Utilization 91-06

CRUISE REPORT

UNOLS 12/89

Ship Utilization Data

Ship Name	2. Operating Institution	3. Cruise (leg) Number
R/V MAURICE EWING	Lamont-Doherty Geological Observatory Palisades, N.Y. 10964	EW91-06

4. Dates of Project:

Begin: 9/21/91

End: 11/1/91

Port Calls

Place	Date
Easter Island	9/21/91
Tonga	10/22-10/24/91
Lyttleton	11/1/91

5. Number, Sea Days	6. Number, Port Days
35 Sci	3 Science
3 Ship Ops	1 Ship Ops

8a. Area of Operations, Area Index and Geographic Description

Marquesas Islands, W. Equatorial Pacific: SP5, SP6, SP4

8b. Research in Foreign Waters?_Yes__

Country: French Polynesia

7. Participating Personnel:

Code Title,Name,Institution	Function on Cruise (Ch.Sci.,Obs.,Tech.,Grad. Student, Undergrad, For.Obsv.)	Dates (if less than entire cruise)
1. Marcia McNutt, Dr. (MIT)	Chief Scientist	
2. Sarah Kruse, Dr. (Eckerd College)	Scientist	
3. James Natland, Dr. (SIO)	Scientist	9/21-10/20
4. Helen Webb, Miss (MIT)	Grad Student	
5. Julie Dieu, Miss (SIO)	Grad Student	9/21-10/20
6. Christine Munch, Miss (Eckerd)	Student	
7. Martha Kuykendall, Miss (Eckerd)	Student	
8. Kelsey Jordahl, Miss (Eckerd)	Student	
9. Bruce Francis, Mr. (L-DGO)	Science Officer	
10. John DiBernardo, Mr. (L-DGO)	Technician	
11. Ropate Maiwiriwiri, Mr. (L-DGO)	Technician	9/21-10/20
12. S. Budhypromano, Mr. (L-DGO)	Computer Technician	
13. Robert Blaes, Mr. (L-DGO)	Computer Technician	
14. William Koczynski, Mr. (L-DGO)	Technician	
15. Roger DiPietro, Mr. (L-DGO)	Technician	
16. Carlos Alvarez, Mr. (L-DGO)	Technician	
17. John S. Corey, Mr. (URI)	Hydrosweep Technician	
18. Dale Chayes, Mr. (L-DGO)	Hydrosweep Engineer	10/24-11/01
19. Peter Block, Mr. (Atlas)	Hydrosweep Engineer	10/24-11/01
20. Michael Braun, Ing. (Atlas)	Hydrosweep Engineer	10/24-11/01

Use reverse of necessary

9. Primary Project(s)

a. Project Title,Principal Investigator,Institution	b.Sponsoring Agency/	c.Grant or Contract	d.Participating Personnel	ee. Discipline
Fracture Zone Hot Spot Interaction along the Marquesas Fracture Zone, Dr. Sarah Kruse, Eckerd College	NSF	OCE 90-12949	Dr. Marcia McNutt	MG&G
			Dr. James Natland	MG&G

10. Ancillary Project(s)

a. Project Title,Principal Investigator,Institution	b.Sponsoring Agency/	c.Grant or Contract	d.Participating Personnel	ee. Discipline
N/A				

11. Science Party:

Scientists_3__ Grad. Students_2__

Undergrads_3__ Technicians_12__

Observers__0__

Foreign Observers_0__

12. Cost Allocation Data

a. Days Charged	b. Agency or Activity Charged	c. Grant or Contract No.
38	NSF	OCE 90-12949
4	Ship Operations	

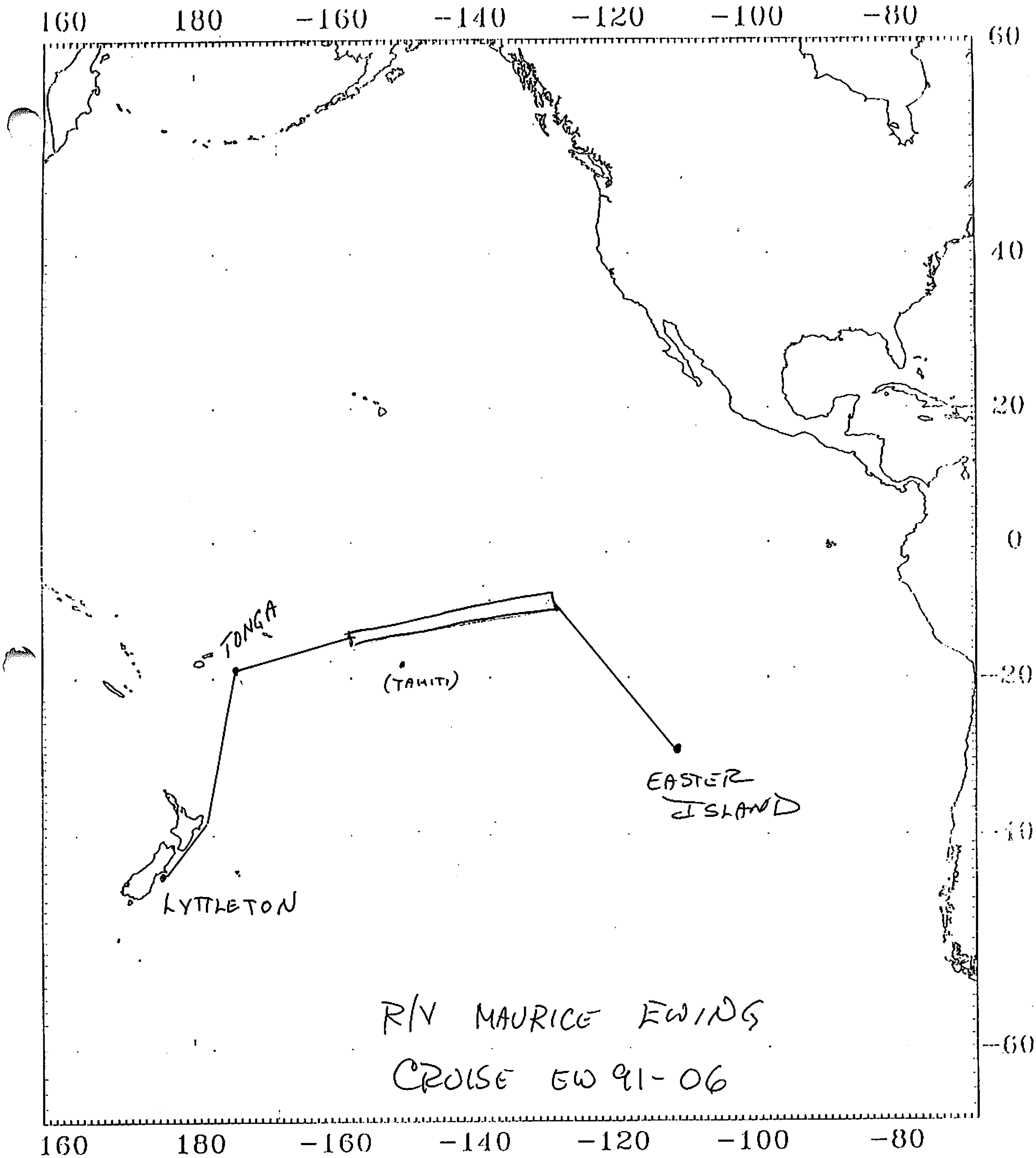
13

Michael Rawson, Marine Science Coordinator; L-DGO

Title, Signature, Operating Institution Official

Date March 4, 1992

3/4/92



160
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TONGA
(TAHITI)
EASTER ISLAND
LYTTLETON
R/V MAURICE EWING
CRUISE EW 91-06

Prof. Dennis E. Hayes
Columbia University
Lamont-Doherty Geol. OBS
Palisades, NY 10964

To:		
	Aitken, T.	L-DGO
	Chayes, D.	L-DGO
	Cox, L.	L-DGO
	Eaton, G	L-DGO
	Hayes, D.	L-DGO
	Weissel, J.	L-DGO
	Science Officer	EWING
	Captain	EWING
	File Copy	MARSCICO

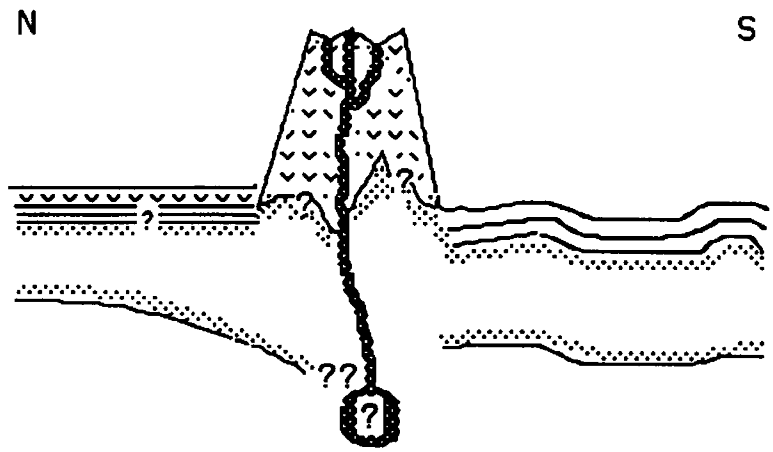
RESEARCH CRUISE REPORT

R/V MAURICE EWING, Leg 91-06

"Fracture Zone-Hot Spot Interactions along the Marquesas Fracture Zone

P.I.: Marcia McNutt
Dates: 21 September 1991 to 1 November 1991
Ports: Easter Island to Nuku'alofa, Tonga-tapu to Lyttelton, New Zealand

Rawson



EW9106 CRUISE REPORT

"FRACTURE ZONE-HOT SPOT INTERACTIONS ALONG THE MARQUESAS FRACTURE ZONE"

Marcia McNutt
Chief Scientist
Massachusetts Institute of Technology

R/V *Maurice Ewing*
Easter Island to Nuku'alofa, Tonga-tapu to Lyttleton, New Zealand
21 September - 1 November, 1991

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SCIENCE OVERVIEW

The principal goal of this expedition was to investigate the thermal and mechanical evolution of one of the major Pacific fracture zones, the Marquesas Fracture Zone, and how it interacts with the underlying mantle. Along the seismically active portions of transform faults near the midocean ridges, the opposing plates slip relative to each other, both laterally in response to differential plate motion and vertically in response to different rates of cooling of the lithosphere on either side of the transform (Figure 1). Beyond the ridge-transform intersection (RTI), the transform fault becomes a fracture zone, and lateral motion of the plates no longer occurs. However, because the plates on opposing sides of the fracture zone are of different ages, the seafloor away from the fracture zone subsides at different rates. If the fracture zone continued to be a zone of weakness, as it was when an active transform fault, vertical motion would continue to occur along the fracture zone even though horizontal motion has ceased. The prevailing view, based on interpretation of the satellite radar altimetry by *Sandwell* [1984], has been that this vertical motion does not happen because the plates become locked beyond the RTI. Rather, the bathymetric scarp that exists at the RTI is locked into the plates and large relief is supported by high stresses along the fracture zone.

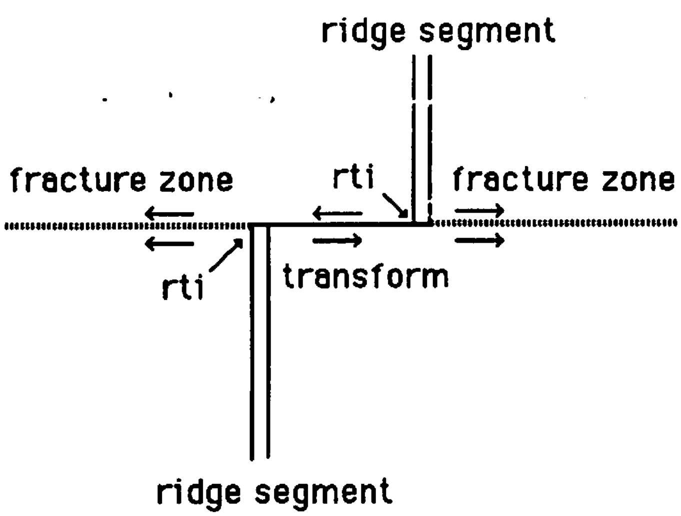
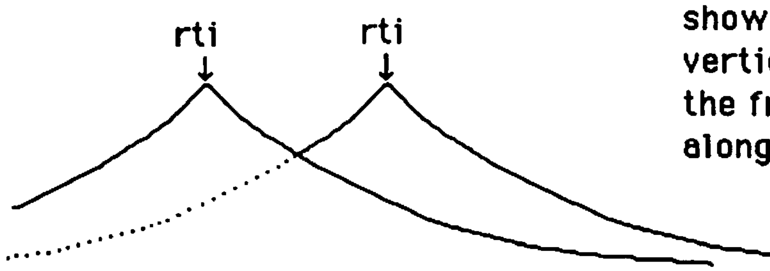


Figure 1.

Map View, showing that differential horizontal plate motion occurs along the transform fault, but not along the fracture zone.



Cross-sectional View, showing that differential vertical motion occurs along the fracture zones as well as along the transform fault.

More recent studies of the Marquesas Fracture Zone (MFZ), one of the great Pacific fracture zones extending more than 2500 km across the central Pacific, suggests that this high-stress model is not applicable to this area. In 1987 during an expedition to study the Marquesas island chain, we mapped part of a 400-km-long, 20-km-wide, 2-km-high ridge that lies at the intersection of the Marquesas swell with the fracture zone (see map for Area 2 in the Figures section). Although we did not dredge datable volcanic rocks from this feature, based on Seabeam bathymetry and geophysical data we interpreted the Marquesas Fracture Zone Ridge (MFZR) to be a volcanic feature formed recently as the fracture zone passed to the northwest over the Marquesas hot spot [*McNutt et al.*, 1989]. Assuming this interpretation to be valid, we concluded that the MFZ is a weak zone within the Pacific plate and that the length of the ridge, projected perpendicular to the absolute motion of the Pacific plate, marks the intrinsic width of a hot spot. We further speculated that similar ridges to the northwest along the Galapagos and Clipperton fracture zones mark the earlier passage of the Marquesas hot spot. The existence of such ridges argues against these fracture zones being regions of great strength. This interaction between the Marquesas hot spot and fracture zones is hardly unusual; similar preferential channeling of hot spot magmas along Pacific fracture zones had previously been noted by *Epp* [1984], *Okal and Cazenave* [1985], and *Sager and Pringle* [1987] in settings of various ages with differing spans of time between the seafloor formation and hot spot interaction.

Further evidence for the weakness of the MFZ is provided by our analysis of satellite altimetry data and existing marine bathymetry and gravity [*Christeson and McNutt*, 1991]. We found that only 2 of 32 deflection-of-the-vertical profiles from the Geosat mission are consistent with *Sandwell*'s [1984] high-stress model, and that none of the 27 bathymetric profiles or 9 shipboard gravity profiles crossing this feature fits his theoretical predictions. Where gravity and bathymetry could be modeled simultaneously, we concluded that the magnitude of the respective signals was not consistent with the Moho flexing conformably with the seafloor, as predicted by the high-stress model, but rather that the relief on the seafloor and the relief on the Moho appear to be mirror images. Interpretation of the gravity data require that the shear stresses along this fracture zone are only 25% of that required to lock the fault.

Prior to this expedition, insufficient marine geophysical data existed along this remote fracture zone to draw any firm conclusions with the data in hand as to the cause of the relief along the MFZ and the extent to which its state of low stress may be caused by interaction with the hot spots of French Polynesia. If the interpretation of the MFZR summarized above is correct, we expect to find similar ridges along the MFZ where other Polynesian hot spots such as Society and Pitcairn have crossed it. Depending on how far west the fracture zone extends, the hot spot(s) responsible for the Cook-Austral chain may also have formed fracture zone ridges. The principal purpose of this expedition was to collect the rock samples and bathymetric, gravity, seismic, and magnetic data needed to determine the origin of the relief along the MFZ and its relationship to hot spot processes in French Polynesia.

SURVEY PLAN

Activity	Days
Transit Easter Island-survey area	6
survey of fracture zone and dredging	8
survey and dredging Marquesas zero age	1
survey of fracture zone and dredging	10
survey and dredging of Cook-Austral and Nuie hot spots	3
Hydrosweep camera installation (and dateline crossing) in Tonga	5
transit New Zealand	7
TOTAL	40

EXPERIMENTAL METHODS

Geophysical Surveying

The main tool we used to follow the trace of the Marquesas Fracture Zone was Hydrosweep. Hydrosweep returns a swath of bathymetric data with width two times the water depth. In the deep sea, the swath width is 8 to 10 km, making it fairly easy to follow the trace of the MFZ to the west. At 4 points along the fracture zone we ran two profiles perpendicular to the trace of the fracture zone out to a distance of 100 km on either side. For Area 1, we also ran a number of shorter contiguous profiles parallel to the fracture zone. The two long swaths perpendicular to the fracture zone allow 3-D modeling of crustal and lithospheric features, while the shorter profiles parallel to the fracture zone define its detailed morphology. Unfortunately, time constraints did not allow us the luxury of running fracture-zone-parallel lines in the other survey areas. The location of these detailed study areas was chosen such that a point midway between hot spot intersections was sampled. At the fracture zone-hot spot intersections, we surveyed and dredged the volcanoes lying along the trace of the fracture zone. Several dredges sampled the fracture zone scarp, but most were conducted on volcanoes at the fracture zone intersections.

Geophysical tools that were used to constrain the origin of major topographic features along the length of the fracture zone included a Bell gravimeter [*Bell and Watts*, 1986], a magnetometer, and a single-channel seismic profiling system. All three data sets will be extremely useful in testing various hypotheses for the origin of the MFZR during post-cruise data analysis. The gravimeter is sensitive to the deformation of the Moho in response to topographic loading. For example, the asymmetric gravity signature over the MFZR that displays a foredeep to the north and no plate deformation to the south indicates that the the ridge is compensated by downward flexure of the older lithosphere to the north.

The magnetometer is a valuable complement to age dating basalt samples for determining the age of the ridge. For example, high magnetization, normal polarity, and low paleolatitude all suggested a young age for the MFZR. Since much of our survey was conducted on lithosphere created during the Cretaceous Quiet Zone, we will use evidence for or against mixed polarity to help in determining which ridges are late-Tertiary midplate volcanoes and which are warped Cretaceous seafloor (such as the scarps in the model of *Sandwell and Schubert* [1982]). In the case of composite topographic features, magnetic polarity and amplitude of magnetization helped in choosing where best to dredge the youngest portion. Nearly real time reduction of the geophysical data aided in selecting dredge sites.

The single-channel seismic data are important for determining relative ages of features and for determining seafloor structure beneath sediment. For example, seismic reflection data revealed flexural troughs north of the fracture zone ridge that were not apparent in the bathymetry and only weakly developed in the gravity signature.

The emphasis in the geophysical modeling is on testing various hypotheses for the origin of fracture zone topography (e.g., a leaky transform [*Menard and Atwater*, 1969], serpentinized diapirs [*Bonatti*, 1978], overshooting ridges [*Lonsdale*, 1986], differential thermal subsidence modified by flexure across a locked fault [*Sandwell and Schubert*, 1982], thermal stress in the plate [*Parmentier and Haxby*, 1986], etc.). For those features which appear from the geophysical data to be caused by extrusive, off-ridge volcanism, the isotopic ages and the geochemical fingerprints we will obtain from shoreside analyses can provide more direct proof of a hot spot origin. Since it was not possible during this cruise to dredge all sections of the MFZ, implementing near-real-time analysis of the geophysical data was essential to realizing our goals. We hope to make our software general enough that it will be of use for other expeditions with different objectives.

Dredging Program

A second, critical use of the Hydrosweep system was for guiding the dredging. Given that fracture zones are likely to be composite features from a number of processes that have occurred since the seafloor was formed, we selected only those that appeared the most youthful from the multibeam image. For example, if young volcanism filled in a fracture zone trough, dredges from its flanks may sample the old fracture zone scarps which confined the flows, whereas a summit dredge would recover young rocks. As we moved westward along the chain, the predicted age of any hot spot features increases. Again, the Hydrosweep system was valuable for siting the dredge along the ridges of volcanic rifts which are most likely to remain free of sediment.

Many of our dredge targets were the northern scarps of east-west-trending ridges. Because the prevailing wind and seas are from the east, we thought it would be extremely difficult to dredge off the starboard A-frame without the use of the bow thrusters to keep the wire from passing beneath the ship. The thruster ports were covered with metal plates at the beginning of EW9103 in order to improve Hydrosweep performance. Dredging, therefore, was entirely done off the stern A-frame.

Confirmation of hot-spot interaction with the Marquesas Fracture Zone will require petrologic study and radiometric dating of these dredge rocks. Ideally, the rocks should resemble those of the volcanoes in the corresponding hot-spot chains. This means that the lavas may range from ocean-island tholeiites to strongly alkalic and undersaturated basaltic rocks and their differentiates [*Natland and McNutt*, 1989] with both high-μ and EMII isotopic and trace-element characteristics [e.g., *Palacz and Saunders*, 1986; *Zindler and Hart*, 1987; *Hart*, 1988; *Desonie et al.*, 1989]. But it is also possible that interactions with hydrous crust and/or mantle in the fracture zone may influence rock geochemistry [*Fisk and White*, 1986].

We can predict ages when plate motion carried the MFZ across the various hot spots, assuming that their locations were fixed with respect to the mantle reference frame. Thus radiometric dating will establish whether particular volcanic landforms in and near the fracture zone and identified during the survey are indeed related to linear-chain volcanism. Simultaneously, dating will test the fixity of four of the five hot-spot traces we examined (Pitcairn, Societies, Cook/Austral, Nuie), and add information to "zero-age" volcanism in the Marquesas.

In the original proposal, we had proposed to spend any remaining ship time dredging and surveying zero age for the Samoan hot spot if Samoa had been our final port. Because we ended up going to Tonga and New Zealand instead, we devoted some time to surveying the Nui seamount chain and confirming its origin as a hot spot feature. However, we did not find any evidence there of young volcanism.

DATA SOURCES

Navigation

The primary source of navigational information is a Magnavox T-set Global Positioning System receiver, logging at 2-sec intervals. A Magnavox MX-1107RS dual frequency Transit satellite receiver was used for backup. Typically, GPS positions were available for more than 23 hours per day.

Bathymetry

Bathymetric data was provided by the Krupp Atlas Hydrosweep system. Along-track sampling was at the rate of once per 6 sec for 4000-m water depths, with higher sampling rate for shallower water and a lower rate for deeper water. Sixty narrow-beam echo sounders provided swath coverage with a total width of 2 times the water depth.

Magnetics

The magnetometer used was a Varian V75 magnetometer, logging the total intensity of the magnetic field at 6-sec intervals. The data were reduced by subtracting the Geomagnetic Reference Field 1985 (IGRF 1985) in order to remove the main field at 1985.0. A predictive model of the secular variation was used to adjust the main field model to dates beyond 1985. Finally, the residual field was calculated by bilinear interpolation across a 1 degree square. The archive data stream contains the total intensity and magnetic anomaly values sampled only once per minute.

Gravity

Two gravimeters were available on the *Ewing*: a Bell Aerospace BGM-3 marine gravity meter and a Boogenwerk KSS-30 gravimeter. The Bell meter proved to provide noisier gravity data than the KSS-30, and therefore we relied entirely on data from the KSS-30 for our final gravity data. The KSS-30 sampled the gravity once per 6 seconds. After merging with the navigation, the Eötvös correction was applied and the 1980 theoretical gravity formula subtracted to yield free air gravity anomalies.

1980 Formula:

$$\gamma_o = 9.780327[1 + .0053024 \sin^2\theta - .0000058 \sin^2(2\theta)] \text{ m/sec}$$

UNDERGRADUATE PROGRAM

This project provided an excellent opportunity to interest undergraduate mathematics or science majors in careers in Earth Science. Three undergraduate students from Eckerd College participated in the field program and will work on the data the following summer for two months at Eckerd College and one month at either Woods Hole (with McNutt) or Miami (with Natland).

The students served in the capacity of watch standers on the ship, one undergraduate per watch, each teamed up with a more experienced graduate student or scientist. Kruse led a seminar course for one hour every other day which covered scientific or technical aspects of the expedition according to the interests of the speakers. These seminars contributed greatly to communication among members of the scientific party on topics ranging from the overall goals of the expedition to the operation of specific scientific equipment. Natland helped the students learn the fundamentals of petrology and geochemistry with particular application to oceanic crust and hot spot volcanism.

We used interactive programs on Sun computers for magnetic, gravity, and bathymetry modeling. The students began modeling depth and gravity data recorded during the expedition using programs written by Gail Christeson and Marcia McNutt.

OPERATIONS AND DATA ACQUISITION

<u>September 18, 1991</u>

The R/V *Maurice Ewing* arrived in Easter Island (Isla de Pascua, Rapa Nui) on May 18 at the termination of EW9105. The vessel proceeded immediately to the refueling point on the south side of the island. Because of high seas and winds, it was decided to disembark the offgoing scientific party and load some of the oncoming freight on this side of the island, even though the dock facilities for loading the launches from shore were practically nonexistent. Transfer of personnel and some of the freight was accomplished successfully despite poor weather and facilities. Launch service had to be suspended after dark due to poor weather and visibility, stranding ashore some members of the crew and scientific party.

<u>September 19, 1991</u>

The ship moved to the west side of the island (Hanga Roa) where better dock facilities existed for loading cargo to the launches. More cargo was transferred, as were members of the crew and scientific party. Later that afternoon, the loading port was closed on account of bad weather. The ship moved back to the refueling point so that launch service ashore could be continued. However, even worse winds and seas on the south side of the island prevented continuing launch service after dark.

September 20, 1991

The ship returned to the "calmer" seas of Hanga Roa. In driving rain and force 7 winds, the rest of the cargo and oncoming scientific party joined the *Ewing*. The scientific party worked to set up the computers in the lab and secure the scientific gear in anticipation of rough seas upon sailing.

September 21, 1991 (Saturday)

Although sailing time was posted for 0900L, the local officials did not arrive on board to complete customs procedures until 1000L. At 1130L, the *Ewing* weighed anchor and proceeded northwest on course 315° towards the Marquesas Fracture Zone. At 1200L, we began underway scientific watches for 3.5 kHz, Hydrosweep and gravity data. The magnetometer was streamed at 1430L and added to the watch duties. We noted that the sewer pump interfered with the 3.5 kHz system, but surprisingly not the Hydrosweep system, and arranged with the Chief engineer to run the pumps twice daily on cue at noon and midnight. This schedule was modified later during the detailed geophysical surveys so that the pump action would not interfere with critically important data.

September 22, 1991 (Sunday)

The first fire and boat drill was held at 1020L, and included an introduction to shipboard living by the Captain and Chief Engineer. We continued to stand underway watches as we steamed across the Easter microplate to the fracture zone. The watchstanders gained lots of experience in tuning the gain on the Hydrosweep system in order to minimize interference from data dropouts (gain too high) and augers (gain too low). The ship's first barbecue of the expedition was held that evening. Weather and seas consistently improved as we moved northward.

September 23, 1991 (Monday)

Continued steaming north. Tested water gun and streamer in the water, and then recovered them. Held first of what became a series of shipboard seminars: McNutt and Natland gave overview of science objectives of the expedition.

September 24, 1991 (Tuesday)

Still steaming to first survey area. Rigged up first dredge bucket with nylon net. Seas were incredibly smooth and Hydrosweep was performing almost flawlessly, even at 11.3 kts. Natland gave seminar on the petrological structure of oceanic crust.

September 25, 1991 (Wednesday)

Continued steaming to first survey area. Natland continued lecture on marine petrology.

September 26, 1991 (Thursday)

Deployed one water gun and single channel streamer at about 2000L in anticipation of arriving at start of first crossing of fracture zone in area 1 during the early morning hours of September 27.

September 27, 1991 (Friday)

Began survey of area 1 at 9°47'S, 129°43'W by running two profiles, each 200 km long and 50 km apart, perpendicular to the strike of the fracture zone. The first crossing showed that the seafloor to the south and to the north of the fracture zone, but well away from it, had depths appropriate to the age of the seafloor (4250 m, 25 Ma and 4600 m, 35 Ma, respectively). The south side of the fracture zone is faulted upward to form a rounded ridge rising to 3700-3800 m. Therefore, near the fracture zone, the relief is 800-900 m compared to the 650 m predicted to exist if vertical slip were allowed to occur on the fracture zone, and 1050 m if the fracture zone had remained locked since the ridge-transform intersection. On the western side, the actual relief may even be greater since there is evidence in the seismic data for a buried trough just north of the scarp. Thus there is evidence in the bathymetry data for some vertical slip on the fracture zone, but not enough to completely account for the differential thermal subsidence.

September 28, 1991 (Saturday)

Began running shorter (60-km long) lines along the direction of the fracture zone over a zone 50-km wide. Data better define the structure of the uplifted ridge and the azimuth of the fracture zone. "Ridge" is actually a series of block-faulted ridges and troughs trending parallel to the fracture zone and completely confined to the younger plate. The ~~older (northern)~~ side of the FZ appears to be entirely undeformed, except for a sediment-filled foredeep at the base of the scarp.

September 29, 1991 (Sunday)

Attempted first dredge. Had to delay launching of the dredge by more than 2 hours because wire meter failed to read meters of wire out and in. Finally launched dredge, but had to recover it before it reached the seafloor because the tensiometer was malfunctioning. In all, more than 6 hours was lost to the failed dredge attempt. It was decided to proceed to the second survey area rather than attempt another dredge in area 1. The tensiometer was recalibrated with a block and tackle on deck, but it was still not obvious why it failed to work for the first dredge attempt. The bosun did manage to catch a white-tipped shark during the aborted dredge, which the Steward prepared for the evening barbecue.

September 30, 1991 (Monday)

Continued zig-zagging along the FZ to the west southwest. FZ scarp is very linear, with small changes in azimuth of less than 5°. As we moved westward, the scarp height continued to grow, reaching a height in the bathymetry of 2 km at 134°W. Taking into account the 0.8 sec of sediment in the flexural foredeep, the total relief is likely to be nearly 3 km! Models of differential thermal subsidence across a locked FZ would predict that if that scarp were relief inherited from the RTI, then the age contrast across the fault would have to be 68 my!!

October 1, 1991 (Tuesday)

Arrived at second detailed survey area at approximately 135°W. The ridge on the southern plate has a sharp scarp facing to the north and a gentler, back-tilted southern slope. Sediment is heavily ponded on the top. The western of the long survey lines perpendicular to the FZ crosses a large number of small volcanoes north of the FZ. The surface of the seafloor is very rough and hummocky, without sediment. This may be the eastern extension of the Marquesas Island carapace.

October 2, 1991 (Wednesday)

Continued survey lines in second survey area. Nearly all lines were run N-S, mostly to sample the volcanic field north of the fracture zone.

October 3, 1991 (Thursday)

Completed series of long lines in the second survey area at longitude -135° on the Marquesas Fracture Zone. Completed first and second successful dredges off the R/V *Ewing*. First dredge sampled a small cone just north of the flexural foredeep of the fracture zone ridge. We recovered one extremely large sample of manganese-encrusted pillow basalt with fossiliferous metallic ooze. We had hoped that the dredge would recover young, glassy alkalic basalts, indicating that we had found young Marquesan volcanism. However, based on the degree of manganese encrustation, we suspect that this might be an older MORB volcano, despite the fact that the seafloor is devoid of pelagic sediments and appears youthful. The second dredge sampled the north-facing scarp of the MFZ.

October 4, 1991 (Friday)

Moved westward to the intersection of the fracture zone with the Marquesas Islands. Here the ridge is over 2 km high in places and is very narrow compared to its morphology further east. Dredged the ridge; recovered a lot of old, manganese-encrusted basalt.

October 5, 1991 (Saturday)

Dredged a high seamount just north of the fracture zone ridge and SE of Fatu Hiva. Recovered lots of fresh basalt, ropy pahoe-hoe, hyaloclastite breccia. Looks like we finally found "zero age" for the Marquesas hot spot! Began moving west on a zig-zag course to our next area for long geophysical lines.

October 6, 1991 (Sunday)

Finished zig-zag survey of fracture zone between the Marquesas Islands and the half-way point along the fracture zone to its intersection with the Tuamotu Islands. Began running two long 200-km geophysical lines perpendicular to the fracture zone.

October 7, 1991 (Monday)

Completed box survey of the fracture zone midway between the Marquesas and Tuamotus. Fracture zone is mostly characterized by a deep trough here, with some amount of uplift on the younger side.

October 8, 1991 (Tuesday)

Began running with Hydrosweep along the fracture zone to its intersection with the Tuamotu Islands. The fracture zone is beginning to get shallower in its trough, but is still marked by a very distinct and easily traceable scarp.

October 9, 1991 (Wednesday)

Ran a long line across the Tuamotu plateau at it's narrowest point in the north. Returned to the southern scarp to dredge.

October 10, 1991 (Thursday)

Recovered basaltic rocks with some glass from the southern scarp of the Tuamotu plateau. Turned to the northwest to dredge the northernmost limit of the plateau where it overprints the Marquesas Fracture Zone.

October 11, 1991 (Friday)

Completed a dredge of the northernmost Tuamotus just north of its intersection with the FZ. Picked up the trace of the FZ again to the west of the islands, and continued surveying west. Here the trace of the FZ is a narrow, spiky ridge.

October 12, 1991 (Saturday)

We completed a box survey in the area just west of the Tuamotus and then continued to follow the fracture zone to the west towards its intersection with the Societies. Now it is only marked by the transition from curving ridge tips of the overshot ridges to the south and a deeper trough to the north.

October 13, 1991 (Sunday)

Lost the fracture zone temporarily where it took a slight jog south and disappeared beneath younger Society cover. Picked it up again in the flexural moat of the oldest Society volcano (Marara). Traced the fracture zone beneath the flanks of this volcano. Completed Hydrosweep-gravity-magnetic survey of Marara and prepared to dredge

October 14, 1991 (Monday)

It required two attempts to obtain enough rock samples from Marara. Rocks are very evolved porphyritic basalt with large crystals. Began to search for continuation of fracture zone west of the Society Islands. Manifestation of fracture zone here appears to be a chain of small volcanoes (perhaps of Society vintage) that have erupted along the fracture zone. North of this line, abyssal hills are clearly N-S trending, but to the south it was difficult to see the seafloor fabric on account of Society overprint.

October 15, 1991 (Tuesday)

We continued to follow this chain of small volcanoes to the west to 159°W, where it abruptly terminated against a series of E-W trending abyssal hills. Spent the rest of the day doing a detailed survey of this area where a plate reorganization occurred.

October 16, 1991 (Wednesday)

Began transit south towards the oldest end of the Cook-Austral chain just west of Palmerston Atoll. Crossed NNE trending abyssal hills and finally located their source at what appears to be an abandoned spreading center which forms the eastern side of Manihiki Plateau.

October 17, 1991 (Thursday)

Surveyed and dredged small volcano on ridge just west of Palmerston Atoll. Recovered some fresh hyaloclastite glass. We suspect that this may be one of the oldest volcanoes in the Cook-Austral chain and propose to name it "Eckerd Seamount". Proceeded west to the island chain of Nuie-Beveridge Reef which has been proposed by Mammerickx to be a hot spot chain.

October 18, 1991 (Friday)

Found that a seamount just north of Beveridge Reef which appears in dbdb5, Gebco, and the navigational charts used on the bridge does not exist. Spent some time surveying southeast of Beveridge Reef looking for signs of younger volcanism. None to be found. Beveridge Reef appears to have a slope break at about 1000m, suggesting that the reef cap is this thick. Therefore, the hot spot which created this volcano must be located very far to the southeast at this time. Launched dredge to sample this feature.

October 19, 1991 (Saturday)

Recovered dredge from attempt to sample volcanic rocks from Beveridge Reef. Unfortunately, dredge bucket was empty. We suspect that thick sediment debris from the reef carpet the slopes. Continued to the northwest from Beveridge Reef along the direction of Pacific-hot spot plate motion towards the uplifted atoll of Nuie. Made a small survey of Nuie to look for the location of the reef-volcano shelf break (approximately 400 m). Broke off science operations at 2300L to steam to Tonga.

October 20, 1991 (Sunday)

Continued to steam towards Tonga. Held dateline crossing ceremony during which numerous members of the scientific party and crew were newly inducted into the Order of the Golden Dragon. Crossed the Tonga Trench where depths exceeded 10 km. Abyssal hill trends were E-W all the way into the trench, where they then were cross-cut by normal faults on the outer trench wall.

October 21, 1991 (Monday)

Cancelled, on account of dateline crossing.

October 22, 1991 (Tuesday)

We arrived in port in Nuku'alofa, Tonga Tapu on time at 8 am. We were met on the dock by Dale Chayes and the underwater welders who immediately got to work on installing the underwater camera system to monitor Hydrosweep cavitation.

October 23, 1991 (Wednesday)

Had to move the ship from the dock to anchorage in the harbor at 0730 on account of the arrival of another ship that required dock space until 1300. This delayed the work of the divers because they did not have a boat to use. The German engineers from Krupp Atlas arrived at 2230L, but one of their metal containers with vital equipment failed to make their connection in Auckland. Had to delay the sailing of the ship originally scheduled for the next morning.

October 24, 1991 (Thursday)

We were informed that there would be no air flights arriving from Auckland on Thursday, and that to charter a flight to bring the lost luggage would cost $30,000. The agent was capable of arranging for the lost item to be put on a flight to Fiji, from which it would be transferred to a flight to Tonga arriving about 0430 on Friday morning.

October 25, 1991 (Friday)

All hands were on board the ship at anchor by 0530L, and the missing Hydrosweep box arrived at 0630L. Ship finally underway by 0700L. Steamed north and west out of Tonga Tapu to transit to New Zealand via the Havre Trough in order to collect geophysical data for David Caress while performing Hydrosweep tests. The starboard-mounted camera designed to videotape cavitation bubbles around the Hydrosweep system failed within an hour or two of leaving port. We suspect that the connector which replaces the battery on the back of the camera came loose. The port camera remained functional, and actually showed more cavitation at 4 knots when we slowed to deploy the magnetometer than it did at 11.5 knots.

October 26, 1991 (Saturday)

Hydrosweep was down for much of the day while Chayes and the Krupp-Atlas engineers performed tests of the system. Watch standers had to hand digitize the 3.5 kHz record at 5-minute intervals. Began survey of Havre Trough during dinner.

October 27, 1991 (Sunday)

Continued survey of Havre Trough. Hydrosweep up for much of the time.

October 28, 1991 (Monday)

Ran two east-west cross-sections of Havre Trough at 31.5°S and 32°S. Continued across the Kermadec Arc and trench to the east. Turned south to steam towards New Zealand.

October 29, 1991 (Tuesday)

In transit to New Zealand. Strong following wind and seas push average speed up to 12 knots. Got good Hydrosweep data along the axis of the Kermadec trench.

October 30, 1991 (Wednesday)

Weather finally became very rough as seas swung around to hit the ship from the south. Noticed lots of bubble burst in the port camera which somehow managed to remain operational during the heavy pounding pitching. Speed of ship slowed to only 9 knots, making it unlikely that we would make arrival at 0900L on November 1 in Christ Church.

October 31, 1991 (Thursday)

Seas still coming form the south, but the wind and swell abated somewhat, pushing the average speed of the ship up to 10 kts. Underway watches suspended at noon for transit to port.

PRELIMINARY RESULTS

Our observations of the Marquesas Fracture Zone (MFZ) during EW9106 have now led us to revise many of the previous beliefs concerning this great Pacific fracture zone. To begin with, our tracing of the FZ extends its western terminus by more than 800 km beyond its previously mapped limit, and places its origin more than 1500 km west of the end of the Cretaceous Superchron. This information provides an important constraint on the timing of the plate reorganization which led to the establishment of the Pacific-Farallon spreading system which dominated Pacific tectonics until the Miocene. Data we collected on the orientation of abyssal hills and the location of a fossil spreading center will aid in determining the early Cretaceous spreading history in the southwestern Pacific before the establishment of the Pacific-Farallon system.

As we moved from east to west, the MFZ exhibited a wide variety of morphological forms, which on random crossings might not have even been recognized as the same tectonic feature. (Refer to cross-sections and maps in the Figures section.) At our easternmost survey area (Area 1, 129°W), the south side of the FZ consists of a north-facing 1-km-high scarp with a back-tilted and block-faulted south side. The north side of the FZ is relatively flat and undeformed, with only a slight hint in the gravity and seismic data that the seafloor might be flexurally downwarped to form a foredeep at the base of the scarp. The width of the faulted region on the south side (approximately 100 km) suggests that at this location we might be seeing the effects of a bifurcated fracture zone such that two closely spaced transforms accommodated the relative motion of the plates. Overall, the gravity anomaly has net positive values on the south side and only slightly negative values on the north side. Thus it appears that the downward flexure on the northern side is insufficient to compensate the total scarp height. We conclude, therefore, that most of the topographic relief must be compensated by deep density contrasts, presumably of thermal origin, and that only a few 100 meters, at most, of the scarp is flexurally supported.

Near 135°W (Area 2), the relative height of the north-facing scarp on the southern plate with respect to the northern plate begins to increase while the depth of the entire region decreases approaching the Marquesas swell. The width of the block-faulted region on the south side is only half as wide. The gravity and seismic data here show clear evidence of a flexural foredeep on the northern plate. Just 50 km to the west, at the eastern end of the Marquesas Fracture Zone Ridge (MFZR), the height of the scarp suddenly jumps to over 1.5 km while the width of the scarp narrows slightly. Again, the gravity and seismic data show downwarping of the northern plate. A group of small seamounts paralleling the trend of the fracture zone suddenly appear on the flexural arch of the northern foredeep. The height of the scarp increases even further as we approached the Marquesas hot spot and the gentle, back-tilted southern slope for the scarp characteristic of crossings further east is now replaced by a well-defined scarp as steep as that which is facing north. The foredeep is well represented in the gravity, but not discernible in the seismic data through the extremely reflective Marquesan carapace. The gravity anomaly has a mean averaged over the area which is closer to zero, indicating compensation of the scarp by downward flexure of the northern plate, but the amplitude of the gravity signal is too small to be consistent with a model in which both the seafloor and the Moho are upwarped in parallel. Dredges of the MFZR provide no support for our previous suggestion that this feature is a young volcanic construct, but it appears that the increase in height of the fracture zone ridge is exactly coincident with its intersection with the hot spot, and that its stress field has clearly influence off-ridge volcanism in this region. One of our dredges on a small seamount on the flexural arch of the foredeep north of the ridge yield young, glassy pillow basalts. We suspect that dates on these rocks will show them to be significantly younger than Fatu Hiva (1.4 Ma), and that in fact this might be "zero age" for the Marquesas hot spot.

At 143°W (Area 3), approximately midway between the Marquesas and Tuamotus, the fracture zone morphology displays the best example we found of the classic Sandwell model of flexure across a locked transform. This is also the same area where *Christeson and McNutt* [1991] found good evidence from the satellite deflection of the vertical for the the high stress model. The bathymetry shows a well-defined step of a few 100 meters, the ridge on the south side has a sharp north face and a gently-sloping southern face, and the downflexed trough on the northern plate is prominent in both the bathymetry and the gravity. The total relief on the north-facing scarp is 1400 m, with peak-to-trough gravity anomalies of nearly 80 mgals.

The intersection of the fracture zone with the Tuamotus is marked by a local thickening of the plateau along the trace of the fracture zone and by a chain of what are presently mapped as disconnected shoals. The northernmost edge of the Tuamotu Plateau is only 100 km north of the fracture zone, which we easily projected beneath the volcanic cover and picked up again on the other side. Our crossing of the plateau suggests that the shoals may actually be a fracture zone ridge along the intersection of the plateau with the MFZ.

Just west of the Tuamotu Islands, at 152°W (Area 4), the fracture zone loses its distinctive morphology in the bathymetry and appears as a more triangular-shaped ridge without clear polarity in the slopes. The flexural trough is almost imperceptible. It is understandable why, before this expedition, the fracture zone had not been mapped this far west. Magnetic lineations place this region well within the Cretaceous Superchron, and random ship crossings of the fracture zone would be interpreted as isolated small seamounts. However, the fracture zone signature is quite apparent in the gravity anomaly, with the flexural low particularly well developed on the older plate. The total gravity signal is between 40 and 50 mgals, peak to trough.

Further west of the Tuamotus, as we approached the northwest end of the Society Islands, even the ridge disappeared. Yet in the Hydrosweep data the fracture zone was quite evident as forming the boundary between smoother and generally deeper seafloor to the north and north-south-trending abyssal hills to the south. As the abyssal hills approach the fracture zone, their tips curve sharpy to the east. This type of structure has previously been noted by Lonsdale on the long-offset transforms of the Pacific-Antarctic Ridge. He suggests that they are the expression of overshot ridges which spill magma into the transform from the southern ridge tip. If so, we have found preserved in the western Pacific seafloor the expression of overshot ridges that formed 100 Ma ago at the ancient Pacific-Farallon Ridge.

We traced the fracture zone westward until it was lost in the flexural moat of the northernmost Society volcano, Marara. We actually found a cluster of volcanoes lying along the fracture zone at its intersection with the hot spot. To the north, the seafloor appeared to be undisturbed north-south trending abyssal hills, while to the south it has been completely paved over by younger Society volcanism.

Less than 200 km west of the Society intersection, the fracture zone abruptly terminated against a series of east-west-trending abyssal hills. We attempted a small survey to understand the nature of the plate reorganization which occurred at this time, but it was clear that the seafloor fabric was complicated and that much more ship time than what we had available would have to be devoted to this purpose.

Southwest of the Society Islands, we crossed a zone of north-south trending highs and lows that appeared on the Gebco chart as structures extending south from the eastern boundary of the Manihiki plateau. Our Hydrosweep data established these features as an abandoned spreading center that gave rise to the north-south trending abyssal hill fabric we encountered not long after turning southwest from the Society Islands.

We crossed the northwest end of the Cook-Austral chain just north and west of Palmerston Atoll. Our data showed that the northwest end of this chain actually consists of a a ridge trending approximately N14°E. The cause of this preferred orientation is still a mystery. Its trend is similar to that of the Marquesas Fracture Zone further east, but it seems quite inconceivable that any fracture zones (e.g., the proposed Tuamotu Fracture Zone) could extend this far west. We surveyed and dredged a small, unnamed seamount west of Palmerston for which we propose the name Eckerd Seamount. Perhaps our seismic and gravity data as well as the dredge rocks will shed some light on the origin of this unusual lineation.

Just before steaming into port in Tonga, we performed a small survey of the Nuie chain. We established that a seamount north of Beveridge Reef appearing in the Gebco charts, DBDB5 data base, and the bridge's navigational charts does not exist. Furthermore, we found no evidence of younger volcanism southeast of Beveridge Reef (although we only searched for a few hours). The line between Beveridge Reef and Niue, an uplifted atoll, lies exactly along the Pacific-hot spot plate motion vector for the late Tertiary, and in fact our track crossed several smaller volcanoes between Beveridge Reef and Nuie that lie exactly along this trend. Thus it appears that the Nuie-Beveridge Reef line is a hot spot chain that formed sometime within the past 43 million years, but probably not extremely recently. The break in slope on Beveridge Reef corresponding to the transition from volcanic slope to reef occurs at approximately 1000 m depth, meaning that the volcano cannot be very young. The same transition for Nuie farther to the northwest is shallower (400 m), but the atoll is uplifted on the flexural arch of the Tonga Trench. Unfortunately, we recovered no rocks from our dredge of Beveridge Reef, and will have to rely on subsidence and gravity modeling to further constrain the age of these volcanoes and to predict the present location of the hot spot which may have caused their formation.

COMMENTS AND RECOMMENDATIONS

EW9106 was an immensely successful expedition in that we achieved our major aims of tracing the Marquesas Fracture Zone back to its origin, obtaining key geophysical cross-sections of the fracture zone at and between hot spot intersections, and sampling volcanic rocks at key points along its length. Beyond that, we found zero age for the Marquesas hot spot, charted and sampled the oldest Cook-Austral volcano, and established the Nuie-Beveridge Reef chain as an older, but post 43 Ma, hot spot chain. Our success in large part can be attributed to the excellent cooperation we received from Captain Ian Young, the crew of the *Ewing*, and the LDGO support personnel. Most of the comments which follow are extremely favorable, although we do include a few recommendations for avoiding in the future the few problems which did surface during the course of this expedition.

Although we understand the logistical requirements which led to the choice of Easter Island as the beginning port for this trip, we found the facilities there to be extremely marginal to nonexistent. In the poor weather we experienced, it was at best difficult and generally quite dangerous to load and unload the small launches which were used to transfer all personnel and cargo. The launch transporting the undergraduates from Eckerd College to the ship from the dock suddenly lost power in high surf. The boatload of passengers had to be rescued by the Chilean Navy. Throughout this ordeal, the scientific party was particularly indebted to the bosun, Blaine Heinze, and other members of the ship's crew who ended up with no shore leave on account of the time and effort required to load, unload, and refuel the ship at anchor in essentially open-ocean conditions. In the future, Lamont might try to avoid this port, particularly during their winter-spring.

The success of both the scientific mission and the undergraduate education program depended on the ability to access the geophysical data soon after it was acquired from the two Sun Sparc workstations shipped to the *Ewing* by McNutt and Kruse. For their efforts to connect the Suns to the ship's local ethernet network, we are very much indebted to Rob Blaes and Budhy Budhypramono. Their job could have been made a little easier if there had been some sort of information provided for P.I.'s on exactly what connectors, software, etc. might be necessary to bring along in order to effectively network with the ship's computers. We understand that the shipboard systems are in transition at the moment, and very much applaud the change-over from the MassComp to the Suns and Macs. This change will surely make importing guest computers far easier in the future for the large sector of the scientific community which now uses Sun and Macintosh computers.

Despite quite a bit of discussion of the requirements for the dredging on this leg during EW9103, the winch and tension meter were still not operational in time for our first dredge. We ended up losing about 6 hours of ship time and the opportunity to obtain rocks from our easternmost survey area at a point farthest removed from any hot spot influence. The science officer, Bruce Francis, the core bosun, Ropati Maiwiriwiri, and the E.T.'s, William Kozinski and Roger DiPietro worked extremely hard for two days to repair the winch and meters in time for our second dredge attempt. If we had not been repeatedly assured that all systems were completely operational by science officers from prior expeditions, most of this work could have been completed during our own 6-day transit to the site so that the vessel would have been ready for the first dredge.

By far the greatest source of confusion and consternation during this expedition was the last-minute change in itinerary caused by the decision to perform Hydrosweep testing before the ship reached New Zealand. The decision to stop in Tonga to mount a camera on the hull was communicated to the Chief Scientist only the day before she left to meet the ship (and only informally by a scientist at LDGO, not by ship scheduling), and we learned that it would lead to a loss in science days (on account of needing two full days in Tonga) and a delay in reaching New Zealand only after leaving Easter Island. The negative impact of this decision could have been reduced enormously if the P.I.'s for EW9106 had been part of the communications loop from the very beginning when the Hydrosweep testing was first contemplated. In the future, the chief scientist should be kept informed of all possible schedule changes, and receive in writing how such changes might affect port, science, and transit days.

Table 1: SCIENTIFIC PARTY

Scientists
Marcia McNutt (MIT) Chief Scientist
Sarah Kruse (Eckerd College)
James Natland (SIO)

Students/Watchstanders
Helen Webb (MIT)
Julie Dieu (SIO)
Christina Munch (Eckerd)
Martha Kuykendall (Eckerd)
Kelsey Jordahl (Eckerd)

Technical Support
Bruce Francis (LDGO) Science Officer
John Dibernardo (LDGO) airguns
Ropati Maiwiriwiri (LDGO) core bosun
Budhy Budhypramono (LDGO) System Manager
Robert Blaes (LDGO) System Manager
William Kozinski (LDGO) Electrical Technician
Roger DiPietro (LDGO) Electrical Technician
Carlos Alvarez (LDGO) airguns
John Sheffield Corey (URI) Hydrosweep

The following technicians joined the ship in Tonga:
Dale Chayes (LDGO) Hydrosweep
Peter Block (Krupp Atlas) Hydrosweep
Michael Braun (Krupp Atlas) Hydrosweep

Table 2: SUMMARY OF REEL NUMBERS

Single channel seismic streamer, 1 or 2 waterguns for seismic source.

	Start				End			
Tape #	Day	Time	File	Shot	Day	Time	File	Shot
1	270	0509	0001	000001	270	094733	1422	001447
2	270	095145	1423	001468	270	212747	4903	004948
3	270	212759	4904	004949	271	0723	7877	007922
4	271	0730	7878	007923	271	1901	1370	011414
5	271	1930	1371	011415	271	225126	2524	012566
6	271	233704	0001	012775	272	111504	3491	016265
7	272	111516	3492	016266	272	112528	3543	016317
8	272	112540	3544	016318	272	181429	5588	018362
9	273	004318	0005	020306	273	121807	3479	023780
10	273	121819	3480	023781	273	235357	6958	027259
11	273	235409	6959	027260	274	112934	0437	030737
12	274	112946	0438	030738	274	230511	3915	034215
13	274	230523	3916	034216	275	0757	6567	036867
14	275	0811	0001	036870	275	193335	3409	040278
15	275	193247	3410	040279	276	070813	6887	043756
16	276	070825	6888	043757	276	180938	0192	047063
17	277	093259	0001	047357	277	210826	3478	050834
18	277	210838	3479	050835	278	044739	5774	053130
19	278	201747	0004	054733	no data	on this	tape	
20	278	202225	0027	054756	279	075541	3486	058214
21	279	075553	3487	058215	279	193037	6961	061689
22	279	193406	6962	061690	280	070416	0437	065164
23	280	070428	0438	065165	280	074743	0650	065377
24	280	074743	0651	065378	280	194650	4125	068852
25	280	194703	4126	068853	281	081946	7600	072327
26	281	081959	7601	072328	281	205257	1076	075802
27	281	205310	1077	075803	282	092553	4551	079277
28	282	092606	4552	079278	282	215850	8026	082752
29	282	215903	8027	082753	283	081623	0874	085599
30	284	025433	0003	085734	284	152652	3475	089206
31	284	152705	3476	089207	285	0400	6950	092681
32	285	0400	6951	092682	285	163245	0426	096156
33	285	163258	0427	096157	286	050600	3901	099631
34	286	050600	3902	099632	286	173920	7376	103106
35	286	173920	7377	103107	287	061134	0852	106581
36	287	061147	0853	106582	287	113149	2330	108059
37	288	002506	0002	111628	288	125607	3475	115101

38	288	125620	3476	115102	289	013035		
39	289	013350	6952	118592	289	140633	0426	122065
40	289	140645	0427	122066	290	023929	3901	125540
41	290	023942	3902	125541	290	151300	7376	129015
42	290	151300	7377	129016	291	021421	0432	132070

Table 3: DRIFTERS

#	Number	Julian Day	Time (GMT)	Lat	Long
1	15625	265	20:26:32	-23°59.98'	-113°16.58'
2	15626	266	15:07:37	-21°46.0'	-115°58.8'
3	15627	267	06:03:10	-20°00.095'	-118°03.608'
4	15628	267	21:03:42	-17°59.999'	-120°18.160'
5	15630	268	16:21:12	-15°37.750'	-123°06.834'
6	15631	294	02:15:08	20°09.2'	-172°57.93'
7	15634	297	05:10	-22°07.115'	-175°58.163'
8	15633	298	18:00	-24°16.140'	-177°04.429'
9	15632	299	14:55	-26°05.8'	-178°01.9'
10					

Positions based on Transit-DR system in wet lab.

Drifter 15629 was not deployed. The magnet which apparently triggers the transmitter was missing, and we were afraid that this drifter would not operate properly.

Table 4: MAGNETIC AGES (courtesy of Helen Webb)

Degrees Longitude	Old Mag	Young Mag	Old Age	Young Age	Age Offset
-128	13	6.5	35.5	23	12.5
-129		7	37.1	25.75	11.35
-130		8	38.8	27.3	11.5
-131		9	40.4	28.7	11.7
-132		10	42.1	30	12.1
-133		11.5	43.7	32.2	11.5
-134		12.5	45.4	34.2	11.2
-135	20	13	47	35.6	11.4
-136	20.6	16	47.9	38.9	9
-137	21.2	17	50.1	40.5	[illegible]
-138	22	18	52.3	42	10.3
-139	23.5		54.8	44.3	10.5
-140	24.5		57.3	46.5	10.8
-141	25.5		59.8	48.8	11
-142	27		63.25	51.1	12.15
-143	29		65.8	53.4	12.4
-144					
-145					
-146					
-147					
-148					
-149		30		67	

Table 5: DREDGE LOCATIONS (courtesy of James Natland)

1. 9°49.14'S 129°47.4'W
Dredge lowered to 3500 m. Winch/tensionmeter problems; hauled back in.

2. 10°17.5'S, 135°22.8'W to 10°17.8'S, 135°21.2'W; 4270 m to 3605 m
Small seamount in field of seamounts to the north of the Marquesas Fracture Zone Ridge. Recovered one 25 kg boulder (basalt, no glass); one glass chip in Mn-nodule; sediments.

3. 10°36.12'S, 135°23.0'W to 10°37.6'S, 135°23.7'W; 4104 m to 3451 m
North scarp of Marquesas Fracture Zone Ridge. Recovered ~500 kg basalt pillows with glass, Mn-encrusted; some hyaloclastities.

4. 11°09.8'S, 137°24.4'W to 11°12.2'S, 137°24.4'W; 2900 m to 2350 m
Marquesas Fracture Zone Ridge. Recovered ~150 kg basalt pillows, some chalk, thick Mn crusts.

5. 10°47.6'S, 137°51.0'W to 10°48.5'S, 137°50.5'W; 2250 m to 1490 m
Seamount south-east of Fatu Hiva and north of fracture zone. "Zero-age" Marquesas. Recovered large haul of pillows, some very glassy and vesicular; little or no Mn-crusts; varieties of alkalic basalt.

6. 14°42.9'S, 149°15.6'W to 14°43.1'S, 149°14.4'W; 3590 m to 3155 m
South-west facing scarp near the northwestern corner of the Tuamotu Plateau. Rcovered moderate-sized haul of vesicular pillow lavas, with some Mn crust. Varieties of alkalic basalt.

7. 14°15.1'S, 150°28.2'W to 14°15.1'S, 150°27.4'W; 2885 m to 2520 m
Seamount in westernmost Tuamotus, along the trace of the fracture zone through the plateau. Recovered several Mn slabs and pillow fragments.

8. 15°11.5'S, 156°53.1"W to 15°12.5'S, 156°50.0'W; 2553 m to 1776 m
Marara Seamount at the oldest (northwest) end of the Society chain. Recovered hyaloclastite, mainly altered to palagonite and clays.

9. 15°12.1'S, 156°51.7'W to 15°11.9'S, 156°51.7'W; 1650 m to 1445 m
Upslope from Drege 8 on Marara Seamount. Recovered one large porphyritic basalt and some smaller fragments.

10. 18°03.1'S, 164°09.0'W; 2811 m to 1698 m
Shoal feature west of large seamount. "Eckerd Seamount". Possibly oldest Cook-Austral volcano. N-S haul to summit. Recovered altered porphyritic basalt pillows, probably alkalic.

11. 20°01.8'S, 167°51.3'W to 20°01.8'S, 167°49.5'W; 2540 m to 1420 m
Southern flank of Beveridge Reef. Recovered croal fragment; 1 piece of pumice; shells; no basalt.

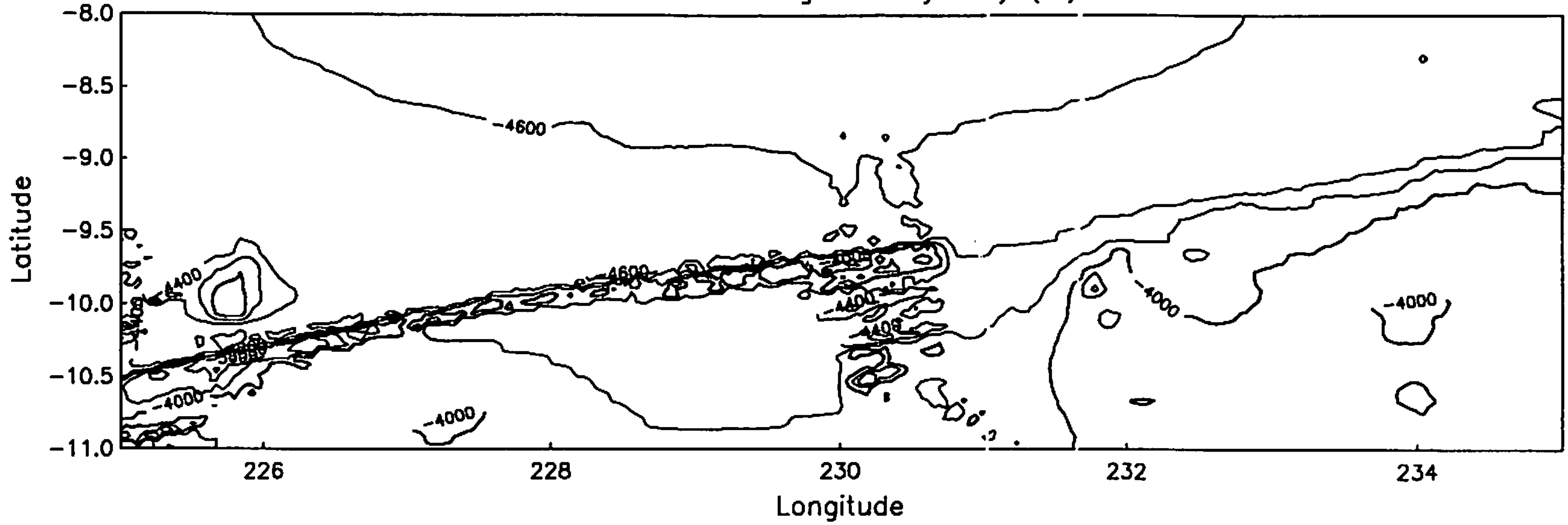
FIGURES

The following figures display some of the data we collected during this expedition. Set one (Figures A-L) contains bathymetric maps from each of 5 survey areas along the Marquesas Fracture Zone plus the northern Cook-Austral area. The areas run from east to west. For each survey area, the first map page compares the new map we created using Hydrosweep data merged with dbdb5 bathymetry with the original dbdb5 map. The second map page compares the merged bathymetric map with the altimetric gravity field from Bill Haxby. Ship track lines are superimposed on both the dbdb5 and the gravity maps. For Area 2, near the Marquesas Islands, the merged bathymetry map contains multibeam data from more than just EW9106 (principally Crossgrain 2 on the *Thomas Washington* and EW9103).

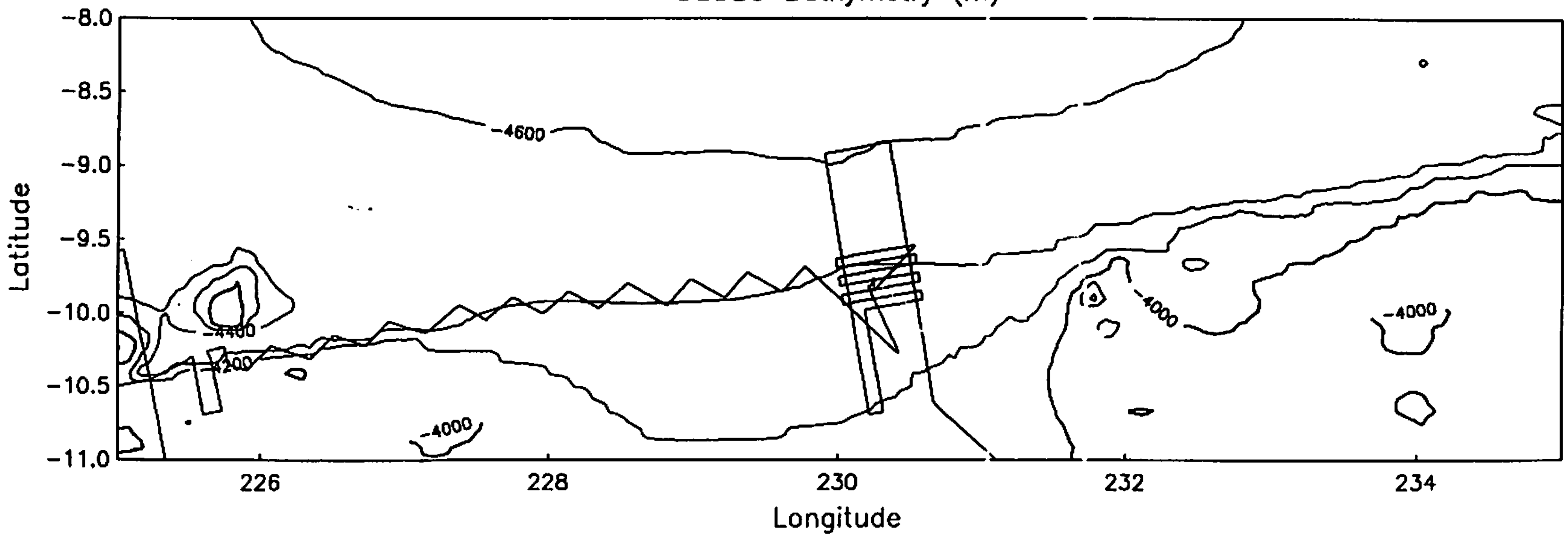
Set two (Figures M-V) contains depth and free-air gravity profiles from the four detailed survey areas, as well as a crossing of the abandoned ridge along the east side of the Manihiki Plateau. Distance along track is plotted as latitude, but because the tracks ran at approximately 10° west of north, the conversion is approximately 1 degree of latitude = 111 km * cos(10°) = 109 km (0.2° tic marks = 22 km). The locations of each of the area surveys are shown in the corresponding area map in set 1, except for the area 4 lines which are on the map marked "Northern Tuamotu."

Finally, Figures W and X show the digitized locations of the north-facing MFZ scarp between 230° and 213° and the depth in meters to the top and bottom of the scarp, respectively. These figures are courtesy of Martha Kuykendall.

Area 1 – Merged Bathymetry (m)

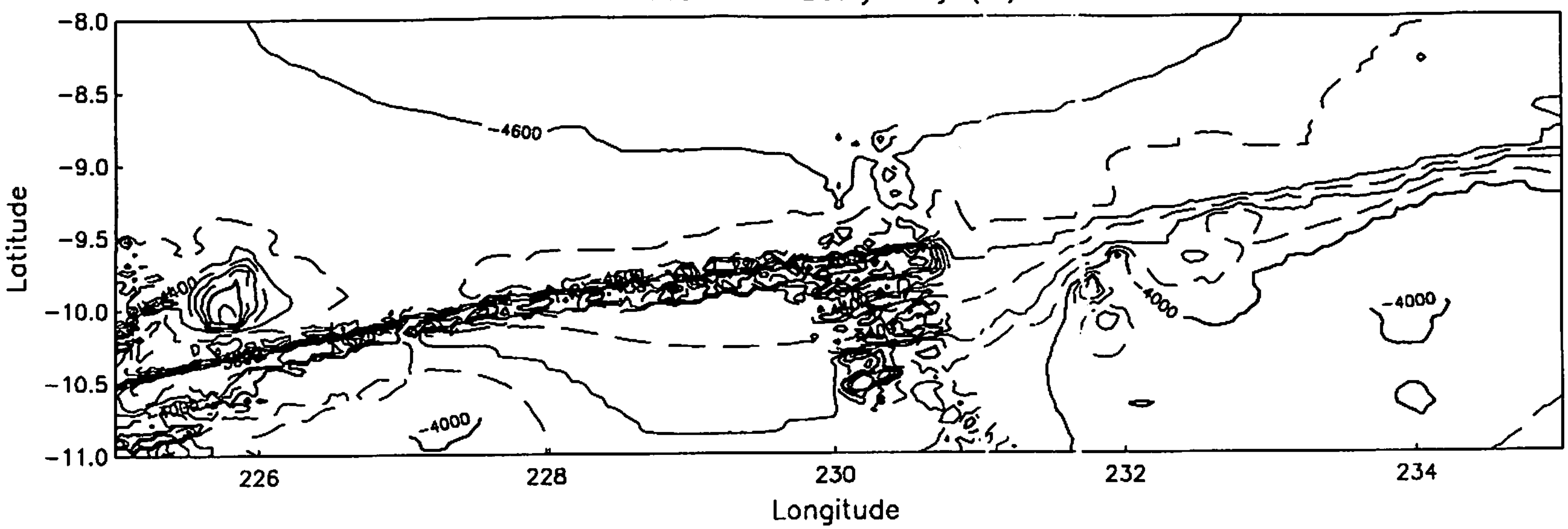


DBDB5 Bathymetry (m)

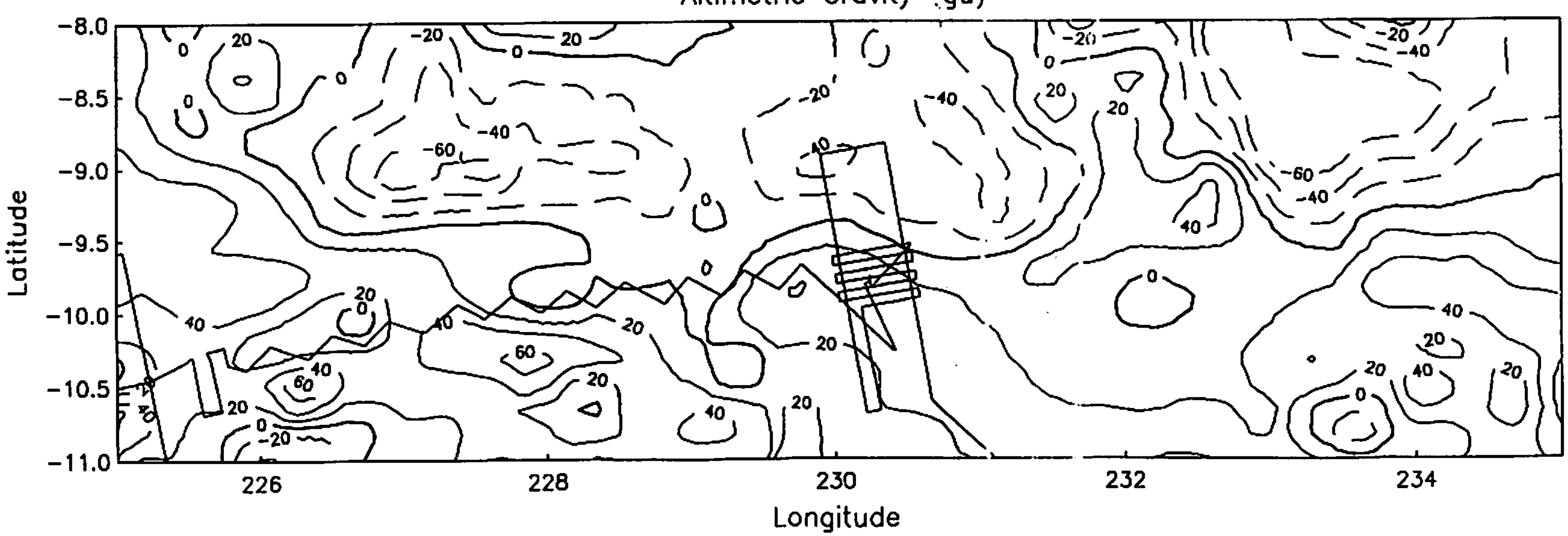


M. McNutt 1991

Area 1 - Bathymetry (m)

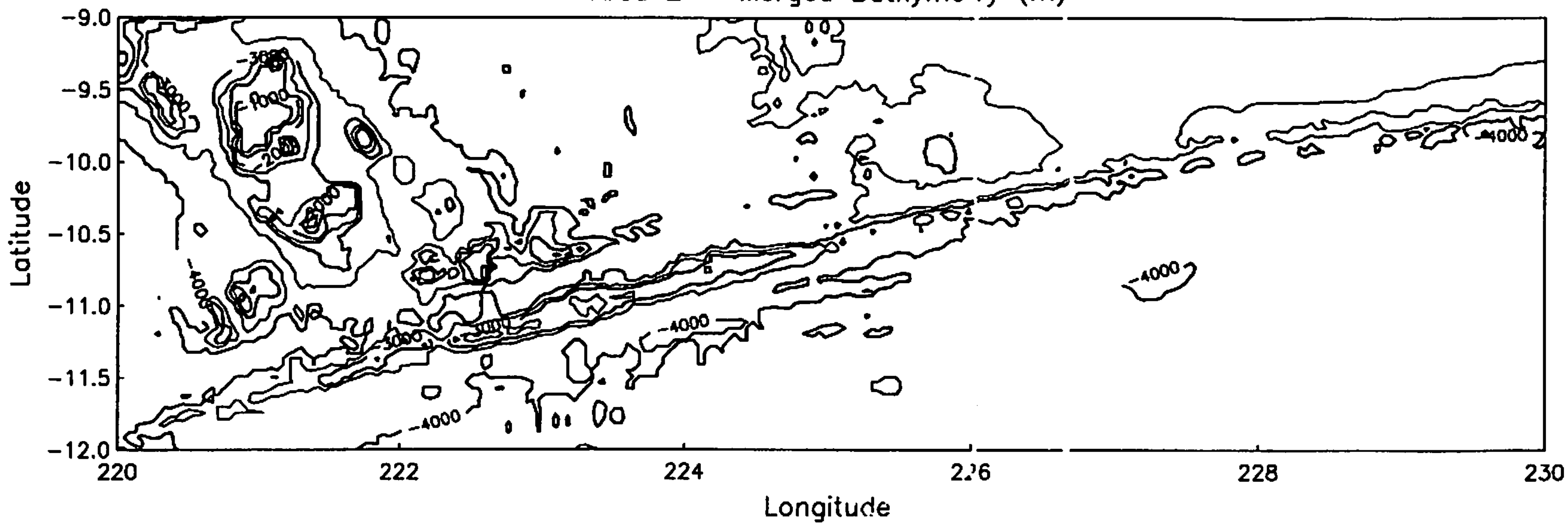


Altimetric Gravity (gu)

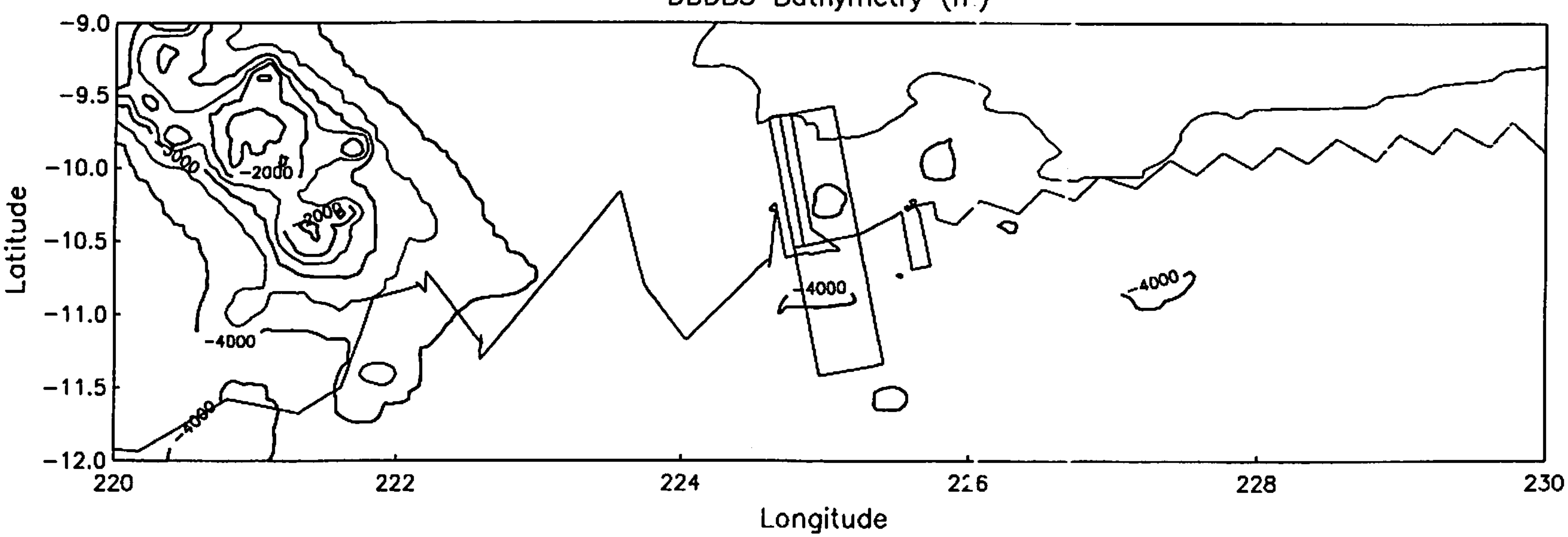


M. McNutt 1991

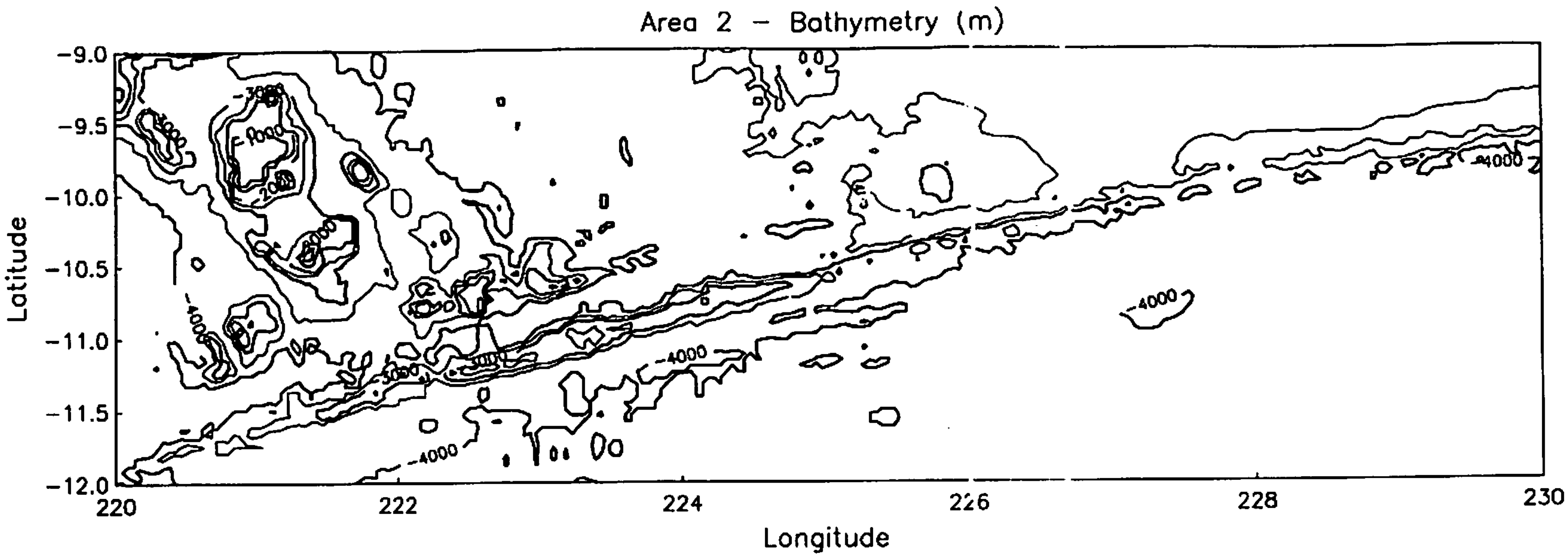
Area 2 - Merged Bathymetry (m)

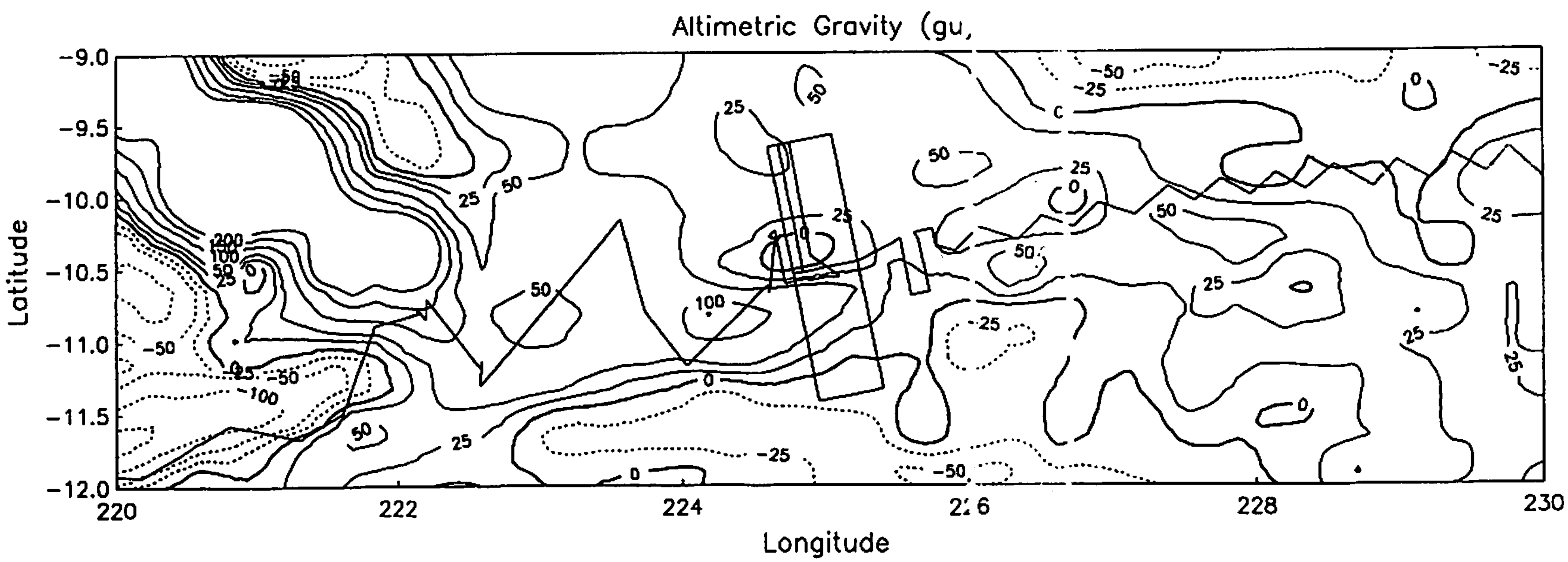


DBDB5 Bathymetry (m)

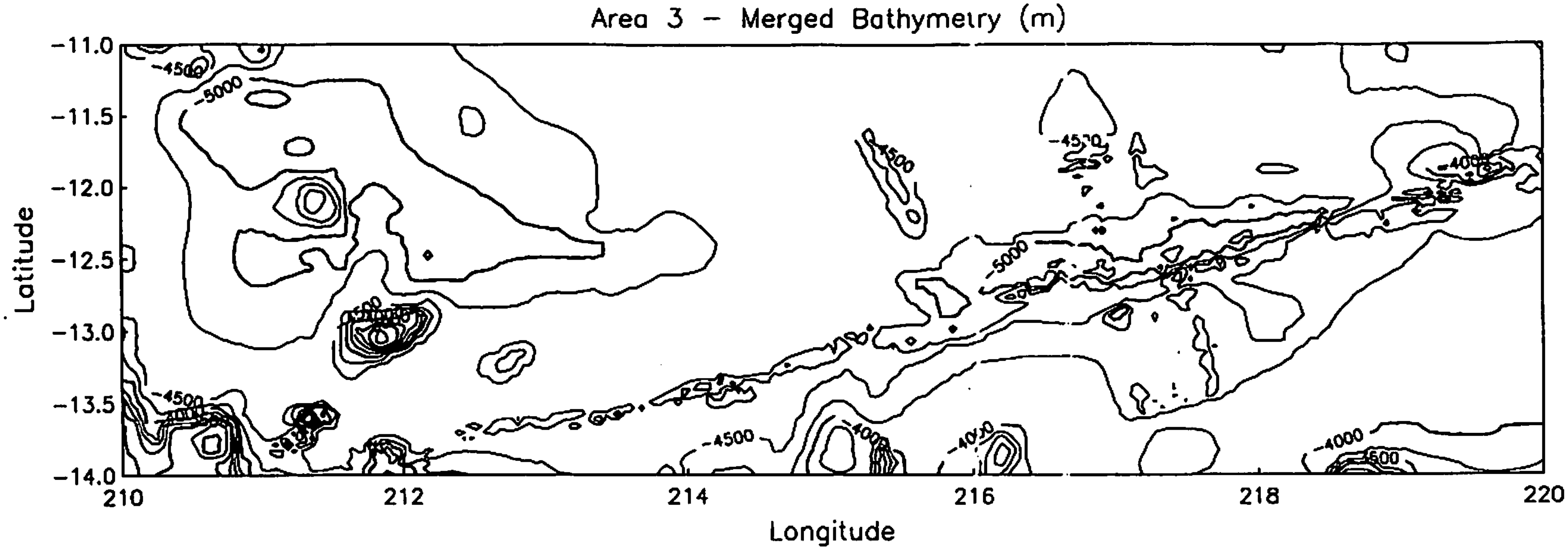


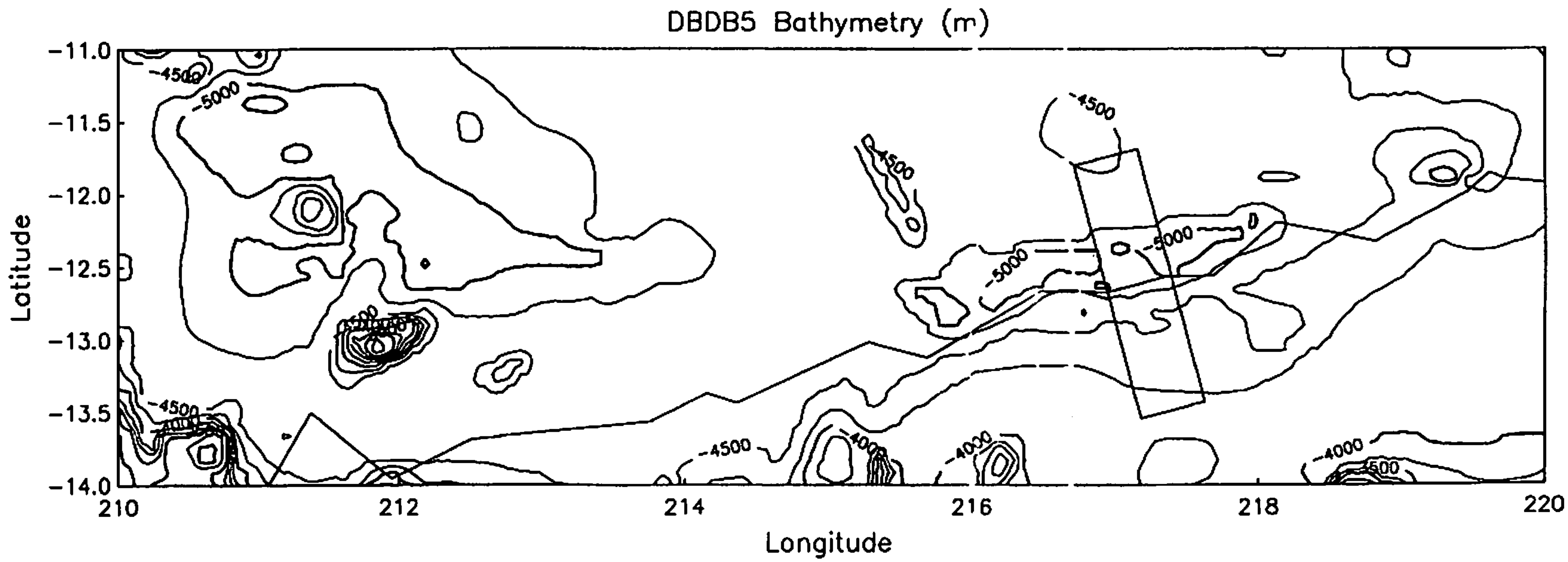
M. McNutt 1991





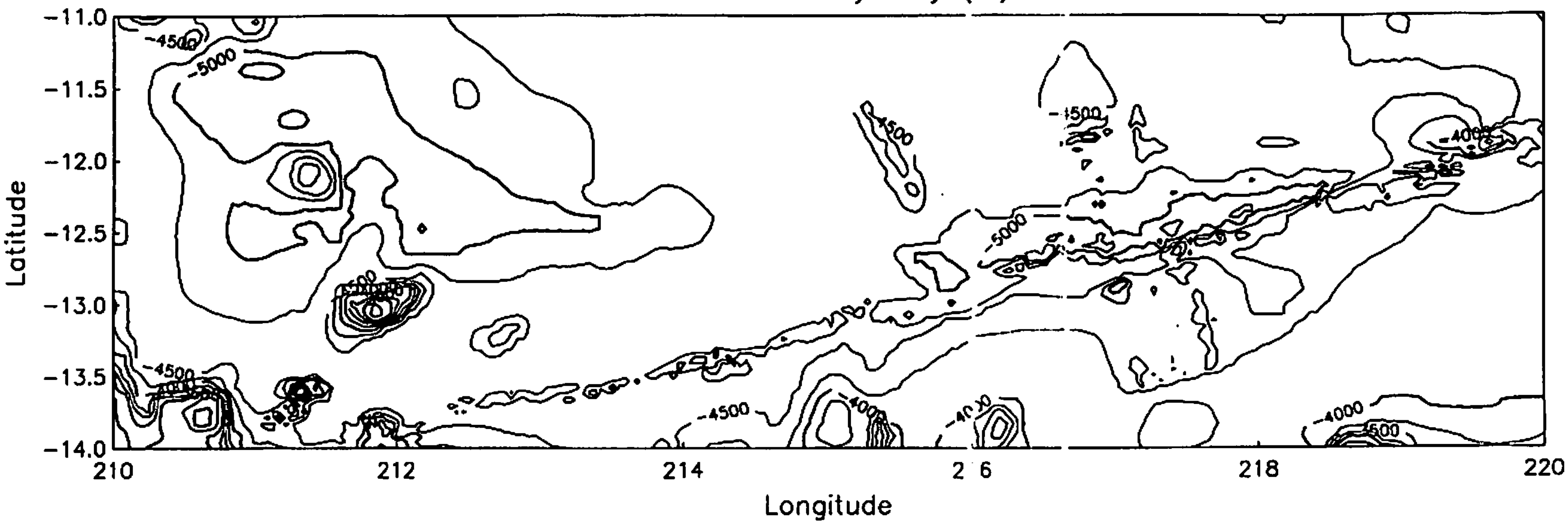
M. McNutt 1991



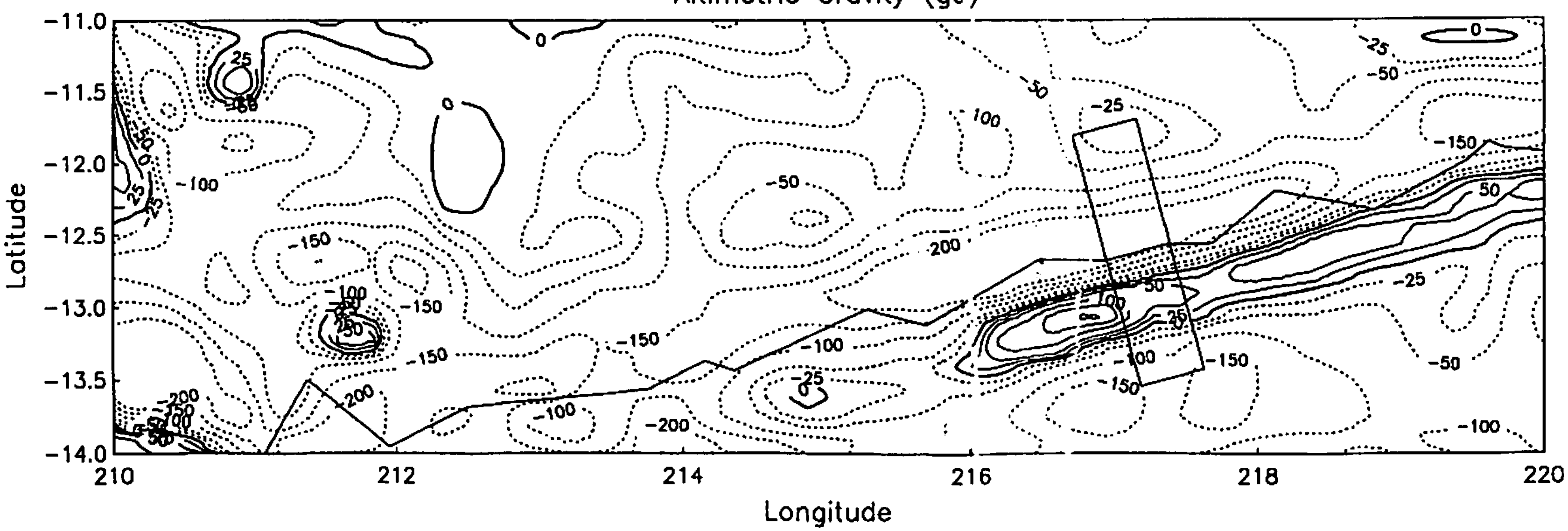


M. McNutt 1991

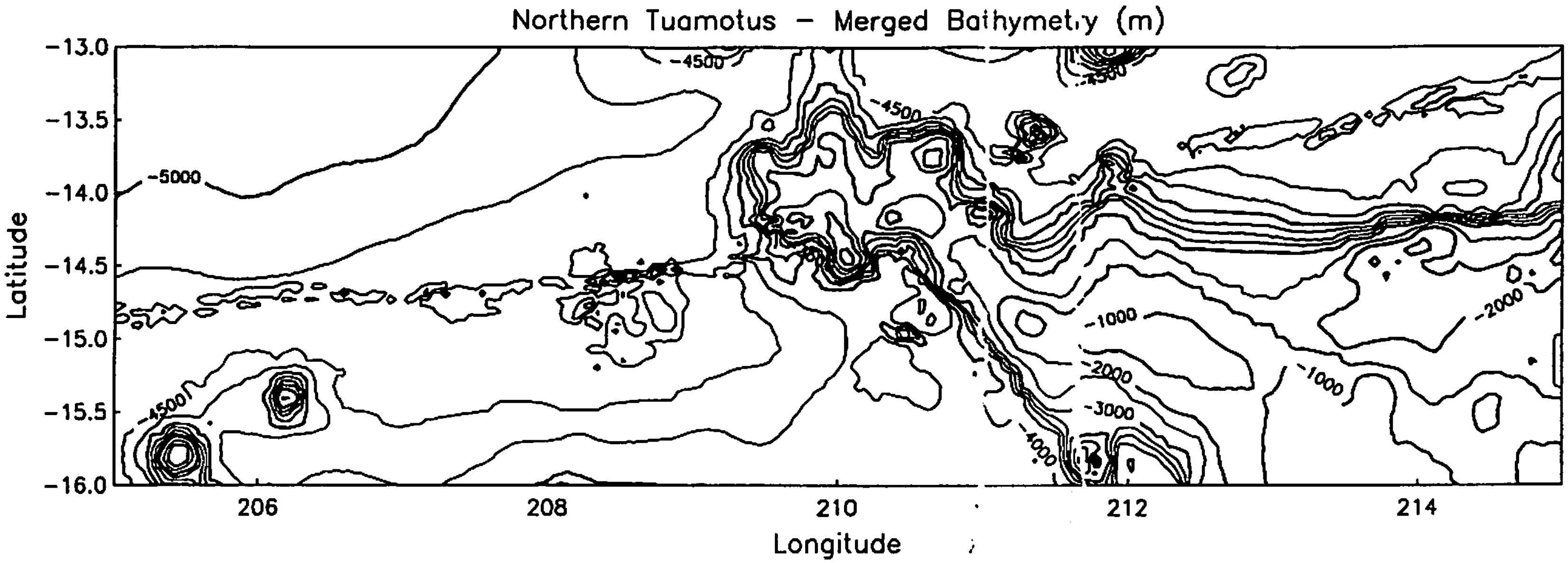
Area 3 – Bathymetry (m)

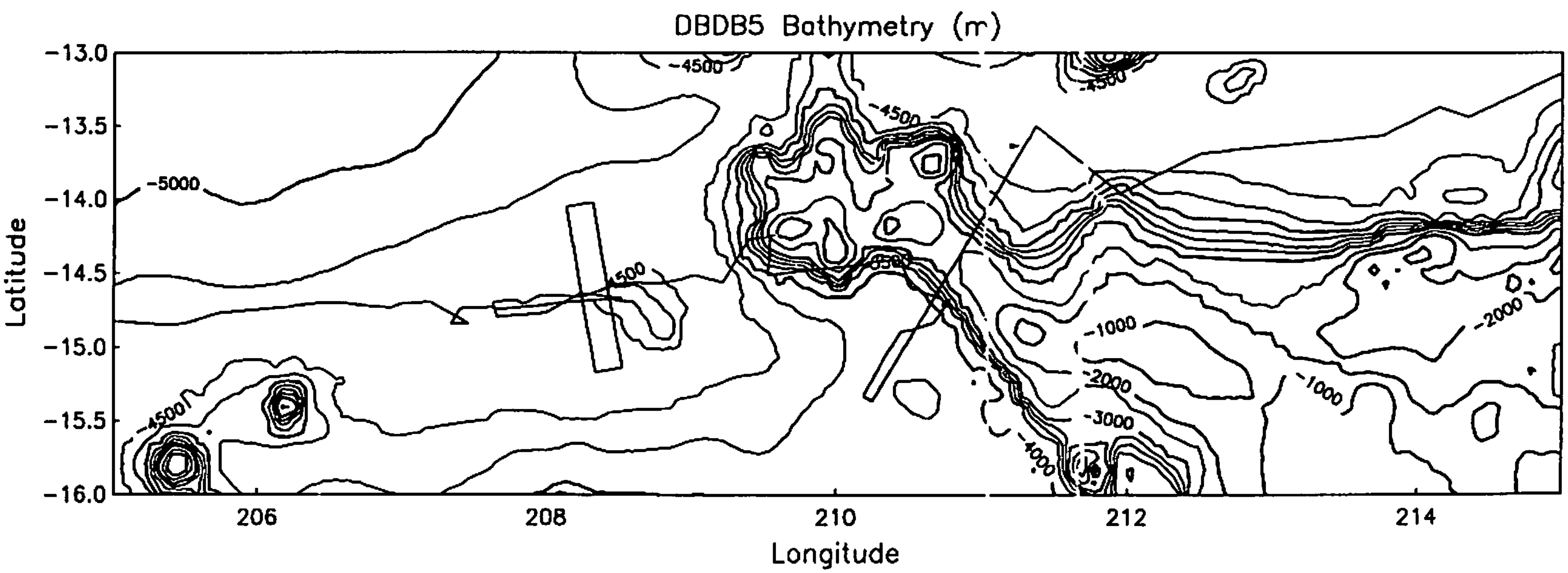


Altimetric Gravity (gu)

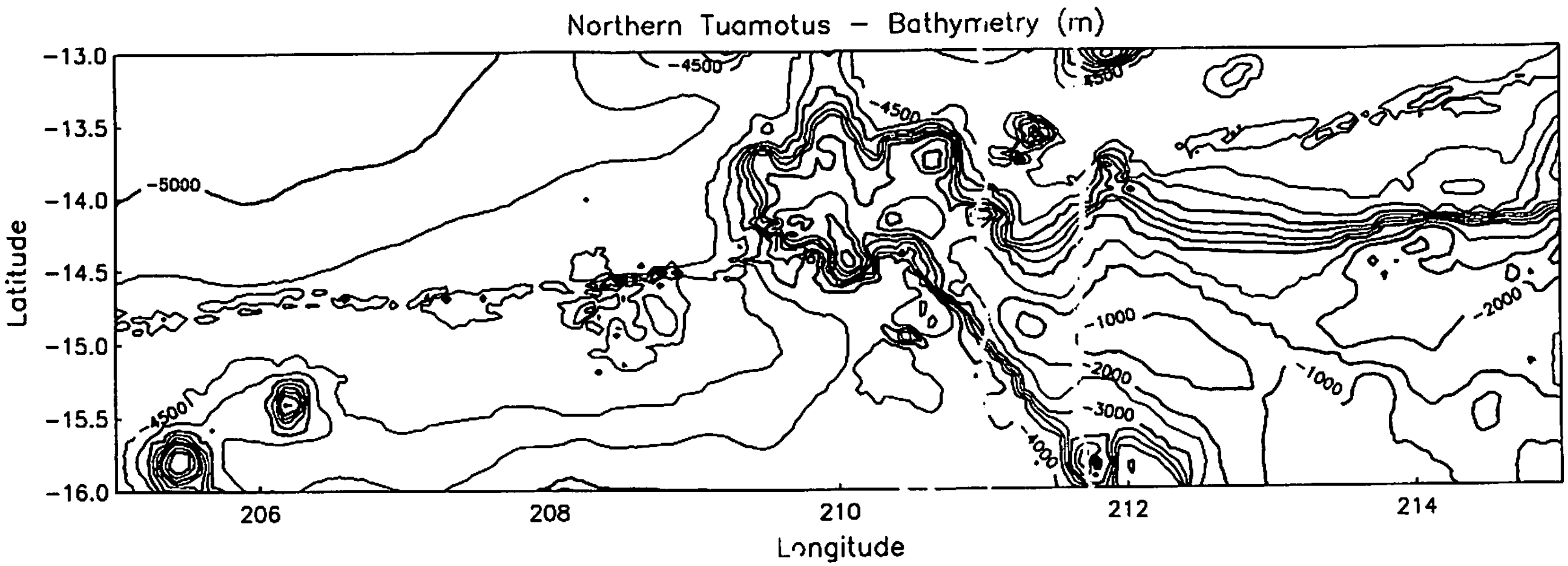


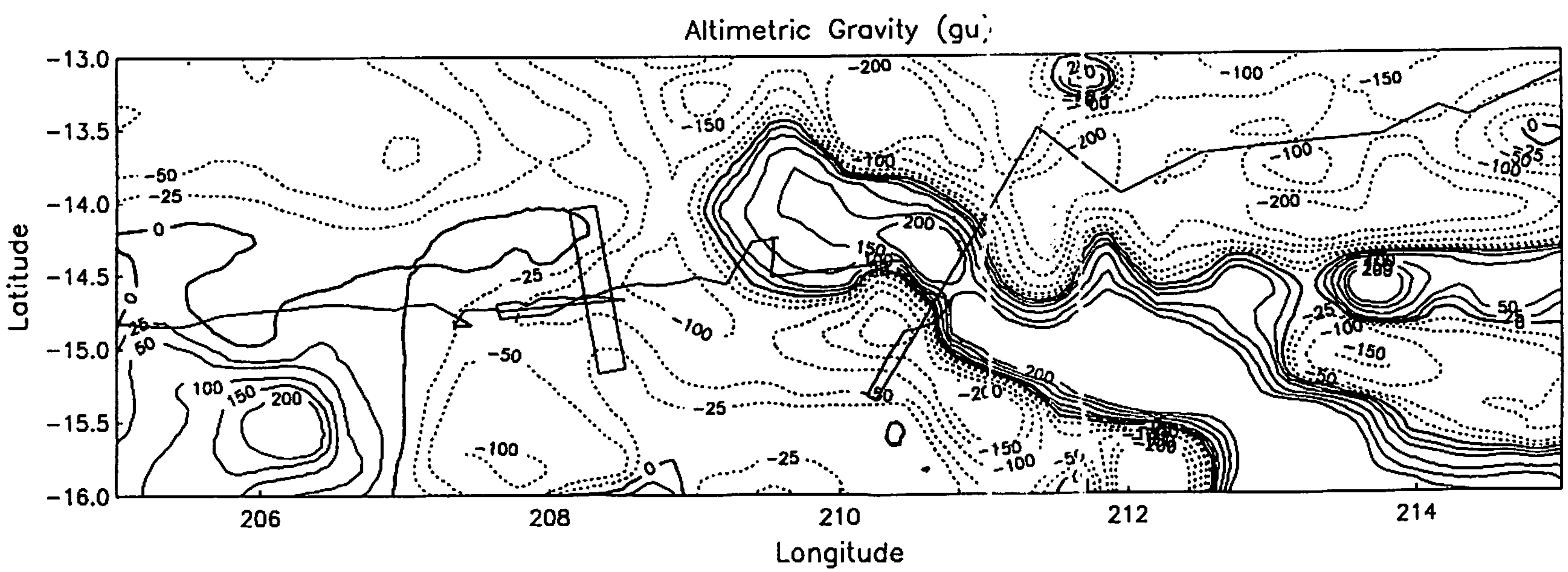
M. McNutt 1991





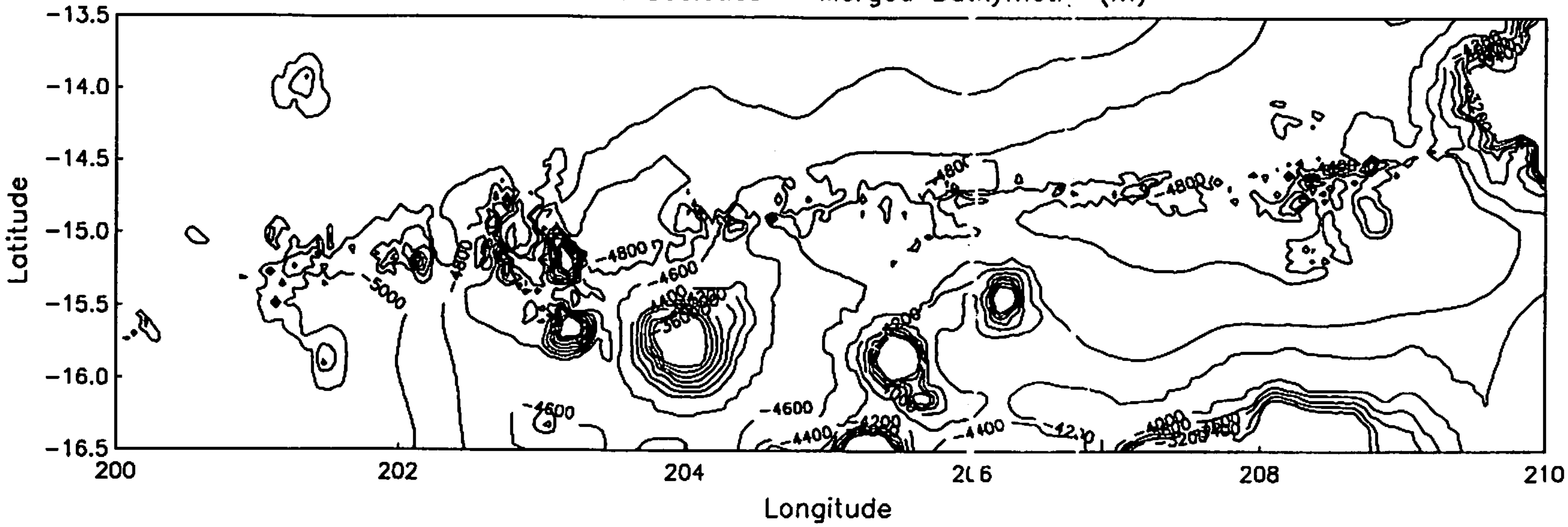
M. McNutt 1991



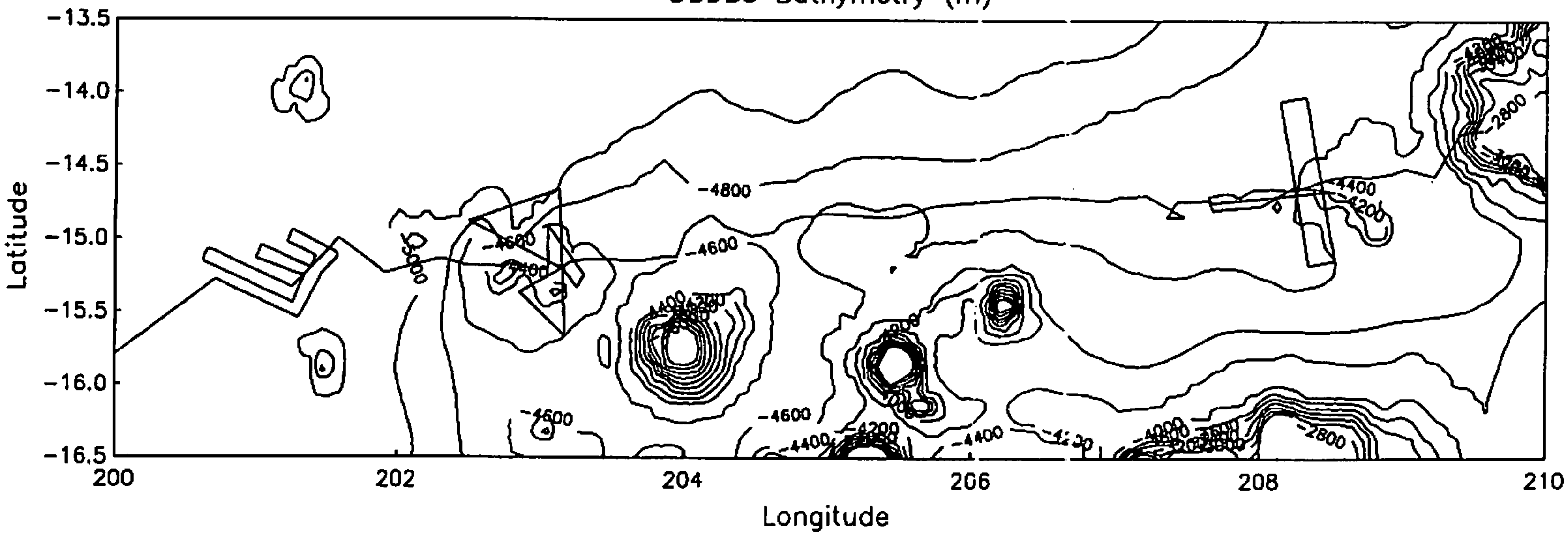


M. McNutt 1991

Northern Societies – Merged Bathymetry (m)

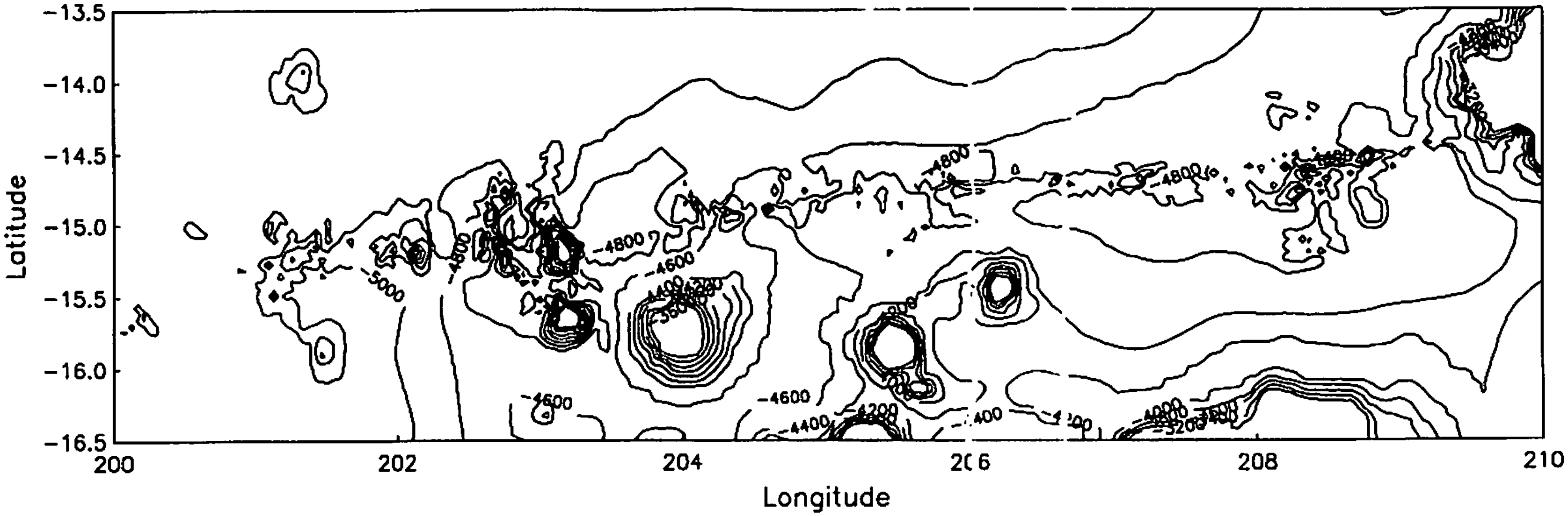


DBDB5 Bathymetry (m)

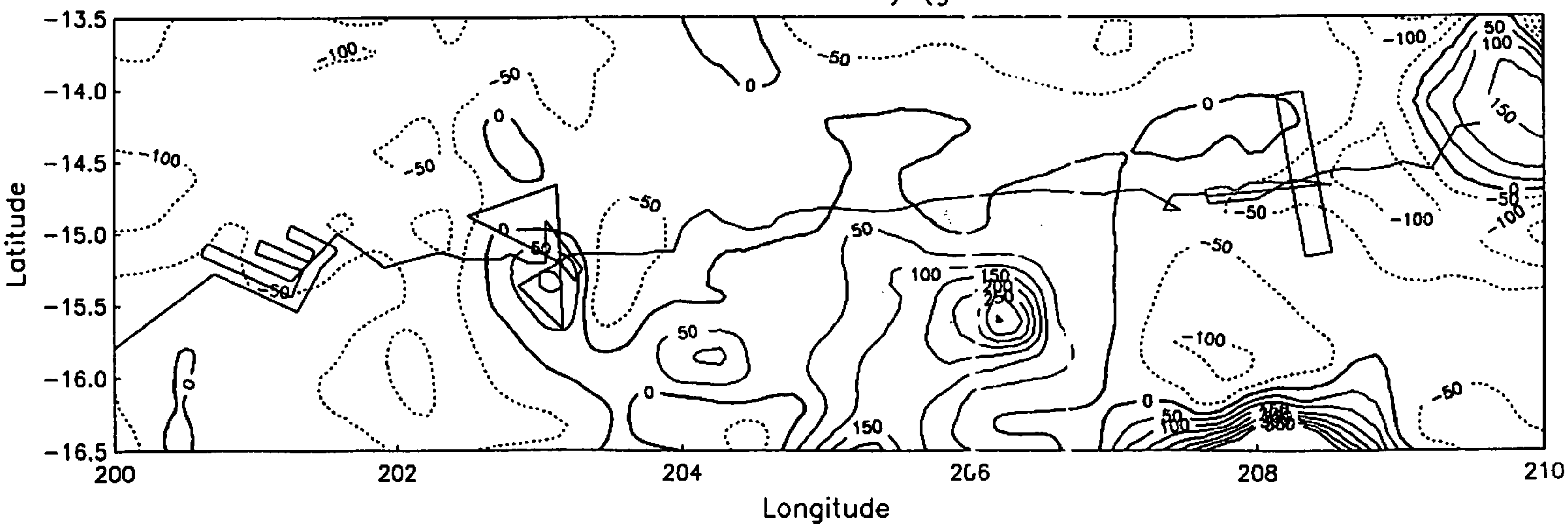


M. McNutt 1991

Northern Societies – Bathymetry (m)

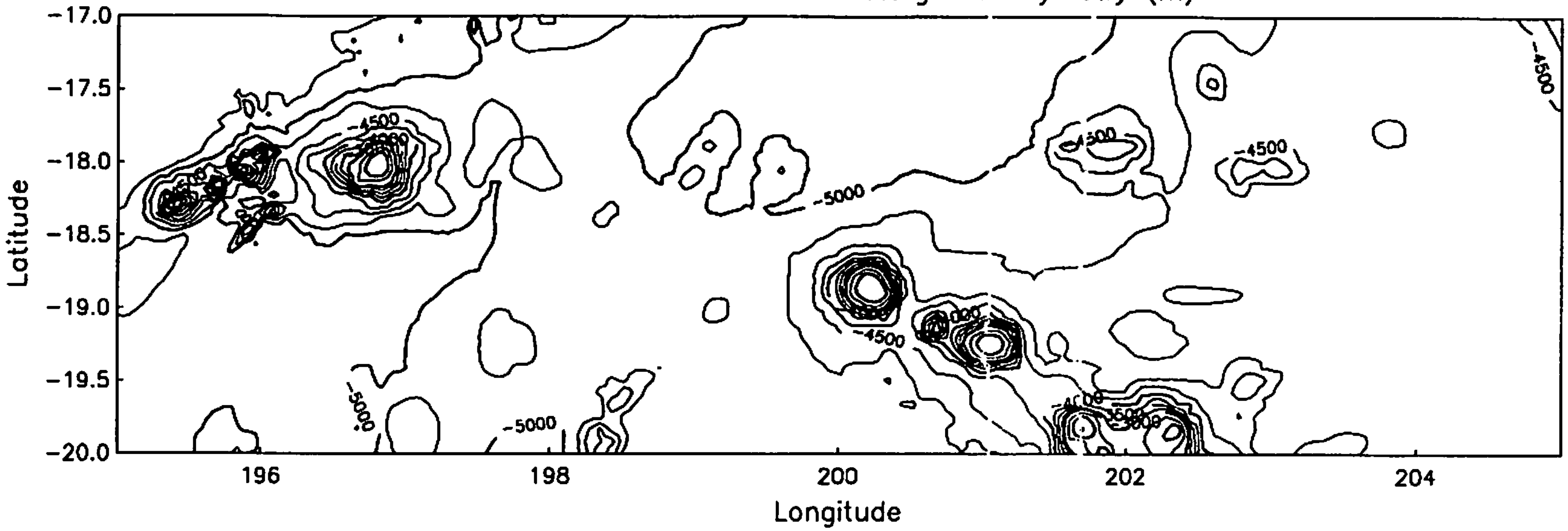


Altimetric Gravity (gu

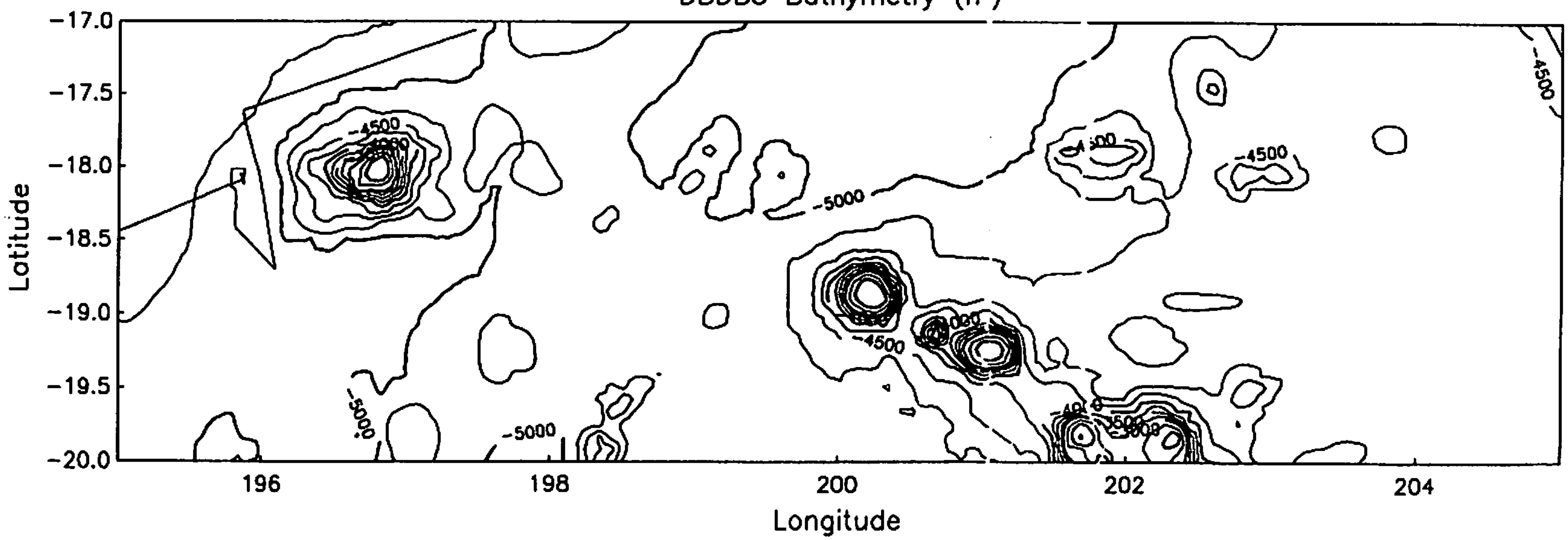


M. McNutt 1991

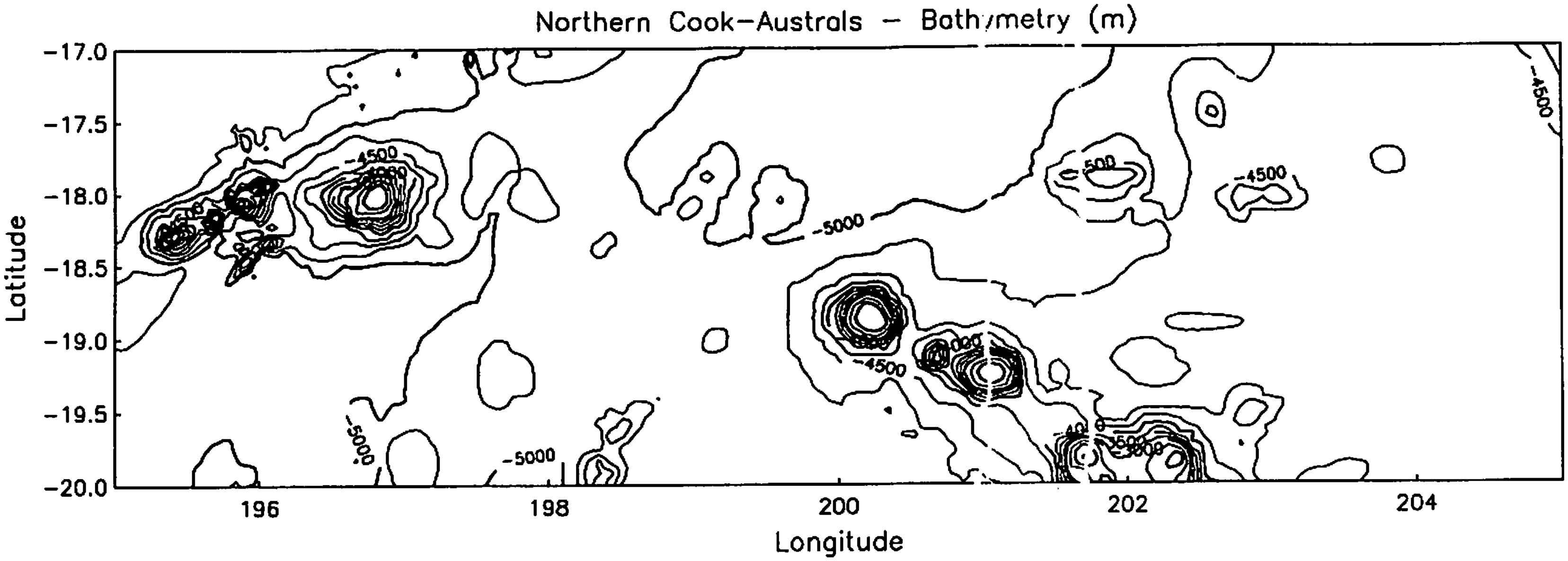
Northern Cook-Australs - Merged Bathymetry (m)

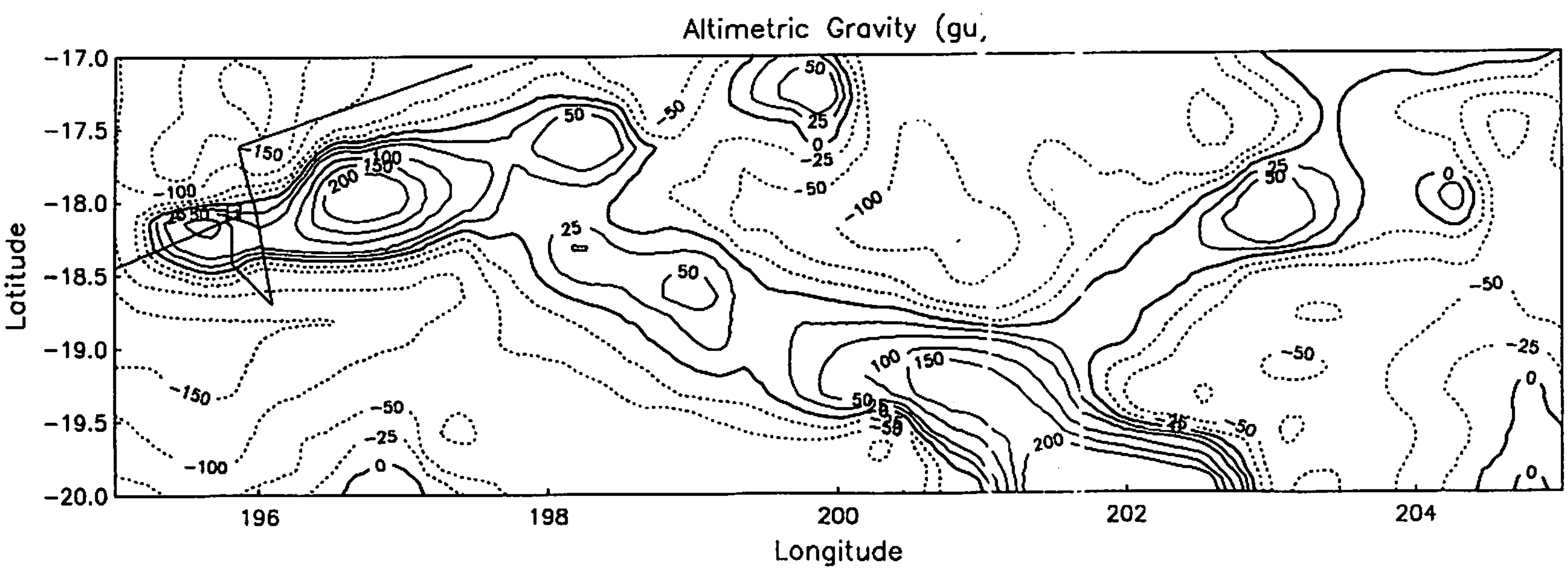


DBDB5 Bathymetry (m)



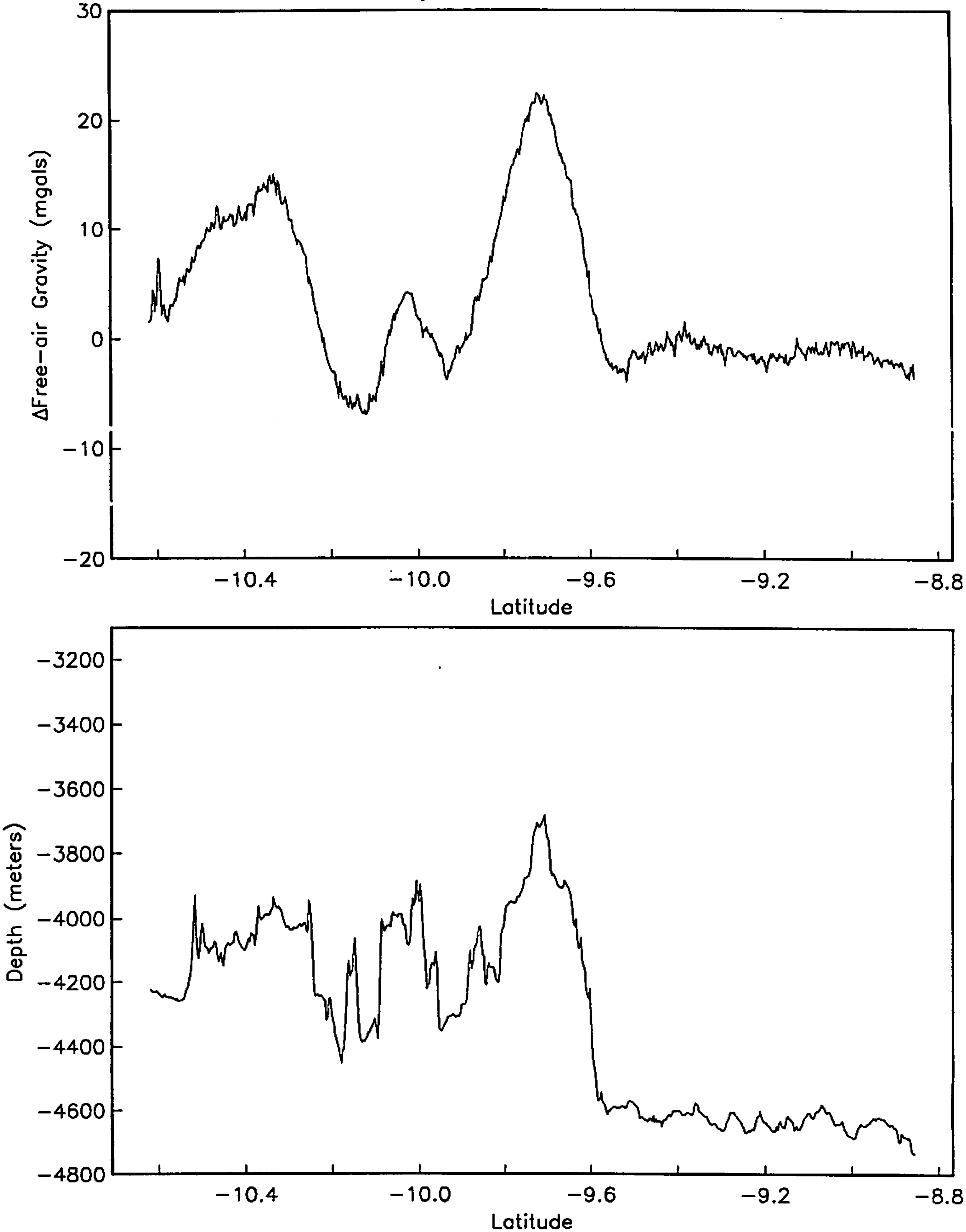
M. McNutt 1991

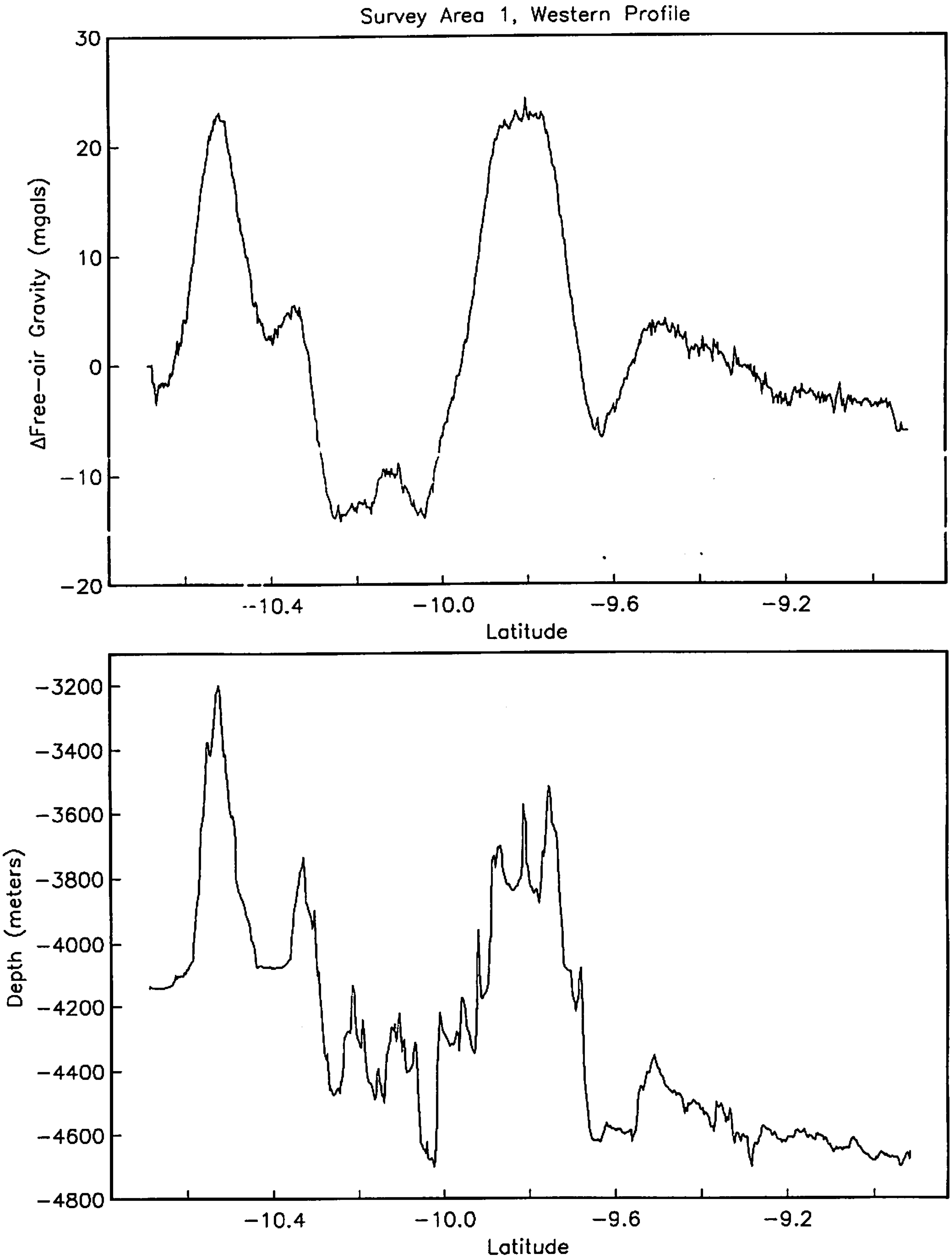




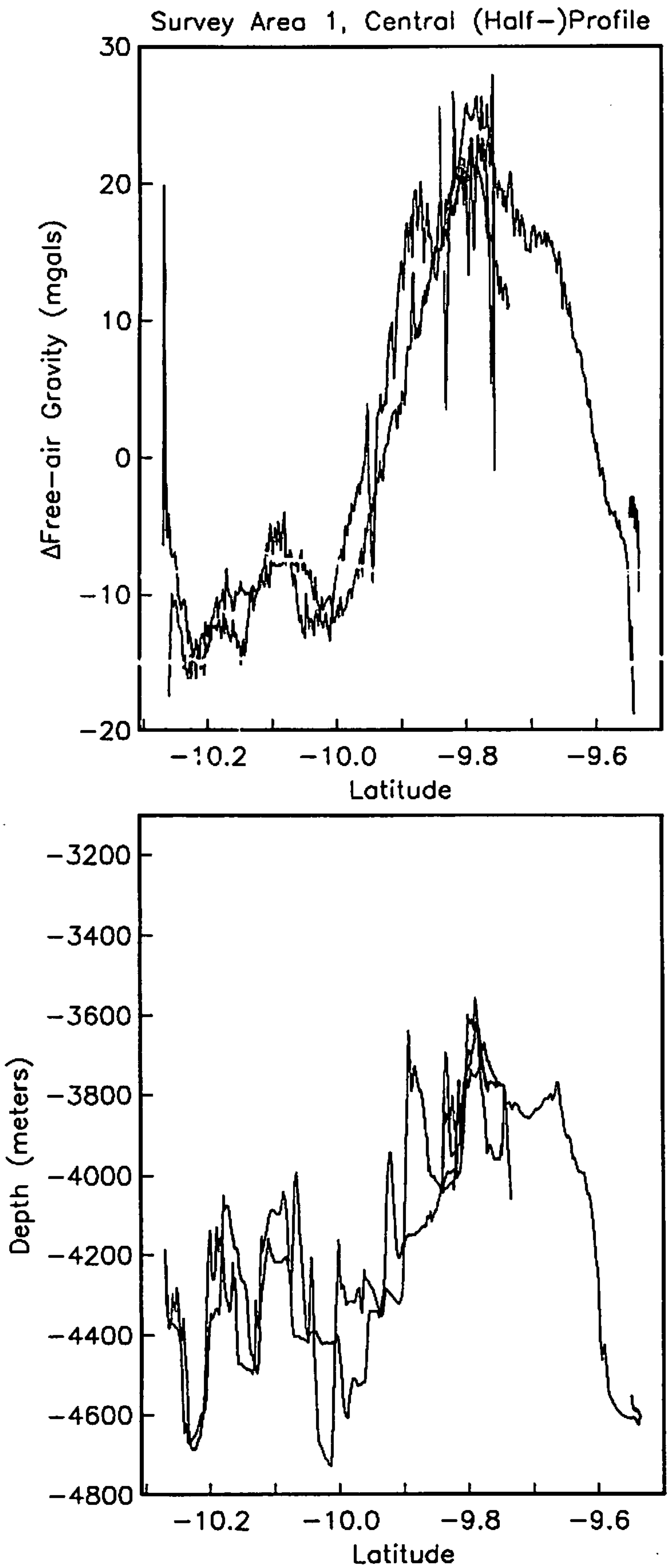
M. McNutt 1991

Survey Area 1, Eastern Profile

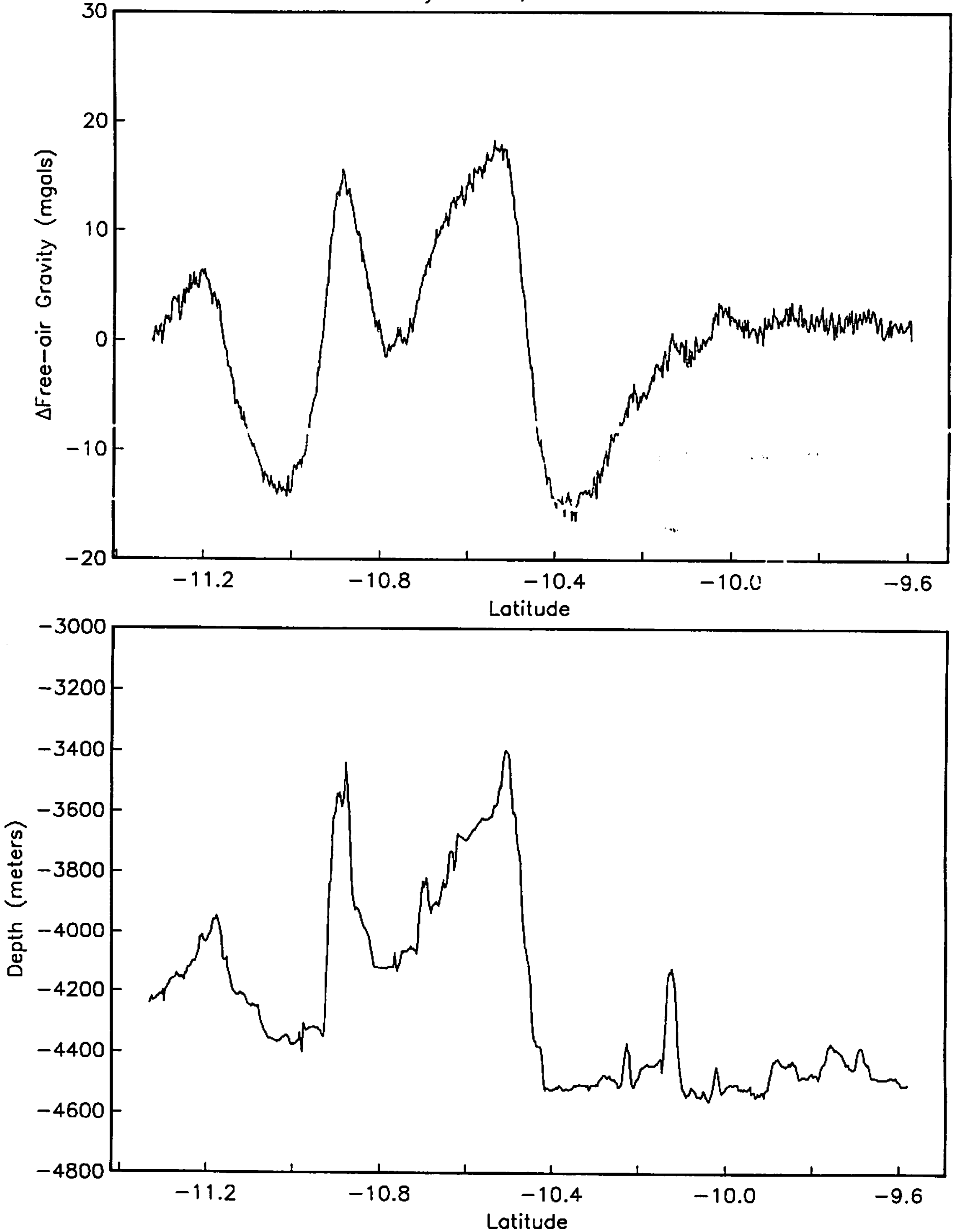


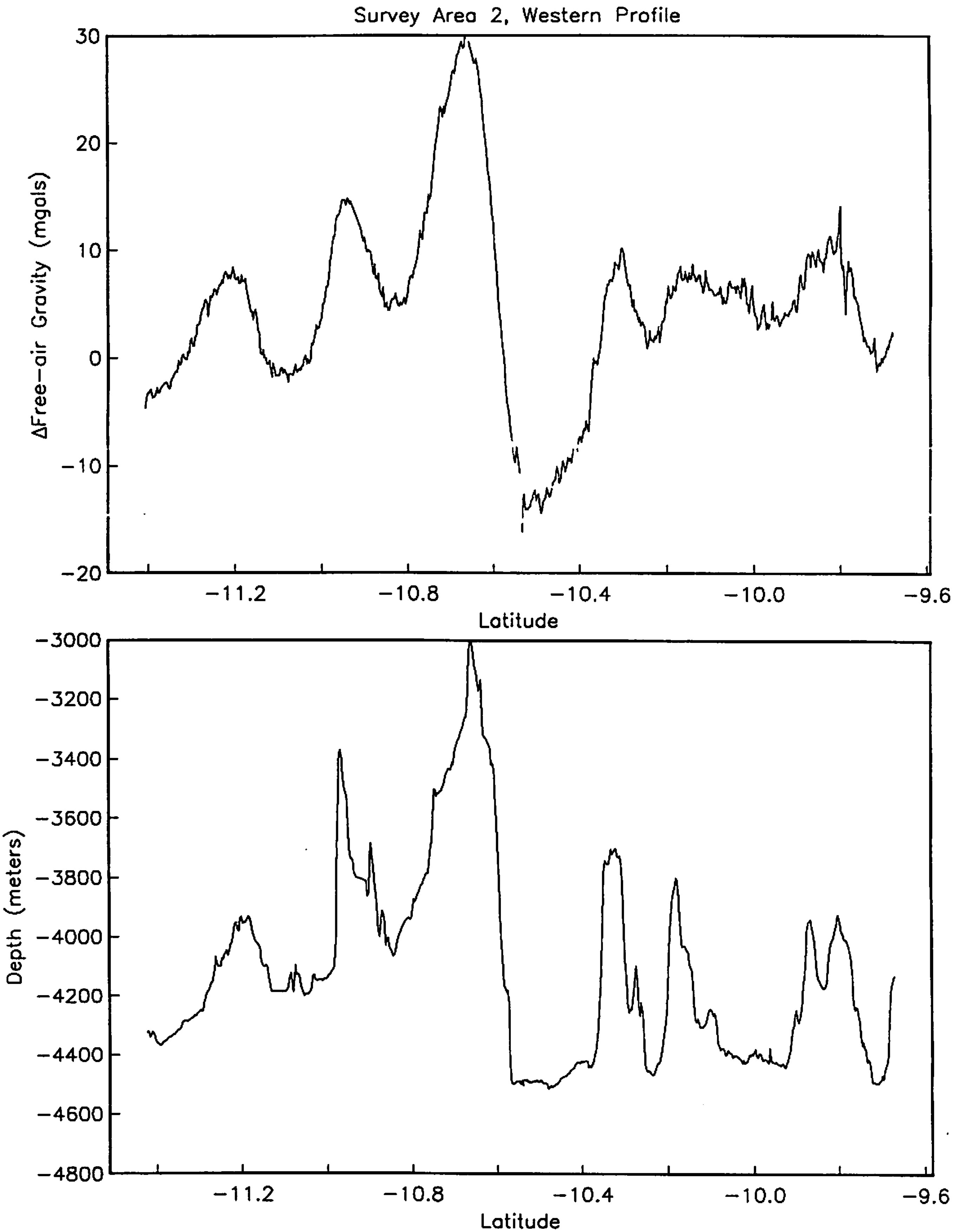


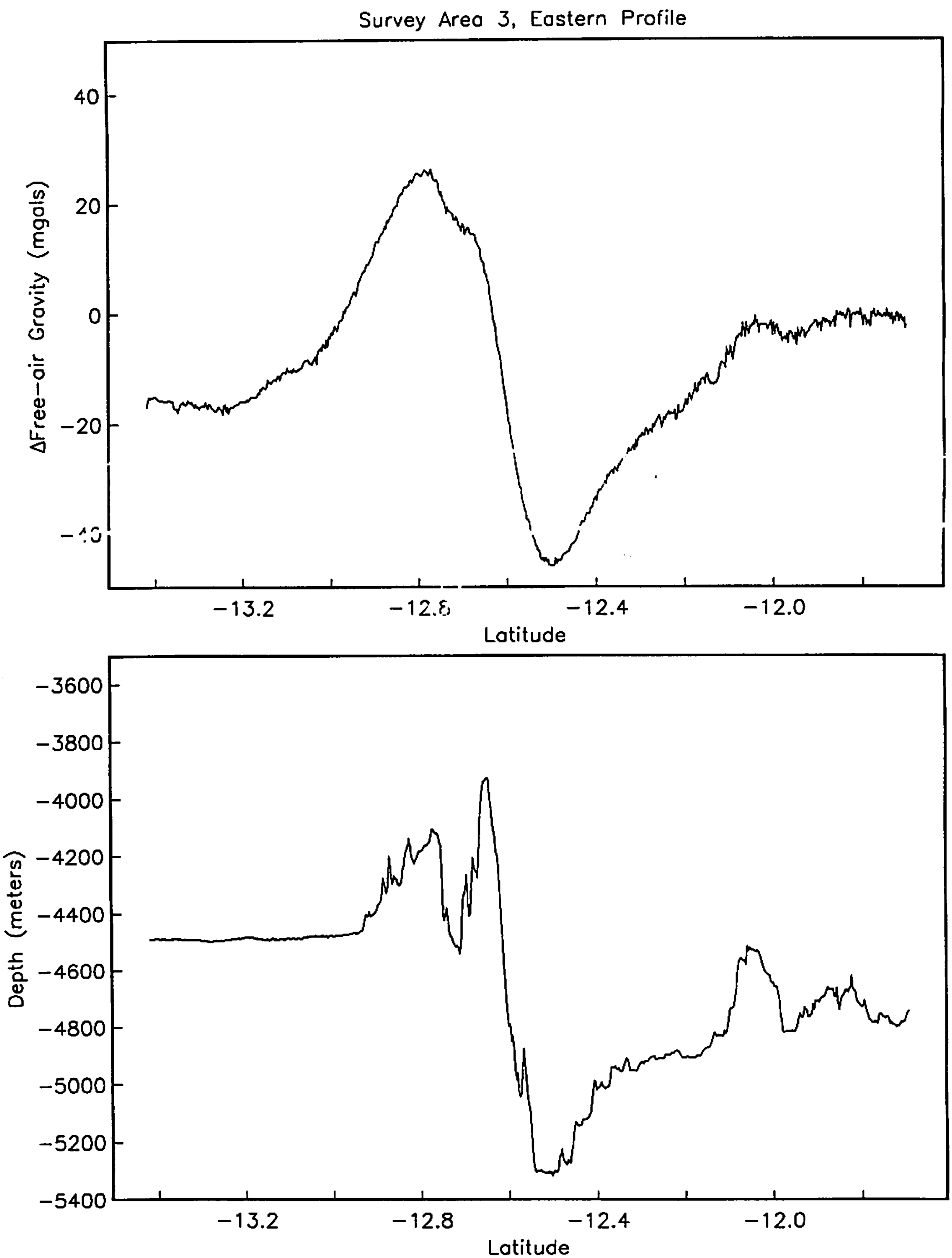
Survey Area 1, Western Profile
ΔFree-air Gravity (mgals)
30
20
10
0
−10
−20
-10.4
−10.0
−9.6
−9.2
Latitude
Depth (meters)
−3200
−3400
−3600
−3800
−4000
−4200
−4400
−4600
−4800
−10.4
−10.0
−9.6
−9.2
Latitude


Survey Area 1, Central (Half-)Profile
30
20
10
0
−10
−20
ΔFree-air Gravity (mgals)
−10.2
−10.0
−9.8
−9.6
Latitude
−3200
−3400
−3600
−3800
−4000
−4200
−4400
−4600
−4800
Depth (meters)
−10.2
−10.0
−9.8
−9.6
Latitude

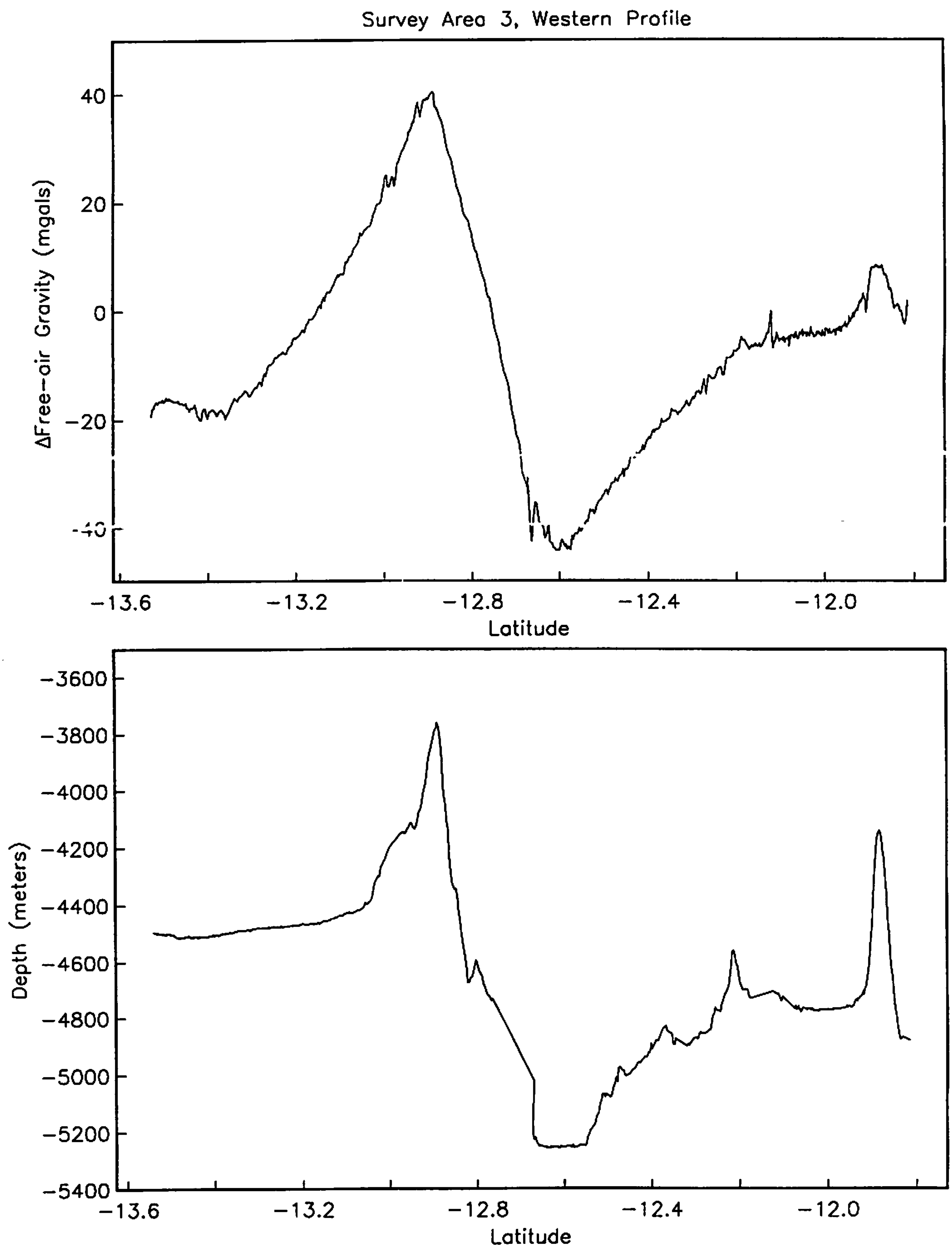
Survey Area 2, Eastern Profile

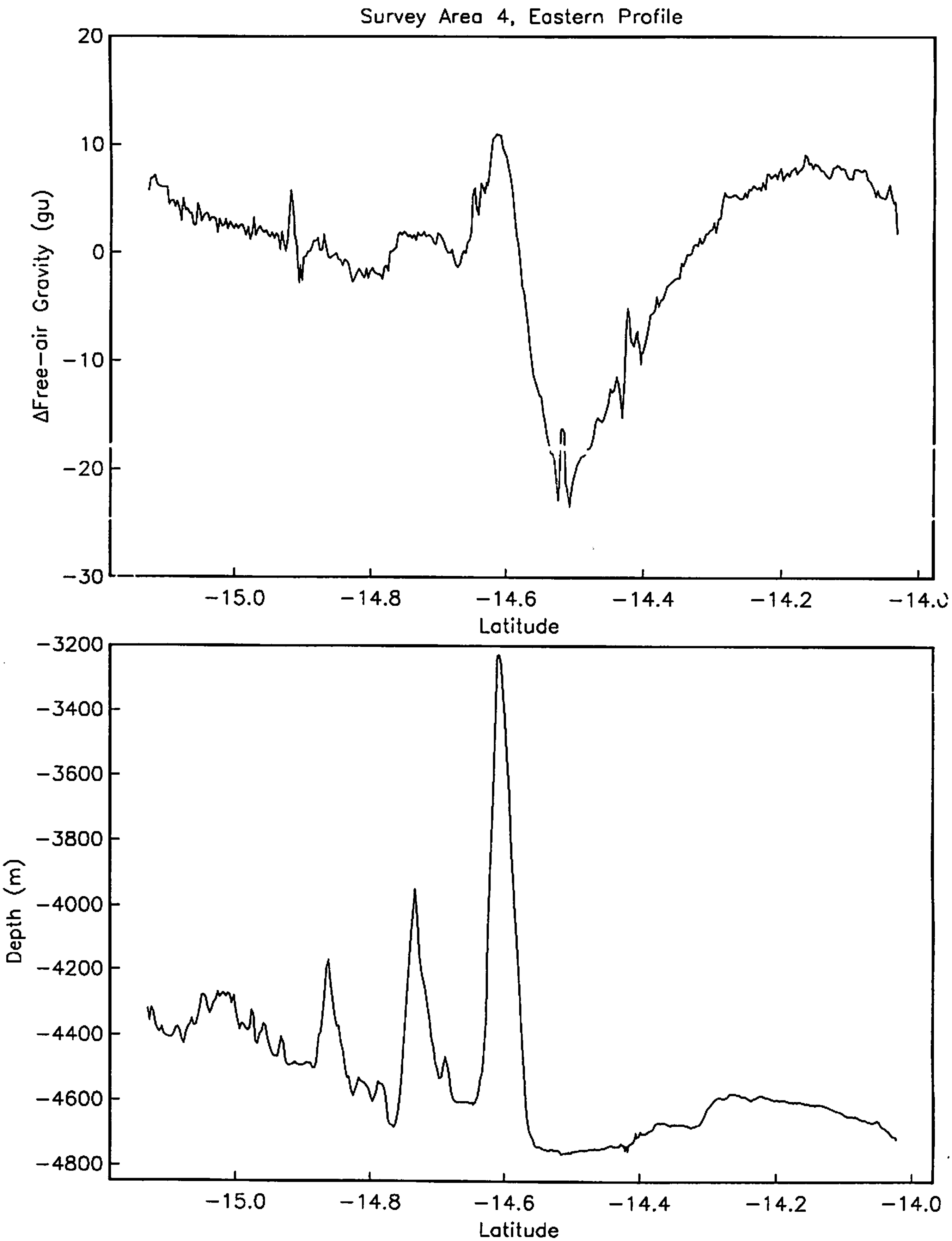



Survey Area 2, Western Profile
30
20
10
0
−10
−20
ΔFree−air Gravity (mgals)
−11.2
−10.8
−10.4
−10.0
−9.6
Latitude
−3000
−3200
−3400
−3600
−3800
−4000
−4200
−4400
−4600
−4800
Depth (meters)
−11.2
−10.8
−10.4
−10.0
−9.6
Latitude

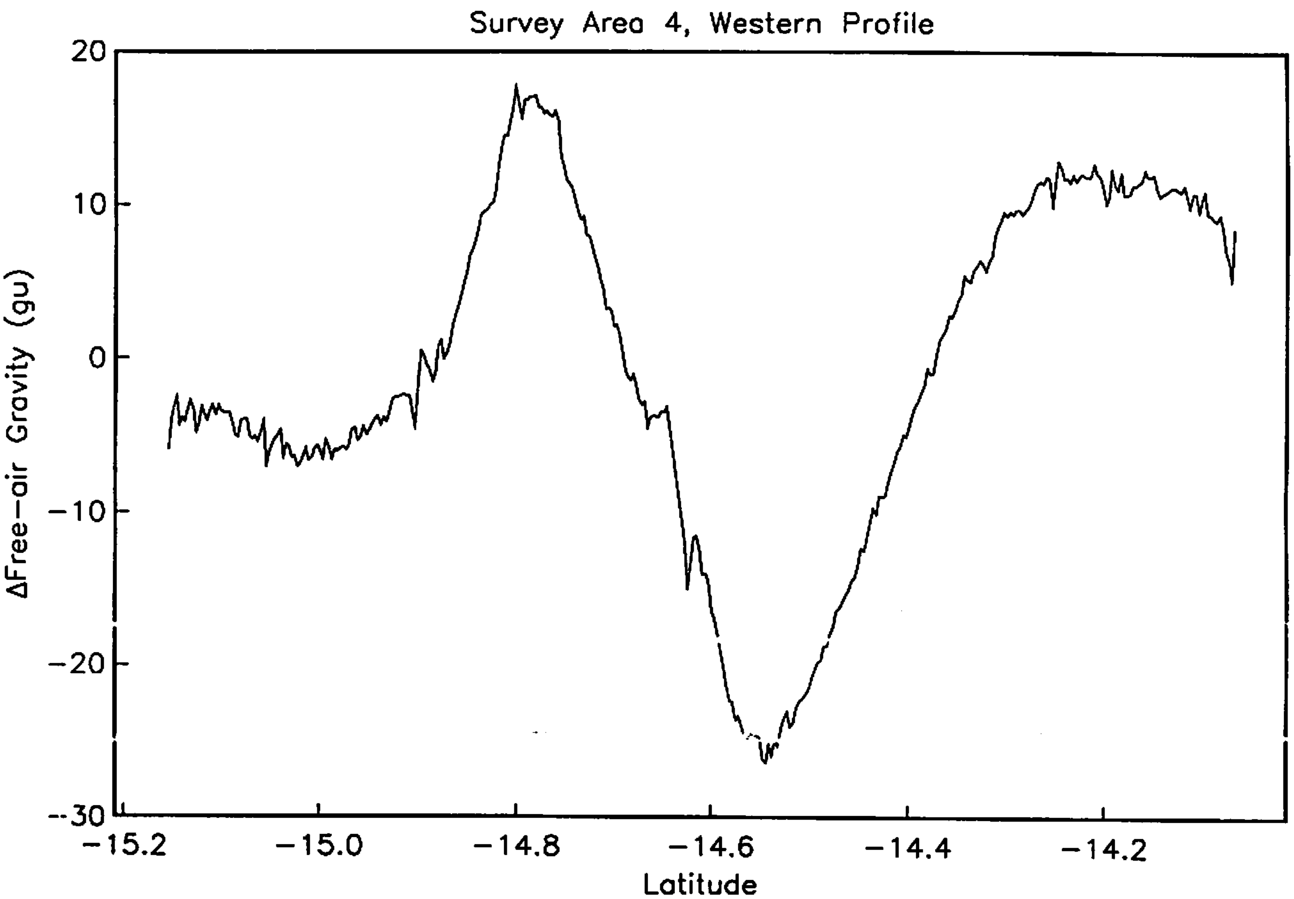


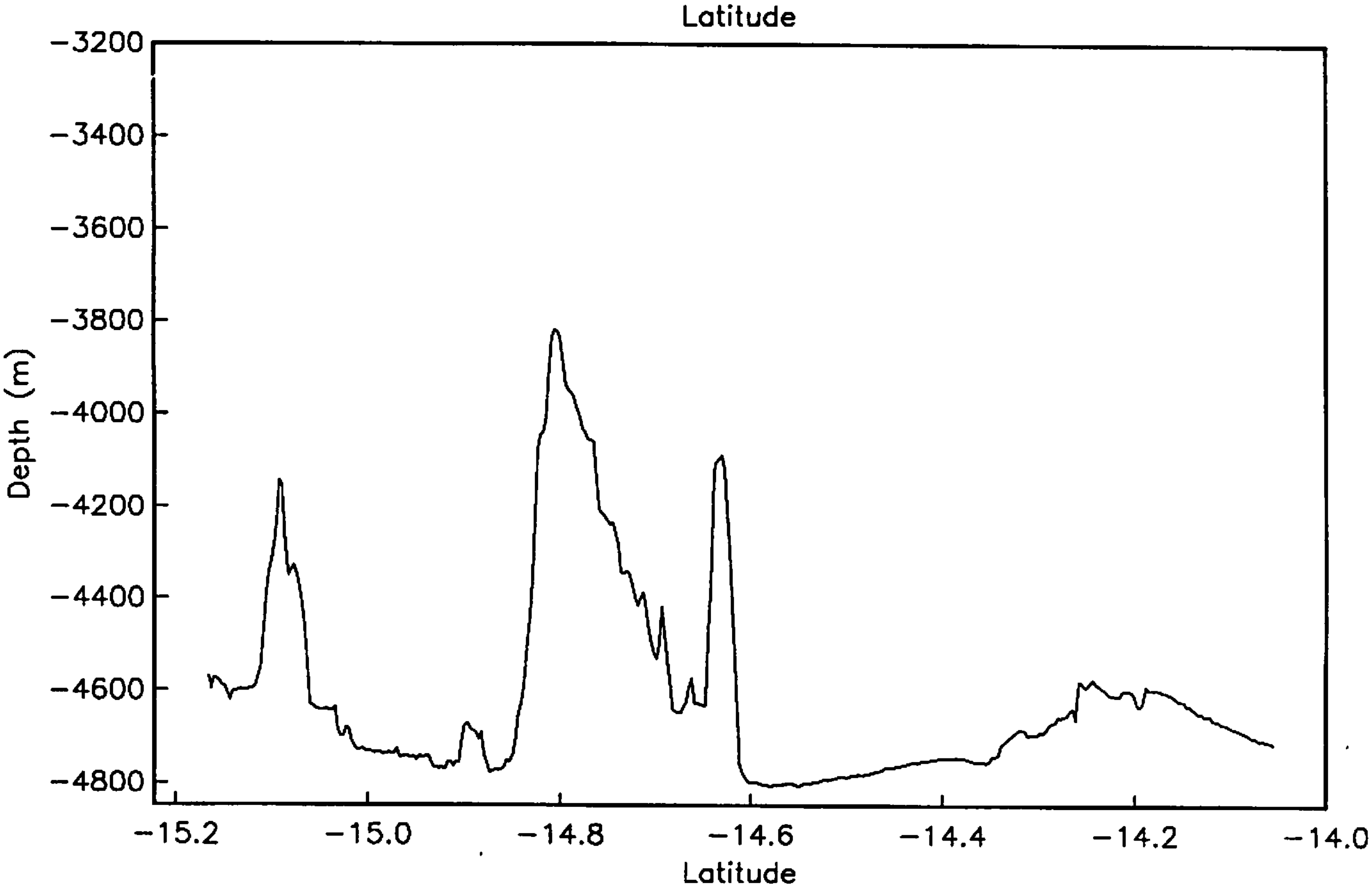
Survey Area 3, Eastern Profile
ΔFree-air Gravity (mgals)
40
20
0
−20
−40
−13.2
−12.8
−12.4
−12.0
Latitude
Depth (meters)
−3600
−3800
−4000
−4200
−4400
−4600
−4800
−5000
−5200
−5400
−13.2
−12.8
−12.4
−12.0
Latitude

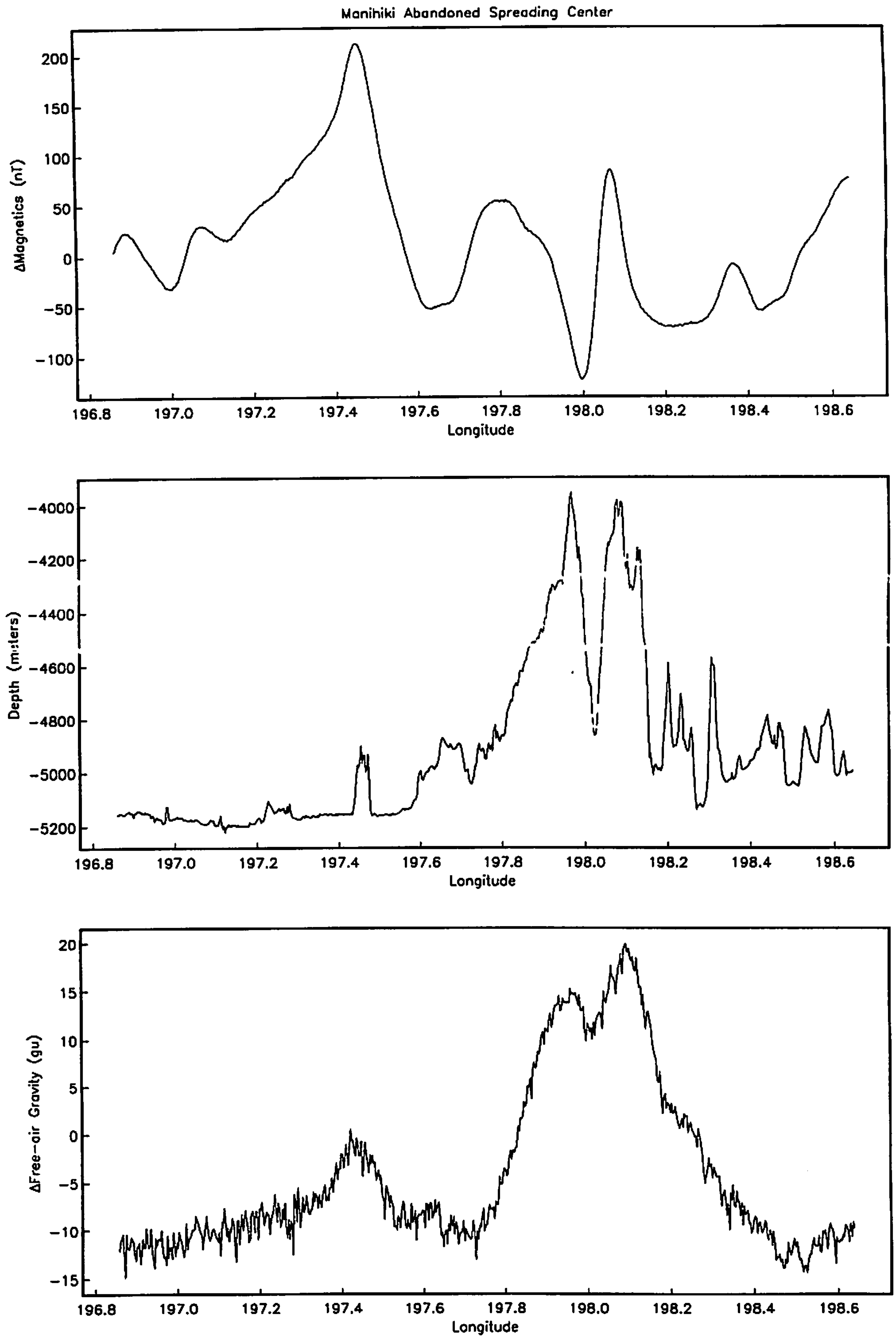

Survey Area 3, Western Profile
ΔFree-air Gravity (mgals)
40
20
0
-20
-40
-13.6
-13.2
-12.8
-12.4
-12.0
Latitude
Depth (meters)
-3600
-3800
-4000
-4200
-4400
-4600
-4800
-5000
-5200
-5400
-13.6
-13.2
-12.8
-12.4
-12.0
Latitude



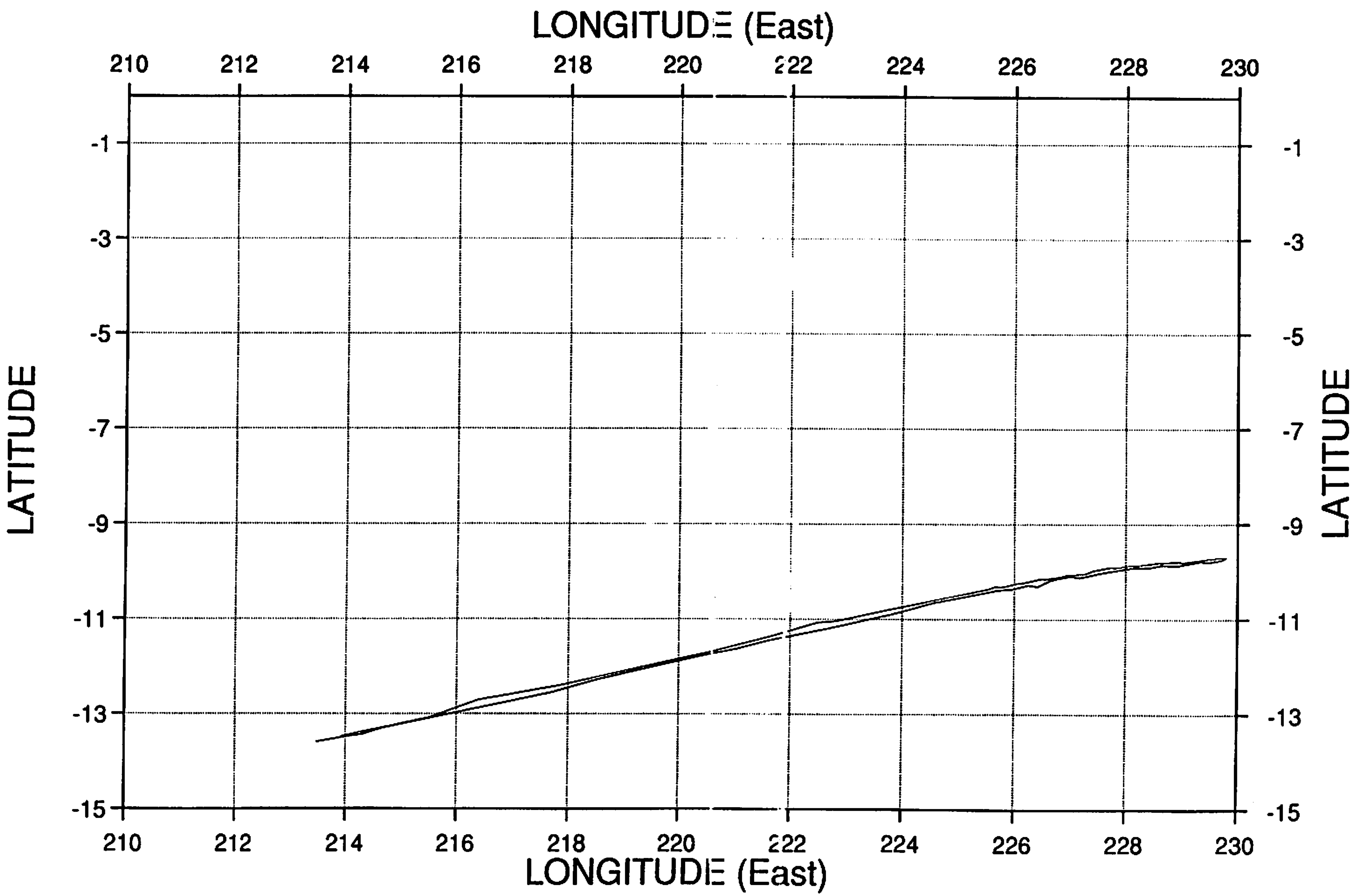
Survey Area 4, Eastern Profile
ΔFree-air Gravity (gu)
20
10
0
−10
−20
−30
−15.0
−14.8
−14.6
−14.4
−14.2
−14.0
Latitude
Depth (m)
−3200
−3400
−3600
−3800
−4000
−4200
−4400
−4600
−4800
−15.0
−14.8
−14.6
−14.4
−14.2
−14.0
Latitude


Survey Area 4, Western Profile
ΔFree-air Gravity (gu)
20
10
0
−10
−20
−30
−15.2
−15.0
−14.8
−14.6
−14.4
−14.2
Latitude

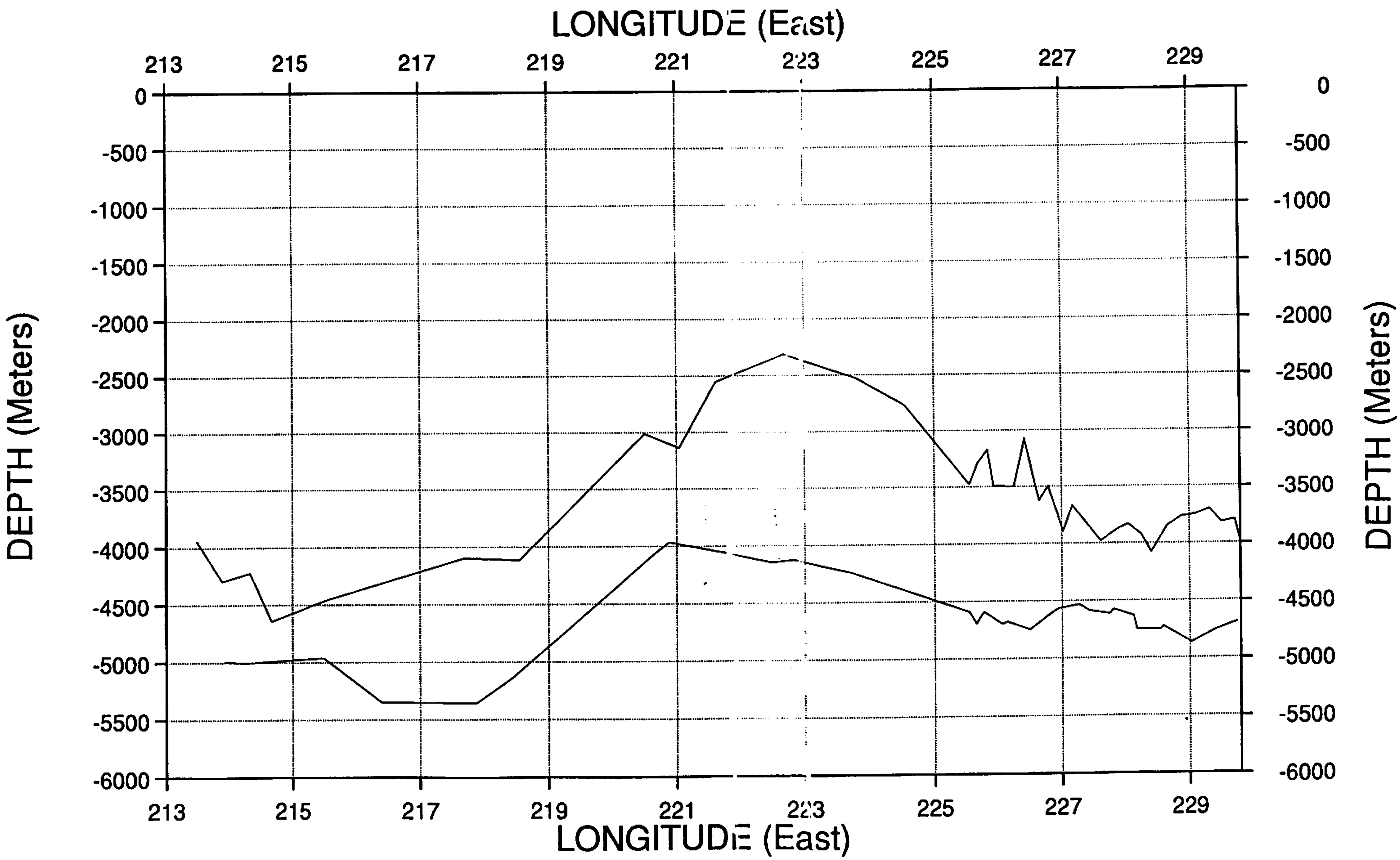

Depth (m)
−3200
−3400
−3600
−3800
−4000
−4200
−4400
−4600
−4800
−15.2
−15.0
−14.8
−14.6
−14.4
−14.2
−14.0
Latitude


Manihiki Abandoned Spreading Center
ΔMagnetics (nT)
200
150
100
50
0
−50
−100
196.8
197.0
197.2
197.4
197.6
197.8
198.0
198.2
198.4
198.6
Longitude
Depth (meters)
−4000
−4200
−4400
−4600
−4800
−5000
−5200
196.8
197.0
197.2
197.4
197.6
197.8
198.0
198.2
198.4
198.6
Longitude
ΔFree-air Gravity (gu)
20
15
10
5
0
−5
−10
−15
196.8
197.0
197.2
197.4
197.6
197.8
198.0
198.2
198.4
198.6
Longitude

MFZ NORTHERN SCARP



MFZ NORTHERN SCARP



APPENDIX 1: Bathymetry and Gravity Maps

This set of maps consists of ascii files written in the following format:
write(file,*) ((a(i,j), j=1,ny),i=1,nx)
in which i and x are longitude and j and y are latitude. Unless otherwise noted, these grids are all nx=240, ny=72, which corresponds to array dimensions of 10 degrees in longitude and 3 degrees in latitude. Array elements are equally spaced at 2.5 minutes in both latitude and longitude. Therefore, no projection has been applied to the data. This should probably be done before any geophysical analysis in order to correct for the distortion of distances on the globe.
Depths are measured negative downward from sea level. Gravity anomalies are in gravity units (=10 mgals).
The pathname for the directories containing these grids is
/pooh/home/marcia/ew9106/grids

Key:
areaname.dbdb5 - original digital depth data from dbdb5.
areaname.haxby - original digital gravity anomalies from the Seasat mission as provided by Bill Haxby.
areaname.cns - new merged grid of dbdb5 bathymetry plus Hydrosweep data from EW9106. The area2 grid also includes data from EW9103 and Crossgrain2. The Hydrosweep swath data was reduced to just three data points per swath, corresponding to averages of the three centermost beams, three outer port beams, and three outer starboard beams. The port and starboard averages were computed from the beams just inside the outer four beams on each side, since there beams were generally noisy. Along-track sampling was limited to every other ping.

Name	Dimension	Lat min	Lat max	Long min	Long max
area1.dbdb5	240 x 72	-11.	-8.	-135.	-125.
area1.haxby				225.	235.
area1.cns					
area2.dbdb5	240 x 72	-12.	-9.	-140.	-130.
area2.haxby				220.	230.
area2.cns					
area3.dbdb5	240 x 72	-14.	-11.	-150.	-140.
area3.haxby				210.	220.
area3.cns					
tua.dbdb5	240 x 72	-16.	-13.	-155.	-145.
tua.haxby				205.	215.
tua.cns					
soc.dbdb5	240 x 72	-16.5	-13.5	-160.	-150.
soc.haxby				200.	210.
soc.cns					

palm.dbdb5	240 x 72	-20.	-17.	-165.	-155.
palm.haxby				195.	205.
palm.cns					
nuie.dbdb5	240 x 72	-20.	-17.	-170.	-160.
nuie.haxby				190.	200.
nuie.cns					

The quality of the merging is highly variable. For area2, there is a significant improvement over dbdb5 and artifacts due to machine merging are minimal. (Not surprising, as three cruises worth of data have been added to dbdb5 in this case.) For most of the other areas, the merging serves little more than to show the location of the fracture zone and its general morphology. The final grid, Nuie, has not been merged since the edited Hydrosweep files were not yet available. I expect to perform this merging back at MIT and can supply the merged bathymetry grid to anyone interested in it.

Profile Data

These consist of a set of ascii files with a (long,lat,depth) triplet on each line. The long,lat convention is used to be compatible with x=long for the gridded arrays. Longitude is given in degrees east of Greenwich (not negative west longitude). This convention must be kept in mind when defining the plotting area for the contour maps if navigation data are to be superimposed.
The pathname for these files is
/pooh/home/marcia/ew9106/profiles

Key:
Julian day.nav - center beam data only
Julian day.hs - Hydrosweep data

Day	# of nav points	# of hs points
270	1436	2449
271	1439	2410
272	1440	2058
273	1425	2333
274	1438	2465
275	1440	2438
276	1439	2008
277	1440	2078
278	1438	2099
279	1434	2459
280	1310	1964
281	1422	2140
282	1421	2397
283	1438	2303

284	1421	2014
285	1412	2209
286	1400	2082
287	1402	1968
288	1413	2132
289	1421	2139
290	1433	2112
291	1435	1928

Command Files

These shade command files are used to make color shaded relief plots of pairs of grids (either merged bathymetry with gravity or merged bathymetry with dbdb5 bathymetry). To create the maps and display the results on the screen, two command files must be run. The first,

shade -m dgmaps*areaname*.shade

-or-

shade -m ddmaps*areaname*.shade

creates an image of the shaded color relief maps in memory. The "dg" files create depth and gravity images (i.e., the scales for the color bars are not in the same units) called *areaname*.maps, whereas the "dd" files creates two depth images called *areaname*.bathymaps. To then display the result on the screen and superimpose the navigation data, type

shade dgmaps*areaname*.navshade (which displays the file *areaname*.maps and superimposes track lines)

-or-

shade ddmaps*areaname*.navshade (which displays the file *areaname*.bathymaps and superimposes track lines)

The area names in the shade files are just as listed in the first table above, but with "area" removed, i.e., 1, 2, 3, tua, soc, palm, and nuie. The second command file can be easily edited to mark points other than navigation on the map (e.g., dredge sites, digitized locations of FZ, etc.) and to leave off track lines.

Unless you have changed the values in one of the grids, want to display different pairs of maps, or wish to change the contour intervals, there is no need to run the first call to shade since the standard base maps are already stored in memory as *areaname*.maps or .bathymaps.

All of the command files are in the directory /pooh/home/marcia/ew9106/grids.

The "shade" program is courtesy of David Caress at LDGO.

APPENDIX 2: RESPONSIBILITIES AND DATA DISTRIBUTION

General Theme Areas

(1) **Overall morphological description of the Marquesas Fracture Zone, -129° to -159°.**
Includes: Interpretation of Hydrosweep and seismic data to determine parameters such as the relative and absolute height of the scarp, width of the ridge, and depth of the trough as a function of longitude, age offset, age, proximity to hot spot etc. Interpretation of Hydrosweep data to determine azimuth of fracture zone as a function of longitude.
Work to be completed by **Martha Kuykendall** and **Helen Webb**. Work to be supervised by **Sarah Kruse** and **Marcia McNutt.**

(2) **Interpretation of deep structure of fracture zone from geophysical data in detailed survey areas.**
Includes: Two- and possibly three-dimensional modeling of Hydrosweep, gravity and magnetic data along long profiles using various models including those of *Sandwell* and *Haxby and Parmentier*. Development of new models to explain "excess topography" relative to predictions of models. Integration of results from all areas in terms of evolution of fracture zone thermal-mechanical behavior with time.
Work to be completed by
Kelsey Jordahl - Area 1, eastern end of expedition
Kelsey Jordahl - Area 2, eastern end of Marquesas Fracture Zone Ridge
Helen Webb - Area 3, midway between Tuamotus and Society Islands
Helen Webb - Area 4, west of Tuamotu Islands
All work to be supervised by **Sarah Kruse** and **Marcia McNutt.**

(3) **Analysis of petrological and geochemical data from fracture zone and volcano dredges.**
Includes: Determination of major element chemistry, rock type, geochemical affinity, and age. Interpretation of data in terms of interaction of hot spot volcanism with fracture zone. Refinement of models for age progression and geochemical evolution of French Polynesian hot spot chains.
Work to be completed by **Julie Dieu.** Work to be supervised by **Jim Natland.**

(4) **Analysis of geophysical data from hot spot volcanoes.**
Includes: Modeling of gravity, magnetic, and Hydrosweep data to determine density of features, mode of isostatic compensation. Integration of geophysical results with petrological/geochemical data.
Helen Webb - Marara and Eckerd seamount surveys.
Garrett Ito - Tuamotu cross-section.
All work to be supervised by **Marcia McNutt** and **Jim Natland.**

(5) **Analysis of geophysical data from East Manihiki Ridge.**

Includes: Modeling of gravity, magnetic, and Hydrosweep data across abandoned spreading center. Comparison with results from similar analyses of abandoned ridges on younger lithosphere. Integration of results with plate tectonic evolution of area.
Work to be completed by **Christina Munch**. Work to be supervised by **Sarah Kruse, Marcia McNutt and Jim Natland.**

(6) **Analysis of fracture zone and abyssal hill trends in terms of Cretaceous plate tectonics of the south Equatorial Pacific.**
Includes: Mapping seafloor fabric from abyssal hill trends. Development of models with propagating ridges, microplates, etc. consistent with overall tectonic patterns.
Work to be completed by **Jim Natland.**

Data Distribution

tar tape of geophysical data - 2 copies, 1 each for McNutt and Kruse
Hydrosweep maps - preliminary navigated and cleaned plots from Shef - McNutt
requested plots (duplicates of above plus extra navigation are gridded plots) - Kruse
seamount surveys as requested - Natland
real-time plots - Chayes
Havre Trough surveys - Caress
Raytheon seismic record - McNutt
Edo seismic record - Kruse
Seismic data tapes - McNutt
Rocks - Natland
Main lab log - McNutt
Seismic log - McNutt
Hydrosweep binary tape - McNutt

Note: We are still entitled to approximately 25 more days of Shef's time for post-cruise processing of Hydrosweep data. I would appreciate it if all cruise personnel would coordinate such requests through me so that we don't end up using up all of his time on making plots that could easily be done at MIT.