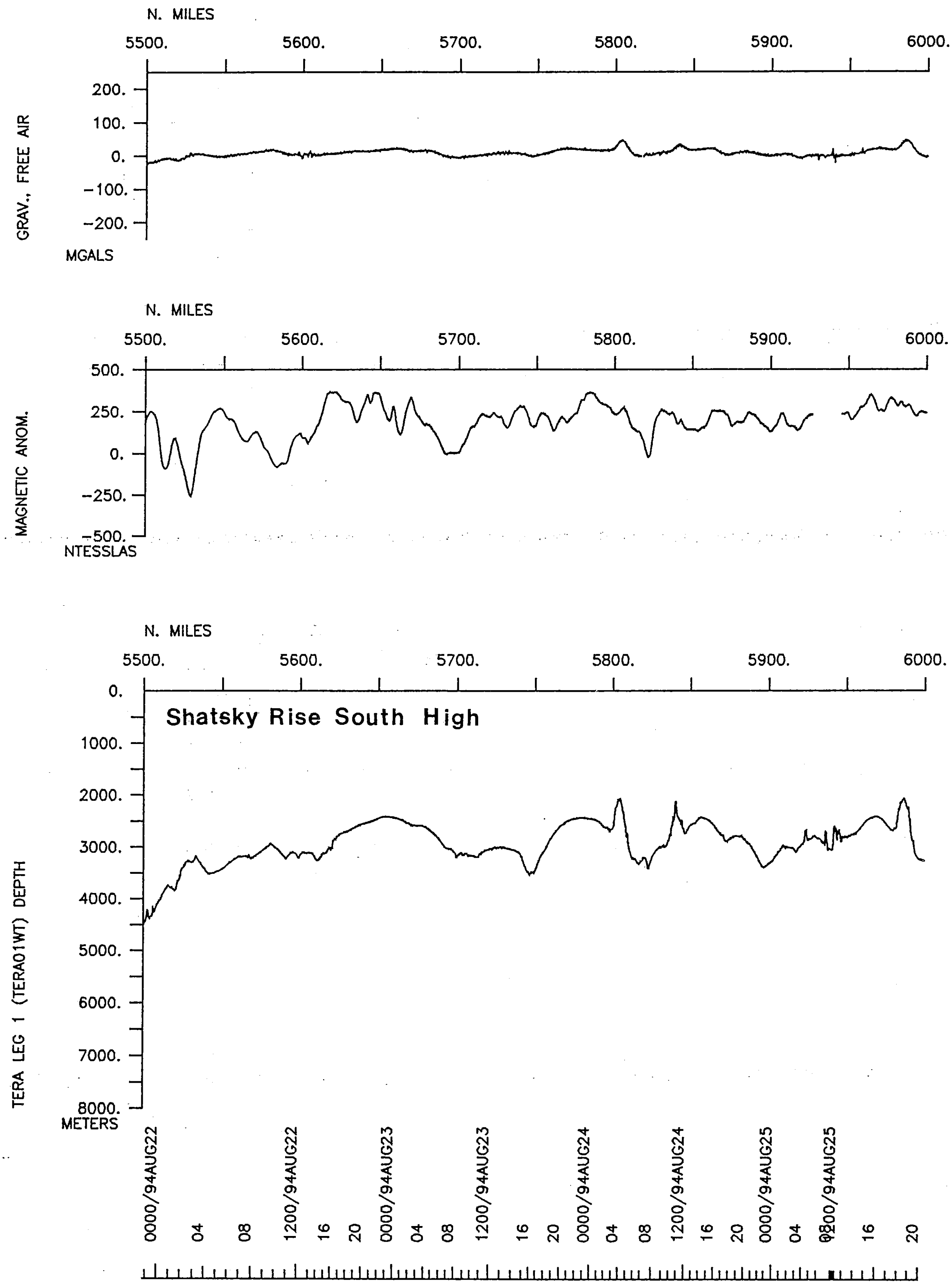

N. MILES
3500. 3600. 3700. 3800. 3900. 4000.
200. 100. 0. −100. −200.
GRAV., FREE AIR
MGALS
N. MILES
3500. 3600. 3700. 3800. 3900. 4000.
500. 250. 0. −250. −500.
MAGNETIC ANOM.
NTESSLAS
N. MILES
3500. 3600. 3700. 3800. 3900. 4000.
Shatsky Rise North Arm
0. 1000. 2000. 3000. 4000. 5000. 6000. 7000. 8000.
TERA LEG 1 (TERA01WT) DEPTH
METERS
0000/94AUG07
1200/94AUG07
0000/94AUG08
1200/94AUG08
0000/94AUG09
1200/94AUG09
04 08 16 20 04 08 16 20 04 08 16 20

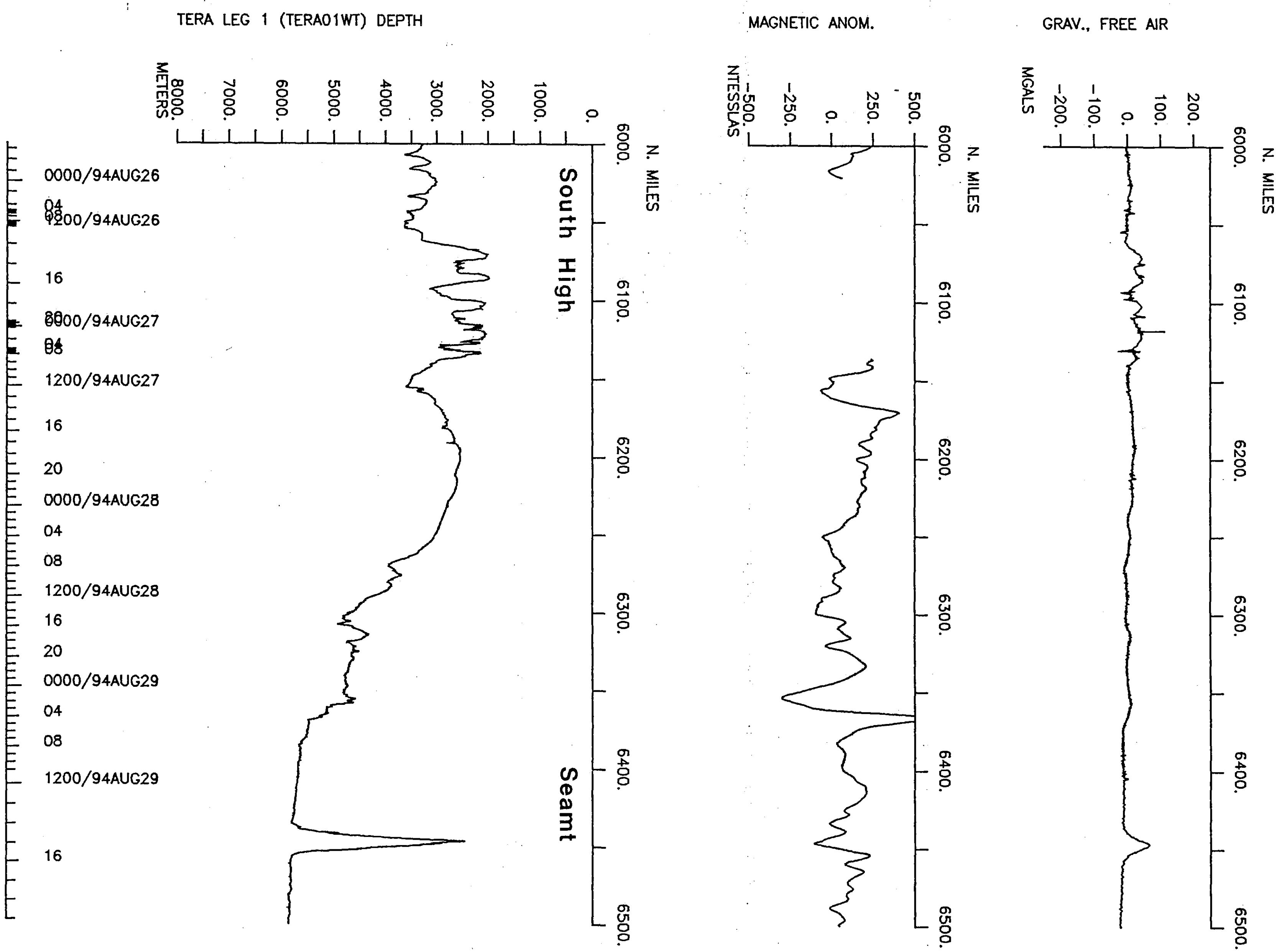

N. MILES
4000.
4100.
4200.
4300.
4400.
4500.
200.
100.
0.
-100.
-200.
GRAV., FREE AIR
MGALS
N. MILES
4000.
4100.
4200.
4300.
4400.
4500.
500.
250.
0.
-250.
-500.
MAGNETIC ANOM.
NTESSLAS
N. MILES
4000.
4100.
4200.
4300.
4400.
4500.
Shatsky Rise North High
0.
1000.
2000.
3000.
4000.
5000.
6000.
7000.
8000.
TERA LEG 1 (TERA01WT) DEPTH
METERS
0000/94AUG10
04
08
1200/94AUG10
16
20
0000/94AUG11
04
08
1200/94AUG11
0000/94AUG12
1200/94AUG12
16
20
0000/94AUG13
08
1200/94AUG13
16
20
0000/94AUG14



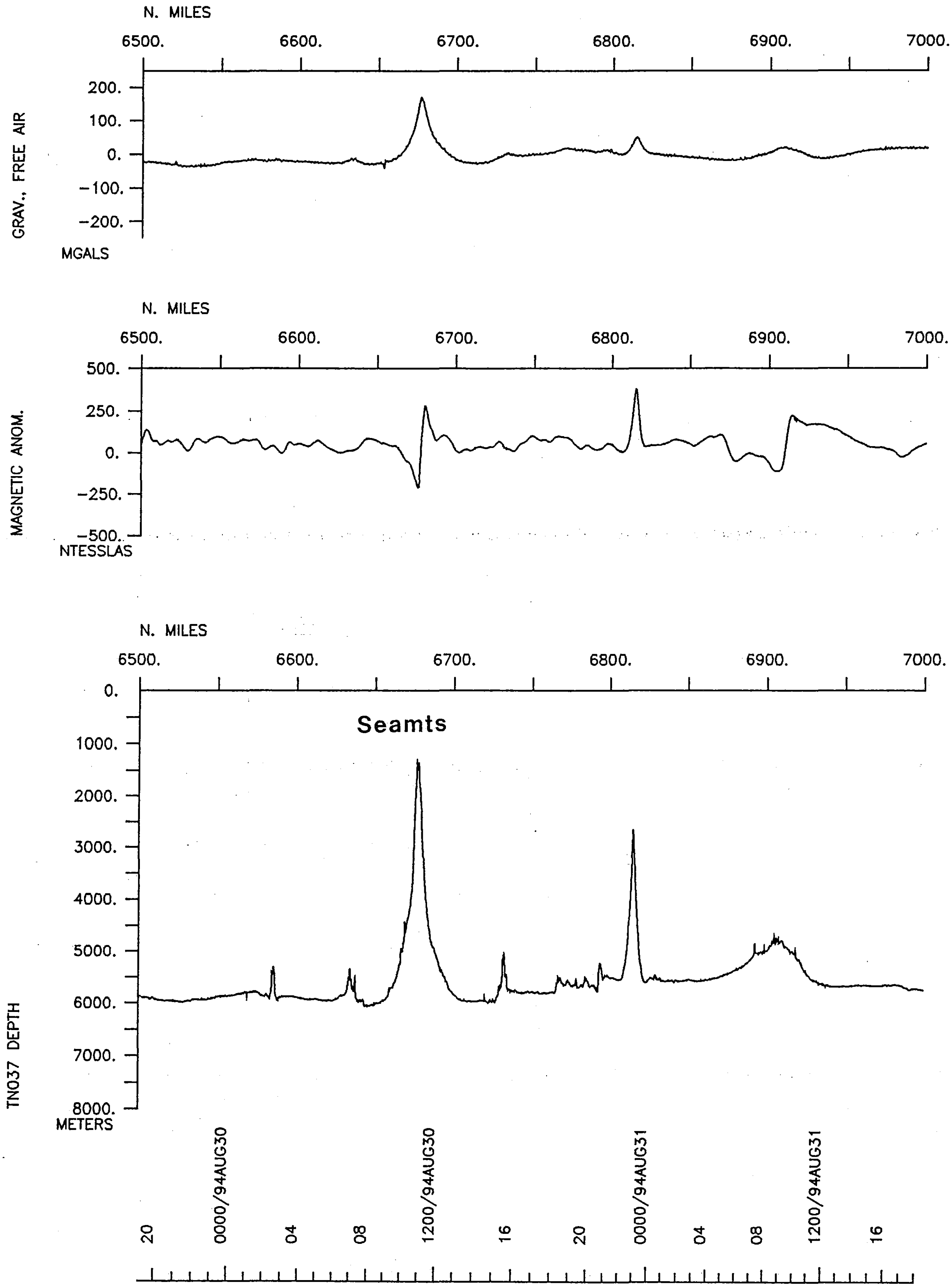
N. MILES
4500.
4600.
4700.
4800.
4900.
5000.
200.
100.
0.
-100.
-200.
GRAV., FREE AIR
MGALS
500.
250.
-250.
-500.
MAGNETIC ANOM.
NTESSLAS
Shatsky Rise Central High
1000.
2000.
3000.
4000.
5000.
6000.
7000.
8000.
METERS
TERA LEG 1 (TERA01WT) DEPTH
1200/94AUG14
0000/94AUG15
1200/94AUG15
0000/94AUG16
1200/94AUG16
0000/94AUG17
1200/94AUG17
04
08
16
20


N. MILES
5000.
5100.
5200.
5300.
5400.
5500.
200.
100.
0.
-100.
-200.
GRAV., FREE AIR
MGALS
N. MILES
5000.
5100.
5200.
5300.
5400.
5500.
500.
250.
0.
-250.
-500.
MAGNETIC ANOM.
NTESSLAS
N. MILES
5000.
5100.
5200.
5300.
5400.
5500.
0.
1000.
2000.
3000.
4000.
5000.
6000.
7000.
8000.
METERS
TERA LEG 1 (TERA01WT) DEPTH
Central High
Cooperation Seamt
16
20
1200/94AUG18
16
20
0000/94AUG19
04
08
1200/94AUG19
16
20
0000/94AUG20
04
04
08
1200/94AUG21
20

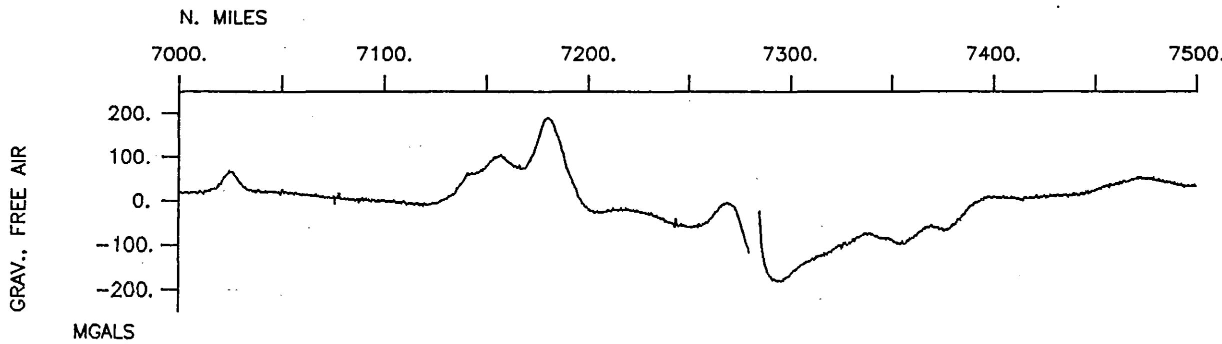

N. MILES
5500.
5600.
5700.
5800.
5900.
6000.
200.
100.
0.
−100.
−200.
GRAV., FREE AIR
MGALS
N. MILES
5500.
5600.
5700.
5800.
5900.
6000.
500.
250.
0.
−250.
−500.
MAGNETIC ANOM.
NTESSLAS
N. MILES
5500.
5600.
5700.
5800.
5900.
6000.
Shatsky Rise South High
0.
1000.
2000.
3000.
4000.
5000.
6000.
7000.
8000.
METERS
TERA LEG 1 (TERA01WT) DEPTH
0000/94AUG22
04
08
1200/94AUG22
16
20
0000/94AUG23
04
08
1200/94AUG23
16
20
0000/94AUG24
04
08
1200/94AUG24
16
20
0000/94AUG25
04
08
1200/94AUG25
16
20

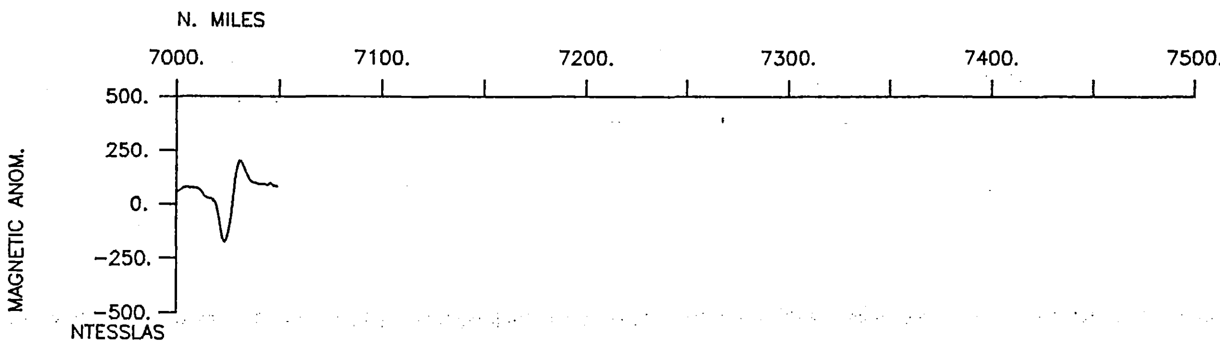


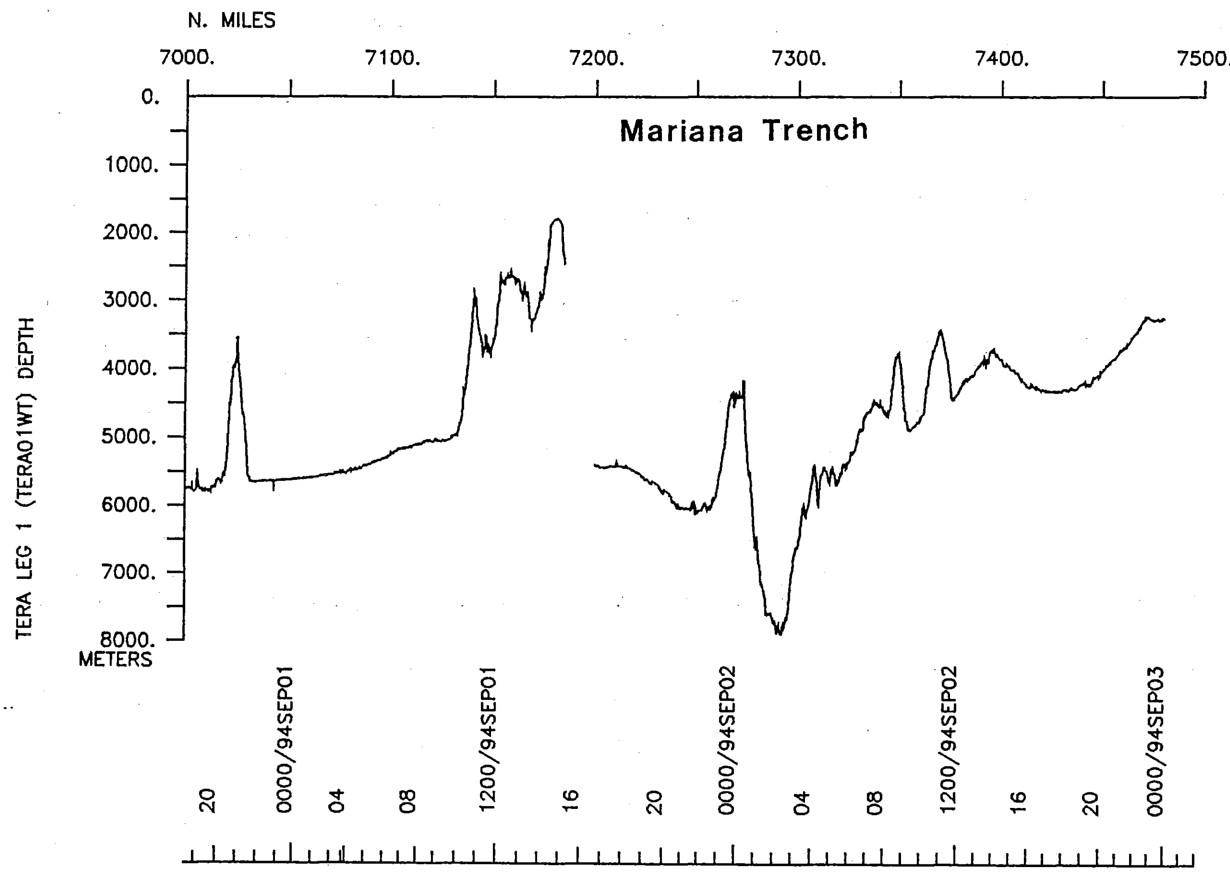
TERA LEG 1 (TERA01WT) DEPTH
MAGNETIC ANOM.
GRAV., FREE AIR
N. MILES
METERS
NTESSLAS
MGALS
South High
Seamt
0000/94AUG26
1200/94AUG26
0000/94AUG27
1200/94AUG27
0000/94AUG28
1200/94AUG28
0000/94AUG29
1200/94AUG29

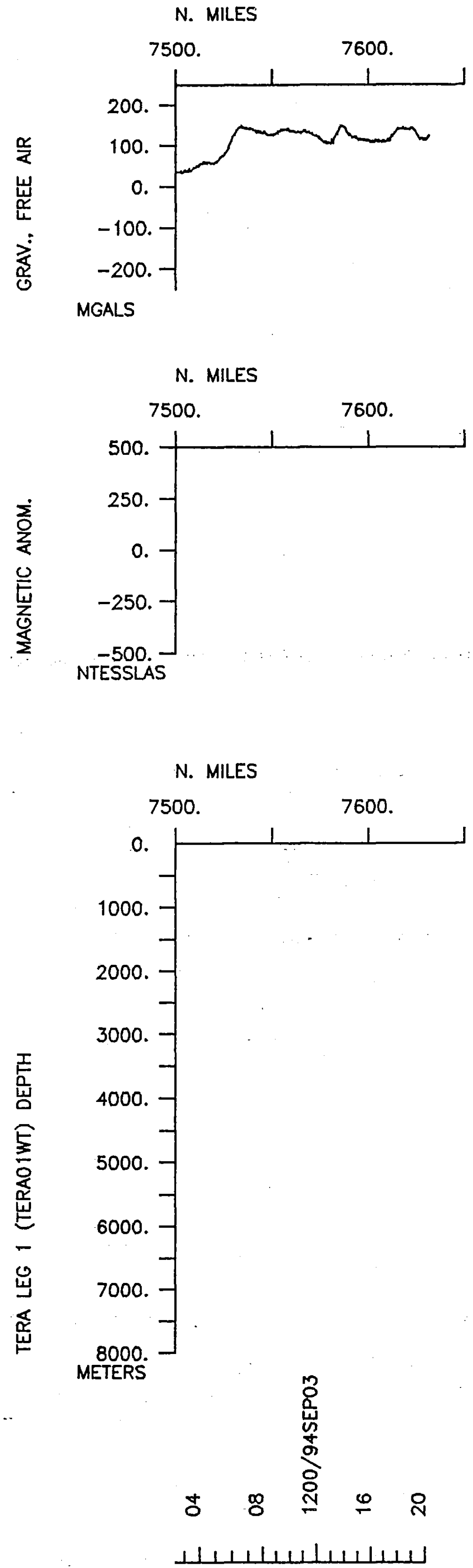


N. MILES
6500.
6600.
6700.
6800.
6900.
7000.
200.
100.
0.
−100.
−200.
GRAV., FREE AIR
MGALS
N. MILES
6500.
6600.
6700.
6800.
6900.
7000.
500.
250.
0.
−250.
−500.
MAGNETIC ANOM.
NTESSLAS
N. MILES
6500.
6600.
6700.
6800.
6900.
7000.
0.
1000.
2000.
3000.
4000.
5000.
6000.
7000.
8000.
METERS
TN037 DEPTH
Seamts
20
0000/94AUG30
04
08
1200/94AUG30
16
20
0000/94AUG31
04
08
1200/94AUG31
16


N. MILES
7000.
7100.
7200.
7300.
7400.
7500.
200.
100.
0.
-100.
-200.
GRAV., FREE AIR
MGALS


N. MILES
7000.
7100.
7200.
7300.
7400.
7500.
500.
250.
0.
-250.
-500.
MAGNETIC ANOM.
NTESSLAS


N. MILES
7000.
7100.
7200.
7300.
7400.
7500.
Mariana Trench
0.
1000.
2000.
3000.
4000.
5000.
6000.
7000.
8000.
METERS
TERA LEG 1 (TERA01WT) DEPTH
20
0000/94SEP01
04
08
1200/94SEP01
16
20
0000/94SEP02
04
08
1200/94SEP02
16
20
0000/94SEP03


N. MILES
7500.
7600.
200.
100.
0.
−100.
−200.
GRAV., FREE AIR
MGALS
N. MILES
7500.
7600.
500.
250.
0.
−250.
−500.
MAGNETIC ANOM.
NTESSLAS
N. MILES
7500.
7600.
0.
1000.
2000.
3000.
4000.
5000.
6000.
7000.
8000.
TERA LEG 1 (TERA01WT) DEPTH
METERS
04
08
1200/94SEP03
16
20