Utilization 9208

CRUISE REPORT

UNOLS 12/89

Ship Utilization Data

1. Ship Name	2. Operating Institution	3. Cruise (leg) Number
W MAURICE EWING	Lamont-Doherty Earth Observatory Palisades, N.Y. 10964	EW 92-08

4. Dates of Project:
Begin: 12-Jul-92
End: 20-Aug-92

Port Calls

Place	Date
San Juan, Puerto Rico	12-13 July 1992
Bridgetown, Barbados	19-20 August 1992

5. Number, Sea Days	6. Number, Port Days
36	4

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

89 NL (Mid Atlantic Ridge 28-30N)
NA10

8b. Research in Foreign Waters?_No_

Country:
N/A

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. Dr. Brian Tucholke, WHOI	Chief Scientist	
2. Dr. Martin Kleinrock, WHOI	Co-Cheif Scientist	
3. Dr. John Goff, WHOI	Scioentist	
4. Dr. Tom Reed, HIG	Scientist	
5. Dr. Jian Lin, WHOI	Scientist	
6. Dr. ken Stewart, WHOI	Scientist	
7. Dr. Robert Fricke, MIT	Scientist	
8. Dr. Margo Edwards, HIG	Scientist	
9. Dr. Ben Brooks, WHOI	Scientist	
10. Ute Herzfeld, SIO	Scientist	
11. Dr. Gary Jaroslaw, WHOI	Scientist	
12. Dale Chayes, L-DEO	Technician	
13. Joel Erikson, HIG	Technician	
14. Jonathan Howland, WHOI	Technician	
15. Daniel Johnson, HIG	Technician	
16. Chris Leidhold, L-DEO	Technician	
17. Peter Lemmond, WHOI	Technician	
18. Tina Mueller, HIG	Technician	
19. Martin Marra, WHOI	Technician	
20. William Robinson, L-DEO	Technician	
21. Joseph Stennett, L-DEO	Technician	
22. Mark Valenciano, HIG	Technician	

9. Primary Project(s)

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

a. "Morphological and Geophysical Investigations of Western North Atlantic Crustal Structure", Brian Tucholke, WHOI

b. US Navy (ONR) c. N00014-90-J1621 d.1-7, 9-11, 14, 17, 19 e.GG

10. Ancillary Project(s)

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

None

11. Science Party:

Scientists_11__ Grad. Students_____

Undergrads_____ Technicians_11_

Observers_____

Foreign Observers_____

12. Cost Allocation Data

a. Days Charged	b. Agency or Activity Charged	c. Grant or Contract No.
40	Navy	N00014-90-J1621

13

Michael Rawson, Marine Science Coordinator
Title, Signature, Operating Institution Official

Date: January 26, 1993

1/27/93

Date: September 8, 1992

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
	MARSCICO,	L-DGO
	Science Officer	EWING
	Captain	EWING
	File Copy	L-DGO

RESEARCH CRUISE REPORT

R/V MAURICE EWING, LEG 92-08

"Morphological and Geophysical Investigations of Western North Atlantic Crustal Structure."

Principal Investigator: Brian E. Tucholke
Co-Principle Investigators: Martin C. Kleinrock and Jian Lin

Dates: 14 July - 18 August 18, 1992

Ports: San Juan, Puerto to Bridgetown, Barbados

ph

Pat Hurban
Marine Department

R/V EWING CRUISE 9208

CRUISE REPORT

14 July - 18 August 1992

by The Shipboard Scientific Party

Brian E. Tucholke
Woods Hole Oceanographic Institution
Principal Investigator

Martin C. Kleinrock
and
Jian Lin
Woods Hole Oceanographic Institution
Co-Principal Investigators

Report Date: 18 August 1992

This report is not for citation

DATA DISTRIBUTION POLICY

Data acquired during *Ewing* Cruise 9208 are proprietary to the Principal Investigators listed on the cover page. Upon request, bathymetric and sidescan sonar data will be distributed to ARSRP-funded investigators, at cost of reproduction, for the purpose of facilitating analyses necessary to the successful conduct of the ONR Bottom/Subbottom Acoustic Reverberation Special Research Program. *Ewing* 9208 cruise data may not be published or further distributed without the written permission of the Principal Investigator.

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PURPOSE OF FIELD PROGRAM

The *Ewing* Cruise 9208 field program is sponsored by the Office of Naval Research under the auspices of the Bottom/Subbottom Acoustic Reverberation Special Research Program (ARSRP). The purpose of the ARSRP is to understand the mechanisms of seafloor reverberation at low frequencies, low angles of incidence, and over long propagation paths. To accomplish this, a series of field programs have been planned within the Acoustic Reverberation Corridor (ARC), located on the western flank of the Mid-Atlantic Ridge in the ONR Atlantic Natural Laboratory. These field programs consist of both acoustics- and geology/geophysics-oriented elements to characterize both the reverberation field and the structure of the seafloor that is responsible for the reverberation.

The initial field program was conducted during summer 1991 on the *Cory Chouest*. It consisted of long-range acoustic reconnaissance surveying using the *Chouest's* low-frequency sound source and beam-forming receiving array. This cruise provided initial data for analysis and confirmed the presence of significant and appropriate reverberation targets for further study within the ARC.

The *Ewing* Cruise 9208 field program is a reconnaissance geology and geophysics survey to establish the geological and geophysical character of the seafloor in the ARC. Of particular interest are seafloor morphology, backscatter characteristics, sediment distribution, and inferred seafloor composition. These data will be compared, in a Fall 1992 workshop, against location and character of reverberation targets to assess first-order correlations between seafloor geology and acoustic reverberation. From these comparisons and correlations, specific sites for further detailed analysis will be selected by the ARSRP investigators.

In 1993, detailed field programs will examine these specific sites. Current scheduling calls for a May 1993 cruise on *Knorr* to conduct detailed near-bottom geological/geophysical investigations with deep-towed sidescan sonar, precision bathymetric surveying tools, video and electronic still photography, and seafloor sampling. These results will be used to guide the location and conduct of subsequent acoustics experiments planned for July 1993. These acoustics experiments will include both short-range and long-range acoustic propagation; as presently schedulted these experiments will be conducted using the ships *Knorr, Cory Chouest,* and *Alliance*.

SCIENTIFIC OBJECTIVES

The fundamental geological and geophysical objectives of this cruise are to better understand the on-axis generation and the off-axis evolution of oceanic crust at a slow spreading ridge. The new off-axis Hydrosweep bathymetry, magnetics, and gravity data set collected abuts previously collected on-axis data of roughly equal type and quality, and the HMR1 sidescan data set completely covers both on-axis and off-axis regions. These data allow us to address the following major scientific issues:

1. The nature, origin, and relative importance of temporal and spatial scales/patterns of episodicity of crustal accretion and tectonism. In particular, the nature of the interplay between faulting and magmatism.
2. The composition, structure, and character of seafloor as a function of position within a ribbon of crust created at a spreading segment on the Mid-Atlantic Ridge axis. In particular, the differences between inside corners and outside corners, and the origin of these differences.
3. The variation in composition, structure, and character of seafloor from one spreading segment to another.
4. The growth, migration, and demise of ridge segments and their offsets. The structure of seafloor within and near offsets and its relation to offset size, plate motion changes, and the balance between magmatic and amagmatic spreading.
5. The origin, fundamental scales, and characteristics of seafloor roughness and structure and their predictability across scales.
6. The relations between structural patterns preserved in oceanic crust and the fine-scale (ca. 1-10 m.y.) history of changes in plate motion.
7. The nature of, controls on, and relative importance of various processes of ocean-crustal aging. In particular, the modifications to seafloor morphology made by sedimentation, mass wasting, off-axis volcanism, serpentinite diapirism, and off-axis faulting.

CRUISE PARTICIPANTS

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OPERATIONS TEAMS

For purposes of data acquisition and processing, the shipboard scientific and technical staff was divided into the following teams, with some individuals having overlapping responsibilities.

Scientific Operations
Brian Tucholke, Chief Scientist
Martin Kleinrock, Co-Chief Scientist

Hydrosweep Acquisition and Processing
Peter Lemmond, Team Leader
Dale Chayes, Raw backscatter acquisition
John Goff, Ping editing
Ute Herzfeld, Data editing
Tom Reed, Sound-velocity and roll corrections

Hawaii MR1 Operations
Margo Edwards, Party Chief
Joel Erickson, Engineer
Dan Johnson, Data Processor
Tina Mueller, Data Processor
Mark Valenciano, Technician

Sonar Processing and Display
Kenneth Stewart, Team Leader
Robert Fricke, Sonar analysis and processing
Martin Marra, Sonar image processing
Tom Reed, Image and display support

Geophysical Data Base
Jonathan Howland, Team Leader, ARC/INFO GIS
Ben Brooks, Echo character and sediment thickness
Gary Jaroslow, Echo character and sediment thickness
Jian Lin, Gravity and magnetics

Geophysical Data Acquisition

Joe Stennett, Science Officer

William Robinson, Standard data logging and processing: navigation, gravity, and magnetics

Dale Chayes, Hydrosweep electronics technician

Chris Leidhold, Electronics technician

SCIENTIFIC WATCHSTANDING

Scientific watchstanding in the Main Lab was in 4-hr.-on, 8-hr.-off shifts, with three scientists/technicians per watch. Watchstander responsibilities included the following:

1) Monitor Hydrosweep performance in CRT displays and real-time Calcomp plot, make appropriate adjustments, notify technician of any data acquisition problems.
2) Monitor HMR1 performance in CRT, LCD, and hardcopy displays, maintain logbook, make appropriate adjustments, notify HMR1 technician of any data acquisition problems.
3) Monitor LDGO Data Logger system, notify technician of any data acquisition problems.
4) Monitor and annotate hardcopy displays of single-channel seismic (SCS) reflection, 3.5-kHz echosounding (ES), and magnetic field intensity; notify technician of any data acquisition problems.
5) Read echo character and sediment thickness from ES and SCS records at 2-minute intervals, and enter data in digital database.
6) Monitor and replace every 2 hours DAT tapes recording 3.5-kHz ES data.

Scientific watches began at 0800 hrs (local) on 19 July and continued to 0200 hrs on 15 August. Scientific watchstanders were as follows:

0000-0400 and 1200-1600: John Goff, Gary Jaroslow, and Tom Reed

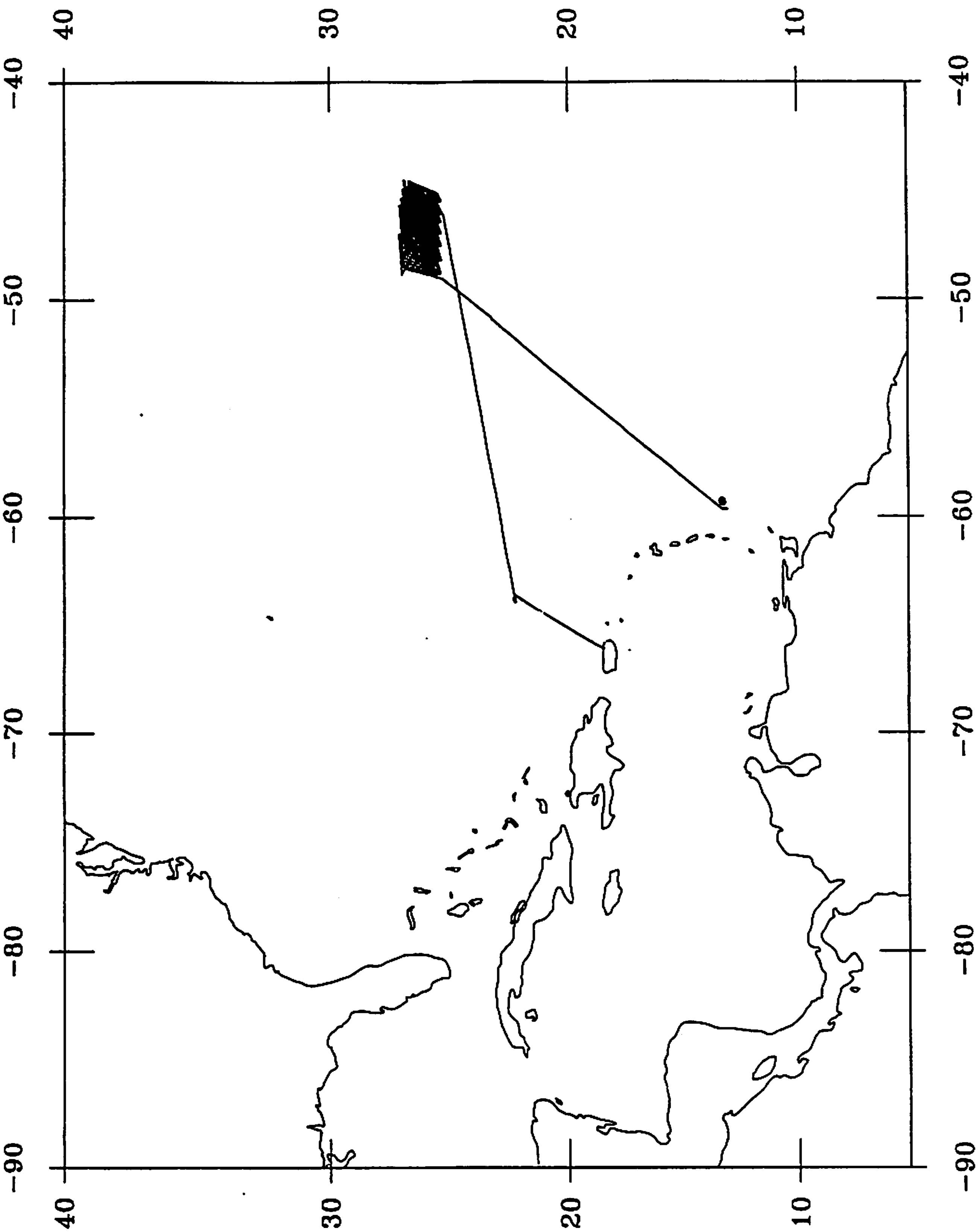
0400-0800 and 1600-2000: Ute Herzfeld, Chris Leidhold, and Martin Marra

0800-1200 and 2000-2400: Ben Brooks, Robert Fricke, and Jian Lin.

Watch times given are local time, GMT+3.

CRUISE NARRATIVE

Ewing Cruise 9208 departed San Juan, Puerto Rico shortly after 1200 hrs. on 14 July 1992. The ship steamed to Waypoint 1 over the flat seafloor of the southeastern Nares Abyssal Plain (Figure 1). We launched the Hawaii MR1 sidescan sonar without incident at that location



EW9208 Puerto Rico-Barbados July 14 - August 18 1992

Figure 1

on the afternoon of 15 July and conducted a small box survey (about 15 x 20 kilometers). This survey served three purposes: 1) to obtain "flat-bottom tables" for the calculation of water depths from the HMR1 phase data to be obtained in our subsequent survey, 2) to test the operation of the HMR1, and 3) to test the Hydrosweep multibeam bathymetric system for cross-swath bias in roll. Following retrieval of the HMR1, we steamed to Waypoint 2, near the southeastern corner of the ARSRP Acoustic Reverberation Corridor, to begin our primary survey. The HMR1 was launched near Waypoint 2 beginning about 2130 hrs. on 19 July 1992 (Julian Day 201), following which we began our survey of the ARC.

Survey line numbers and survey waypoints are summarized in an accompanying table. In most cases waypoints were at corners in the survey grid, and they consequently were not crossed by the cruise track. Ninety-degree turns typically began 1.7 km before the waypoint; starts of turns were advanced or retarded for higher- or lower-angle turns, respectively. All turns made while towing the HMR1 were at 10°/minute.

Survey lines were laid out in a WSW to ENE orientation so as to insonify the dominant topographic grain (i.e., abyssal hills paralleling the Mid-Atlantic Ridge axis) at angles ranging between about 15° and 35° (Figure 2). This orientation also permitted acquisition of interpretable magnetic anomaly profiles that are subparallel to plate flow lines. Line spacing varied both latitudinally and longitudinally throughout the survey. The spacing was adjusted so as to optimize Hydrosweep bathymetric coverage over both shallow and deep seafloor areas while minimizing overlap in the bathymetric swaths. At the shallower-water, eastern margin of the survey area, line spacing ranged between 4 and 6 kilometers, and at the deeper-water, western margin of the survey area, the line spacing varied from 8 to 9 kilometers. The HMR1 system routinely recorded sidescan sonar data to 10 km on either side of the ship track (20 km total swath); thus the entire survey area has a minimum of 200% sidescan sonar coverage, with coverage ranging up to 500% in some areas. This coverage allows construction of two separate sidescan mosaics, each with a single look direction (one looking north and west, one looking south and east). To our knowledge, this is the first survey ever to obtain such coverage over a large seafloor area.

There were three kinds of deviations from the standard grid survey pattern shown in Figure 2. First was a box survey (Lines 36 to 43, near 46°20'W) that was run around "Sites A and B"; these are two locations selected by the ARSRP acoustics community as having potential high priority for futher detailed and long-range acoustics experiments to be conducted in 1993. In this area we obtained >100% Hydrosweep coverage of the seafloor and sidescan sonar coverage in four separate look directions (generally E, W, N, S).

The second deviation was a pair of tracks run *along* the rift valley of the Mid-Atlantic Ridge at the eastern edge of the ARC survey (Lines 47 to 55). With these tracks included, the

EWING 9208 WAYPOINTS AND LINE NUMBERS

WAYPOINT	LATITUDE	LONGITUDE	START OF LINE NO.	END OF LINE NO.
Port	San Juan, Puerto Rico			
1	22 21.900N	63 35.000W		
2	25 21.200N	46 06.300W	1	
3	25 45.600N	45 10.000W	2	1
4	25 55.000N	45 10.000W	3	2
5	25 29.800N	46 26.100W	4	3
6	25 25.800N	46 24.800W	5	4
7	25 49.100N	45 21.000W	6	5
8	25 47.100N	45 21.000W	7	6
9	25 29.800N	46 03.000W	8	7
10	25 26.900N	46 01.500W	9	8
11	25 47.000N	45 15.400W	10	9
12	25 55.200N	45 15.400W	11	10
13	25 25.500N	46 57.400W	12	11
14	25 29.700N	46 58.800W	13	12
15	25 58.400N	45 12.400W		
16	25 59.100N	45 10.000W	14	13
17	26 02.500N	45 10.000W	15	14
18	25 25.400N	47 32.100W	16	15
19	25 29.800N	47 33.300W	17	16
20	26 07.900N	45 02.000W	18	17
21	26 11.400N	45 02.000W	19	18
22	25 25.200N	48 11.800W	20	21
23	25 29.900N	48 13.100W	21	20
24	26 15.500N	44 58.500W	22	21
25	26 18.900N	44 58.500W	23	22
26	25 26.900N	48 49.100W	24	23
27	25 31.900N	48 50.500W	25	24
28	26 23.100N	44 54.700W	26	25
29	26 26.600N	44 54.700W	27	26
30	26 12.100N	46 04.200W		
31	26 11.500N	46 07.000W		
32	26 09.800N	46 08.000W		
33	26 05.400N	46 28.900W		
34	26 06.400N	46 30.800W		
35	25 35.900N	48 57.800W	28	27
36	25 40.300N	48 58.800W	29	28
37	26 30.000N	44 51.500W	30	29
38	26 32.800N	44 51.500W	31	30
39	25 45.900N	48 53.600W	32	31
40	25 50.400N	48 54.800W	33	32
41	26 36.100N	44 48.500W	34	33
42	26 38.700N	44 48.500W	35	34
43	26 21.500N	46 25.500W	36	35
44	26 05.000N	46 25.000W	37	36
45	26 06.100N	46 18.900W	38	37
46	26 22.600N	46 19.500W	39	38
47	26 20.400N	46 31.600W	40	39

EWING 9208 WAYPOINTS AND LINE NUMBERS (CONT'D.)

WAYPOINT	LATITUDE	LONGITUDE	START OF LINE NO.	END OF LINE NO.
48	26 07.400N	46 31.100W	41	40
49	26 11.800N	46 08.600W	42	41
50	26 07.200N	46 13.200W	43	42
51	26 23.500N	46 13.800W	44	43
52	25 55.600N	48 51.300W	45	44
53	26 00.200N	48 52.300W	46	45
54	26 43.000N	44 40.000W	47	46
55	25 57.100N	45 02.600W	48	47
56	25 54.800N	45 11.600W	49	48
57	26 00.200N	45 11.600W	50	49
58	26 03.200N	44 59.500W	51	50
59	25 39.300N	45 11.100W	52	51
60	25 30.900N	45 30.900W	53	52
61	25 26.000N	45 28.400W	54	53
62	25 35.800N	45 06.200W	55	54
63	26 47.300N	44 31.500W	56	55
64	26 05.800N	48 47.700W	57	56
65	26 10.500N	48 48.300W	58	57
66	26 48.041N	44 46.700W	59	58
67	26 50.900N	44 47.200W	60	59
68	26 15.900N	48 44.800W	61	60
69	26 20.500N	48 45.700W	62	61
70	26 56.100N	44 31.700W	63	62
71	26 59.000N	44 32.100W	64	63
72	26 25.800N	48 40.900W	65	64
73	26 30.400N	48 41.700W	66	65
74	26 59.000N	44 55.000W	67	66
75	27 02.000N	44 55.600W	68	67
76	26 35.800N	48 37.300W	69	68
77	26 40.300N	48 38.100W	70	69
78	27 02.200N	45 20.000W	71	70
79	27 05.200N	45 20.300W	72	71
80	26 45.500N	48 33.800W	73	72
81	26 50.000N	48 34.300W	74	73
82	27 06.500N	45 39.800W	75	74
83	27 09.900N	45 40.000W	76	75
84	26 55.000N	48 30.200W	77	76
85	26 59.300N	48 30.700W	78	77
86	27 06.700N	47 00.000W	79	78
87	27 10.600N	47 00.400W	80	79
88	27 01.880N	48 49.580W	81	80
89	26 55.100N	48 35.100W	82	81
90	25 24.700N	49 01.900W		82
Port	Barbados			
	13 10.000N	59 20.000W		

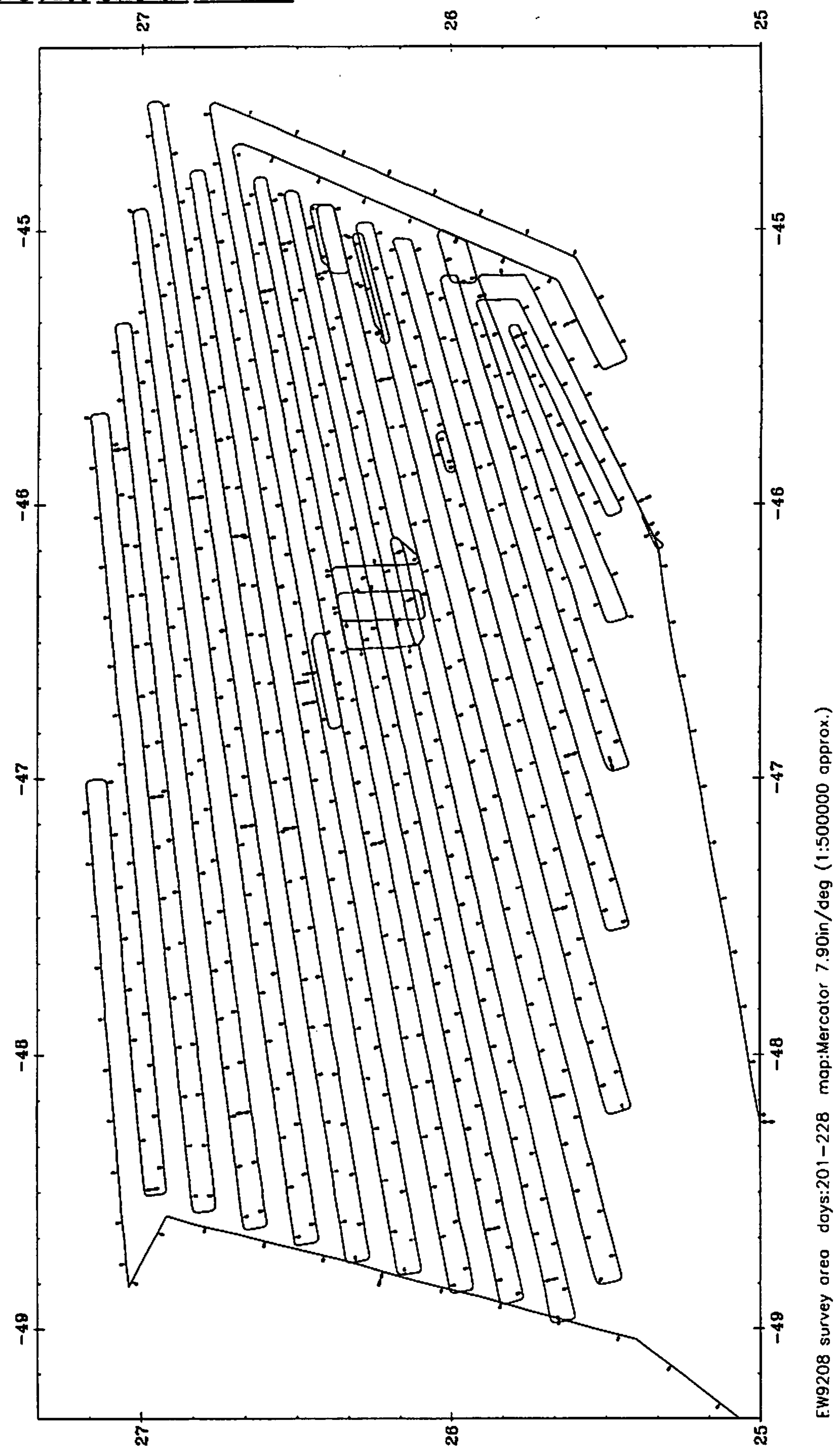

27
26
25
-45
-46
-47
-48
-49
EW9208 survey area days:201-228 map:Mercator 7.90in/deg (1:500000 approx.)

Figure 2

survey gives complete sidescan sonar coverage (in two directions) of the seafloor extending from the present spreading axis out to ca. 30 m.y.-old crust.

The third deviation consists of instances where part of a survey track was repeated so as to fill in a gap in swath bathymetry where the Hydrosweep system had temporarily failed to operate. These deviations occurred about one-third of the way into Line 19; at the beginning of Line 23; at the end of Line 25, through Line 26, and at the beginning of Line 27; and about halfway through Line 46. The extra, off-line tracks required to accomplish these repeats are given letter suffixes and include Lines 19A, 23A, 23B, 27A, and 46A.

On 1 August, thirteen days after launch, the HMR1 tow vehicle was retrieved as far as the depressor weight, and electrical and mechanical connections were checked and found to be sound. A new zinc corrosion protector was attached to the connector above the depressor weight, and the system was redeployed within about 1.5 hours.

The HMR1 survey was completed at the northwestern corner of the ARC. At the end of the survey we towed the HMR1 with ping disabled to record tow noise of the system; about 45 minutes of tow noise was recorded with watergun, 3.5 kHz profiler, and Hydrosweep operating, and about 45 minute was recorded with these systems disabled. The geophysical gear and HMR1 were then pulled beginning at 1445 Local on 14 August, with all gear aboard at 1600. We then redeployed the magnetometer and began a track to obtain Hydrosweep, 3.5-kHz, and magnetics data down the western edge of the survey area before beginning our transit to port in Barbados. This line was run at about 11.5 kts, too high a speed to obtain either seismic reflection or HMR1 data. Scientific watches were discontinued at the southwest corner of the survey area early on the morning of 15 August. Transit time to Barbados was occupied by intensive data processing efforts.

WINDS AND SEAS

Weather during the cruise was remarkably constant. Winds ranged from about 10 to 22 knots from the NE to the SE and averaged 15 knots from the east. Seas were 1 to 2 meters from the ENE to the ESE and averaged 1.6 meters from the east (Beaufort Scale 3 to 5). *Ewing* rode the seas very smoothly on downwind (westerly) tracks but pitched significantly, often strongly, on easterly tracks.

TIME, DATE, AND RECORD KEEPING

All records and logs kept on *Ewing* Cruise 9208 were recorded in GMT (Zulu), which was three hours ahead of local, ship time during the survey. Date annotation was in either Calendar Day or Julian Day. The table below gives the calendar days and corresponding Julian days for the cruise.

CD	JD	CD	JD	CD	JD
14 July (T)	196	26 July (S)	208	7 August (F)	220
15 July (W)	197	27 July (M)	209	8 August (S)	221
16 July (T)	198	28 July (T)	210	9 August (S)	222
17 July (F)	199	29 July (W)	211	10 August (M)	223
18 July (S)	200	30 July (T)	212	11 August (T)	224
19 July (S)	201	31 July (F)	213	12 August (W)	225
20 July (M)	202	1 August (S)	214	13 August (T)	226
21 July (T)	203	2 August (S)	215	14 August (F)	227
22 July(W)	204	3 August (M)	216	15 August (S)	228
23 July (T)	205	4 August (T)	217	16 August (S)	229
24 July (F)	206	5 August (W)	218	17 August (M)	230
25 July (S)	207	6 August (T)	219	18 August (T)	231

Hard copy paper logs were kept for the following:

-LDGO Main Lab Log (Original to Chief Scientist, yellow copy to LDGO)
-HMR1 Log (Original to U. Hawaii, copy to Chief Scientist)
-R/V *Ewing* Hydrosweep Log (Original to LDGO, copy to Chief Scientist)
-VAX/Hydrosweep Watchstanding Log (Original to Chief Scientist)
-3.5 kHz Acoustic Character Log (Original to Chief Scientist)
-3.5. kHz DAT Tape Log (Original to Tom Jordan)
-Seismic Recording Log (Original to LDGO, copy to Chief Scientist)

DATA ACQUISITION: SYSTEMS, PERFORMANCE, AND PROCESSING

Positioning of sensors

The sonars and other sensing instruments used on *Ewing* were not located directly under the GPS antenna. The displacement of each of the sensors with respect to the GPS antenna is as follows:

-Common seafloor midpoint between watergun and center of seismic streamer	174 m aft
-Magnetometer	234 m aft
-HMR1	363 m aft
-3.5 kHz	1 m aft
-Hydrosweep	14 m forward
-Gravimeter	1 m aft

(Note: MR1 data files have been corrected to account for these offsets; others have not.)

Ewing data logging system

The main logging system is built around a MASSCOMP 5550 computer running the MASSCOMP operating system RTU (Real Time UNIX). From this computer RS-232C serial lines go to the serial port of each of the intruments logged (e.g. GPS receiver, gravity meter). Each type of instrument has its own separate and slightly specialized logging program. In general, each data record ouput by the instrument through its serial port is captured, time stamped with the CPU's current time, and appended to the current daily file for the instrument. The GPS clock is also logged for comparison with the CPU clock. The CPU time tags are later adjusted for offset and drift relative to the GPS clock. These adjusted times are used for data from the Furuno speed log, BGM-3 gravimeter, KSS-30 gravimeter, magnetometer, and Hydrosweep bathymetry. For GPS and Transit data the time of position comes from the time established by the receiver for the position. When a logging process receives a new record from an instrument it also passes it to another process that in turn "broadcasts" the data on the real-time network. This allows other computers on the real-time network to receive the new data and do such things as draw real-time plots. The MASSCOMP computer logs all data directly except for the Hydrosweep swath data. The Hydrosweep has a Silicon Graphics (SGI) Personal Iris workstation as its direct logging computer. The SGI workstation sends the Hydrosweep navigation collected from the network broadcast, reads the Hydrosweep's output data, and broadcasts these data on the network. The MASSCOMP computer logs these Hydrosweep data broadcasts as a backup.

Daily data reduction generally started shortly after GMT midnight, and post-processed navigation, gravity free-air anomaly, magnetic anomaly and center-beam bathymetry were available within 5-6 hours. Data reduction was carried out on a SUN Microsystems SPARCstation.

Performance of the *Ewing's* data logging system was excellent. One brief system crash halfway through the survey resulted in about an hour of data lost. We circled and retraced the track so that no gap was produced in the survey data.

The sections below list the instruments and steps in the data logging and reduction sequence for all instruments used during cruise *Ewing* 9208. Asterisks (*) indicate data logged on the *Ewing* data logging system.

Time*

Instrument: Kinemetrics GPS Synchronized clock, Model GPS-DC

Logging: 60 second intervals

Speed and Heading*

Instrument: Furuno CI-30 2-axis doppler speed log

Logging: 3 second intervals

Checking: Visual check of plot of data

Smoothing: Mean value of all good values within the same minute

Transit Satellite Fixes*

Instrument: Magnavox MX-1107RS dual frequency Transit satellite receiver

Logging: All fixes from two receivers: Transit #1 (lab) and Transit #2 (bridge)

Notes: The fixes from the Transit system are logged in case there is a significant gap in GPS coverage. Transit fixes were not needed to produce final shipboard navigation for this cruise.

GPS Satellite Fixes*

Primary navigation was from Magnavox T-Set Global Positioning System (GPS) receivers. GPS navigation from these receivers was used in the *Ewing's* Way Watch program to steer the ship. Good GPS navigation generally was obtained for more than 23 hours per day.

Dead reckoning based on Furuno speed and heading data was used to cover any small gaps in the GPS navigation.

Instrument: Magnavox T-Set Global Positioning System 5-channel receivers
Logging: T-Set #1 at 2 second intervals, T-Set #2 at 20 second intervals.
Note: T-Set #1 is logged at 2 second intervals to provide real-time positioning for the Hydrosweep; these GPS data are decimated to 20 second intervals before use in the reduction.
Checking:

-minimum number of sats: 3
-dilution of precision (DOP) maximum: north = 4.0, east = 4.0
-carrier signal-noise ratio minimum: 35.0
-compare GPS speed and course with Furuno smooth speed and heading
-compare positions with Transit-Furuno navigation
-reject fixes producing Eotvos correction errors in gravity

Interpolation: Interpolated positions at 00, 30 seconds of each minute
Smoothing: Smoothed interpolated positions with 41 point running average
Notes: The GPS data has a sinusoidal-like wave in it which is assumed to come from DoD degradation of GPS quality for civilian users. This wave seems to vary in period and shape and is not a perfect sine curve. The periods are less than 20 minutes. The amplitudes and period vary over 24 hours but they always seem to be present in the data. This degradation produces a false ship's track for real-time navigation and introduces extreme errors, up to 10 mGals, in the Eotvos correction for the gravity. To handle this problem the following steps have been used to process the GPS:

1. the smoothing has been increased from a 9 point (4 minute) running average of the interpolated positions to a 41 point (20 minute) running average.
2. this smooth GPS data is deleted at turns because the heavy smoothing greatly "widens" the turns.
3. the remaining smooth GPS data is decimated to 20 minute intervals.

These GPS processing steps, together with using the smooth speed and heading data from the Furuno for dead reckoning between the decimated GPS positions, produces good navigation and gravity data.

Differential GPS Satellite Fixes

GPS Satellite data were also recorded both on the ship and simultaneously at a base station at Woods Hole Oceanographic Institution using Ashtech M-XII single frequency C/A receivers and 386 PCs. This was done for the purpose of computing long-baseline Differential GPS (DGPS) navigation with a manufacturer-quoted accuracy of ca. ten meters or less. A preliminary computation performed on test data transmitted from shore to ship indicates that the final processed shipboard navigation falls within a few tens of meters of the DGPS navigation. Further analyses, with precisely known position of the GPS antenna at WHOI, will be required to fully evaluate navigational accuracy.

Navigation*

A "1 minute navigation" was produced from the shipboard GPS and Furuno sources. The smoothed speed and heading data are used to fill the gaps between the processed GPS positions by computing 1 minute dead reckoned positions corrected for set and drift. The dead reckoned positions are produced at 00 seconds of each minute.

Center-Beam Bathymetry* (see Figure 3)

Instrument: Atlas Hydrosweep DS

Logging: Every ping

Checking: Visual check of plot of data. Bad data points removed with an interactive graphics editor.

Final data: Interpolated depth value (meters) at 00 seconds of each minute.

Notes: These readings are the center beam of the swaths during the actual survey.

Magnetics* (see Figure 4)

The magnetic field was recorded using a Varian 75 magnetometer system with the bottle towed 234 meters behind the GPS antenna on the ship. Digital recording was provided by the LDGO data logging system, and a paper strip chart record was also obtained.

Aside from some noise during the initial startup, the magnetometer performed well throught the cruise.

Instrument: Varian V75 magnetometer

Logging: 6 second intervals

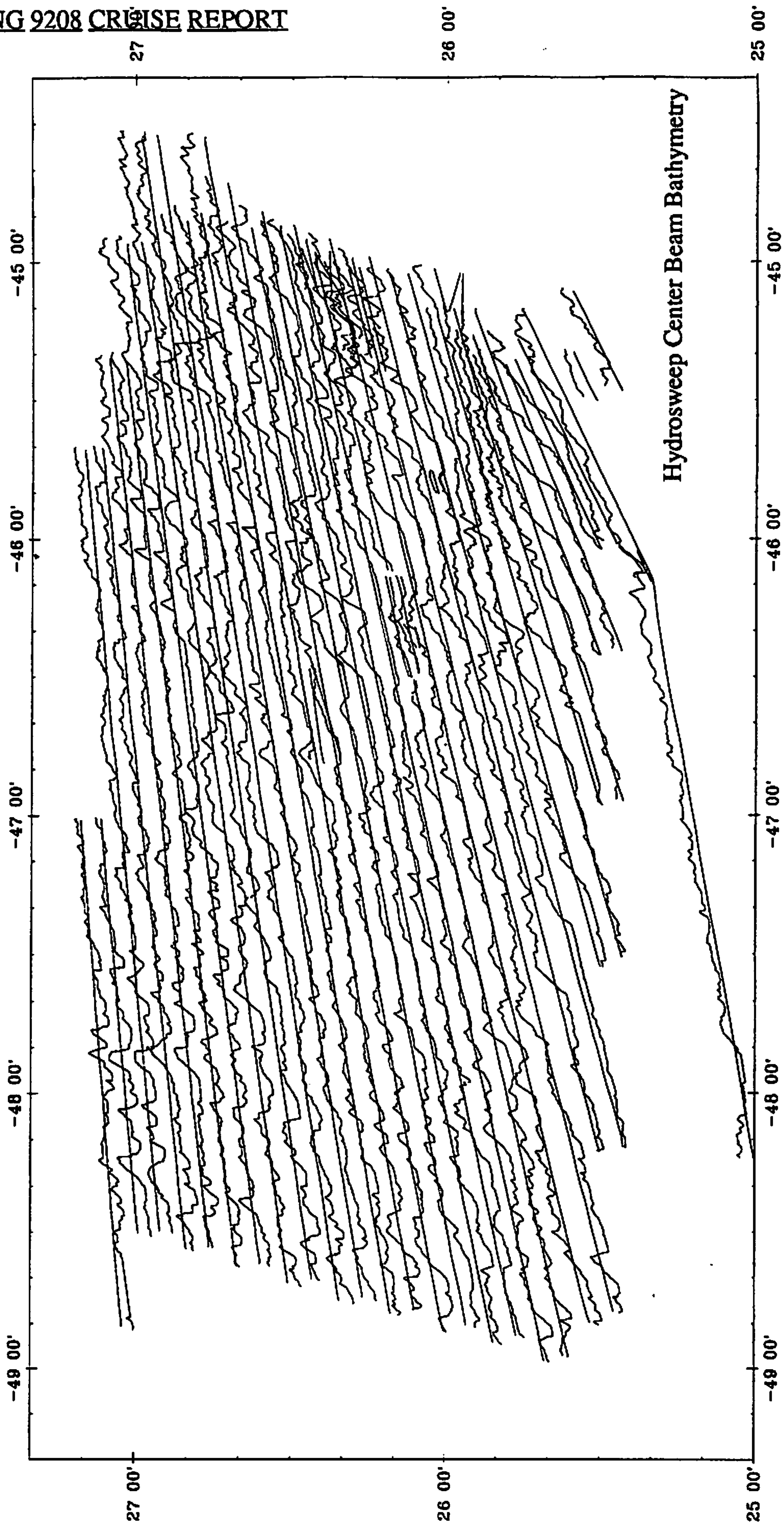

Hydrosweep Center Beam Bathymetry
-45 00'
-46 00'
-47 00'
-48 00'
-49 00'
27 00'
26 00'
25 00'
27

Figure 3

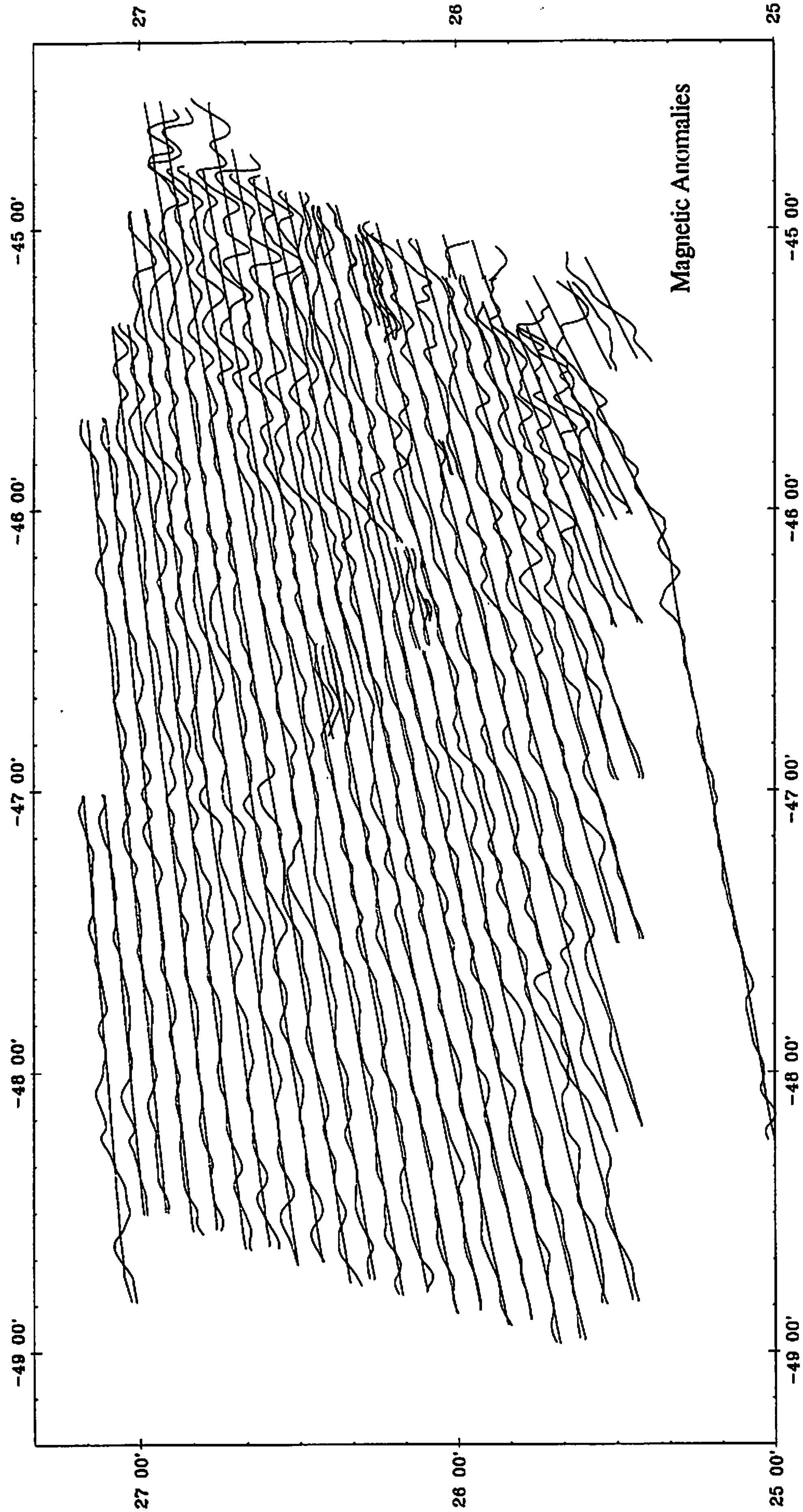

Magnetic Anomalies
27
26 00'
25 00'
-45 00'
-46 00'
-47 00'
-48 00'
-49 00'
27 00'
26 00'
25 00'

Figure 4

Checking: Visual check of plot of data. Bad data points removed with an interactive graphics editor.

Reference field: International Geomagnetic Reference Field 1990 (IGRF 1990) model of the main field at 1990.0 and a predictive model of the secular variation for adjusting to dates between 1990.0 and 1995.0

Final data: Median values at 00 seconds of each minute calculated from the values +-30 seconds of this time.

Gravity* (see Figure 5)

The gravity field was recorded on two gravimeters, one a BGM-3 and the other a KSS-30. Performance of both the KSS-30 and BGM-3 gravimeters was excellent and trouble-free. KSS-30 data were of slightly better quality and were used as the primary gravity data set.

Instrument No. 1: Bodenseewerks KSS-30 Marine Gravity meter

Logging: mGal values at 6 second intervals

Smoothing: Mean values at 00 seconds of each minute calculated from the logged values +-30 seconds of this time. This stage also adjusts the times of the logged values for a 75 second delay due to the filtering of the gravity by the KSS-30.

Merge with navigation: Calculate Eotvos correction and Free Air Anomaly. The velocities (from the navigation) that are used in the Eotvos correction are smoothed with a 5 point running average for all days.

Checking: Visual check of plot of data to determine satisfactory Eotvos corrections; delete spikes of data at turns.

DC shift: -980169.32 mGal

Final data provided by LDGO: Free Air Anomaly value at 00 seconds of each minute. 1980 theoretical gravity formula.

Instrument No. 2: Bell Aerospace BGM-3 marine gravity meter

Logging: 1 second counts

Filtering: An observed gravity value in mGal is calculated by filtering the 1 second counts with a 360 second Gaussian filter, scaling the result, and adding a bias. A value in mGal is calculated for 00 seconds of each minute.

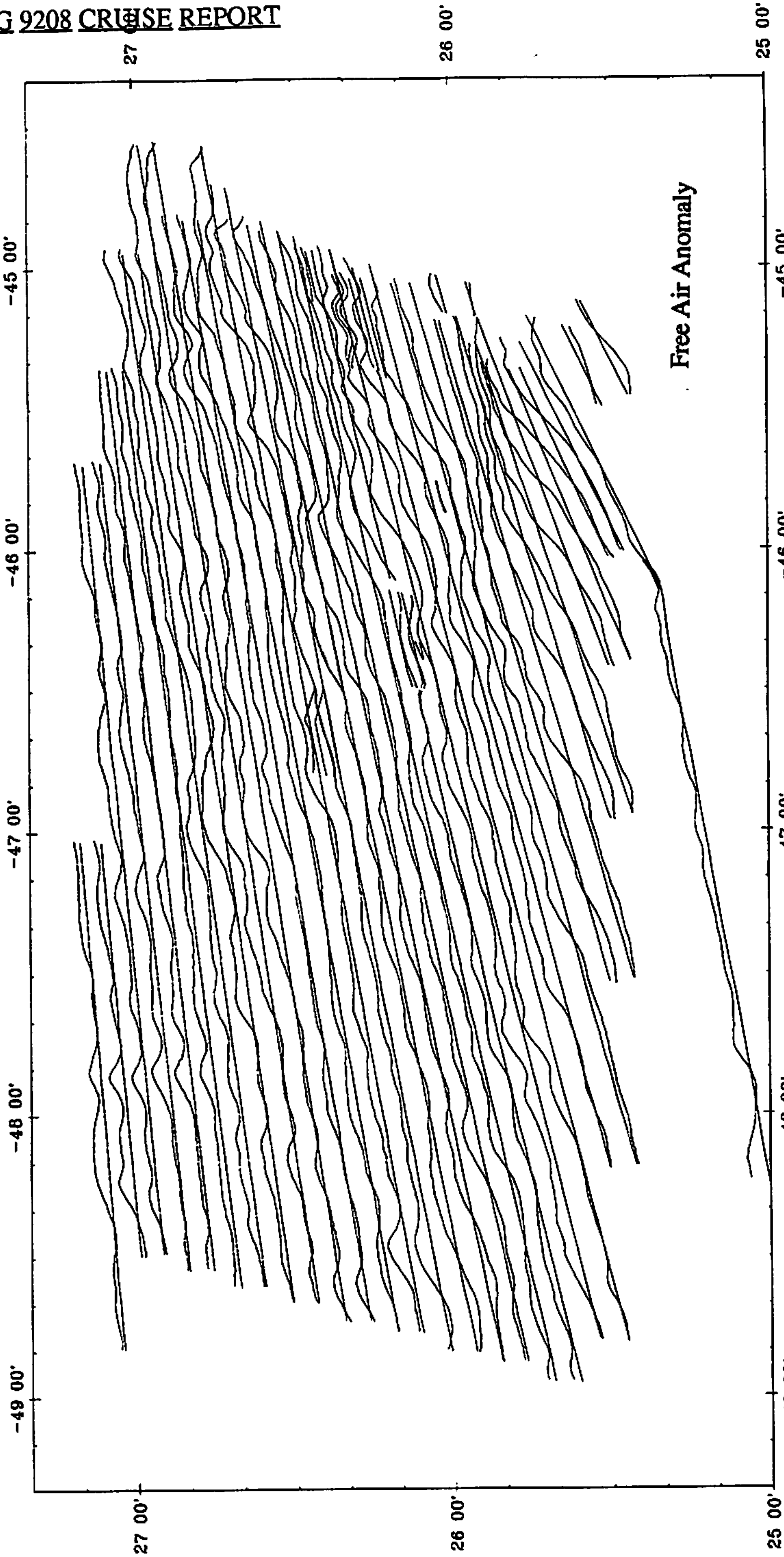

Free Air Anomaly
27
26 00'
25 00'
-45 00'
-46 00'
-47 00'
-48 00'
-49 00'
27 00'
26 00'
25 00'

Figure 5

Merge with navigation: Calculate Eotvos correction and Free Air Anomaly. The velocities, from the navigation, used in the Eotvos correction are smoothed with a 5 point running average for all days.

Checking: Visual check of plot of data to determine satisfactory Eotvos corrections, delete spikes of data at turns.

DC shift: -7.7 mGal

Final data provided by LDGO: Free Air Anomaly value at 00 seconds of each minute. 1980 theoretical gravity formula.

The first calibration of the ship gravitometers was made on 9 July, 1992 by LDGO Science Officer Joe Stennett in San Juan, Puerto Rico. A second gravity tie will be carried out by Joe Stennett in Barbados on 18 August, 1992. It is expected that the total drift of the KSS-30 and BGM-3 gravitometers will be less than 0.5 mgal for the entire 35-day cruise.

The gravity base stations in San Juan, Puerto Rico and Barbados were not corrected for the 13.6 mgal "Potsdam Error". We therefore use the 1980 international formula in calculating the free-air anomaly, because this formula has a built-in correction for the Potsdam error.

Free-Air Anomaly (Figure 5)

The raw gravity data were reduced to free-air anomaly (FAA) by Bill Robinson using the LDGO software "m_grv.c". This Eotvos reduction process corrects for artificial gravity effects due to changes in ship course and speed:

eotvos_corr = 7.5038*vel_east*cos(lat) + 0.004154*vel*vel

where vel is ship speed in knots and vel_east is eastward velocity. These velocities were derived from a smoothed GPS and Furuno navigation using software developed by Bill Robinson. Preliminary examinations revealed that the RMS cross-over error for the 70 cross-over points of ship tracks is less than 1 mgal.

The FAA was also corrected for a regional field based on a 1980 theoretical gravity formula:

$$gtheo = 978032.7*[1.0+0.0053024*\sin^2(lat)-0.0000058*\sin^2(2*lat)]$$

We note that the "m_grv.c" software also contains an option for the 1967 formula:

gtheo = 978031.846*[1.0+0.005278895*sin^2(lat)-0.000023462*sin^2(2*lat)]

and the 1930 formula:

gtheo = 978049.0*[1.0+0.0052884*sin^2(lat)-0.0000059*sin^2(2*lat)]

It appears that earlier LDGO cruises have used the 1967 and 1930 formula in calculating free-air anomalies. Since the 1980 formula differs by a constant value from the 1930 formula, it is important to check the formula used in a specific LDGO survey when merging it with our current study.

Mantle Bouguer Anomaly

The primary purpose of this gravity survey is to determine the distribution of crustal and mantle density beneath the evolving ridge segments. To reveal the more interesting sub-seafloor density features, Jian Lin reduced the free-air anomaly to the mantle Bouguer anomaly (MBA) by removing the gravity effects of water/crust and crust/mantle interfaces. This modeling approach follows that of previous three-dimensional gravity mapping of Kuo and Forsyth (1988) and Lin et al. (1990).

The mantle Bouguer corrections were made based on Hydrosweep bathymetry data collected during this cruise. The gravitational effects of the topographic relief at the sea surface were calculated using a Fourier Transformation spectrum method of Parker (1972). The initial model assumes a 6-km constant-thickness crust and constant densities for water (1030 km/m^3), crust (2700), and mantle (3300). The mantle Bouguer anomaly directly reflects the deviations from this simple model.

Digital bathymetry in a region (49°-44° W, 25°-27.5°N) was reformatted into a 512x256 grid by Jon Howland using ARC/INFO gridding software, with longitude and latitude spacings of 0.9805 and 1.0909 km, respectively. Several test calculations were carried out, which show that the chosen spacings were adequate in accurately modeling the gravity effects at the sea surface.

For every free air anomaly measurement g_faa at point P (long, lat), we calculated the mantle Bouguer gravity effect c (long, lat). The mantle Bouguer anomaly at point P is then obtained as

g_mb = g_faa - c (long,lat)

Approximately 36,500 points of good free-air and mantle Bouguer anomalies were obtained using the above method. The mantle Bouguer anomaly increases away from the ridge axis at a average gradient of 0.28 mgal/km, a value very close to that predicted by the 3-D lithospheric cooling model of Lin et al. (1990). Besides these long-wavelength anomalies, however, there are significant local residual anomalies (up to 60 mgal) within and across the ridge segment corridors. These anomalies will provide important constraints on models of ridge migration and tectonics of the Mid-Atlantic Ridge.

Hydrosweep

Description

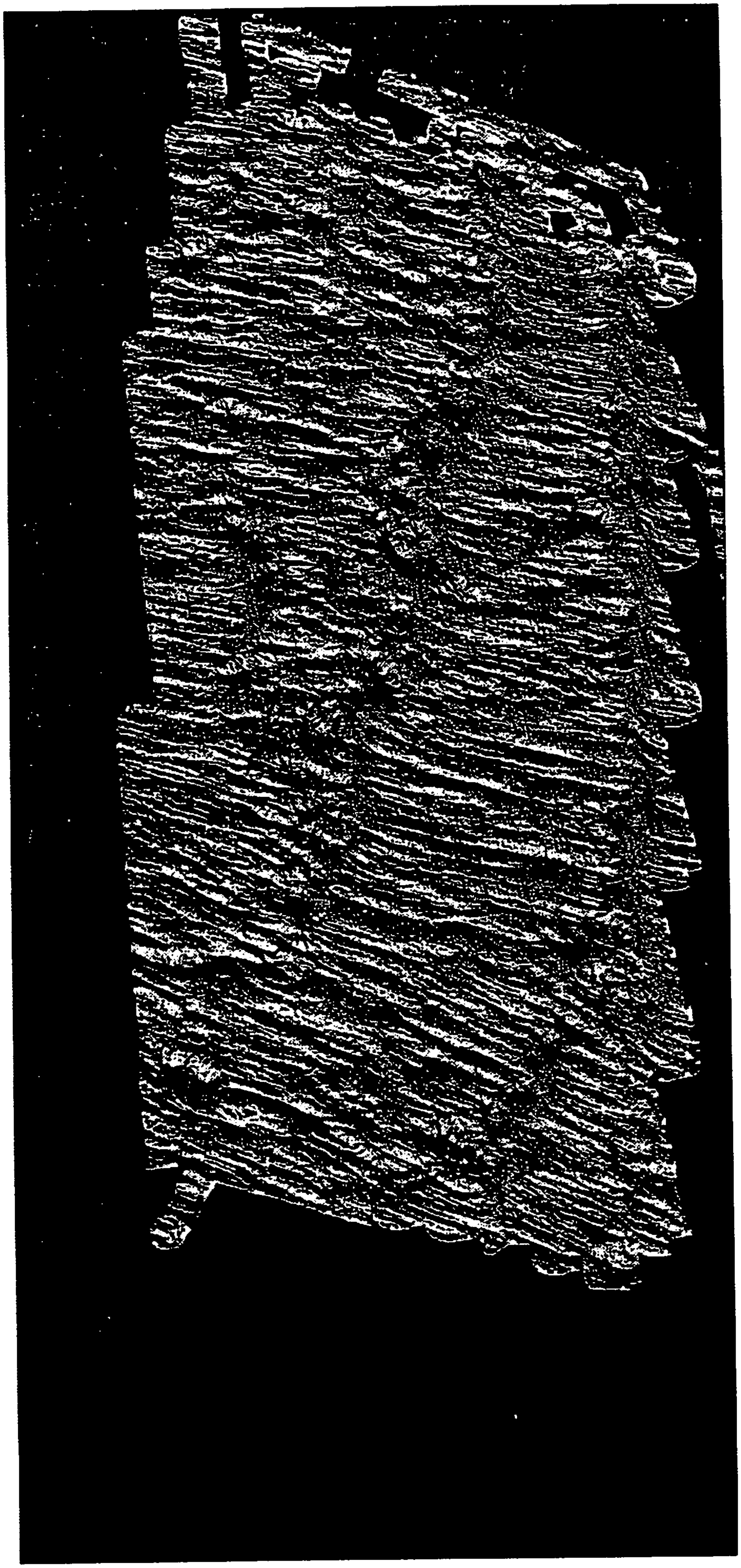
Hydrosweep is a 15 kHz multi-narrow-beam echosounding system that maps a seafloor swath equal to twice water depth. For each insonification of the bottom, the system measures the round-trip travel times of 59 beams (29 port, 29 stbd, and 1 at nadir), each of approximately 1.5 degrees angular width athwartships, and estimates the depths. The system also logs echo amplitude and duration. An average sound velocity for the water column is used to convert the two-way travel times to estimates of depth and distance across track. The real-time processing estimates a depth, and cross-track distances do not take into account raypath bending due to variations in sound speed.

During the earliest part of the cruise Hydrosweep cycled at its own rate, independent of HMR1. This introduced noise on the HMR1 records; the noise was later found out to be from the Hydrosweep calibration pings, which are directed fore and aft. Once Hydrosweep was slaved to the HMR1, this noise was no longer a problem in the HMR1 records. Later, Hydrosweep was again allowed to cycle independently of HMR1 but with the calibration pings disabled. The resulting faster ping rate increased the along-track data density and it appears to have improved the ability of Hydrosweep to track the bottom and produce better quality data.

Performance

Hydrosweep swath bathymetry was obtained continually throughout the survey except for brief periods (usually during turns) when it was being worked on in attempts to improve performance. Hydrosweep coverage varied between about 90% and 105% throughout the survey. The swath coverage obtained, with inter-swath interpolation to fill the gaps, can be seen in Figure 6.

Hydrosweep performance was substandard. Augers and data drop-outs were very common, particularly in areas of high relief, providing a "moth-eaten" appearance once the bad data (augers, shingles, and curl-up at edges) were removed using the interactive beam-editor. It had been reported that Hydrosweep's previous (1990-1991) serious problems had been corrected



Shaded relief bathymetry, illuminated from the east

Figure 6

and that the system was working very well. This was not the case on our cruise. Particular problems were observed in beams 14-22 (where 1 is the port-most beam, 59 is the starboard-most, and 30 is nadir). Data drop-outs and augers were most common in this block of beams.

Attached are three figures (Figures 7-9) which summarize one way of estimating the performance of Hydrosweep. One covers all of the data from *Ewing* 9208, one covers the first 11 days of Steve Cande's recent leg *Ewing* 9201, and one covers Jim Cochran's leg *Ewing* 9105.

DROPS are beams for which Hydrosweep returns a zero depth. Beams are dropped either because the signal to noise ratio is below the internal criteria set by Hydrosweep, or because the received signals are so strong that the receiver clipped. FLAGS are beams that have been marked as unacceptable during post processing. In the case of our cruise, these are beams that John Goff deleted with the interactive editor (PEDIT). The total number of (possible) beams is the number of pings in the day multiplied by 59 (the maximum number of beams that Hydrosweep can return). The raw numbers come from running *mbinfo* on the data files after editing.

By inspection, we can see that our data after day 217 is not dramatically worse than that from *Ewing* 9201. Two significant things happened on day 217 (August 4th): Dale Chayes finally managed to get both transmitter cabinets running the same (and current) version of software, and he found and corrected an improperly set configuration switch on a board in the -001 transceiver cabinet (this is the board that was replaced upon departure from St. Thomas).

Neither we nor Chayes, however, consider the data from our leg "up to par" for two reasons. First, the weather was much worse on *Ewing* 9201, which recorded better data. Most of *Ewing* 9208 was in seas of less than two meters and relatively light winds. Most of *Ewing* 9201 was in heavier seas and winds. Secondly, the consistent pattern of low signal strength in the vicinity of beams 14-22 does not exist in the *Ewing* 9201 data.

Numerous efforts by Dale Chayes, in particular, as well as by Joe Stennett and Chris Leidhold led to moderate improvements, but the data were never up to expectations. Further problems with sound-velocity corrections, roll bias, and other artifacts are noted below.

Processing

Raw Hydrosweep ping data were edited by John Goff using PEDIT, LDGO's interactive beam editor. This removed the worst of the spurious data (augers, shingles, edge curl-up). Further editing of data at swath edges, especially where adjacent swaths overlap, may be necessary once the data are more carefully analyzed.

During the course of the cruise Tom Reed developed a set of algorithms for processing and analyzing Hydrosweep data in various formats. The capabilities of these routines largely parallel those of the LDGO "MB" routines with some added capabilities, especially the ability to retain and process the Hydrosweep amplitude data. In the course of processing the Hydrosweep data from the cruise, several further problems were encountered, as documented below.

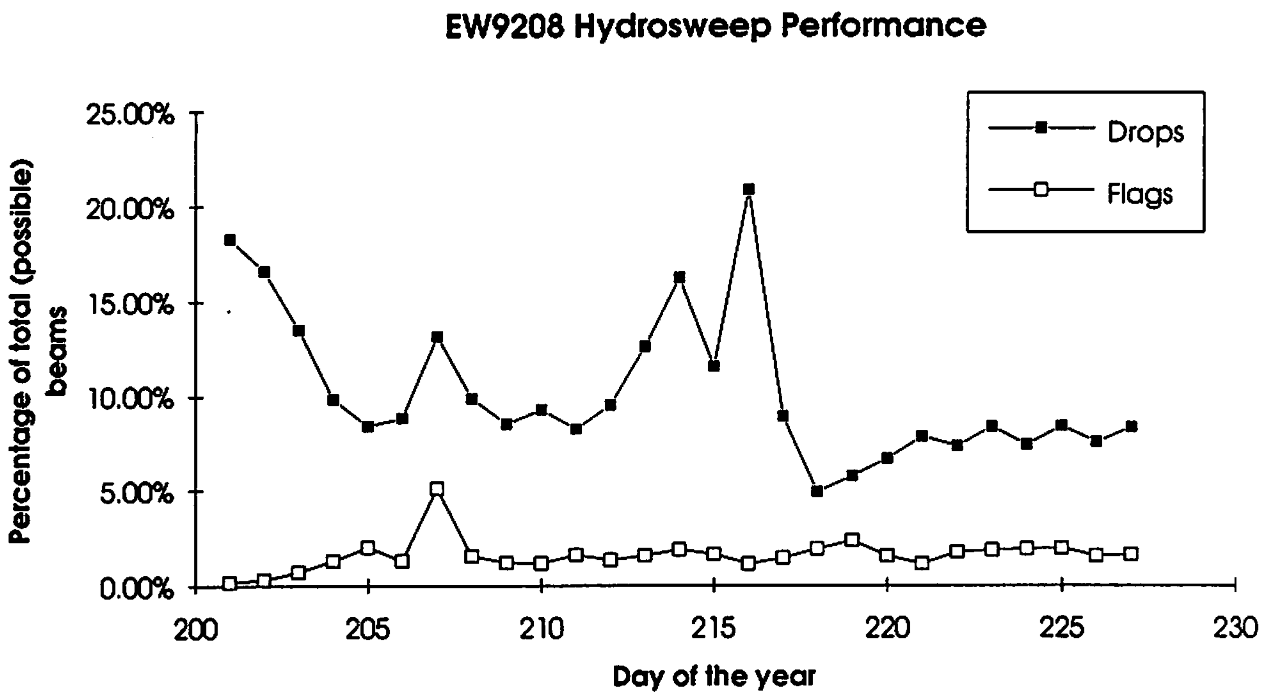

EW9208 Hydrosweep Performance
Drops
Flags
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
Percentage of total (possible) beams
200
205
210
215
220
225
230
Day of the year

Figure 7

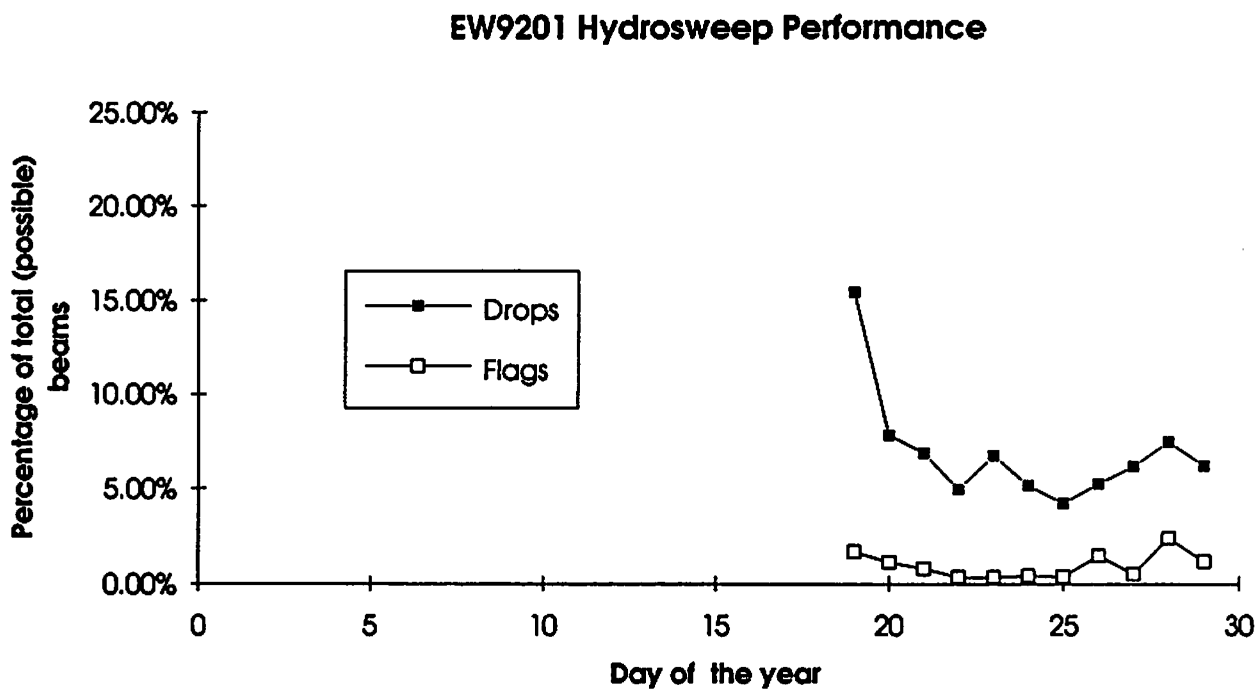

EW9201 Hydrosweep Performance
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
Percentage of total (possible) beams
Drops
Flags
0
5
10
15
20
25
30
Day of the year

Figure 8

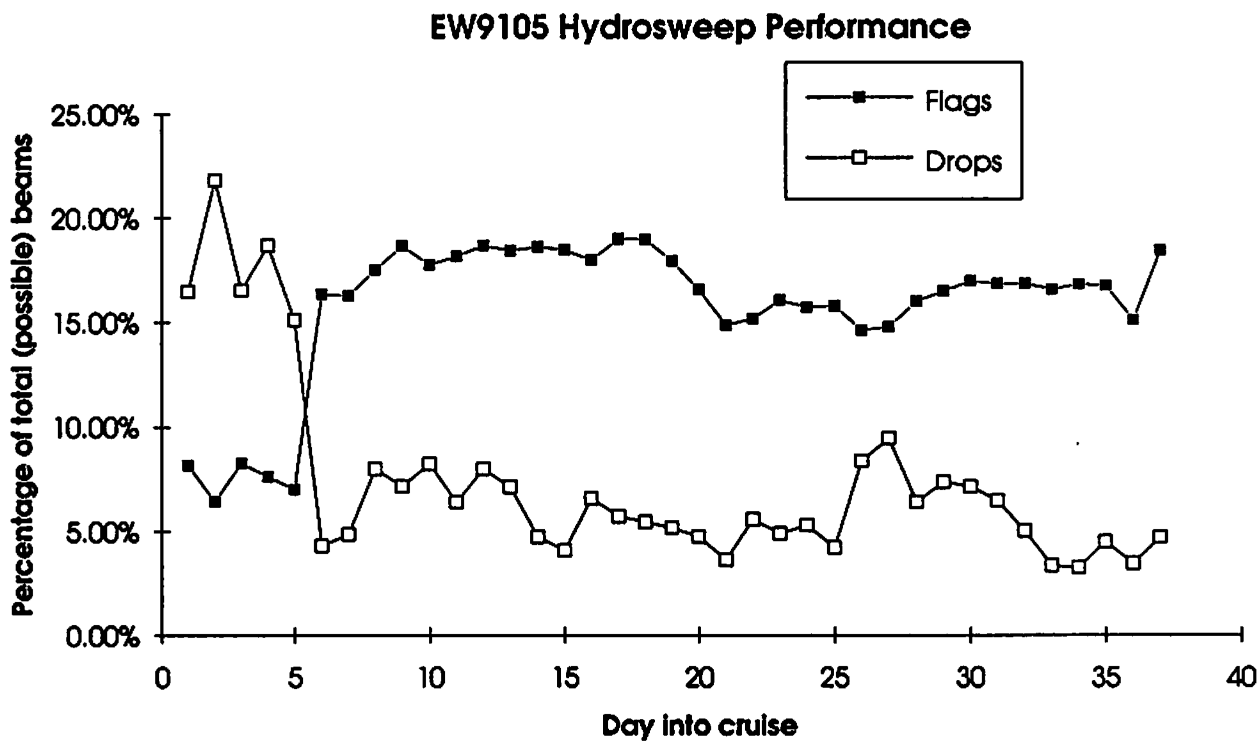

EW9105 Hydrosweep Performance
Flags
Drops
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
Percentage of total (possible) beams
0
5
10
15
20
25
30
35
40
Day into cruise

Figure 9

Sound Velocity Corrections

According to the Hydrosweep documentation, the average sound velocity used for each ping should be 1) the default value that is resident in the system (1500 m/sec) and is employed just after any startup or restart, 2) the average calculated from the user-supplied sound velocity profile, or 3) the automatically determined best fit from calibration pings. The second should closely mimic nadir depth, as this changes the relative percentage contribution of different velocities at different depths. The Hydrosweep system logs the entered sound velocity profiles (ERGNCTDS record) on a request basis, which averaged one record per day of the cruise. The sound velocity at the keel and a mean sound velocity is logged about once every ten pings (ERGNHYDI records). This mean sound velocity is unkown, but presumably is one of the three velocities noted above.

In examining these records, it seems that (a) several different velocity profiles were recorded, (b) as was realized, the earlier profiles did not reach depths where the pressure factor dominated the velocity and, hence, would have yielded spuriously low average values, and (c) a computation of the apparent sound speed used from (Nadir_Depth/Nadir_Time) did not agree with the logged mean sound velocity.

Tom Reed wrote a ray-path bending algorithm (Snell's Law, N-layers, linear velocity change in each layer) and applied it to the raw Hydrosweep travel-time data, but the resulting plots exhibited significant upward curl at the edges, indicating the estimated sound velocity profile that we used in real time was not appropriate. Furthermore, bathymetry produced from the raypath bending code and the beam travel time data was significantly noisier than that from the raw Hydrosweep bathymetry record (ERGNMESS), which is claimed to have been created by applying the logged mean sound velocity to the aforementioned travel times (i.e. we can't make Hydrosweep's raw data into their processed data with their logged parameters and documented algorithms; some internal filtering that we are not aware of must be occurring). It was resolved to attempt to determine a better sound-velocity profile post-cruise and to then apply full corrections as best we can.

Roll Bias

On several crossings of sediment ponds, we noted that starboard-to-starboard track-joins were always deeper than nadir values, and port-to-port joins were shallower. The ponds, from track-to-track nadir depth values and general appearance, were pancake flat, so these 200-m-amplitude cross-track depth variations were cause for concern.

Tom Reed extracted individual pings over the flat areas and fitted least-squares lines to their bathymetry values. It became apparent that the system suffered a roll bias and that the best fit was obtained by fitting a roll bias of -1.2 degrees to starboard and of +0.9 degrees to port.

While at first glance this would not seem possible, conversations with Dale Chayes indicated that a hardware configuration error, corrected on Julian Day 217, may have been responsible for the laterally distinct roll biases. Further analysis of data from flat ponds is clearly necessary to determine what values are best to apply to correct this situation.

Time corrections

The current LDGO multibeam processing software does not support a compact (binary) format for amplitude data. Reed developed algorithms to parse this data out of the raw record and place it into a format with which the MBIO routines could cope. This record was passed through the MB time-calibration algorithm to sync data times with GMT times so that the amplitude records could be properly merged with the correct, edited, re-navigated bathymetry records. In so doing, it was noted that EDMB format records, which had passed through the MB processing suite, had time stamps 1 to 3 seconds greater than the unprocessed records. Peter Lemmond had previously discovered this bug, and late in the cruise Dave Caress at LDGO emailed to us an updated version of the library. With a ping repetiton rate of 15 seconds, the misalignment in time was not a problem for us in any case; however, for shorter rep rates this time leak could pose a problem.

Amplitude Data

Reed produced a mosaic of Hydrosweep amplitude data (Figure 10). While in general the amplitude image reflects changes in surface slope (steeper, facing facets are more reflective) there is a general "pock-marked" aspect to the imagery that is difficult to explain. The numerous individual bright spots are difficult to reconcile with current knowledge of local geology and are assumed to be somehow related to system errors. We are investigating possible explanations.

"Shingles"

During the course of processing the Hydrosweep bathymetry data, it was noticed that there exists significant along-track correlation. This was most apparent in shaded relief maps, such as shown in Figure 6. The swath exhibits alternating inward-dipping and outward-dipping track-parallel facets. A hint of this pattern can be seen in individual ping data, as shown by the nine consecutive ping profiles in Figure 11. The profiles were taken from a flat sediment pond (Acoustics Site “B”) and they have been offset vertically to facilitate display. The least squares line gives a measure of the roll bias (as discussed above). The periodic variation about the mean trend of each ping seems to indicate that the system is alternately over- and underestimating the correct range to target.

In Figure 12 is shown a 60 ping average of the ratio of the observed range versus the theoretical range, i.e. that which would be expected for a flat bottom, at the observed nadir depth and the given beam angle. The least squares lines again give estimates of the system roll bias, while the alternating over- and underestimation of range is more obvious. We attempted to

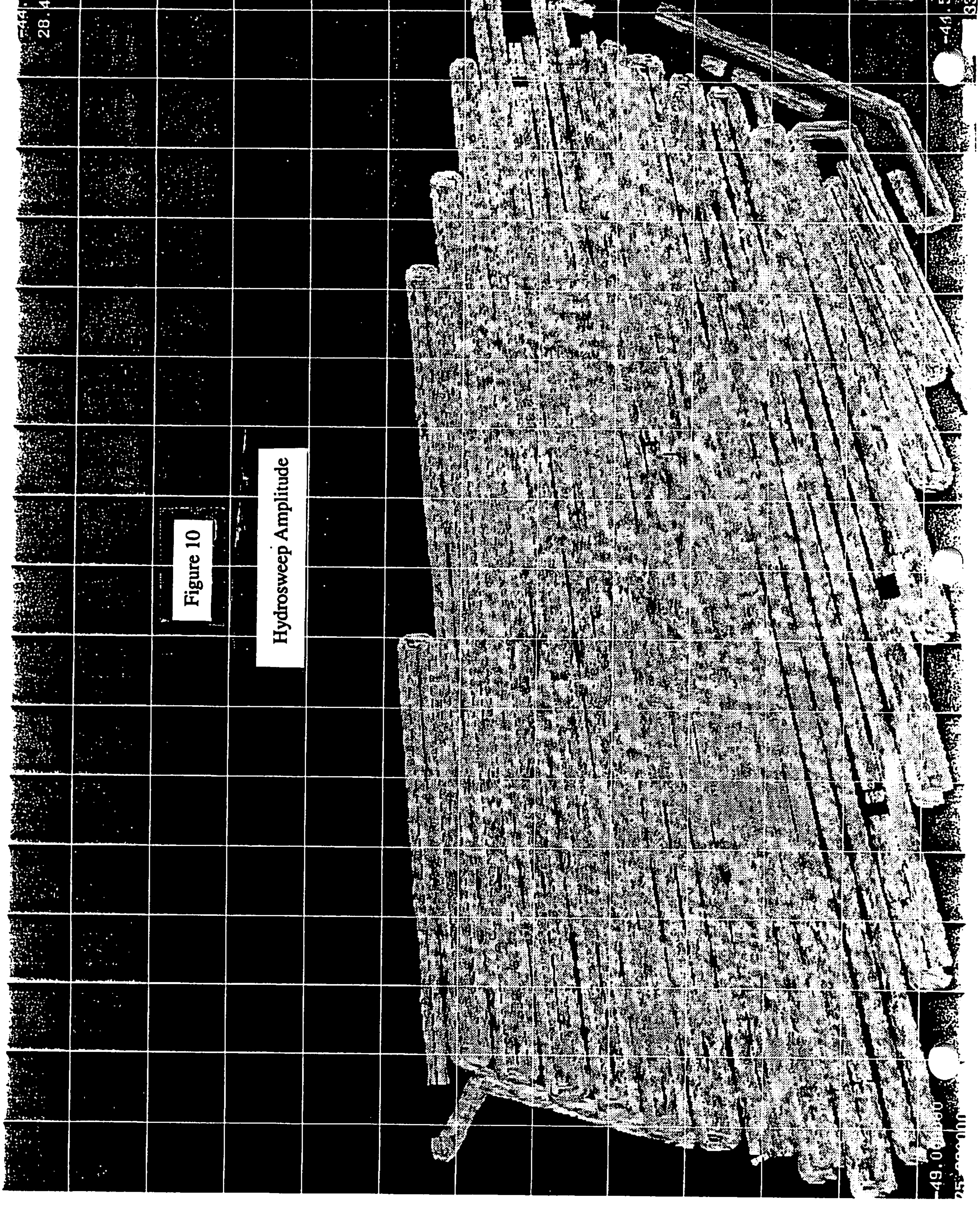


Figure 10

Hydrosweep Amplitude

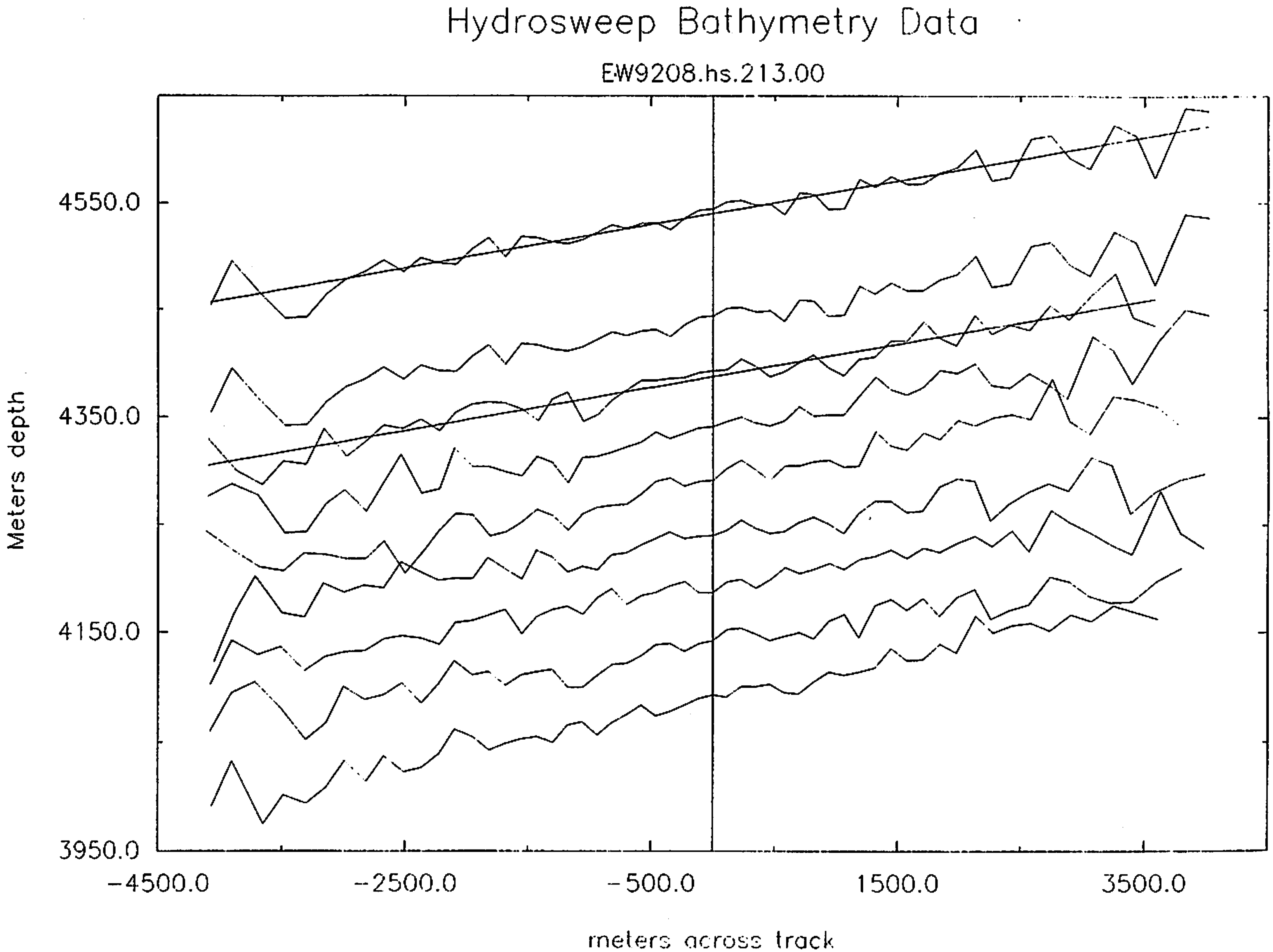

Hydrosweep Bathymetry Data
EW9208.hs.213.00
Meters depth
4550.0
4350.0
4150.0
3950.0
-4500.0
-2500.0
-500.0
1500.0
3500.0
meters across track

Figure 11

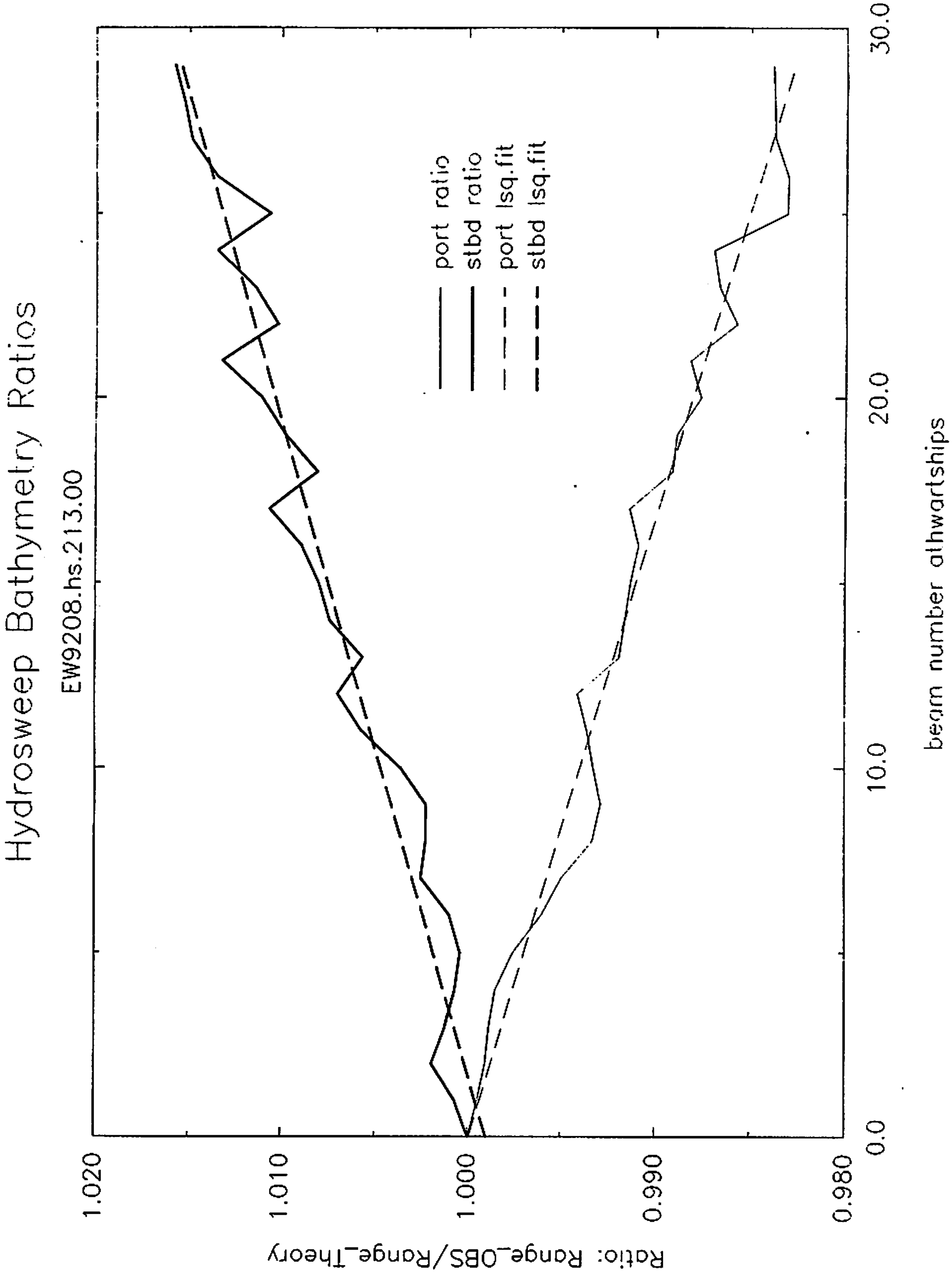

Hydrosweep Bathymetry Ratios
EW9208.hs.213.00
port ratio
stbd ratio
port lsq.fit
stbd lsq.fit
Ratio: Range_OBS/Range_Theory
1.020
1.010
1.000
0.990
0.980
0.0
10.0
20.0
30.0
beam number athwartships

Figure 12

remove this alternating system bias from the ping data, but as not all data exhibit these artifacts, the correction did not improve the overall image quality.

Alternating patterns of this nature have been observed in SeaMARC II data (Reed and Tucholke, 1991) and referred to as "shingles" in reference to the appearance they impart to the data. They were ascribed to lobes in the beam pattern resulting in non-uniform insonification of the bottom. The appearance of similar features in the Hydrosweep data suggests that the system beam pattern may not be as uniform as assumed.

Raw Backscatter

For a number of reasons including Dale Chayes' underestimate of the amount of effort required, previous commitments, late deliveries, and a failure of the acquisition computer, the backscatter data acquisition system was not ready for installation (and operation) upon departure from San Juan. Chayes made good progress toward completion of the hardware and initial software until shortly before arrival on site when it became apparent that the Hydrosweep system was not working properly.

Because of the importance of the Hydrosweep bathymetry data to the overall success of the leg, Chayes put aside the back scatter effort and worked exclusively on trying to improve the quality of Hydrosweep data from July 19th until August 10th when he returned to the backscatter effort.

On the 16th, Chayes was able to log a few very short bursts of full bandwidth digital data from Hydrosweep while recording digital pitch and roll. These short bursts represent data from the port side staves; they should be adequate to evaluate the acquisition hardware and to use in developing and validating the required real-time digital demodulation and subsampling required for real-time logging of backscatter data.

HMR1

Description

The HIG Acoustic Wide Angle Imaging Angle Imaging Instrument Mapping Researcher 1 (HAWAII MR1, or HMR1) is a shallow-towed, 11 kHz (port) - 12 kHz (stbd), phase-difference, split-beam sidescan sonar system designed to provide phase-derived bathymetry over a swath about 3.4 times water depth and 16-bit sidescan backscatter imagery over a swath up to 20 km wide. Quoted specifications for the system are that bathymetry at the 50 m contour-interval level should be reliable. Data are sampled at 1 ms intervals starboard and 11/12 ms port in slant-range and continuously from the beginning of the ping until immediately before the beginning of the next ping. On each side, 500-1000 bathymetry samples (at ~10-20 m intervals) and ~2000 backscatter samples (at 5 m intervals) are produced and recorded. The system was operated at full power. Pulse length was 2 ms. Real-time output consists of imagery on a Raytheon TDU-850 grayscale printer, bathymetry on a color Tektronix printer, and display of both on a Sun workstation. Data are stored on Exabyte 8mm tapes.

We towed the system at 8 knots through the water during the first few days of the cruise and subsequently increased our speed through the water to an average of 9.8 knots. Speed through the water during some intervals reached 10.2 knots. We did not find any noticeable decrease in signal-to-noise ratio at any of these speeds.

Performance

Performance of the HMR1 system was bimodal. The sidescan data are good, and the regularly achieved 20 km swath-width exceeded expectations (see Figure 13). Along-track bands of coherent noise, apparently from telemetry system, were the primary problem encountered with the sidescan (see below), and they were particluarly bad on the outer part of the starboard swath; this noise was partially removed in post-processing. Reprocessing to be done by HMRG post-cruise is expected to better correct for this noise. During the first few hours of the survey interference from the watergun and Hydrosweep systems was observed in the sidescan data. Sequencing, as described below in the section on synchronization, corrected the watergun problem. Initial attempts at sequencing displaced the watergun noise to the extreme fringes of the HMR1 data swath, but this interference was corrected within about a day. As described in the section on Hydrosweep, sequencing was initially used to keep the Hydrosweep signal out of the HMR1 data; later disablement of Hydrosweep calibration pings was used to eliminate the problem without sequencing.

The HMR1 bathymetry data were very disappointing and, as available at sea, virtually useless. Significant telemetry noise severely degraded most of the swath phase data. It is hoped that the HMRG will be able to develop routines to correct for the noise post-cruise and ultimately to produce usable HMR1 bathymetry.

The HMR1 vehicle itself performed robustly, and recovery was never required during the survey; it was towed continually for 26 straight days. Halfway through the survey, the depressor weight was brought aboard to check the termination and to replace the zinc block which was substantially corroded.

Logging computer system crashes occurred numerous times (typically every few days), but recovery generally took only 10 minutes. Thus only a total of 107 minutes of data were lost during the 26-day survey (31 minutes of this was during the depressor check). Because of the extensive overlap in HMR1 coverage no attempt was made to resurvey these very small areas.

Processing

The following synopsis of HMRG data processing techniques is presented in the order performed:

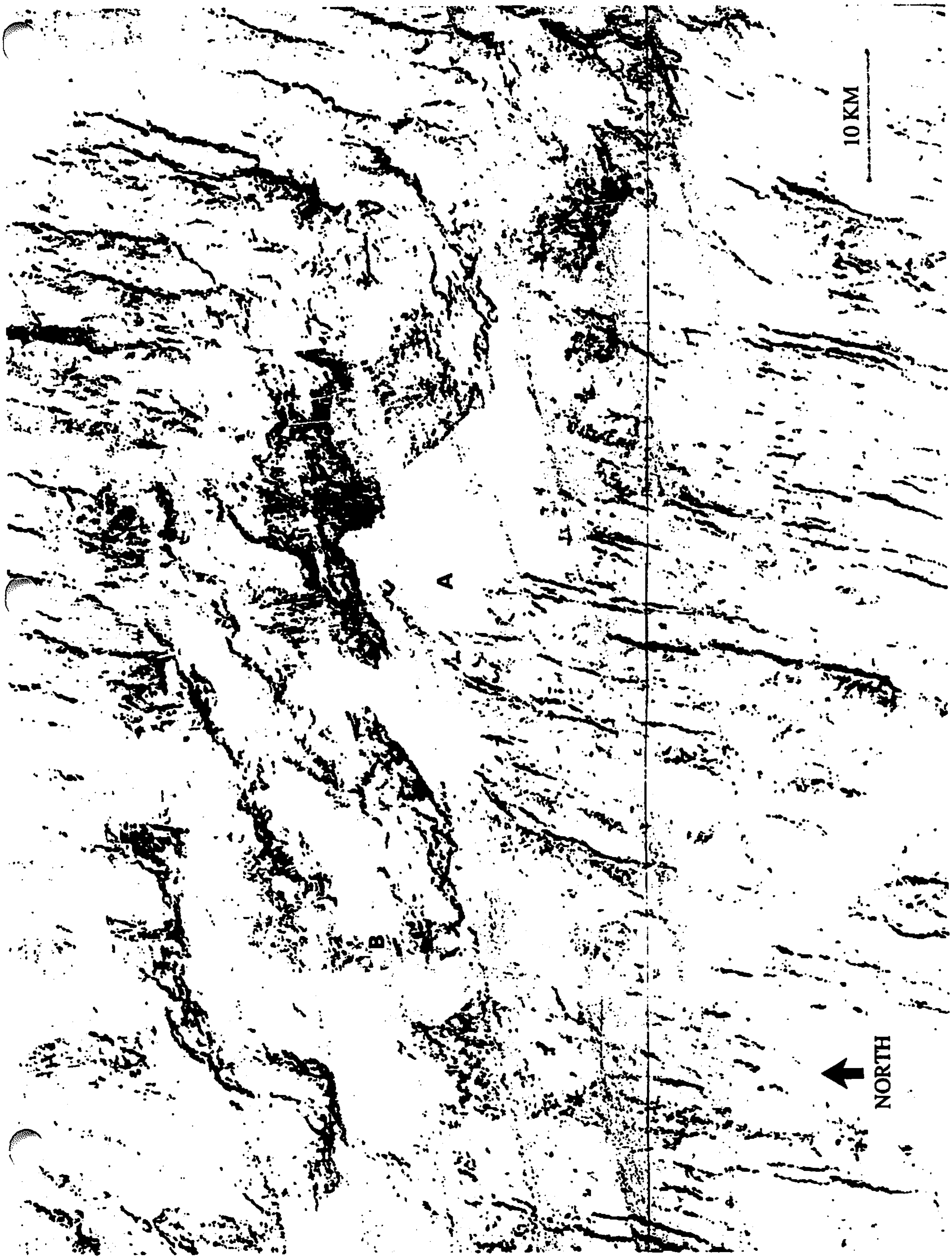


Figure 13 Example of preliminary shipboard digital mosaic of sidescan-sonar imagery, insonified to the north. Scale approximate. "A" is pond area and "B" is ridge, both targeted by ARSRP acousticians as areas of potentially high interest for 1993 fine-scale experiments.

Bottom detection

Bottom is detected by examining the raw HMR1 data for the highest amplitude returns. Bottom is considered to be the first value below a minimum depth that has some fraction (usually 1/10) of the maximum return strength. Bottom detect values are interactively edited by HMRG data processors based on the Hydrosweep center beam data.

Bathymetry generation

Available software was unable to generate meaningful bathymetry data on this cruise.

Ping flipping

Occasionally rows A and B record each other's raw acoustic data resulting in pings that are out of phase by approximately 90 degrees. These pings are visually evident and are interactively "flipped" by the HMRG data processors.

Backscatter generation

All data for *Ewing* 9208 were generated using a flat-bottom assumption with the seafloor depth determined by the bottom detect for each ping. Assuming a constant speed of sound in water of 1500 m/sec, return times are converted to ranges and then to horizonal distance from nadir using the assumed seafloor depth.

Backscatter despeckling

Values in the backscatter data are compared to neighboring values (for *Ewing* 9208 a 3x3 boxcar filter was used) and if found to be anomalously high or low compared to a percentage of the boxcar's average, are replaced by the median of the boxcar.

Navigation merging

Navigation provided by the *Ewing* data processor Bill Robinson was splined and incorporated into the header for the HMR1 processed files. A 125 second delay was added to the ship's navigation to generate navigation for the fish. This value was based on multiplying average ship's speed by the sum of the average effect of the relatively constant vehicle pitch and the distance by which the vehicle trailed behind the ship inferred from both a geometrical correction to wire out and a sonar signal from the vehicle received at the ship's 12 kHz hull-mounted hydrophone. The HMR1 vehicle was assumed to follow exactly in the ship's track.

Angle variable gain correction

16 hours of non-continuous data over terrain that did not have track-parallel seafloor features were used to generated "average ping intensities" for the HMR1 system. These averages were inverted and used to remove systematic track-parallel intensity variations in the HMR1 backscatter data.

Destriping of backscatter data

Lines which had more northerly or southerly headings than the majority of the survey lines were observed to have pings that were anomalously high or low compared to their neighbors. These pings were detected both statistically and visually and replaced by the average of the "good" pings to either side of them.

Sinuous track mosaicking

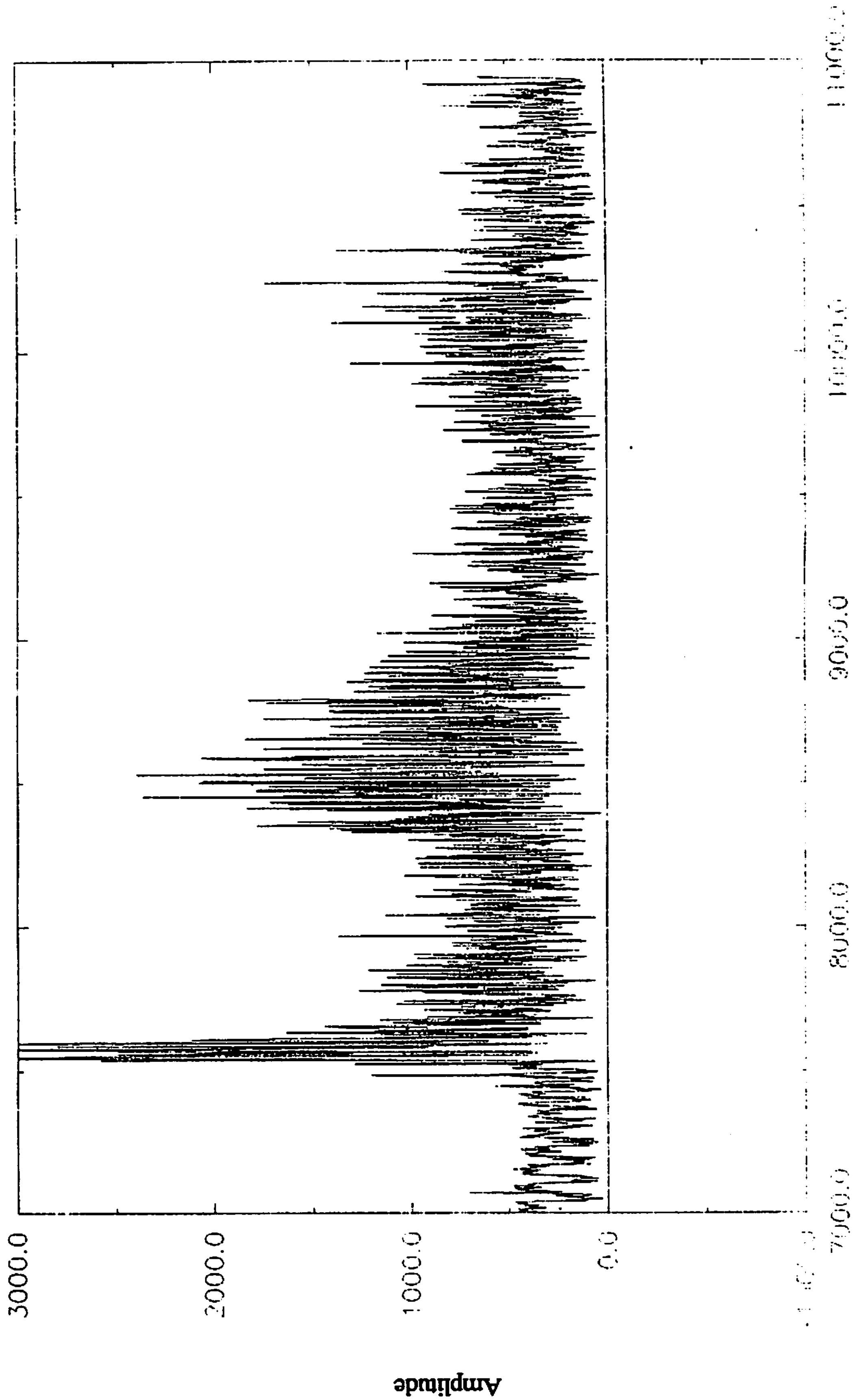
The processed backscatter data were output to hard copy using the navigation merged into the processed HMR1 files. The system's compass heading plus a constant magnetic declination of 4 degrees was used to describe vehicle yaw.

Analysis of HMR1 Noise

Early in the cruise we detected the effects of a coherent noise source in the HMR1 system. This noise contamination significantly degrades both the sidescan image and the bathymetry estimation. Upon checking with HIG personnel it was determined that the noise had been identified and studied previously by John Hughs Clarke at the University of New Brunswick. Despite being aware of the problem prior to this cruise, HIG did not correct the deficiency or notify us that the survey would be compromised because of this noise. In an attempt to better understand the problem and devise a solution, Ken Stewart and Rob Fricke undertook an analysis of raw HMR1 data. Figure 14 shows amplitude versus sample number (~1 ms/sample) for a single ping. The periodic noise component can be clearly seen before bottom return at about sample 7500. This plot highlights the seriousness of the problem since it is evident that signal-to-noise ratio is poor and, in fact, is less than unity for large portions of the data.

In early analysis it was noted that the noise is synchronous with telemetry transmission cycles, which occur at intervals of 64 complex samples (~64 ms). The character of the noise appears to correspond directly with the telemetry transmission duty cycle, showing a distinct periodicity that matches the separate port and starboard packet frequencies. For each ping cycle also, the noise initially appears following the first 64 samples, corresponding to the first packet transmission. Although we could not validate our noise model against the hardware without interrupting the survey, further analysis tended to confirm this initial characterization.

Clarke was contacted by e-mail about his approach to the problem. He responded with a description of attempts to remove the noise by averaging the magnitude of the noise (complex envelope) and subtracting the result from the raw data. The result was an improvement, but the noise was still present. This is consistent with our complex-envelope analysis (assuming an underlying coherent noise source), which shows that a dominant noise component can be



Amplitude
3000.0
2000.0
1000.0
0.0
Sample Number
7000.0
8000.0
9000.0

Figure 14

subtracted if the amplitude and phase of the contamination can be estimated. However, our results indicate that, while the amplitude is ping coherent (we produced consistent estimates and improved the imagery), the phase of the noise is random from ping to ping. This suggests that Clarke's partial success is attributed to the removal of a second-order term but the leading-order noise component remains.

The fact that the amplitude is coherent from ping to ping and the phase is not suggests that the contamination is a narrow-band process. In this case, the envelope modulating a "carrier" frequency might be coherent from ping to ping, but the phase of the "carrier" would vary. The term "carrier" is emphasized because it apparently is not directly related to the sonar carrier frequencies of 11 and 12 kHz but to digital sampling and telemetry rates. In fact, analysis of the raw noise records shows that the coherent noise carrier frequency is around 80 Hz. The specific source of this carrier and its modulation could not be determined without hardware troubleshooting.

Although the noise phase is random from ping to ping, we hypothesized that there might be a fixed reference within any single ping. If this were the case, the noise could be estimated and modeled in quiet sections of the ping record, then extrapolated and subtracted from the "active" portion of the ping record. In pursuit of this goal Fricke applied a Karhunen-Loeve (KL) decomposition of the noise using two portions of the ping record as templates: before the water bottom arrival and at the tail of the record. It was felt that at these two times the geologic contribution to the ping record would be minimal. Coefficients for the KL expansion were estimated and used to weight complex exponential basis functions to model the noise. Some success was evident but not sufficient to completely suppress the noise. It was felt that additional work along these lines was not warranted while at sea, although further modeling efforts might have produced better performance and it may be useful to pursue this work for post-processing back on shore.

By design, we took a noise-only sequence of about 160 pings at the end of the cruise; this will be used to mitigate the noise problem during post-processing. Our results demonstrated that the amplitude signal-to-noise ratio can be greatly improved by incoherent subtraction of the noise envelope. We are pessimistic, however, about the possibility of directly estimating the noise phase since this is likely related to the frequency-shift keying used in the telemetry system. In this case the phase will be data dependent, varying as the telemetry carrier frequency shifts according to a random bit sequence. However, an approach to improving the quality of phase-difference estimates for the bathymetry is to use the noise characterization as a basis for estimating the signal-to-noise ratio (SNR) for each sample. The periodic nature of the noise would allow low-SNR phase estimates from the high-noise portion of each duty cycle to be rejected. This would eliminate 20-80% of raw samples (differing between port and starboard) but would significantly improve the bathymetry. The separate problem of angle-angle conversion can be addressed after phase estimates are culled. We suggest that empirical angle-angle tables should be derived using Hydrosweep bathymetry from the survey area. This would produce (multiple) tables from the region of operations and allow the incorporation of higher SNR samples rather than those taken from a (presumed) flat sediment pond, which has a lower scattering strength with lower corresponding received signal.

Single Channel Seismic Reflection Profiling

Single-channel seismic (SCS) reflection profiles were recorded throughout the survey area. The sound source was a single 80 cubic inch Seismic Systems Inc. watergun fired at a 15-sec repetition rate. Peak output of this watergun is at ca. 140 Hz. The seismic streamer used to receive reflected signals was an ATG streamer manufactured by CGNG. It consisted, from front to back, of a 10 m weighted section, a 25 m stretch section, a 12 m dummy section, a 25 m and two 50 m active sections, and a 25 m stretch section. Active sections each have 45 hydrophone elements; the various active sections were switched in and out of the circuit during the cruise to minimize intermittent noise problems. The streamer was towed behind the ship on a 200 m tow cable.

The reflection profiles were recorded on two paper recorders (band-pass filtered at 90-200 Hz) and on tape. One paper profile was recorded at a 5 sec sweep and with variable delay on a Raytheon 1800M LSR (Line Scan Recorder). The other was recorded at a 10 sec sweep on an EPC recorder. Digital tape recording was on 3480 "square" tape cartridges.

Data gaps in the SCS records occur mostly at turns following the completion of a long survey line. These gaps reflect short periods when the compressor was shut down to check the oil and slightly longer periods when the compressor was shut down for an oil change.

SCS profiles were intermittently noisy. Some noise originated in one or more of the streamer sections. Electronically switching various sections in and out of the circuit helped to reduce this noise. A second source of noise appears to have been of biologic origin. Noticeable increases in noise occurred beginning ca. 1900 GMT each day, with decreases in early morning (ca. 0700 GMT). This noise was most severe on 10-14 August (JD 223-227), i.e. the dates around full moon on 13 August.

Sediment thickness was hand-digitized at two-minute intervals from the SCS records. The values were entered in the ARC/INFO Geographical Information System for on-shore access and contouring.

3.5 kHz Echosounding

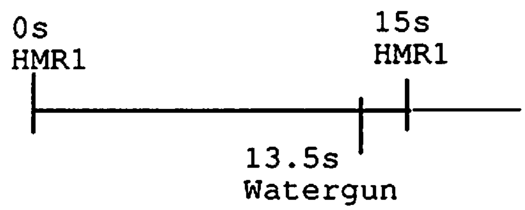
Echosounding with hull-mounted EDO 3.5 kHz transducers (12 bottle array), an EDO 550 transceiver, and 10 kW booster was conducted continuously throughout the cruise. Paper profiles were recorded on a Raytheon 1800M LSR using an ungated 1 sec sweep. Within the ARC survey area, the 3.5 kHz signals were digitally recorded on digital audio tapes (DAT) using recorders provided by Tom Jordan. The 328 tapes recorded will be turned over to Tom Jordan for post-cruise analysis.

The 3.5 kHz system performed well throughout the cruise in water depths of 2000-5000m. Occasional noisy records were caused by ship maintenance operations (needle gun, wire brushing). Intermittent noise spikes were also imposed on most of the records by the watergun, which was fired every 15 seconds.

Echo characteristics were hand-digitized at two-minute intervals from the 3.5 kHz records. The picks were entered in the ARC/INFO Geographical Information System for on-shore access and areal categorization of echo character.

Synchronization

To minimize the effect of interference between the various sound sources, a synchronization system was used. From the beginning of the survey, the watergun was slaved to the HMR1 trigger pulse which fired every 15 seconds. After initial experimentation lasting several hours, we settled on having the watergun firing 13.5 sec after HMR1, which gated out any watergun interference in the HMR1 record of interest. Hydrosweep was initially unsynchronized because its external trigger system was inoperable, and it put some noise on the early HMR1 records. Once the external trigger was fixed, Hydrosweep was triggered by and pinged at the same time as HMR1. Later in the cruise it was found that the Hydrosweep calibrate pings (oriented fore and aft) were the pings that interfered with HMR1 when Hydrosweep was in the free-running mode. From that time, the calibrate pings were disabled and Hydrosweep was allowed to operate in the free-running mode. This coincidentally improved the quality of Hydrosweep recording (fewer dropouts and augers), apparently because Hydrosweep was able to ping more frequently than when slaved to the 15-sec HMR1 rate, thus being able to track bottom more effectively. Our conclusion is that the optimum sequencing of HMR1 and the water gun is as shown below, with Hydrosweep allowed to run freely at its normal repetition rate but with the calibration pings disabled.



DIGITAL DATA PROCESSING AND MANAGEMENT

Prior to the cruise, development of an integrated system for processing and managing the SRP digital database was undertaken by WHOI's Deep Submergence Laboratory (DSL), under the leadership of Ken Stewart, to complement efforts underway at the WHOI Digital Image Analysis Laboratory (DIAL), managed by Peter Lemmond. The resulting software and information management techniques were applied to all digital data collected during the cruise, will incorporate data from previous surveys, and will be extended to encompass the high-resolution survey to be undertaken in 1993. Our goal is to produce a consistent multisensor, multiscale database that can be made available to SRP researchers along with software tools to facilitate data access.

Along-Track Data

A first step in handling most SRP data was a conversion to a common format. Soon after edited center-beam bathymetric data, magnetic data, gravity data, and navigation became available from the LDGO Data Logging System, they were converted to standard ASCII records with consistent record types and time stamps. Along-track echo character parameters (from 3.5-kHz ES records) and along-track values for sediment thickness (from the seismic profiler records) were also entered into the DSL format using custom software and then merged with navigation.

Acoustic Swath Data

A modular sonar-processing suite developed by Ken Stewart was augmented by Stewart and Reed to access HMR1 and Hydrosweep data formats. This allowed signal processing, gridding, and display of all sonar data collected during the survey using common tools with a consistent window-based user interface. Processing pipelines for all swath data used a consistent set of ASCII file descriptors to characterize file contents and data types. These also served to document processing steps and produce a description of the final (to this point) database.

Gridded Database

The final form of most processed data will be a gridded, digital database directly accessible for acoustic modeling, interactive display, and the production of hardcopy maps. Our approach was to partition the survey area into overlapping tiles with sizes and resolutions appropriate to the different sensors and derived data types. Gridded Hydrosweep bathymetry and HMR1 imagery were produced aboard ship for the entire survey area. Additional processing was done by Marty Marra of DSL to extract maps of slope azimuth and dip. Additional features will be extracted in post-cruise efforts.

Hydrosweep data were preprocessed in two parallel paths: corrections developed by Tom Reed (described above) and ping editing with LDGO routines. The final edited data were then block averaged to a 200-m grid spacing and fitted with a splined surface using routines from the GMT software package (developed at LDGO and Scripps). The gridded data were masked with a DSL morphological routine, then passed to DIAL software for final production by Peter Lemmond of contoured hardcopy maps.

HMR1 swath amplitude data, preprocessed by HIG, were reprocessed and gridded with the DSL sonar suite by Ken Stewart. Applying results of the noise analysis (described above), some improvement in SNR was achieved. However, this effort was hampered by HIG processing, which applied a time-varying-gain that accentuated the noise and an angle-dependent gain that varied over the survey area. The corrected data were then gridded to a 50-m resolution in two separate look directions. The final results, available before reaching port in Barbados, were a complete digital database and digitally produced maps of the entire survey area.

The final production of hardcopy products was facilitated by DSL software for digitally compositing tiles at selected sizes and resolutions. These could be conveniently displayed, interactively queried for position and values of interesting features, or selectively saved by region of interest. This software, along with a more complete description of the database contents and format, will be made avilable to SRP researchers after the cruise.

Geographic Information System

After conversion and initial processing, along-track data were entered in an ARC/INFO geographic information system (GIS) managed by Jon Howland of DSL. These data were kept current throughout the cruise and were accessed by the scientific party as new results became available. The various layers in the GIS (gravity, magnetics, echo character, etc.) form a comprehensive, geographically registered data base of all along-track digital geophysical data collected during the cruise. These data can be queried spatially and relationally, then superimposed on gridded bathymetry and sidescan imagery from the tiled database.

An additional gridded database will be created for sediment thickness following the cruise. Sediment thicknesss will be contoured from the along-track data, with bathymetry providing strong constraints (since most sediment occurs in relatively flat ponds). These contours will be digitized and gridded for entry into the GIS. Sediment thickness values added to the bathymetry also will provide a gridded data set of depth to ocean crust.

ACKNOWLEDGEMENTS

The scientific and technical staff members worked as a collegial and efficient team during the cruise, and they are to be complimented for their efforts.

The LDGO staff provided excellent support both during the cruise and in port. We express our particular appreciation to Bill Robinson, Dale Chayes, and Joe Stennett for their extensive contributions that helped to assure a successful field program.

The HMR1 team, led by Margo Edwards, conducted launch and recovery operations, as well as shipboard data reduction, very professionally and efficiently. We thank them for their excellent efforts.

Our thanks are also extended to the Master and crew of the *R/V Ewing*. Their ready assistance and professionalism contributed greatly to the successful conduct of our program.

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