Department Of The Interior
U.S. Geological Survey

Cruise Report, Hawaiian GLORIA Leg 5 F5-88-HW

by

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INTRODUCTION

Cruise F5-88-HW was the fifth GLORIA survey in a multi-year program designed to image the Hawaiian Island EEZ using GLORIA, a long-range side-looking sonar. The objective of this program is to produce an atlas that shows the geologic and morphologic features of the seafloor so as to better evaluate the economic potential, geologic hazards, and other possible uses of the Hawaiian EEZ.

Cruise F5-88-HW followed F5-86-HW and F6-86-HW that were carried out in late 1986 (Holmes et al., 1987, and Normark et al., 1987), and F3- and F4-88-HW that immediately preceded it in March-April 1988 (Normark et al., 1989). One "ground-truthing" leg, F2-88-HW, was conducted in February 1988 over areas covered during the two 1986 campaigns (Clague et al., 1988). The 1986 legs covered the EEZ areas surrounding the island of Hawaii at the southeastern end of the Hawaiian chain. Legs F3 and F4-88-HW imaged an unfinished portion of the EEZ region northeast of the islands of Hawaii and Maui; the area east of central Maui out to the 200 mile limit; and the region northwest and northeast of central Maui up to about the southern tip of Kauai (Normark et al., 1989). Figures 1 and 2 provide geographic reference and trackline coverage for the area covered by this leg. The area is west of the Island chain, from southwest of the island of Hawaii north to Niihau and out to the 200 mile limit.

Two additional GLORIA legs, F6-88-HW and F10-88-HW, were conducted in May and October 1988 and completed the imaging of the "state" waters (the area around the islands between Hawaii and Kauai, as far west as Necker Island). The remaining territorial waters of the Hawaiian EEZ will be imaged between 1989 and 1991.

In addition to collecting GLORIA data, operations include collecting two-channel seismic-reflection profiles using an air-gun sound source, 3.5 kHz high-resolution profiling, 10-kHz echo-sounding, magnetic and gravity potential-field measurements, and upper water column temperature profiles using expendable bathythermographs.

OPERATIONS

The GLORIA surveys are conducted from the R/V Farnella that is under lease to the U.S. Geological Survey through the Institute for Oceanographic Sciences (IOS) in Wormley, England. The Farnella arrived in Honolulu, Hawaii on 5 April, 1988, following the F3 and F4-88-HW GLORIA legs. There was a complete changeover of both the USGS and IOS personnel, and the two days in port allowed sufficient time to be briefed on the vessel by the personnel of the previous leg, thereby smoothing our transition to shipboard activities.

GLORIA surveying responsibilities are split between USGS and IOS personnel. IOS personnel are responsible for all operations involving GLORIA, deck operations, and maintenance of the seismic-reflection and 3.5-and 10-kHz profiling systems. They are also responsible for the GLORIA watch-standing, and the ABC navigation and data logging system. The USGS personnel are responsible for monitoring the gravimeter, gradiometer, the seismic reflection, and 3.5- and 10-kHz profiling systems. USGS personnel are also responsible for the real-time navigation, and the co-chief scientists (both USGS and IOS) are responsible for cruise planning, the production of two field mosaics of the GLORIA data, and preliminary science report.

The two day port stop was hampered by an inordinate amount of shifting from pier to pier for fuel and repair work. The first pier allocated for docking, pier 40D, was immediately adjacent to- and down wind of- a large freighter that was off-loading concrete mix. This filled the air with dust and grit, making it nearly impossible to breathe, see, and effect repairs to the GLORIA hydraulic pump in the cradle/tow winch assembly. After voicing an objection to the ships' agent, the Farnella shifted to pier 10, at 1400 on 5 May. The following day the ship shifted from pier 10 to pier 34 for fuel, then back to pier 10 after taking on fuel.

Original departure time for the F5-88-HW GLORIA survey was delayed 3 hours from 0900 on 7 May to 1200 hrs (local) owing to problems with the hydraulic pump unit in the cradle/tow winch assembly. Repairs that began on the afternoon of 6 April were completed by 1130 hrs (local) on 7 April, and we departed pier 10 Honolulu at 1200 hrs.

The following is a list of the scientific personnel, a schedule of field operations and a review of the equipment employed during the survey:

SCIENTIFIC STAFF FOR F5-88-HW

U.S. Geological Survey

Mann, Dennis	Geophysicist
Nicholson, Jim	Electronic technician
Ruppel, Byron	Geophysicist/Navigator
Sliter, Ray	Geophysicist
Torresan, Michael	Chief scientist

Hawaii Institute of Geophysics

Shor, Alexander	Co-chief scientist

Institute of Oceanographic Sciences, U.K.

Campbell, Jon	GLORIA supervisor
Gray, Allen	Mechanical technician
Heath, David	Mechanical technician
Walker, Ross	GLORIA technician
Wilson, John	Co-chief scientist
Woodward, Emma	Geologist/photographer

National Environmental Research Council

Research Vessel Services (U.K.)

Jones, Doriel	Navigator

Summary of Field Operations

The following list starts with the day of the year/Greenwich Mean Time (GMT), for the starting point of the major survey segments. When converting to local time note that day 098 is April 7, and that GMT is 10 hours ahead of local Hawaiian time, e.g., 2200 GMT is 1200 local. Figure 1 is a trackline summary to provide a reference for the various stages of the survey, and figure 2 provides a geographic reference for the region covered by this survey.

1. 098/2200 Depart from pier 10 Honolulu, Hawaii.

2. 099/0100 Deploy GLORIA fish and all seismic gear.

3. 099/0100 Official watchstanding begins. All gear on line except for the two-channel seismic reflection system that came on line at 099/0331.

4. 099/0300 Start line 1, a shallow water survey at a heading of 190° with the objective of filling in an area immediately adjacent to the termination of the F6-86-HW Survey. This portion of the survey takes us across an area imaged in 1986, to complete imaging the Lanai slide. and provide tie-lines with accurate navigation to correct for the incorrectly positioned features imaged in 1986.

5. 100/1450 Begin the standard deep-water trackline pattern that trends 122°/302° with a spacing of 16 nm (30 km). This continues the survey pattern initiated in 1986.

6. 109/2140 Finish the portion of survey unfinished by the F5-86-HW survey. Continue to survey last and outermost deep-water lines at headings of 302°/122°.

7. 112/1832 Complete the outermost lines in the northwesterly portion of the survey area including the Molokai Fracture zone. Turned on to heading of 062° and began working our way east.

8. 114/0834 End line 15A and turn onto heading of 048° towards Oahu to begin our shallow water survey pattern.

9. 115/0700 End line 18 off the North shore of Oahu. Start line 19 (heading 302°), the eastern most

line of the survey. Start surveying between Oahu and Kauai, that will bring us west back out to overlap with line 15.

10. 123/0325 End line 32A, and end cruise. Steam for Honolulu.

Equipment Review

This review describes problems encountered with the shipboard data collection systems. Appendix 1, taken from Normark et al., 1989, summarizes the standard operational procedures that were established for the 1986 surveys (Holmes et al., 1987; Normark et al., 1987 and 1989). Complete reviews of the trouble-shooting and repairs for each system are available in the electrical technicians' report.

Gravity Meter

The gravity meter, a LaCoste and Romberge S-53, functioned continuously since the Farnella departed Redwood City, California, on 23 February, 1986. A gravity tie was established at the dock in Honolulu where this cruise terminated.

Magnetometer

The magnetometer was deployed following the streaming of all other seismic gear (about 099/0100). Official logging began at 099/0200. The data are recorded on both a strip-chart and magnetic tape, with the same recorder used for the gravimeter. There were no problems with the system.

Expendable Bathythermographs (XBT's)

The XBT probes were deployed once daily to measure the thickness and temperature of the surface mixed layer, and the temperature profile within the thermocline. The probes available were: T-4 and T-6, capable of profiling to 460 m, and T-7 XBT's that are good to depths of 760 m. Owing to a limited number of T-7 probes, they were deployed once weekly. T-6 and T-4 probes were used on the other days. The system is incorporated with a micro-computer that handles recording, plotting, formatting and data transmission. Data transmission is accomplished via satelite. The system performed well, with little or no fouling of the wire in the towed seismic gear. A training session by the chief scientist of the previous leg saw to it that the deployment and fouling problems encountered on earlier surveys were avoided. Probe launching was carried out on the port side of the vessel, about 20 ft fore of the stern. The following list is a record of the location of daily XBT drops and their success rate.

Day	XBT Depth Rating	Record Length	Latitude	Longitude
099	T-7 760 m	Full	19°46.7′ N	157°33.9′ W
100	T-6 460 m	Partial (260 m)	17°06.7′ N	156°34.2′ W
101	T-6 460 m	Full	16°09.1′ N	155°30.1′ W
102	T-6 460 m	Full	17°55.9′ N	158°27.1′ W
103	T-6 460 m	Full	19°43.0′ N	161°26.1′ W
105	T-6 460 m	Full	18°13.0′ N	159°28.6′ W
105	T-6 460 m	Partial (360 m)	16°27.1′ N	156° 33.6′ W
106	T-7 760 m	Full	16°06.1′ N	156°29.2′ W
107	T-4 460 m	Partial (280 m)	16°44.7′ N	158°37.9′ W
109	T-6 460 m	Full	16°00.4′ N	156°53.0′ W
109	T-4 460 m	Full	17°44.6′ N	159°13.2′ W
110	T-4 460 m	Full	19°29.8′ N	162°14.2′ W
112	T-4 460 m	Full	18°16.2′ N	161°12.0′ W
112	T-4 460 m	Full	19°32.5′ N	162°27.5′ W
114	T-7 760 m	Partial (245 m)	18°41.7′ N	159°11.8′ W
114	T-4 460 m	Full	20°43.0′ N	157°58.3′ W
115	T-4 460 m	Partial (250 m)	21°28.4′ N	160°09.4′ W
117	T-4 460 m	Full	21°04.5′ N	158°41.2′ W
118	T-7 760 m	Partial (310 m)	19°58.6′ N	158°02.0′ W
120	T-4 460 m	Full	21°14.0′ N	160°24.1′ W
121	T-4 460 m	Full	19°25.1′ N	158°10.5′ W
121	T-7 760 m	Partial (350 m)	20°17.4′ N	160°12.4′ W
122	T-4 460 m	Full	18°58.0′ N	159°06.4′ W

3.5-kHz High-Resolution Profiling System

The 3.5-kHz reflection tow fish was deployed on 098/2315. The system was operational and official logging commenced at 098/2358. The system performed well with only routine maintenace throughout the course of the cruise. Generally, record quality degrades in water depths greater than 4800 m.

10-kHz Echo-Sounding System

The 10-kHz echo-sounding system employs a tow fish similar to that of the 3.5-kHz system, and was deployed on 098/2330. The system worked flawlessly, with down time restricted to routine maintenance, and blade and paper roll changes.

Two-Channel Seismic Reflection System

The two-channel seismic reflection system employs a 2600 cm^3 (160 in^3 air-gun sound source, coupled with an 800 m long, two-channel streamer (including a weighted stablizing line). Two 50 m long active sections are towed about 500 to 600 m behind the air gun. The air gun is fired every 10 seconds. Data is recorded on a MASSCOMP computer, and a one-channel, six-second analog record is displayed on a Raytheon line scan recorder (LSR) and a CRT monitor. The memory function of the LSR was used to print the profile with a constant orientation (west and north end of the profile are on the left, east and south profiles are on the right) and to reduce vertical exaggeration. Vertical exaggeration is about 4:1 at a speed of about 8.5 knots.

The two channel seismic-reflection system was plagued by a number of problems over the course of the survey. The streamer and air gun were deployed by 099/0100, but official logging did not begin until 099/0331 because the gun required time to pressurize and synchronize. Air hose leaks, MASSCOMP hang-ups, excessive streamer noise, and LSR jams required extra attention. Problems and solutions regarding the LSR were similar to those described in Holmes et al., 1987, and Normark et al., 1987 and 1989.

The LSR recorder was vulnerable to a loss of sweep/sync that was manifested by a decrease in the paper feed rate (about 50%). Record quality was not affected by this problem, that proved to be a dirty optical coupler on the A1 sensor board. Alert watch keeping, regular cleaning, and eventual replacement solved the problem.

The two-channel streamer proved to be a major source of problems. At 099/2200 channel 1 expired after degrading from random occasional noise spikes to total obliteration of the data. At 100/0225 the streamer was retrieved to determine the source of the noise. Initial inspection revealed that a few of the connectors appeared contaminated with salt water. Both active sections appeared slightly waffled, but were not stretched. All connectors were cleaned and the active sections were filled and reballasted with oil. The streamer was redeployed, but the affected channel showed no improvement. The streamer was retrieved again, and the first active section was then replaced with a new one, which solved the problem. We were operational again at 100/0614.

At 104/0206 the new active section was inspected to ascertain if stretching or waffling was occurring. It was not obvious. Despite the swap of the number 1 active section, the random, mechanical noise spikes were still being generated. At 104/1134 the spiking was so pronounced that we communicated the problem to Marfac at 104/2015. We were told that the problem appeared similar to that experienced on the previous leg, and that inspecting and cleaning the winch and lab connectors should solve the problem. We retrieved the streamer at 104/2100 and cleaned and inspected all the connectors. However, after re-deploying the streamer and noting improved signal to noise ratios, the noise remained.

By 106/1600 the quality of the data degraded such that the noise would be impossible to filter out during post-cruise processing. We retrieved the streamer at 106/1615 and performed continuity and noise tests to ascertain if we could duplicate the noise and isolate the bad connector or section. The connectors and streamer were inspected for cleanliness, salt water contamination, and potential pin damage, and all appeared well. We redeployed the streamer at 160/1851, only to find the noise was worse. We again retrieved the streamer at 106/1915, changing out the front three sections (the first stretch, the weighted and the first active). We cleaned all new and external connections, including the slip-rings and SRP connections. The streamer was re-deployed at 106/2100, and by 106/2119 the system was back on line and fully operational.

On 113/0845 the two-channel seismic reflection system again began to experience noise. By 113/1933 the noise level necessitated an inspection, and the streamer was retrieved, flaked out on deck and put through several diagnostic tests and a visual inspection of the streamer and connectors. We verified that the problem did not reside in the Geomechanique or SRP preamp, by swapping the banana plugs at the hydrophone interface and routing channel two of the streamer into channel 1 of the rest of the system. We then performed a series of continuity checks to establish which sections or connectors were creating the problem, and we attempted to ascertain if the noise was mechanical or electrical. All continuity checks proved to be negative.

Careful examination of the streamer and connectors showed evidence of two possible electrical problems. The first was a bundle of wiring in the lead stretch section that we believed was a factory defect. The bundle in question was sandwiched between the streamer jacket and a blue bulkhead/spacer, possibly crushing the wiring under the load created during survey operations. The second visible flaw was in the weighted section. The section showed evidence of internal chafing on the lead (Pb) weight strands and possibly the wiring, by the stainless steel cable used to prevent stretching. We believe this to be a Teledyne design flaw because we never towed the streamer at speeds of greater than 8 kt through the water.

To correct the problem associated with the lead stretch section, we swapped the lead and tail stretch sections to insure that the noise would remain behind the active sections. Routine inspection of all connectors showed that some had filled with oil, when they were all originally connected and deployed in the dry state.

The next step involved measuring all sections to determine if there were any that were stretched beyond specifications. This proved to futile because all sections were shorter than their nominal lengths, and there was no way to evaluate stretching. However, none of the sections appeared to be stretched.

Finally, a third active section was added to the configuration allowing us to bypass any problems that may arise in one of the other two sections. After undergoing a series of inconclusive diagnostic inspections, the streamer was re-deployed and on 113/1933 the system was operational with no visible noise.

On 122/1830 noise re-appeared on the streamer. It began as a random spike, and progressed until it was about 2 Hz and not as random as it was when it initially started. The bridge was asked to change prop RPM and most of the noise disappeared. Some random noise remained, but we discovered a valuable fact, that prop RPM and pitch could combine to seriously degrade the two-channel seismic reflection data.

The following is a summary of down-time for the seismic reflection system:

Component	Down	Up	Reason
MASSCOMP	099/0409	099/0450	MASSCOMP crash
Air gun	099/0915	099/1036	Air hose leak near gun
Air gun	099/1611	099/1700	Air hose leak near gun
MASSCOMPP	099/2016	099/2019	Reboot to clear noise
Streamer	100/0225	100/0614	Replace active section
Air gun	104/0206	104/2059	Swap air gun (routine)
LSR	104/0206	104/0259	Dirty optic coupler
Streamer	104/0206	104/0259	Inspect new section for stretch/noise
MASSCOMP	105/2258	104/2358	System failure
Air gun	106/0703	106/0810	Air hose leak
Air gun	106/1056	106/1228	Replace gun, bad solenoid.
Streamer	106/1615	106/2115	Noise in Channel one Replace weighted and first stretch sections, add ballast oil. Check all lab connections.
MASSCOMP	107/0531	107/0542	Crash on tape swap
LSR	107/1645	107/1900	Replace optic sensor board, general maintenance.
MASSCOMP	108/1959	108/2125	Printer out of paper caused tape to stop. Restart system. Program bug!
Air gun	109/1650	109/1812	Routine air gun swap New gun leaked owing to cracked connector. Changed connector between hose and gun.
Streamer	113/1933	113/2349	Degradation of data owing to excessive streamer noise in both channels. Complete diagnostic inspection, routine maintenance, and partial reconfiguration.

Air gun	114/0620	114/0642	Swap gun (routine)
Air gun	114/0920	114/1151	Replace gun, misfiring
Air gun	118/1350	118/1515	Gun not firing, bad air trigger lead. Fix lead and replace gun.
Streamer	122/1830	to end cruise	Streamer noise about 7 hrs before end of cruise. Change of propeller RPM removed most of the noise.

Shipboard Positioning Systems

Similar to Clague et al., 1988, and Normark et al., 1989, the shipboard positioning systems generally performed well. We were able to avoid most of the problems encountered during the first two GLORIA cruises (Holmes et al., 1987, and Normark et al., 1987) owing to the improved GPS network coupled with the addition of the real-time, rho-rho Loran positioning system. The new system (described in Normark et al., 1989) incorporates a real-time trackline display for the ships' bridge personnel, that displays ships position relative to the desired survey line.

The GPS system worked well, providing about 12 hours per day navigation. When GPS is unavailable, the rho-rho Loran C was used. The rho-rho performed well, except when close to the baseline between station X and the north side of the islands. The situation was particularly bad between the hours of 1400 and 1800 GMT, and during these times we relied on transit satellite fixes and hyperbolic Loran C processed by the ABC system aboard the Farnella. A review of the limitations of navigating with this technique is described by Holmes et al., 1987, and Normark et al., 1987.

The navigation system suffered from two re-occurring problems, one of which remains unexplained. The first problem occurred on 110/2230 when the computer that displays the ship track suddenly quit. The computer was removed from its cabinet and a few boards were removed and replaced, and the system came back up. The system was inoperable for about 1/2 hour.

The second situation occurred on 112/2025 and 117/2040, when navigation lost both LORAN and GPS to a succession of crashes with the LORAN program, the ARNET board, and data broadcaster.

The ARNET board hung up, halting all navigation output. The problem resided in an unknown power glitch. Recovery of navigation was made by turning the system off, and performing a hard start of the rho-rho computer. Assuming that the hard start re-initialized the ARNET board made it appear that the glitch occurred in the ARNET board. A new ARNET board and ISOBAR surge protector was requested by the chief navigator to keep the situation from reoccurring on future cruises.

Hard starts following system crashes were plagued by what the navigator called a reformatting of the floppy disk, onto which the navigation data are stored. Unfortunately, the result of this apparent reformatting is a loss of much of the previously collected navigation. The situation was not flagged by either prompts or messages from the computer, and thus the navigator did not realize the data loss was occurring during the hard start. Only after the navigation system was operational did we realize that the disk had substantially more storage space than it had prior to the hard start. A request was made to reprogram the system during the port stop, thereby eliminating the problem.

GLORIA Side-scan Sonar System

The deployment and operation of the GLORIA system is covered in extensive logs by the IOS personnel. More detailed summaries are available in Sommers et al., 1978, Laughton, 1981, and references therein. A summary of the GLORIA pass record and the number of files is presented in Appendix 2. Note that one pass equals 6 hours.

The GLORIA system was launched on about 098/2330 and operated flawlessly for the duration of the survey. Except for course changes, the system operated continuously until the termination of the survey on 123/0325.

GLORIA Shipboard Image Processing

The techniques employed in shipboard processing are described in detail in Normark et al., 1987 and 1989, and accordingly will not be elaborated upon here. Unlike Normark et al., 1989, no special shading techniques were applied. Following the printing of the GLORIA images, the images were laid down over corrected and smoothed navigation plots and mosaiced. Interpretations of the images, contouring the bathymetry, and isopaching soft sediment thickness was done following the mosaicing.

PRELIMINARY SCIENTIFIC RESULTS

Summary of Observations, F5-88-HW

1. An enormous blocky slide (roughly 6000 km^2 in area and at least 3000 km^3 in volume) extends southward from the Kauai margin, filling a major portion of the Oahu Deep. It is generally similar in surface morphology to the previously described Alika and Lanai slides, but larger than both. Our observations suggest that the slide is moderately old and could have formed during the active island growth phase of Niihau-Kauai, as is suggested as a mechanism for huge slide initiation off Hawaii through study of the Alika slide (Lipman et al., 1988).

2. The western Oahu margin is the site of major mass wasting of a different style from that observed off south Kauai. A large rotational slump (3500 km^2) composed of enormous blocks up to 30 km long, appear to have slid down 2000 m of slope, more or less intact. The surface lacks the blocky facies of the other large slides off the Hawaiian ridge, suggesting that the slide may be deeper rooted than the south Kauai slide.

3. The Molokai Fracture zone was mapped for more than 500 km from the 200 mile EEZ limit into the Lanai Deep. The strike across most of this distance is 076°, apparently changing to 085° in the Lanai Deep. Gloria imagery is best to the west where the thick turbidite sequence from Oahu Deep has not obscured the tectonic fabric. Internal morphology is complex, with a typical profile consisting of troughs both north and south of a medial ridge. In some profiles there are multiple fracture zone "strands".

4. Fresh-looking lava flows were identified in two areas of the survey. A site on the ridge between

Oahu and Kauai is the locus of four flows and numerous conical vent structures. The lava flows and vents cover about half of an area 1500 km^2, extending from a depth of at least 3000 m to the base of the slope at 4500 m. The vent field occurs beneath volcanic activity reported in 1956 by pilots; if associated, then these may be recent.

The second set of lava flows is on the rise that separates the Oahu and Lanai Deeps. Flows here are not associated with small cones, but rather with smaller seamounts atop the broad rise. There is less certain indication of their age than for the other field, but they have a distinctly "fresh" appearance on the GLORIA mosaic, and appear to intrude and/or overlie adjacent sediments as based on the 3.5 kHz records.

5. Sediment distribution in the western end of the region is simple. Aside from transparent drape, there is a single source of turbidite sediments, mainly originating from the Oahu Deep. The turbidites cross the Molokai Fracture Zone near 160°30′ W where the fracture zone troughs have filled and the ridge apparently buried. The turbidites are diverted northwards around the edge of the seamount complex, and follow the seafloor fabric, oriented about 166°, gradually thinning to the south. Sediments thin fairly rapidly from >50 m near the Molokai breach point to less than 20 m on our outer lines. A transparent (pelagic ?) drape of 10 to 20 m is observed to overlie the turbidites throughout the entire area surveyed, and we interpret this to show that major turbidity current activity ceased not long after the cessation of growth of Oahu. It is possible that a major component of the turbidite apron is associated with the Kauai slide and/or the West Oahu Giant Landslide, although there is no real way to know without sampling.

RESULTS

Owing to the extensive existing coverage, we have opted to present this report as a series of topical sections, guided by the results obtained previously. We were fortunate in having copies of cruise reports from each of the previous three Farnella GLORIA legs and the ground-truth leg with us, as well as copies of the shipboard mosaics from the previous leeward side survey (though not the windward side surveys).

The topics addressed will include the following:

1. Cretaceous Sea Floor
   a. Molokai Fracture Zone
   b. Seafloor Spreading Fabric
   c. Seamount Distribution and Characteristics
   d. Sediments and 3.5 kHz Echo Character
   e. Sediment Dispersal Patterns
2. The Hawaiian Hot Spot
   a. Quaternary Volcanism
   b. Lithospheric Flexure: The Trough and Arch
3. Island Degradation: Slumps, Slides and Debris Flows
   a. Lanai Platform
   b. Oahu Margin
   c. Kauai Margin
4. Topography of Unknown Origin

1. Cretaceous Sea Floor

a. Molokai Fracture Zone

Surveys of the Molokai Fracture Zone (MFZ) on the leeward side were carried out in two parts. The westernmost portion of the Molokai to lie within the EEZ was surveyed on six crossings, one line approximately parallel to the MFZ and two short segments between crossings. These lines were run during the first 14 days of the cruise. Following surveys of the Oahu and Kauai platform slopes, the remainder of the MFZ was surveyed as the outer Oahu Deep surveys were completed during the final week of the cruise.

Figure 3 shows the major tectonic lineations within the Molokai Fracture Zone (MFZ). The MFZ strikes consistently 076° over most of the 440 km where it is recognizable on the GLORIA mosaic.

The westernmost 50 km surveyed is oriented more northerly than the main trace (about 065° rather than 076°) and there is an oblique ridge intersecting the fracture zone near its eastern termination on the GLORIA image. There is also evidence for a continuation of a buried ridge eastward (from its eastern termination on the mosaic) along the 076° trend for another 100 km, in the bathymetry contours that were prepared using the 10 kHz echosounder data from this cruise.

The fracture zone is bounded to both the north and south by ridges that enclose deep troughs and up to 3 fracture zone strands that are generally parallel to the major 076° trend. The character and relief of the southern ridge varies considerably along the feature. In contrast, the northern wall is very straight and uninterrupted west of 161°20′ W; east of this point turbidites appear to fill the adjacent northern trough so that the wall is no longer visible. There is considerable topography, and the northernmost fracture zone trough shoals from a maximum depth depth of more than 5400 m in the west to less than 4800 m less than 100 km to the east. The western MFZ is relatively barren of sediments except within the deep trough(s) of the fracture zone, and thus the surface texture and tectonic fabric are apparent in the GLORIA images. Contrasting, the eastern termination of the MFZ probably results from its burial by the turbidites of the Lanai Deep, and thus, only the central ridge structure of the fracture zone there is recognizable (fig 3).

In the west, between 162°00′ N and 162°20′, within the MFZ one observes that the lineations on the central ridge are highly oblique to the overall MFZ trace, being oriented at about 326° (an equivalent MFZ strike would be 056°, or almost 20° clockwise). The corridor on which they rest is oriented at about 076°. There is evidence on the south side near the western limit of the MFZ survey, of a subsidiary strike of about 055°, however, directly linking the MFZ with a deep rift to the south, located at about 19°00′ N and 162°00′ W (figs 3 and 4). The likely explanation for these lineations lies in the presence of this deep rift south of the MFZ. The rift neatly splits a seamount in half near 18°50′ N, 162°00′ W (fig 4), and is almost certainly an abandoned spreading center. For it to be retained on the plate, the ridge must have jumped east. We suggest that the ridge jumped to a point only about 30 km east where the new orientation of 076° in the intra-strand lineations begins. The presence of a ridge jump in the near vicinity of a change in fracture zone azimuth suggests why there may be some complexities in the structures observed further east.

East of the ridge jump section the fracture zone broadens somewhat, and five discrete parallel strands are observed between 161°30′ N and 162°00′ W, all with spreading lineations, and all showing sinistral bends at the strand margins (fig 3). They are located, as are most of the well lineated segments of the MFZ, on a local bathymetric high. The suggestion is that following the ridge jump and reorientation, the change in spreading direction was accommodated by formation of multiple small relay segments. A similar geometry has been postulated by Gallo et al., 1987, for the Siqueiros Transform Fault and by Searle et al., 1986, for several of the multiple offsets of the East Pacific Rise.

Contrasting the western termination of the MFZ within the survey area, the termination of the Molokai Fracture Zone at the eastern end may result from its burial by the turbidites of the Lanai Deep, as suggested by a slightly shoaling ridge continuing in the bathymetry. However, the structures visible on the GLORIA mosaic suggest that there were also significant tectonic changes near the point of disappearance. The termination on the side-scan occurs at 20°00′ N 159°00′ W. Extending the fracture zone from this termination point along the 076° strike would place the central fracture zone ridge directly beneath the insular slope of eastern Maui as it crosses the Hawaiian Ridge, and aligns with strand C of the four strands described from Leg F4-88-HW on the windward side (Normark et al., 1989). There is also an oblique ridge intersecting the fracture zone near its termination that we interpret as the extension of the fracture zone to the east. This probable change in orientation, discussed below, suggests that a simple direct extension of the main fracture zone beneath the island chain is probably incorrect, and that the intersection probably lies further to the southeast. It also makes correlation of individual strands on the windward and leeward sides difficult.

Immediately south of the eastern termination of the MFZ, at 19°45′ N, 159°30′ W, a ridge branches off to the east striking 095° (a 20° divergence to MFZ trace). The extrapolated point of connection between the two features comes at 19°50′ N, 160°00′ W, where the MFZ exhibits highly oblique lineations in the terminal strand. This 095°-striking feature connects with the highly elongate Powers Seamount, which is nearly orthogonal to it, and shows the sinistral bends at both terminations that characterize the smaller fault blocks observed so commonly in the "strands" or "relay zones" of the MFZ. It seems possible that the extrapolated intersection between the MFZ and the 095°-striking ridge is the point at which "strand A" of the windward side (Normark et al., 1989) intersects the south side of the Molokai strand that we surveyed on this leg. In fact, there is a clear bend in the underlying spreading fabric immediately to the east, from 074° to 083°, as seen near 19°45′ N, 158°30′ W, strongly supporting this as the intersection point, therefore making the more easterly-striking orientation of the MFZ the younger.

The possible position of the spreading center on the north side of the fracture zone at the time of the reorientation is suggested to be near 21°00′ N, 161°10′ W. There is a 10° bend in the orientation of the northern fracture zone wall here, and a seamount or ridge structure developed at the intersection point. Unfortunately, this lies at the northernmost edge of our survey, and we must await the fall cruise until this region is properly imaged.

There are, however, further complexities in the tectonic pattern in the vicinity of the MFZ termination, and we may be looking at a region where some amount of non-rigid plate behavior, an abandoned spreading center and/or formation of a small microplate interfere with a simple interpretation. In particular, a structure north of the termination oriented perpendicular to the MFZ strike near 20°30′ N, 159°20′ W connects via a series of MFZ-strike bright reflectors to a short ridge segment (?) striking about 010°, similar to Powers Seamount. This could result from simultaneous changes in the spreading direction on two parallel strands of the MFZ in the simplest case, but we have no evidence of such a parallel strand further to the west. It is necessary for the subsequent leeward leg to determine whether a parallel fracture zone trace exists before we can call on this simplest explanation for these ridge structures. More detailed study of the data collected is necessary to unravel the complex history of this feature.

A final note concerning the westernmost segment of oblique spreading orientation is that it is possible that this could be the equivalent of the northern strand observed on the windward side if the eastern portion were subsequently abandoned at a later eastward ridge jump.

b. Seafloor Spreading Fabric

Holmes et al., 1987, describe the crust away from the Hawaiian Ridge as having a NNW grain, which they infer to be primary spreading fabric (e.g. parallel to original spreading direction) of horst-graben character (figs 3 and 5). Individual faults are spaced 5-15 km and are 50-150 m high, with lengths of "many tens of km". They are blanketed by sediments "up to 15 m thick", although locally ponding is observed. The fabric is less evident as one approaches the Hawaiian Ridge due to blanketing by sediments from the volcanic ridge and islands; sediment thickness becomes difficult to determine owing to a concomitant increase in surface sediment reflectivity and reduced penetration by the 3.5 kHz echosounder. It is unknown how much of the apparent reduction in observed crustal fabric results from sediment burial and how much from extrusive volcanism and/or re-cracking of the crust tectonically.

Normark et al., 1987, describe similar grain southeast of the islands, but state that "relief on the present fault scarps is commonly 20-50 m, rarely as much as 100 m" and "where most conspicuously developed, spacing of the faults seems to be in the range 2-5 km, although any quantitative treatment of spacing tends to be biased towards the larger faults." They suggest that spreading was more rapid than that occurring on the Juan de Fuca and Gorda Ridges based on smoother character of the seafloor, and also suggest that spacing and relief might be useful as indicators of spreading rate during the Cretaceous quiet zone period.

Normark et al., 1989, discussing the seafloor east of Hawaii, describe a 5-10° change in orientation of seafloor spreading fabric north and south of Molokai Fracture Zone, with lineation north of the MFZ 165-168°, and south of it 173-176°. We note, based on the results from this leg, that the predominant spreading fabric of most of the region west of Oahu is about strike 165°, normal to the observed trend of the Molokai Fracture Zone to the north. The fabric is difficult to measure accurately within the seamount province, but in the easternmost part of our survey area the trend is clearly more northerly (about 175° rather than 165°), and this apparently holds true throughout the remainder of the seamount province (in those fairly rare areas where well developed, straight fabric is observed). There is also a clear bend in the spreading fabric east of the "join point" where we believe the F4-88-HW strand A takes off (Normark et al., 1989; see near 19°45′ N; 158°30′ W), and there are some parts of the western MFZ in which oblique fabric is locally observed. The spacing of fabric has not been evaluated quantitatively. As the above reports note, it is of the scale of a few kilometers, and it seems that particularly the western portion of our surveys would be a good region to quantitatively evaluate the statistics of horst-and-graben spacing.

The seafloor fabric is obscured throughout the eastern Oahu Deep by thick sediments, and we were unable to determine orientations anywhere north of the MFZ other than in the Lanai Deep east of the termination point.

c. Seamount Distribution and Characteristics

Numerous seamounts, ranging in diameter from less than two km to a maximum of 25 by 50 km, were imaged during the survey (figs 3 and 5). The overwhelming majority are part of the large seamount province first imaged by Normark et al., 1987, and stud the seafloor south and west of the island of Hawaii. Most seamounts lie in a corridor between 157°00′ W and 158°00′ W and 15°30′ N and 18°00′ N, although others are infrequently scattered throughout the survey area.

Seamount height ranges from a minimum of less than 100 m to a maximum of about 2500 m. Seamount shape varies from near textbook examples of fresh, symmetrical cones with summit calderas to old-appearing, dissected edifices and multiple-peaked elliptical ridges. Some of the older seamounts are saddled with lows between the crests. At least two guyots were also imaged and they appear to be capped with sediment.

One interesting observation is the juxtaposition of both young and old-appearing seamounts. The older ones display a prolonged 3.5 kHz echo character, and are interpreted to be mantled with coarser volcanogenic debris. The older and larger seamounts also show evidence of gravitational slide/flow deposits along their flanks and out to the surrounding plain. Some appear to be surrounded by debris aprons or lobes.

The most obvious point concerning seamounts observed during this leg is the extremely sharp boundary between the seamount province east of 158°00′ W and the horst-and-graben terrain to the west. The boundary is extremely sharp, although it was not entirely imaged during the present cruise. There is a pronounced seamount chain running east between 15°30′ and 16°00′ N from 158°00′ W, an area generally described as the "Snowden Seamount Group" on the Chase, Menard and Mammerickx chart (Bathymetry of the North Pacific, 1970). The reason for this linear chain's development is not known, although two obvious possibilities are hot spots and fracture zones. It will be necessary to examine the numerous trends in these and the seamounts further north that were surveyed in 1986 before the overall pattern can be discerned.

We saw no fresh appearing lava flows within the seamount province, although there was a region of fresh lava on an adjacent line surveyed in 1986 and subsequently sampled (Clague et al., 1988). At this point we have no evidence to suggest that any of these features are younger than the seafloor on which they reside.

Many of the seamounts surveyed were uncharted, and some that were charted were mislocated. The largest new seamount rises to shallower than 3000 m with a base of about 25 by 50 km^2, and sits at the southeasternmost extremity of our survey pattern near 15°30′ N, 155°15′ W.

Outside the seamount province, seamounts are far less frequent, and even small circular hills are almost absent for hundreds of km^2. This is unlike the section of the East Pacific Rise between 13°-15° N, where SeaMARC II surveys identified more than 100 seamounts within an area of 55,000 km^2 (Fornari et al., 1987, and personal communication). Scattered seamounts are present, however, with more in the general vicinity of the Molokai Fracture Zone than further SE and a concentration extending NW from 158°00′ W into the Oahu and Lanai Deeps (fig 3). Of particular interest here are several elongate seamounts, including Powers Seamount, all oriented more or less N-S. They may have some relationship to the spreading history south of the Molokai Fracture Zone, possibly representing short abandoned spreading centers formed during the time of reorientation from strike 076° to 083° (see above).

d. Sediments and 3.5 kHz Echo Character

The sediment cover in and around the Hawaiian Ridge consists of pelagic and volcanogenic material. The thickness of sediment blanketing the volcanic basement is a function of age, proximity to source and dispersal pattern. The thickness typically ranges from a minimum of under 5 m to 50 m as based on 3.5 kHz profiles, although some basinal, flat-lying sediments that are interpreted to be turbidites, have thickness of up to 0.5 seconds on air-gun profiles. Most of these turbidites are interpreted to reflect the building phase of island development, whereas the transparent sediment that drapes the seafloor of the survey area is interpreted as reflecting the deposition of pelagic and possibly airborne material, with lesser inputs of turbidite derived sediment.

GLORIA images the thickest sediment as low backscatter material (fig 4), and thinly covered areas are imaged as higher backscatter (fig 6). The 3.5 kHz echosounder and two channel seismic reflection systems display a variety of reflection characters, and the combination of these two techniques provides additional information on thickness and facies variations within the sediments around the Hawaiian Ridge.

Bottom types are divided into groups based on 3.5 kHz echo character. In general, areas returning distinct bottom reflections with continuous to discontinuous, parallel subbottom reflectors are thought to contain fine silts and muds, with little or no coarse sediment. Areas returning distinct but prolonged bottom reflections with either no or faint subbottom reflectors are believed to have higher concentrations of coarser material and a thinner sedimentary cover. Hyperbolic returns are typically associated with either rugged seamount crests, slide material produced by gravity-controlled mass flow or failures (debris avalanches or flows), erosional surfaces (gullied or furrowed), or rugged lava flows.

The variety of echo characters observed during our surveys, and the inferred sediment types determined from the 3.5 kHz profiles are listed below:

1. Strong bottom reflector with multiple, parallel (well laminated) subbottom reflectors. Some areas have a relatively thick transparent cap (figs 7 and 8) that is draped over the seafloor topography (equivalent to Normark et al., 1987, acoustically transparent basin sediments). These are interpreted as pelagic and fine-grained interbedded pelagic and turbidite deposits. Generally, turbidites are located below the transparent drape.

2. Same as above, with little or no transparent cap, but with multiple, parallel subbottom reflectors. They are typically flat-lying and basin filling, and do not drape the seafloor topography. This facies is equivalent to Normark et al., 1987, acoustically opaque basin sediments. Interpreted as relatively coarser material derived primarily from turbidites and composed of volcanogenic material.

3. Prolonged reflectors with faint or no subbottom reflectors (equivalent to Normark et al., 1987, smoothly reflecting slopes). These are believed to indicate coarser volcanogenic sediment on steep

slopes or flanks of seamounts, and thin cover over older flat lava and Cretaceous seamounts.

4. Mushy reflectors with weak to faint surface reflector and no subbottom reflections. Interpreted to be "fresh" lava flows such as those evident on Line 27, 118/0800-118/1200 GMT (fig 7).

5. Hyperbolic reflections and weak acoustic returns that are equivalent to Normark et al., 1987, rough bedrock bottoms. These are indicative of two situations: (a) rough bedrock bottoms with weak returns and hyperbolics that reflect the rugged and irregular crests of seamounts, with only a limited and coarse sediment cover; or (b) a strongly hyperbolic bottom with intense reflections associated with the hummocky submarine landslide and debris avalanche deposits along the Oahu-Kauai margin (fig 8). Also associated with the rough and gullied topography along the upper portion of the margin (Lines 20-20D).

e. Sediment Dispersal Pattern

Sediment distribution, based on acoustic penetration on the 3.5 kHz subbottom profiler, was digitized every 6 minutes and plotted over bathymetry contours for all surveyed regions. While this map (which is not included in this report) does not exactly represent total sediment thickness, particularly near the islands, it gives a good first order picture of the dispersal pathways and sedimentary processes, and for the areas further from the islands it gives a fairly accurate picture of total sediment accumulation.

The most obvious feature of the outer part of the leeward EEZ is that the seamount province and the crustal segment lacking seamounts differ considerably in the amount and distribution pattern of the soft sediments. The seamount province shown in figure 5 has a thin 5 to 20 m cover of sediments. The pattern is locally complex, but fundamentally controlled by proximity to seamounts, from whence sediments are shed to preferentially accumulate on adjacent lows. Similarly, the seafloor to the northwest, between the seamount province and the Molokai Fracture Zone seen in figures 3 and 5, shows a pattern of preferential accumulation in the long, linear lows of the horst and graben texture formed at the spreading center. There is a larger pattern superimposed, however, resulting from turbidite transport away from the Hawaiian islands, and a local maximum occurs in a long, narrow band aligned with the crustal fabric.

Turbidites have crossed the Molokai Fracture Zone from the Oahu Deep in the vicinity of 160°15′ W to 160°30′ W, and the bulk of turbidites observed south of Molokai Fracture Zone in our western surveys apparently originated on the margins of Oahu Deep rather than islands further east in the chain. There is, however, a contribution from Lanai Deep, and the pathway is well defined around the nose of the main strand of MFZ, across the more easterly-striking ridge immediately adjacent (at about 19°45′ N, 159°15′ W, and then along the western margin of the seamount province. In fact, there is a particularly well developed set of abyssal bedforms along this route near 18°55′ N, 159°20′ W, just west of Bishop Seamount, at a point where the local gradient steepens sharply and basin width is restricted by topography on both sides. These deserve further study with higher resolution side-scan and sampling to discern their nature and age.

Sedimentation patterns closer to the islands are more complex, owing to the interaction of slope failure and other sediment transport processes operating in the islands. The extremely thick sequence of blocky slide material south of Kauai could arguably be called something other than sediments (as there are no sieves available for measuring grains in the -14 to -15 phi range). We estimate, based on airgun profiles, that the south Kauai deposit is between 500 and 1000 m thick on average, and we believe that it is as thick as 1200 m near the toe (fig 9). A large slump on the Oahu margin is probably similarly thick, at least at the toe, where the basal ridge rises more than 1000 m from the basin floor. The central basin of the Oahu Deep has variable thickness of turbidites, probably 100 to 400 m is typical for water depths below 4600 m. The cap on the Oahu Deep sediment section is not turbidites, however, but rather a sequence of 10 to 30 m of transparent material, indicating that even in the lows turbidite deposition ceased soon after the main phase of island building ceased 3 to 5 million years ago (Kauai, Oahu).

2. The Hawaiian Hot Spot

a. Quaternary Volcanism

Two lava fields were mapped during the cruise, one on the flanks of the Oahu-Kauai Ridge and one over the rise (possibly the trace of one strand of Molokai Fracture Zone) between the southern

Oahu Deep and Lanai Deep (figs 6 and 10). There is also an indication on the GLORIA mosaic of one relatively fresh lava flow within the blocky terrain of the south Kauai slide, although there is no supporting evidence from the 3.5 kHz profiles. Lava flows are recognized on the GLORIA records as patches of sea floor with high backscatter and irregular margins (fig 6), and no perceptible relief. They tend to return a uniform, high backscatter. Except for small cones, they rarely show much other evidence of internal relief. The 3.5 kHz records over the flows typically show a "mushy" return (fig 7) consisting of numerous extremely small overlapping hyperbolae (such as one would expect from pillow-size roughness elements). The subbottom profiler also commonly shows an abrupt transition from acoustically laminated sediments into the lava flow with only a meter or two of relief, and sometimes none.

The lava field on the Oahu-Kauai Ridge (figs 6b and 10) lies just downslope from the site of a report of discolored water by U.S. Navy and airline pilots and fishermen on May 22 thru 28, 1956 (Macdonald, 1959). The flows thus may be very recent. The youngest known flows on Kauai are 0.5 MY and occur on the east coast (D. Clague, personal communication). A number of small volcanic cones lie at the upslope end of the lava field. Water depth over the flows ranges from 3800 to 4600 m, extending up to depths of 2800 m over the shallowest recognizable cones. It is possible they extend even shallower, as the extremely high reflectivity from the starboard (upslope-facing) side of GLORIA obscures features on the upper slope. The field occurs within an area roughly 60 km long and 25 km along the slope, and consists of 4 discrete lava flows and numerous small conical vents. Three of these flows are in contact with one another, though distinguishable, and it is possible that each of the four flows emanates from multiple vent sources. There is no obvious rift or linear source for the flows. Small cones are observed both within and adjacent to the flows, typically 1000 m diameter or smaller, with estimated relief of < 100 m. Some cones appear to have axial calderas, or at least low backscatter zones on top. Backscatter of the flows varies somewhat on GLORIA images, due at least in part to varying range from the vehicle and insonification direction, but probably indicating to some degree different amounts of burial by sediment cover and/or facies changes. The only flow crossed directly had the highest backscatter, and the absence of detectable sediment cover over it on the 3.5 kHz profiler does not necessarily show that the other flows are as recent. There does seem to be a progression from fresher appearing flows high on the ridge to lower backscatter, and hence possibly older, flows deeper on the ridge flank. If this is the case, then it suggests that the most recent volcanic events are probably occurring near the small vents and vent clusters upslope from the shallowest flow.

The lava field over the rise between Oahu and Lanai Deeps (fig 6a) covers an area of about 1000 km^2. It sits on a broad ridge separating Oahu Deep and Lanai Deep. The ridge lies immediately north of the principal (076° strike) trace of the Molokai Fracture Zone. There are indications within the lava field of both spreading- and fracture zone-parallel topography, although owing to the surrounding high reflectivity of the lava flow they do not stand out well on the shipboard records. Shadows and more irregular returns, however, are similar in character to images from further west in the fracture zone, and the 3.5 kHz shows local relief of 200 m or more above the lava flows. The flows themselves have little or no relief above the adjacent sediments (fig 7).

We encourage sampling of both the Oahu-Lanai Basin and Kauai Channel flows later this year to determine their age and nature. It seems advisable as well to sample the seamounts of the Oahu-Lanai Basin region to determine whether the structures here are related to the flows.

b. Lithospheric Flexure: The Trough and Arch

Crustal deformation related to the load of the Hawaiian chain appears to have continued in the Oahu Basin after deposition of turbidites. There is a small but pronounced seaward rise from the western margin of the Kauai slide towards the Molokai Fracture Zone, which is almost certainly a result of either continued depression of the lithosphere adjacent to the island chain or a seaward elevation as compensation. The turbidite plain that we presume sloped westward at the time of deposition, now rises towards the west by about 30 m between 21°20′ N, 159°50′ W and 20°45′ N, 160°30′ W, a distance of 75 km, before returning to a more normal downward slope along the sedimentation pathway. The well developed trough and swell observed on the windward side is absent on the south side of the chain, presumably owing to substantial infilling by turbidites. The steepened westward gradient near Bishop Seamount probably marks the region immediately west of the crest-line of the Hawaiian Arch, however, and the axis thus probably extends roughly along the 4600 m contour connecting 19°00′ N, 159°00′ W and 20°45′ N, 160°30′ W.

3. Island Degradation; Slumps, Slides and Debris Flows

a. Lanai Platform

Figure 11 shows the location and extent of the major slides surrounding the Hawaiian Islands, including the Lanai slide. Lipman et al., 1988, discuss the Lanai Platform slope slide segment that was imaged in 1986. The source area is indicated as 1000-3000 m on the margin; it is seen as at least 100 km long on the imagery obtained in 1986. They suggest that "the Lanai slides may have caused the giant tsunami that washed as high as 325 m on adjacent islands at about 100 Ka (Moore and Moore, 1984)" but state a need for more information on size and age.

During the present leg we completed the GLORIA imagery of the Lanai slide, obtaining two passes further to the west that define the western boundary of the blocky slide (fig 11). This boundary does, as predicted, roughly coincide with the bulge in bathymetric contours that they discuss.

b. Oahu Margin

A feature named the West Oahu Great Landslide by Campbell et al., 1987, extends 100 km along the southwest Oahu and Penguin Bank slopes (figs 10 and 11). The toe of the feature, which has the appearance of an immense rotational slump, lies about 35 km seaward of the slope break off southern Oahu, arcing closer to the slope off Penguin Bank. Except for a small, indistinct patch of blocky slide material near 21°00′ N, 158°50′ W the failed mass does not resemble the large blocky slides observed elsewhere on the leeward side.

Image interpretation was helped considerably by detailed contours provided by J. Frisbee Campbell of two planned submarine telephone cable routes through the WOGL. The principal features of the slope within the WOGL are four large ridges, each about 30 km long and subparallel to the slope, which vary from 2 to more than 10 km wide (fig 10). These blocks rise several hundred m above the adjacent slope; their linear shapes suggest failed pieces of the uppermost island slope. If this is the case, then they have slid varying distances between about 15 and 30 km. The two segments that have slid the furthest lie immediately upslope from the toe of the slump.

In addition to the four large blocks, there are many other reflective targets, mainly aligned up- and down-slope, which are interpreted as debris trails from the larger pieces. There is also a large gash, or canyon, bounding the WOGL on the northern end. This feature trends parallel to the north coast of Oahu, and appears to extend from a fault connecting it to the north coast. It may be the principal failure zone, and if so, the slump must have rotated, opening towards the SE as it slid. This is consistent with trailing structures behind the westernmost block, that show it opening to the SE.

The slump toe over the northern 75 km of the WOGL is a steep slope of 1000 to 1500 m rising from the basin turbidites more than 4600 m deep to a bench or enclosed trough at about 3000 m. There appears to be a large mass, near 21°00′ N, 158°40′ W that has shed blocks into the basin, perhaps owing to oversteepening (there does not appear to be a trough, though).

The presence of the WOGL immediately across the basin from the south Kauai slide (next section) and just around the corner from the Alika and Lanai slides raises questions about the mechanics of slope failure and about the mechanisms proposed for initiation of the blocky slides. The only information available on the ship about slopes off the west and northwest Oahu margin was the bathymetry contours on the base maps. These data do show that gradients reach 15° over the section between 1000 and 2500 m west of Oahu -- similarly steep slopes are observed on the southern Hawaii margin. Steep slopes and seismic activity accompanying dike injection along rift zones, are proposed to have resulted in initiation of the blocky slides of the Alika slide (Lipman et al., 1988).

If the steep slopes are a principal cause of the initiation of movement, then one must ask the question "Why are the Oahu blocks so large, and why don't they continue past the base of the slope out into the basin?" It seems unlikely that an entire set of smaller blocks are buried beneath the Oahu Deep turbidites, and the other blocky slides show the "typical" blocks of a few hundred to a couple of thousand m diameter well up the slopes in any event. Another problem concerns the nature of the slump toe. The abrupt termination at a 1000+ m wall, together with what look like deformation structures, suggests ductile behavior of the slide mass followed by an abrupt halt to the flow. This seems inconsistent with basalt or reef limestone blocks unless the slump is thick, and the stresses resulting in fragmentation are not transmitted to the slide surface except locally.

At this stage we have not been able to define the base of the Oahu slump mass in the air-gun records. More work is necessary to complete the descriptive phase of study of this feature. A satisfactory interpretation of its mode of movement and the reasons it is so different from that of the nearby blocky slides, seems a ways off.

c. Kauai Margin

Normark et al., 1989, briefly describe an enormous slide on the southern Kauai margin, that they encountered on their final line that was run to the lee of Kauai to be in better weather if problems occurred with the winch while retrieving GLORIA.

The slide off southern Kauai covers the largest area of the three huge blocky slides (Alika, Ka Lae, Lanai, Kauai) observed on the leeward side of the Hawaiian chain (figs 10, 11, and 12). The blocky portion of the south Kauai slide covers an area roughly 60 by 100 km, or 6000 km^2 (figs 10, 11, and 12). We estimate a slide thickness of 200 to 1000 m based on seismic profiles and bathymetry (fig 9). Using an average thickness of 500 m gives a slide volume of 3000 km^3 for the blocky portion alone. For comparison, the total volume of the Alika slide (the largest described in the literature to date) has been estimated to be 1,500 to 2,000 km^3, of which less than half comprises the blocky section. The area of the Lanai slides is intermediate between the two. For further comparison, the total volume of the existing Niihau pedestal from sea level to 2000 m depth is about 4000 km^3.

The south Kauai slide appears to have three lobes (fig 12), with the principal lobe the oldest, extending seaward almost directly from the Kauai-Niihau Channel. The toe of the principal lobe is located at 117/1400 GMT, on line 26, 150 km seaward of the Kauai-Niihau Channel (figs 9, 10, 12 and 13). Given the volume of the slide, this lobe may have removed a major portion of Niihau, and possibly an older island or shoal connecting the two remaining islands. Assuming 1200-2400 km^3 in the principal lobe, a slab 15 to 20 km wide and 2 or 3 km thick connecting the entire 40 km between the Niihau and Kauai could have been removed.

The postulated second and third lobes are based on subtle ridges of blocks observed within the slide mass, both of which penetrate towards the west, and both of which appear to have originated on the Kauai margin. We are not able to estimate thickness of either, as they lie over the main lobe for most of their course, and there are no obvious internal reflectors on the seismic profiles. The youngest, which has the most westerly course, and that is almost immediately adjacent to the base of the Niihau slope, heads at a broad canyon off SW Kauai, the floor of which is littered with blocks seaward of 2500 m water depth.

Block size within the south Kauai slide varies from pixel dimensions (50 x 125 m) to discrete pieces more than 5 km on a side. Discrete blocks have relief of at least 50 or 100 m on 3.5 kHz records, as seen in figure 14 where three buried blocks were observed immediately seaward of the toe. Most recognizable blocks fall in the 500 m to 2 km size range, although there are numerous smaller pieces. In general appearance, the blocks making up the south Kauai slide are larger and more widely spaced than those in the Alika, and similar in size but more widely spaced than those in the Lanai complex. This may be deceptive, however, as the smaller blocks of the Kauai slide may be buried, in contrast to the Alika and Lanai, both of which are discussed as Late Pleistocene (100 Ka?) events.

The toe of Lobe 1 of the south Kauai slide is an abrupt ridge rising 400 m in less than 5 km, then more gently rising another 400 m in an additional 15 km (line 26, 1242-1406 GMT; figs 8, 9, and 13). The blocky slide rises through and above surrounding turbidites of the West Oahu Basin, and about 0.5 seconds (600 to 800 m) of turbidites are seen to bury blocks forward of the main slide mass, which extends about 4 km beyond the turbidite apron. Assuming the seafloor was flat at this point, then the slide approximately 10 km back from the original toe was at least 1200 m thick, at a point more than 100 km from the Niihau margin (and more than 80 km from the base of the modern Kauai-Niihau slope). Although the shipboard monitor records have severe side echo and ringing problems in the blocky slide terrain, the base of the slide does appear to have been imaged reasonably well throughout much of the area, and appears to be typically 1 second or deeper below the seafloor (fig 9). There are also suggestions of imbricated sheets of debris within the forward section of the slide, although ridges on the surface will give side echoes with similar character (fig 9). Processed seismic lines will be an important element of the study of the Kauai slide, and unlike the Alika where thickness could not be directly measured from seismic profiles, there does appear to be a possibility of preparing an isopach map of the south Kauai slide. Up to 27 m of transparent sediments are seen on the more gentle slope near the front of the slide (1250-1310 GMT, line 26; fig 8). This observation suggests that the slide is quite old, although there is no direct evidence in our data for either absolute or relative age other than partial burial, and we have no information concerning either regional accumulation rates or the possibly important contribution of suspended fine-grained sediments of the slide event itself. (Note, however, that the Alika slide blocks show only a few cm of sediment -- Lipman et al., 1988). The observation of substantial sediment cover is consistent, at least in a general way, with the interpretation by Lipman et al., 1988, that the Alika slides results from oversteepening, unbuttressed slopes, dike injection, and seismic activity occurring during the island-building phase. Probably the most effective means of dating the slide would be to drill in the Kauai-Niihau Channel and date the oldest sediments overlying basement near the modern slope break. It is also possible that reef fragments on some of the blocks might be dated.

4. Topography of Unknown Origin

A final topic of some interest has to do with the origin of the seafloor ridge that separates the Oahu and Lanai Deeps. For discussion purposes we will call it Ambiguity Rise. Our interpretation for most of the cruise was that this was the extension of the Molokai Fracture Zone, subsequently buried or partly buried by sediments. However, once the mosaic was nearly complete it was apparent that the principal strand of the Molokai imaged during this cruise does not intersect Ambiguity Rise, but rather passes south of it. We suggest, therefore, three possible origins, none confirmed by any available data, and none strongly supported at this point by any of us. There are almost certainly other possible origins as well.

1. Extension of a northern limb of the Molokai Fracture Zone. This requires that the surveys carried out on the leeward side during this cruise entirely missed any evidence for a separate strand of the Molokai north of that imaged except as a topographic expression at Ambiguity Rise. This is not impossible, as our westernmost surveys terminated at the northern wall of the strand imaged, and GLORIA

images in Oahu Basin could have missed a buried strand owing to extensive turbidite fill, especially if topography in this strand was less pronounced than in the surveyed strand. As of the penultimate day of the cruise it appears that the surveyed portion of the Molokai lies 50 km south of, and has the same azimuth as, the northern strand surveyed during Leg F4-88-HW, and thus will not intersect it. Instead it aligns with the "D" strand, also striking 076°. This could, therefore, project an intersecting segment of the Molokai beneath Ambiguity Rise.

2. A "Little Oahu", or failed hot spot volcano adjacent to Oahu that failed to reach sea level. This could account for fresh appearing lavas interspersed in lows adjacent to seamount topography on the rise surface, but has trouble explaining their apparent position overlying and/or intruding adjacent transparent and laminated sediments. It is certainly not out of the question, however, despite being off the main hot spot trace (as are Niihau and Kaula Island, among many other examples).

3. A major slide, probably a part of the WOGL. This seems unrealistic because at least at first glance it requires moving an intact large volcano down the slope and up against the north wall of the Molokai Fracture Zone without breaking up. The question is, is it really an unbroken volcano? Are the vaguely visible linear ridges interspersed within the lava flow (they are real topography, just not confirmed to be ridges without further processing) possibly the crumpled toe of the slide analogous to the major ridge at the base of the Oahu slope in the WOGL?

Some Final Thoughts

The Oahu and Lanai Deeps together form one of the most intriguing pieces of side-scan imagery imaginable. Juxtaposed in a single modest-sized GLORIA mosaic are a major fracture zone with a kink, three enormous slope failure deposits of two different types, two sites of recent (possibly) volcanic activity away from the hot spot (but also off of the Hawaiian Arch), a thick turbidite apron that obscures almost all of the remaining topography, and a low rise of unknown origin separating the sediments of the two basins almost completely. The whole region is bounded by two significantly different morphologies of seafloor, one littered with seamounts and one nearly free of any structure other than a pervasive horst-and-graben grain. The ground broken by previous legs in the Hawaiian EEZ made it possible to interpret many of these structures in at least a preliminary manner, and we are grateful to our predecessors for their extensive discussions in the cruise report, and particularly for the detailed discussion of the Alika slide (Normark et al., 1987, and Lipman et al., 1988).

ACKNOWLEDGEMENTS

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FIGURE CAPTIONS

Figure 1. Major Geographic features of the Hawaiian Islands showing the area covered by F5-88-HW.

Figure 2. Trackline chart for U.S.G.S. GLORIA Cruise F5-88-HW.

Figure 3. Map showing tectonic lineations of the Molokai Fracture Zone, and seafloor lineations and seamount distribution for a portion of the Hawaiian EEZ off leeward Hawaii.

Figure 4. GLORIA image showing the deep rift splitting a seamount, located south of the westernmost MFZ. Note the low backscatter typical of areas of relatively thick sediment cover (about 40 m as based on 3.5 kHz profiles).

Figure 5. Seafloor fabric lineations and seamount and volcano distribution for a portion of the leeward Hawaiian EEZ.

Figure 6. GLORIA images showing high backscatter common for lava flows in the Hawaiian EEZ. Figure 6a: GLORIA image of the lava flows and seamounts on the rise separating the Oahu and Lanai Deeps. The rise is immediately adjacent to the eastern termination of the Molokai Fracture Zone in the Lanai Deep. Figure 6b: GLORIA image showing the flows and vents on the flanks of the ridge between Oahu and Kauai, directly downslope of the site of reported activity in the Kauai Channel, May 22-28, 1956 (Macdonald, 1959). Location of these flows is seen on figure 10.

Figure 7. 3.5 kHz profile showing transparent, well laminated and "mushy" reflectors. This profile was collected over the region of lava flows located adjacent to the eastern termination of the 076° strand of the Molokai Fracture Zone in the Lanai Deep (Line 27, 118/1018-118/1106 GMT). These "mushy" returns on the 3.5 kHz profiles are typical for lava flows in the Hawaiian EEZ. Note that the flows appear to intrude and/or overlie the adjacent transparent and laminated sediments.

Figure 8. 3.5 kHz profile from the toe of the Kauai slide (line 26, 117/1240-117/1406 GMT). Note the hummocky and hyperbolic reflectors between 117/1313Z and 117/1342Z, and up to 20 m thick transparent drape between 117/1250 and 117/1318 GMT.

Figure 9. Unprocessed Air-gun profile and preliminary interpretation over a portion of the south Kauai slide (line 26, 117/1200-117/1430 GMT).

Figure 10. Map showing the distribution of slide debris, lava flows, volcanos and vents for a portion of the leeward Hawaiian EEZ, imaged during F5-88-HW. The lava flows located south of the WOGL are located on the rise that separates the Oahu and Lanai Deeps.

Figure 11. Map showing the location and extent of the major slides surrounding the Hawaiian Islands.

Figure 12. Preliminary map showing the 3 interpreted lobes of the south Kauai slide.

Figure 13. Shipboard GLORIA image of the toe region of the south Kauai slide (line 26, about 117/0900-117/1600 GMT). The image covers the area shown on figures 8, and 9.

Figure 14. 3.5 kHz profile of debris blocks from the south Kauai slide. The blocks are situated 5 km in front of the toe of the slide, they are partially buried by turbidites, and they have up to 15 m of transparent sediment draped over the blocks.

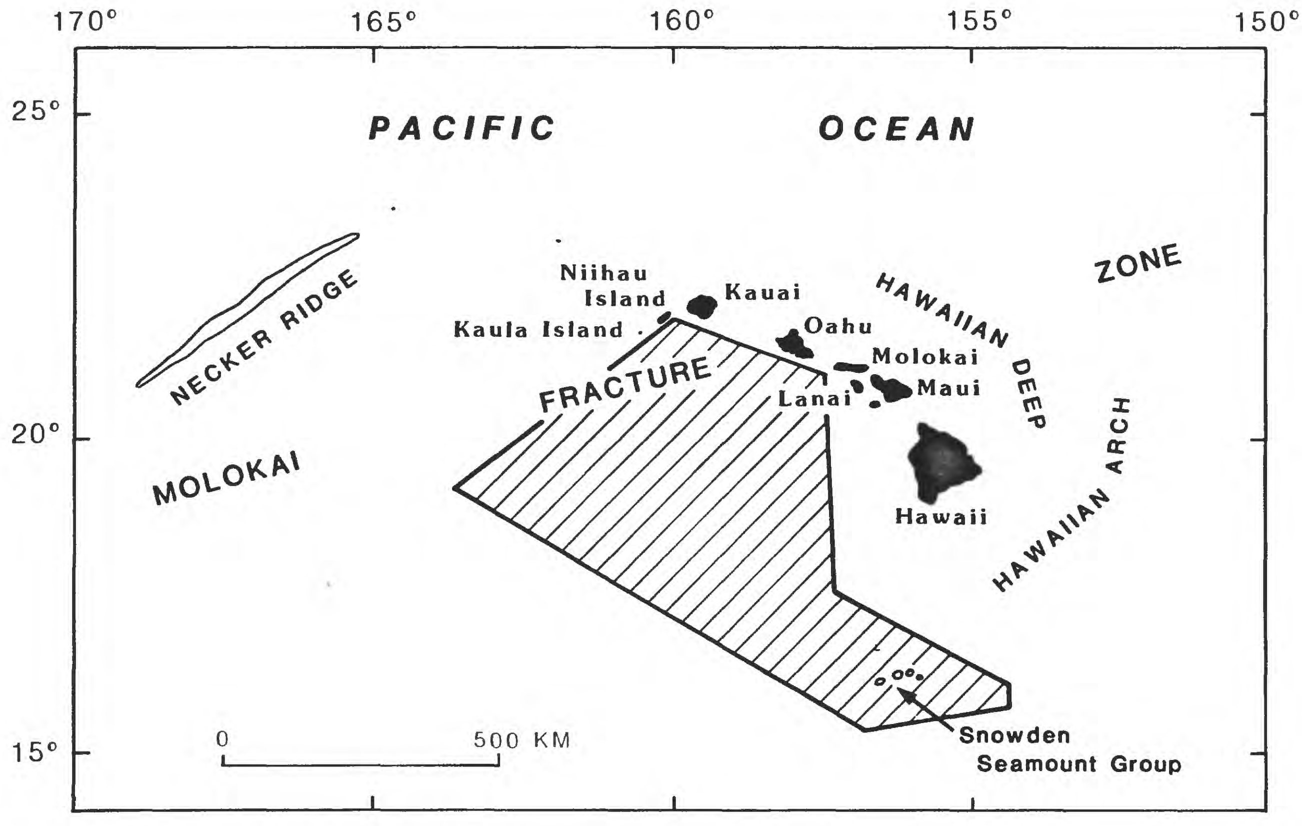
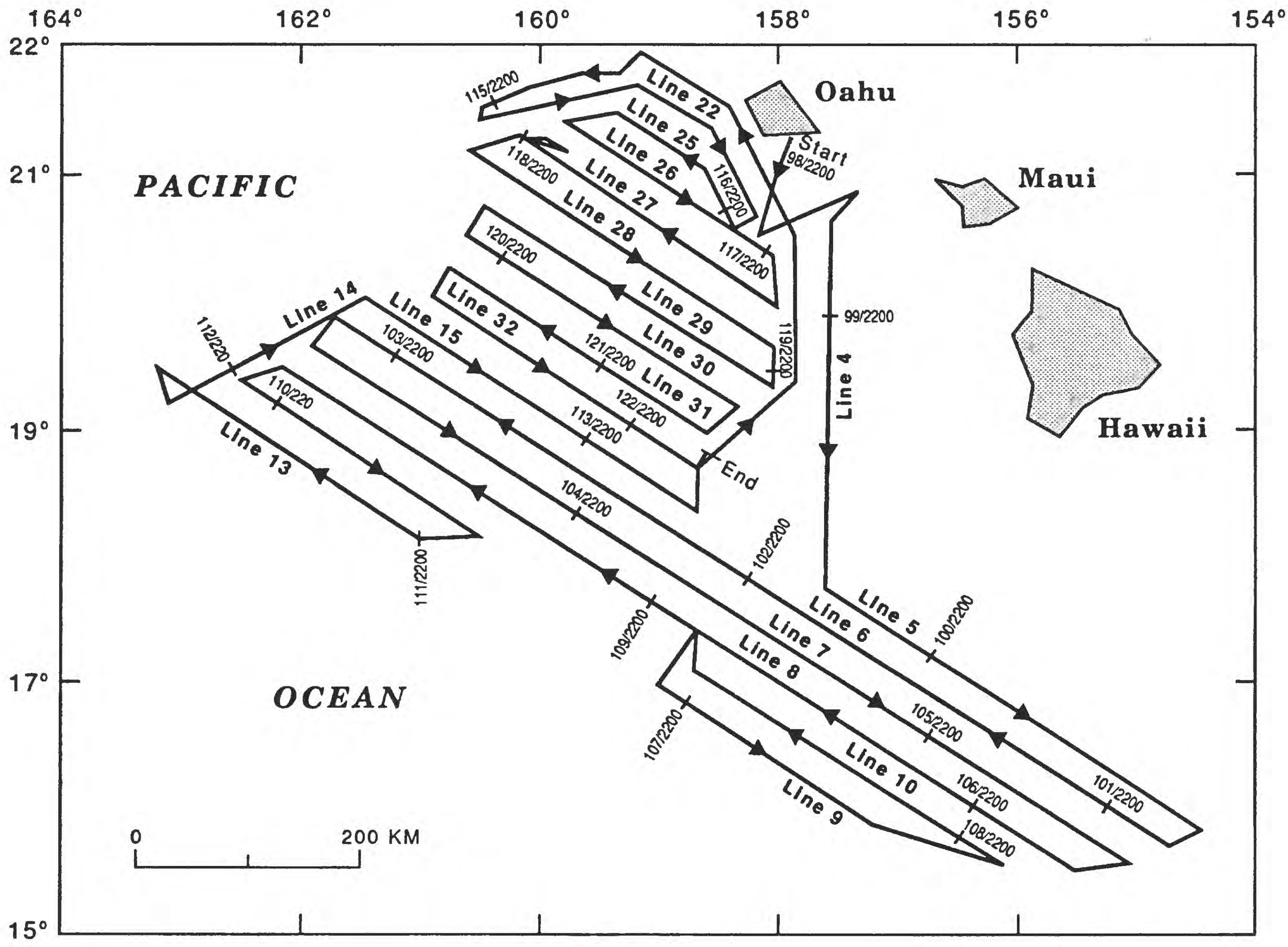
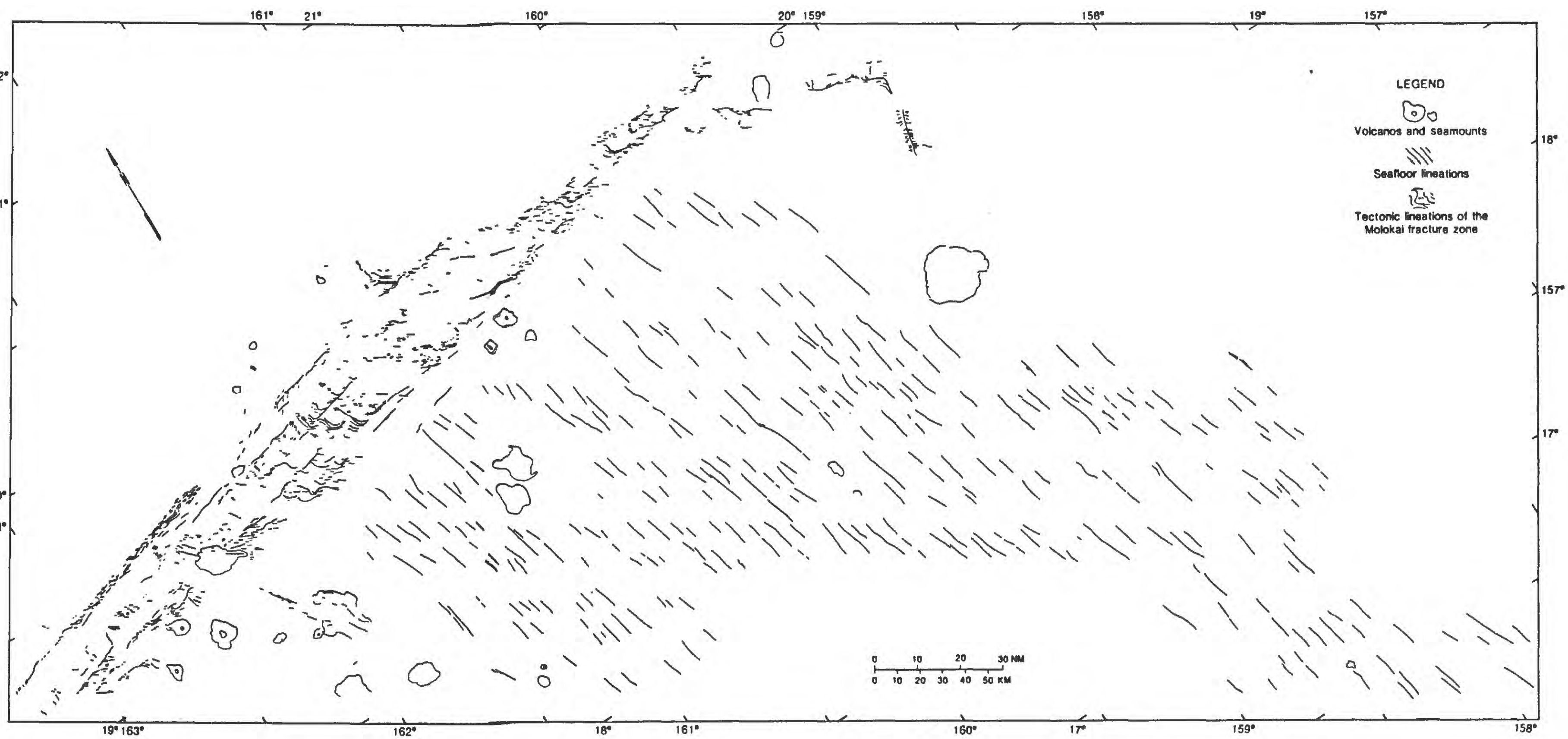

170°
165°
160°
155°
150°
25°
20°
15°
PACIFIC
OCEAN
ZONE
Niihau
Island
Kauai
Kaula Island
Oahu
Molokai
Maui
Lanai
Hawaii
NECKER RIDGE
FRACTURE
MOLOKAI
HAWAIIAN DEEP
HAWAIIAN ARCH
Snowden
Seamount Group
0
500 KM

Figure 1



164°
162°
160°
158°
156°
154°
22°
21°
19°
17°
15°
PACIFIC
OCEAN
Oahu
Maui
Hawaii
Start
98/2200
End
Line 4
Line 5
Line 6
Line 7
Line 8
Line 9
Line 10
Line 13
Line 14
Line 15
Line 22
Line 25
Line 26
Line 27
Line 28
Line 29
Line 30
Line 31
Line 32
99/2200
100/2200
101/2200
102/2200
103/2200
104/2200
105/2200
106/2200
107/2200
108/2200
109/2200
110/220
111/2200
112/220
113/2200
115/2200
116/2200
117/2200
118/2200
119/2200
120/2200
121/2200
122/2200
0
200 KM

Figure 2



LEGEND
Volcanos and seamounts
Seafloor lineations
Tectonic lineations of the Molokai fracture zone
0 10 20 30 NM
0 10 20 30 40 50 KM
161° 21° 160° 20° 159° 158° 19° 157°
162° 21° 20° 163°
18° 157° 17°
19° 163° 162° 18° 161° 160° 17° 159° 158°

Figure 3

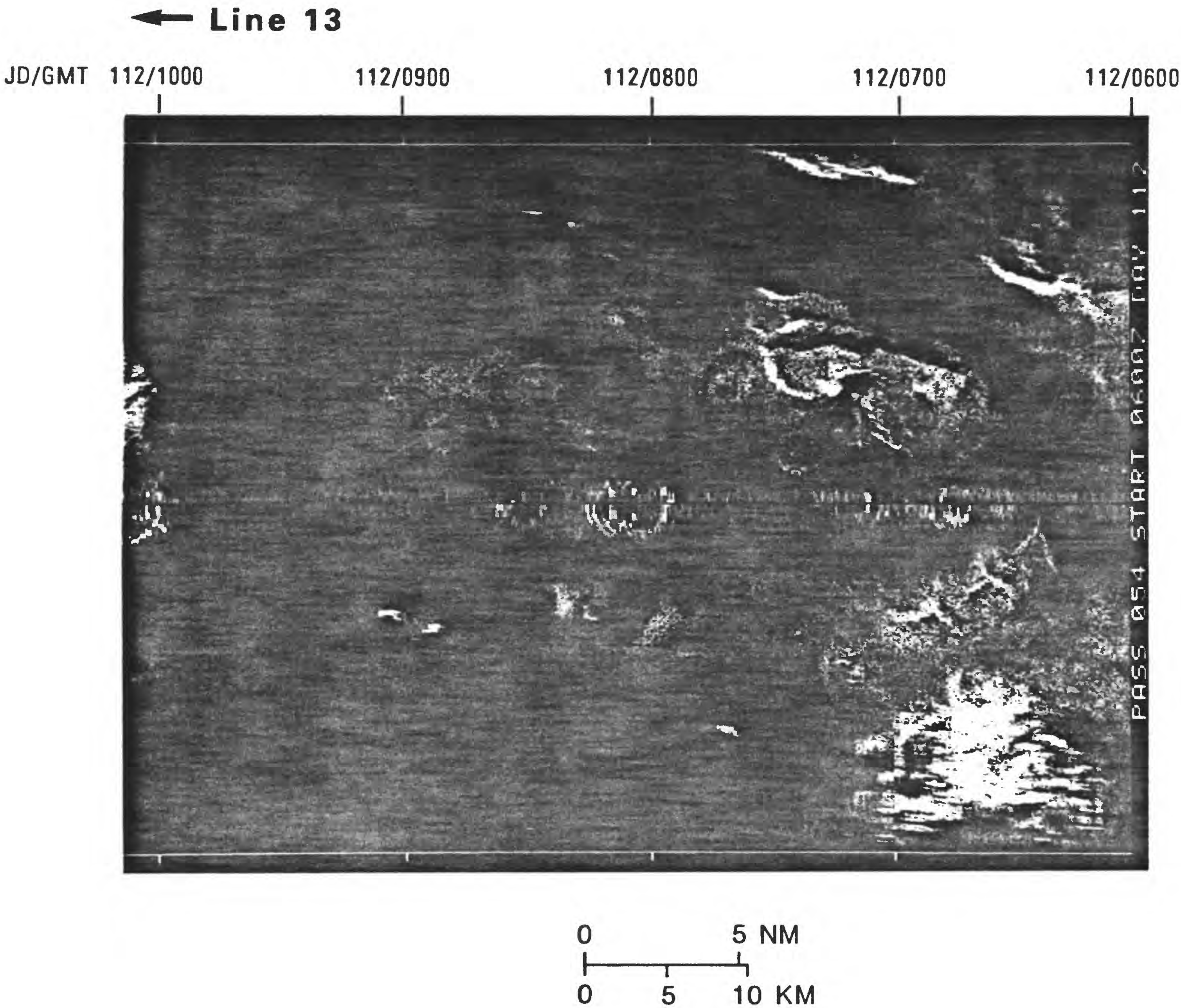

Line 13
JD/GMT
112/1000
112/0900
112/0800
112/0700
112/0600
0
5 NM
0
5
10 KM

Figure 4

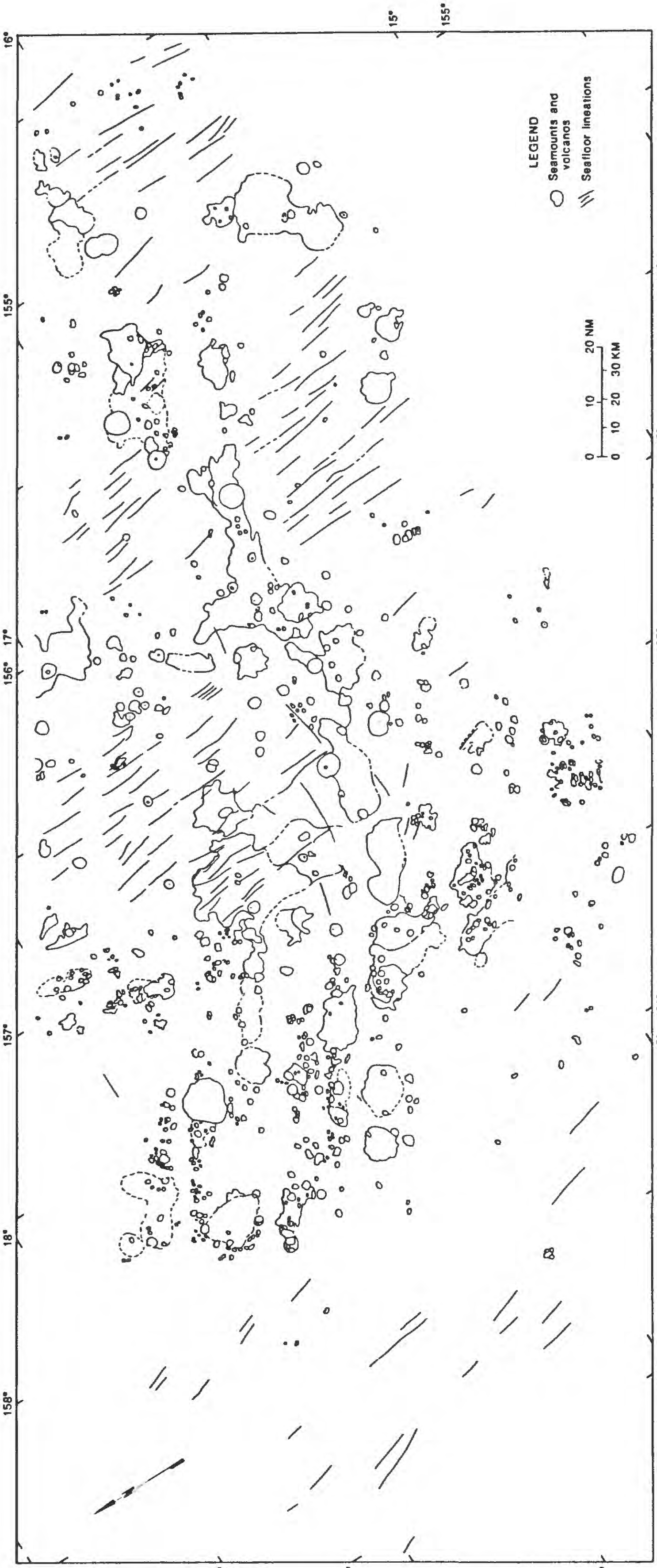

LEGEND
Seamounts and volcanos
Seafloor lineations
0 10 20 NM
0 10 20 30 KM

Figure 5

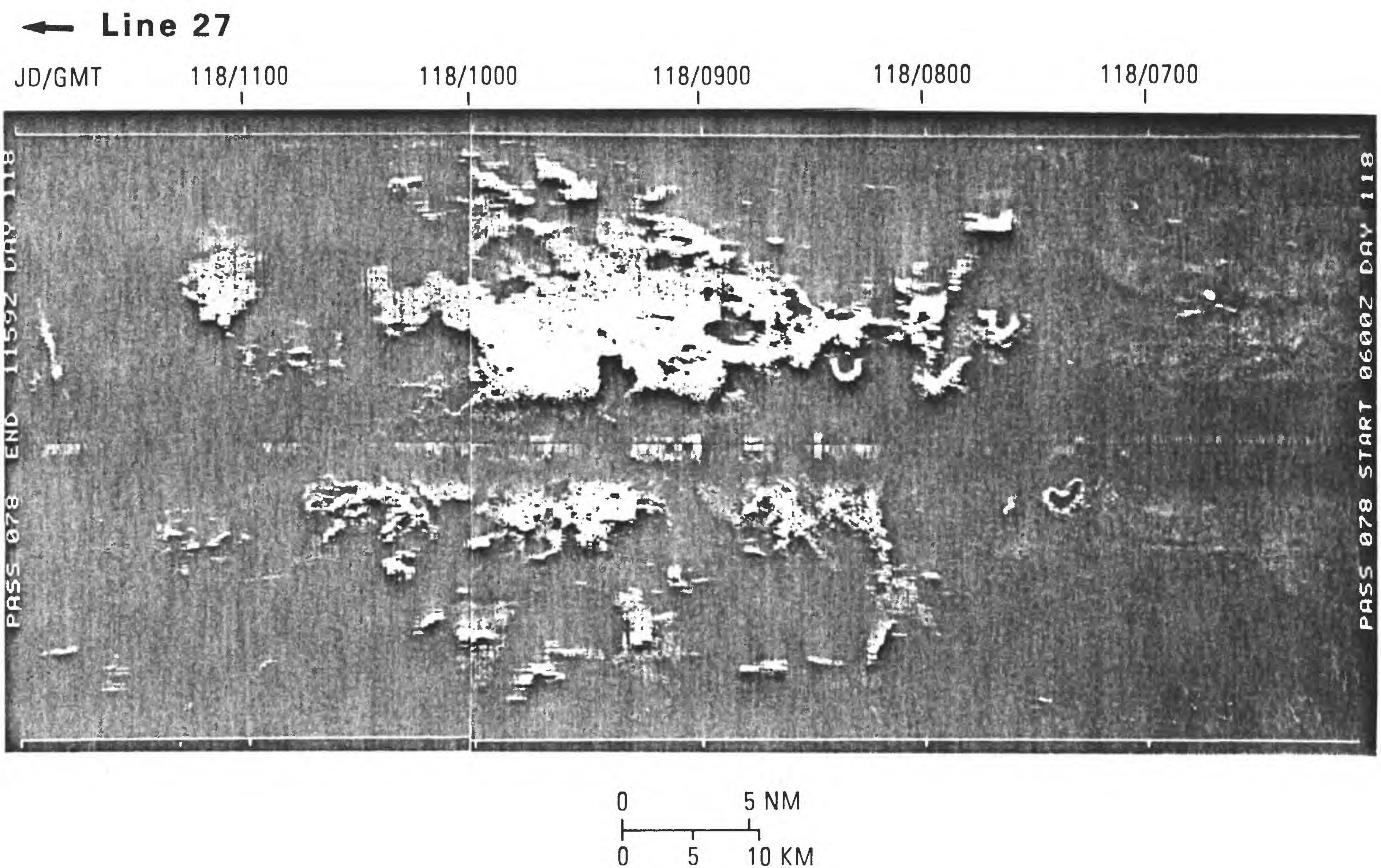

← Line 27
JD/GMT
118/1100
118/1000
118/0900
118/0800
118/0700
PASS 078 END 11592 DAY 118
PASS 078 START 06002 DAY 118
0
5 NM
0
5
10 KM

Figure 6a

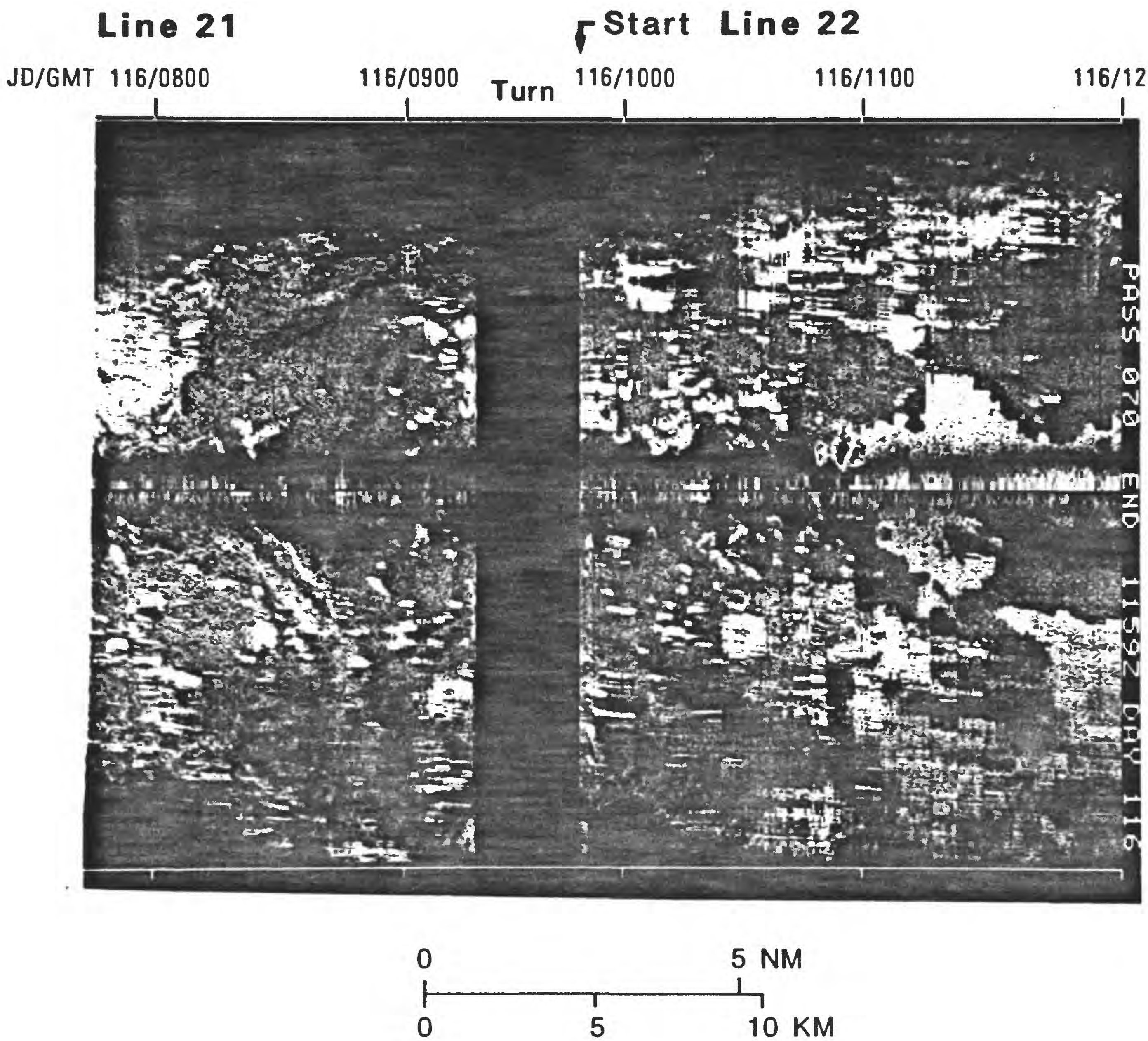
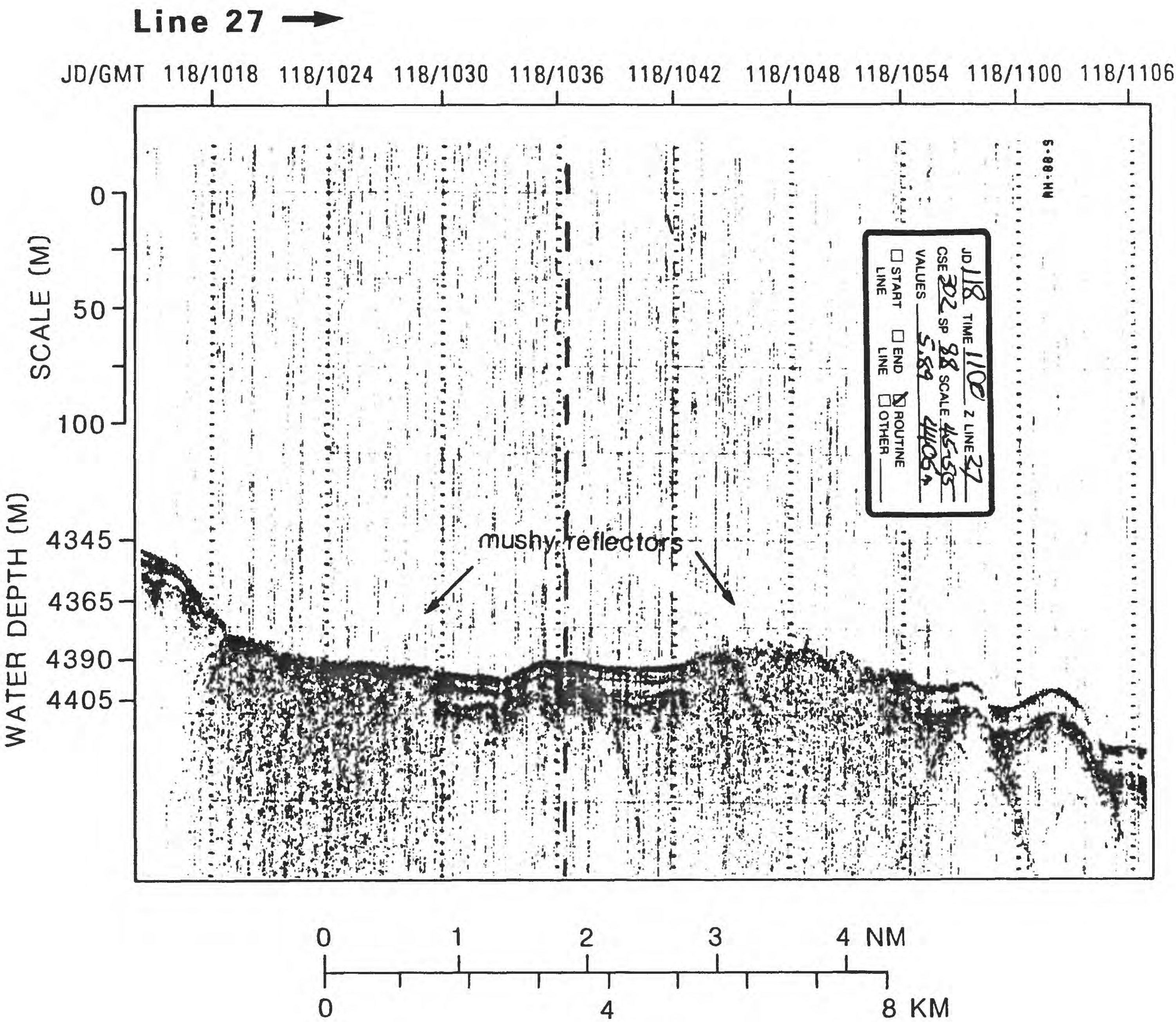
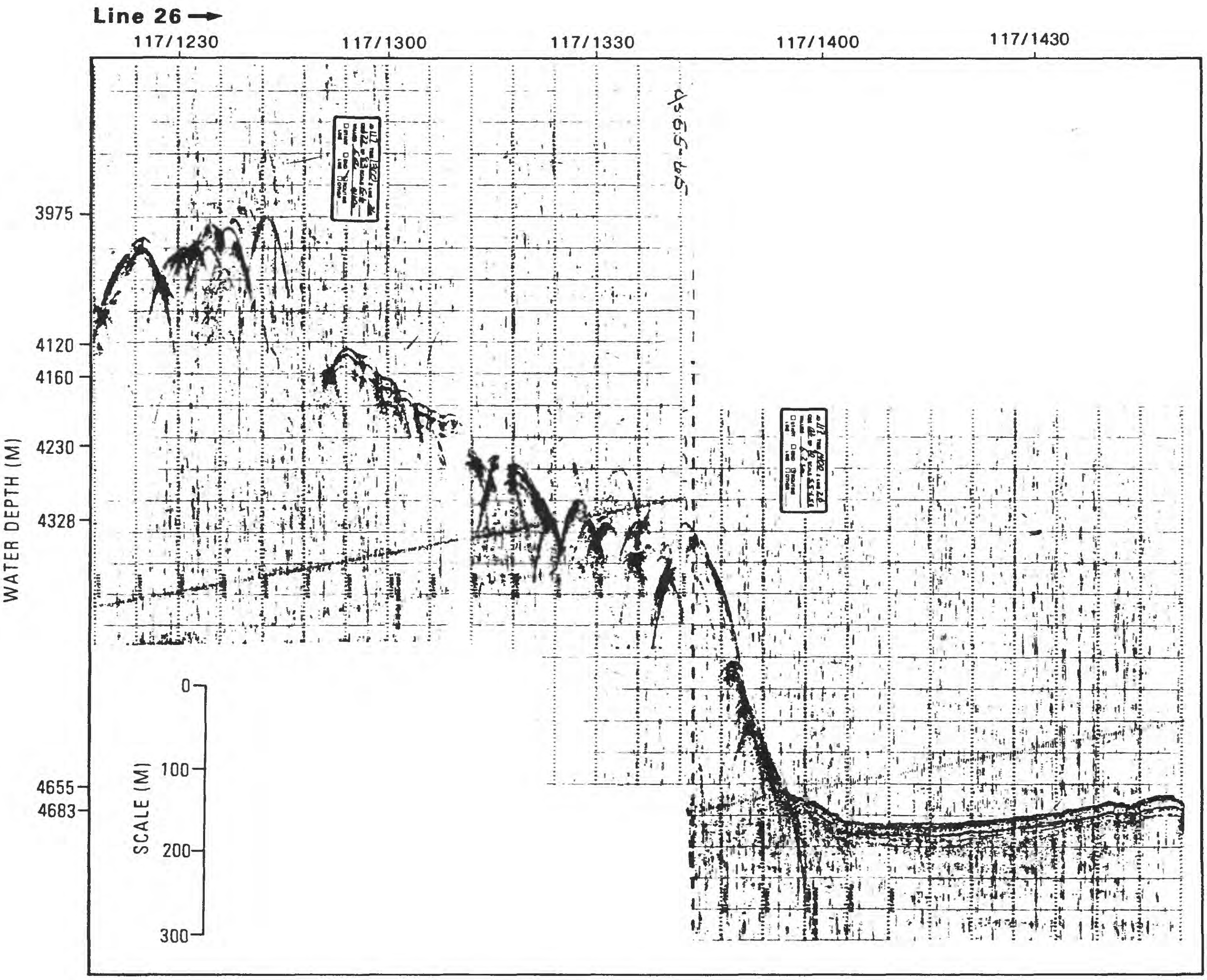

Line 21
Start Line 22
JD/GMT 116/0800
116/0900
Turn
116/1000
116/1100
116/1200
PASS 070 END 11592 DAY 116
0
5 NM
0
5
10 KM

Figure 6b



Line 27
JD/GMT
118/1018
118/1024
118/1030
118/1036
118/1042
118/1048
118/1054
118/1100
118/1106
SCALE (M)
0
50
100
WATER DEPTH (M)
4345
4365
4390
4405
mushy reflectors
0 1 2 3 4 NM
0 4 8 KM

Figure 7



Line 26
117/1230
117/1300
117/1330
117/1400
117/1430
3975
4120
4160
4230
4328
4655
4683
WATER DEPTH (M)
SCALE (M)
0
100
200
300

Figure 8

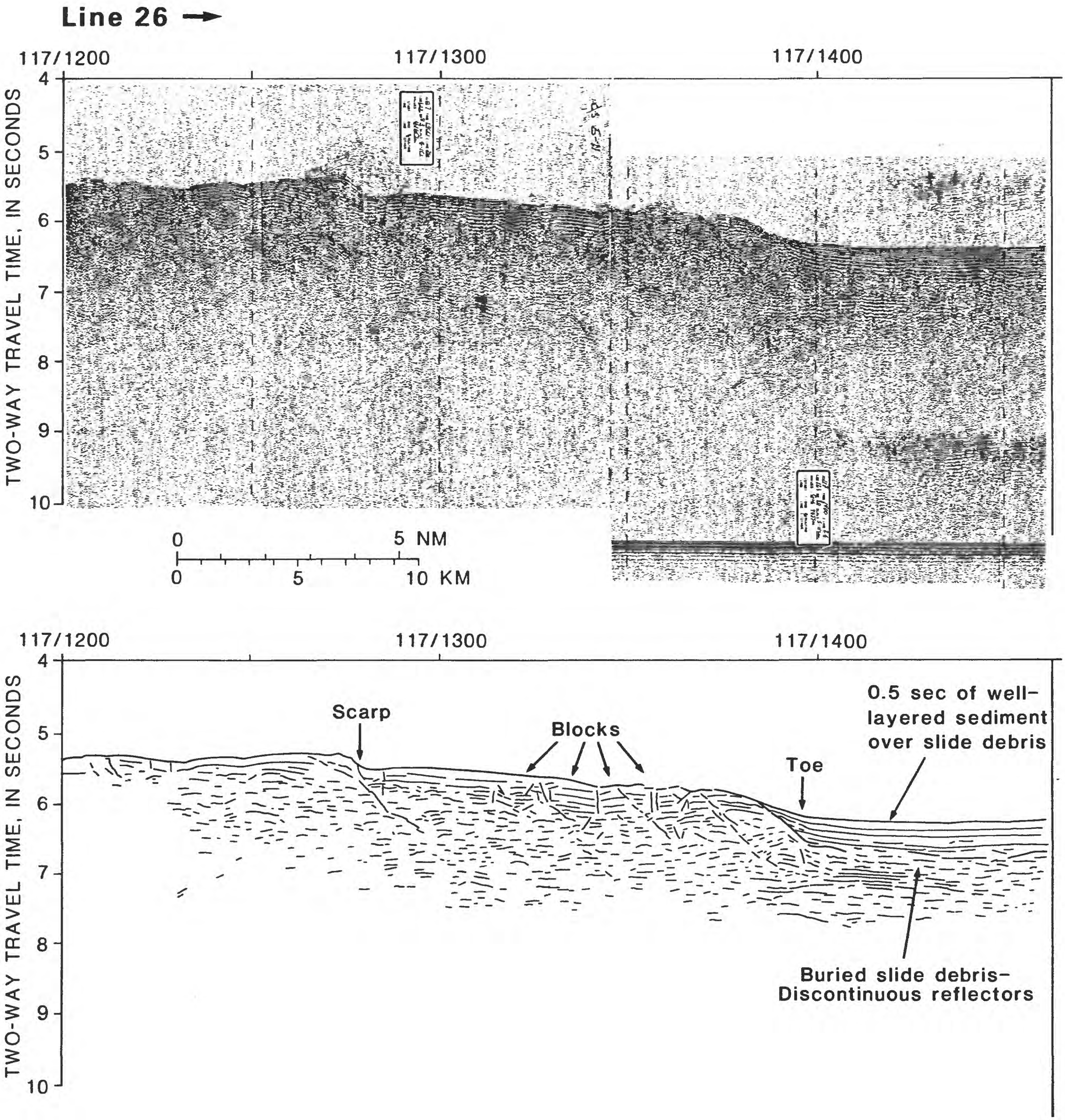

Line 26
117/1200
117/1300
117/1400
TWO-WAY TRAVEL TIME, IN SECONDS
4
5
6
7
8
9
10
0
5 NM
0
5
10 KM
117/1200
117/1300
117/1400
TWO-WAY TRAVEL TIME, IN SECONDS
4
5
6
7
8
9
10
Scarp
Blocks
Toe
0.5 sec of well-layered sediment over slide debris
Buried slide debris-Discontinuous reflectors

Figure 9

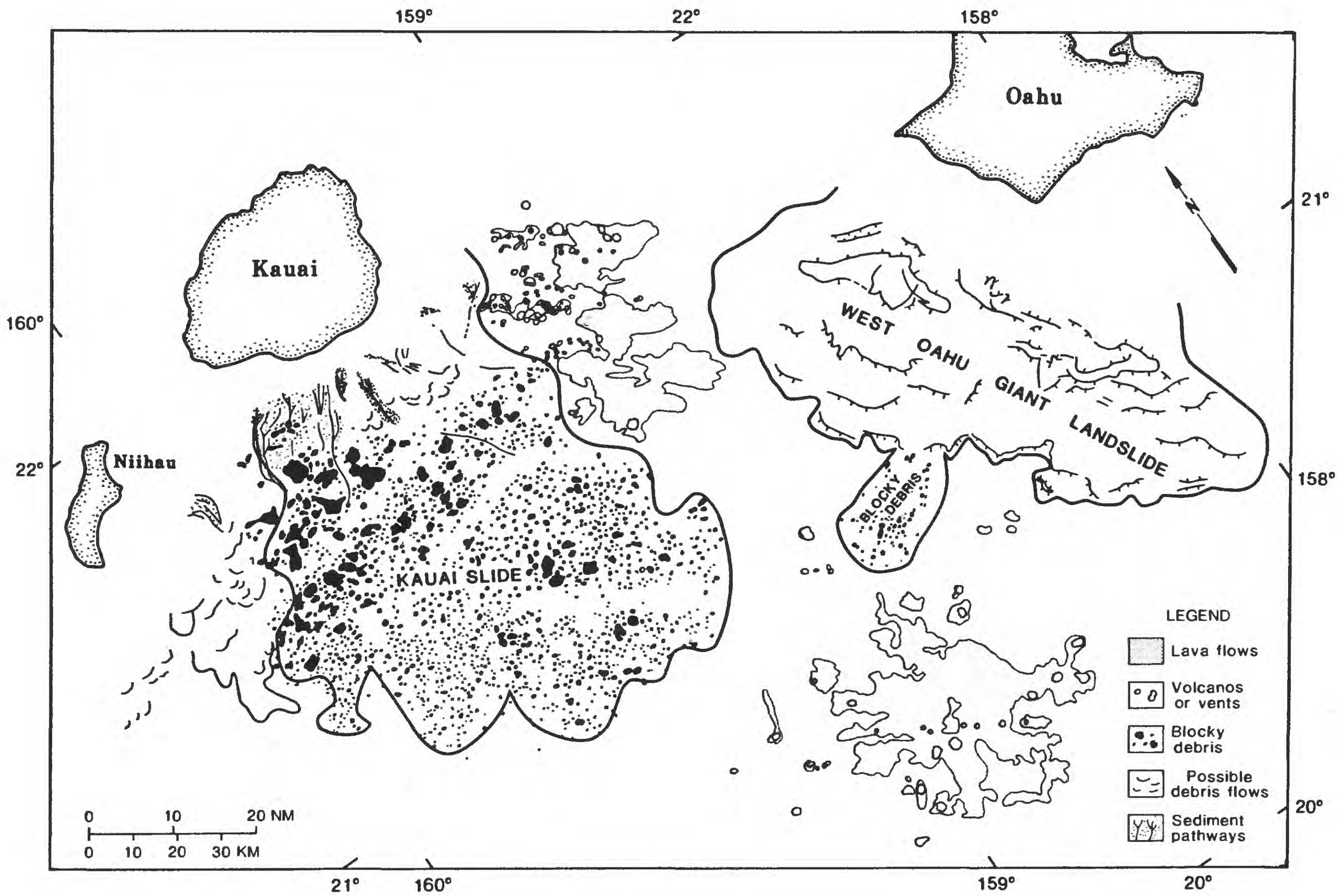

159°
22°
158°
Oahu
21°
Kauai
160°
WEST OAHU GIANT LANDSLIDE
22°
Niihau
158°
BLOCKY DEBRIS
KAUAI SLIDE
LEGEND
Lava flows
Volcanos or vents
Blocky debris
Possible debris flows
Sediment pathways
20°
0 10 20 NM
0 10 20 30 KM
21°
160°
159°
20°

Figure 10

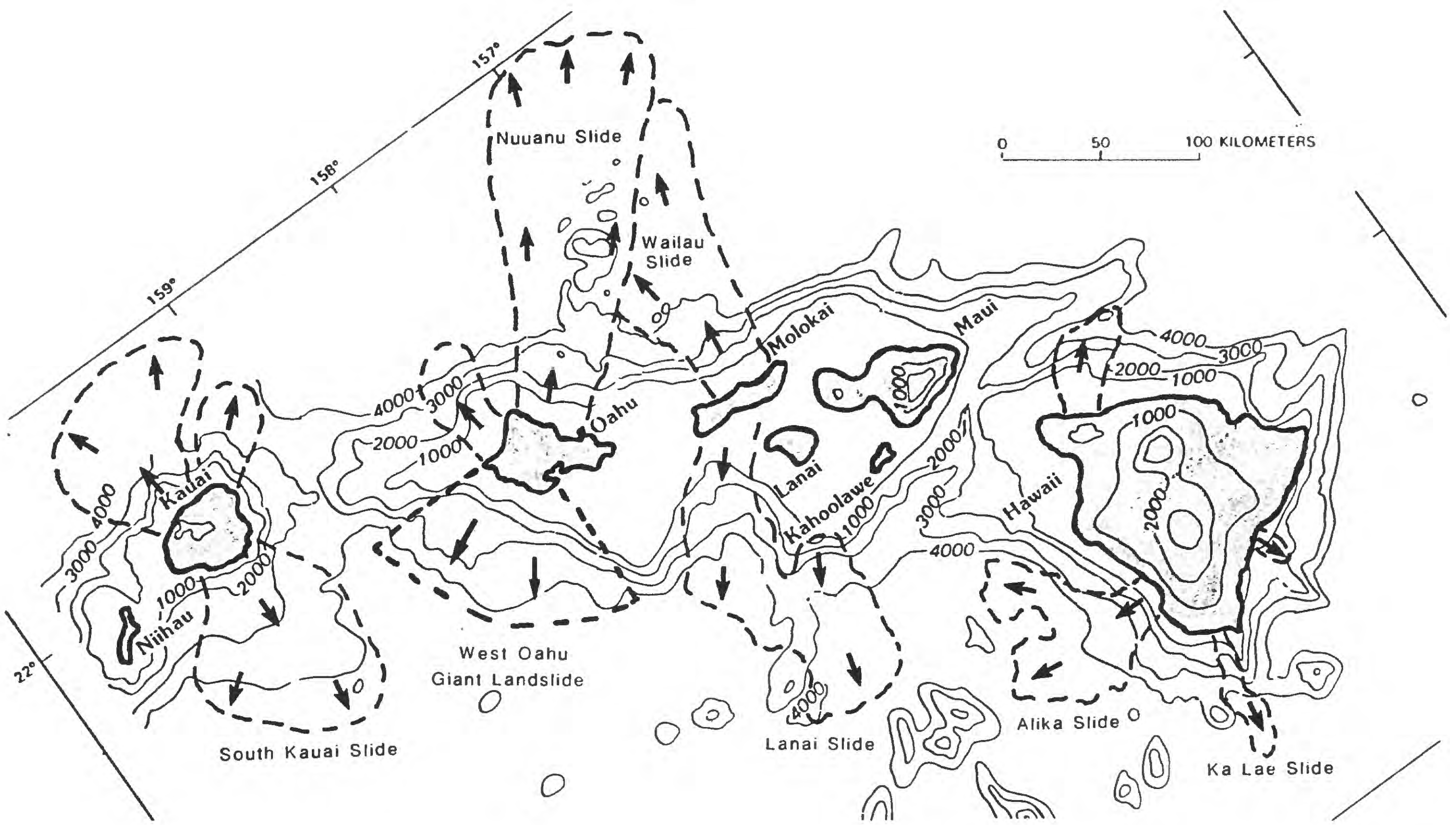

157°
158°
159°
22°
0 50 100 KILOMETERS
Nuuanu Slide
Wailau Slide
Molokai
Maui
Oahu
Kauai
Niihau
Lanai
Kahoolawe
Hawaii
West Oahu Giant Landslide
South Kauai Slide
Lanai Slide
Alika Slide
Ka Lae Slide

Figure 11

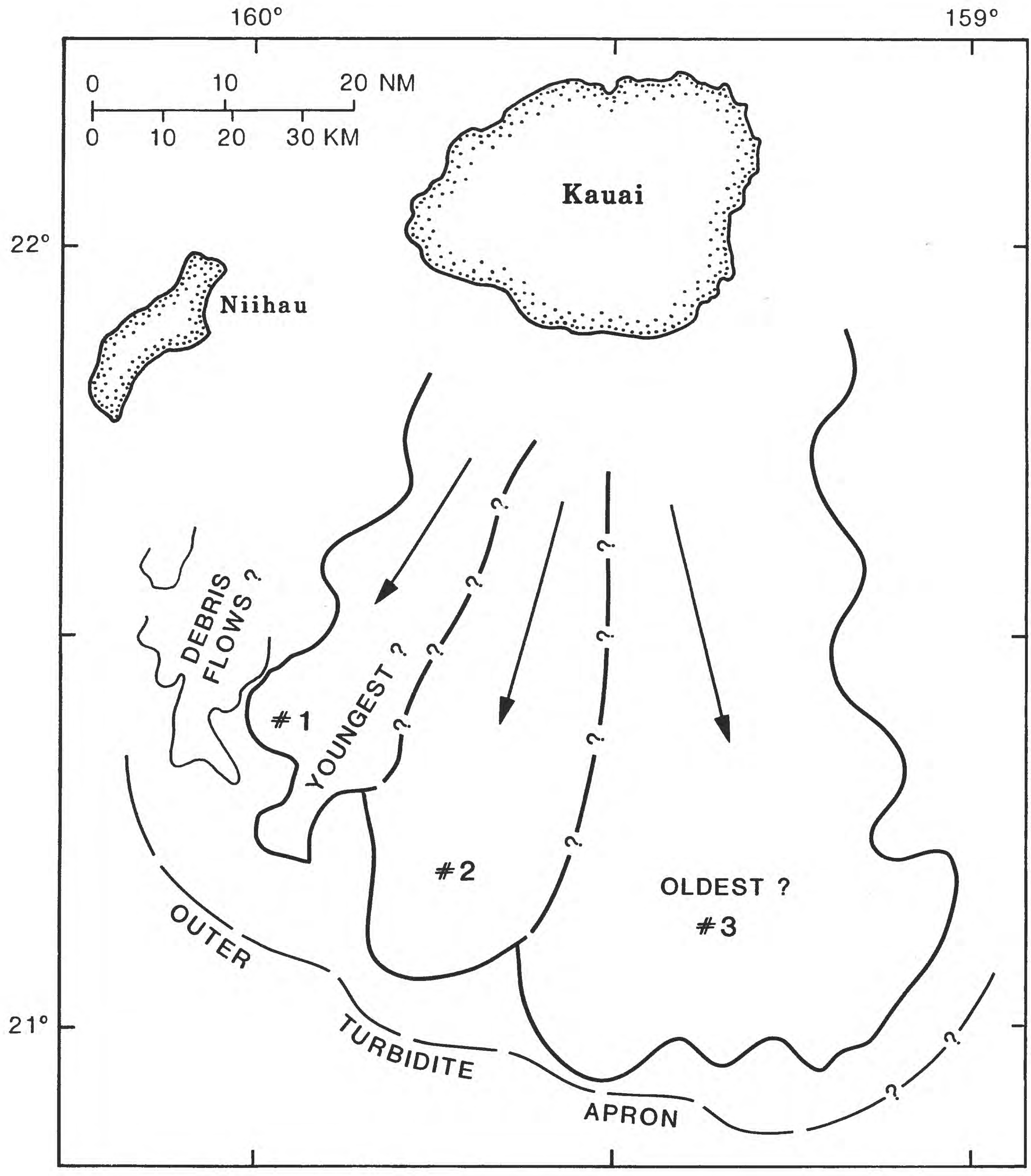
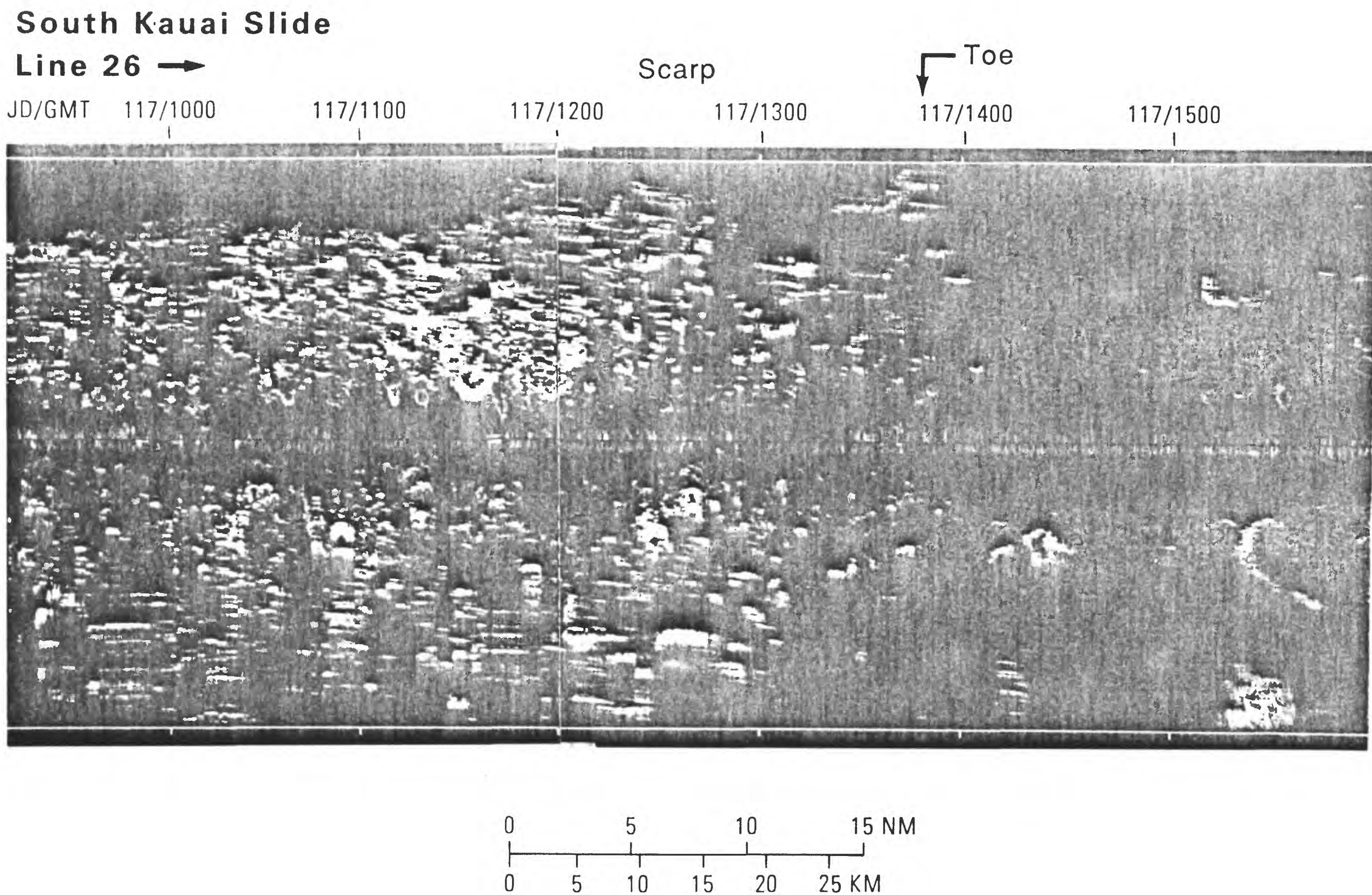

160°
159°
0
10
20 NM
0
10
20
30 KM
Kauai
22°
Niihau
DEBRIS FLOWS ?
YOUNGEST ?
1
2
OLDEST ?
3
OUTER
TURBIDITE
APRON
21°

Figure 12



South Kauai Slide
Line 26
Scarp
Toe
JD/GMT
117/1000
117/1100
117/1200
117/1300
117/1400
117/1500
0
5
10
15 NM
0
5
10
15
20
25 KM

Figure 13

Line 27 →

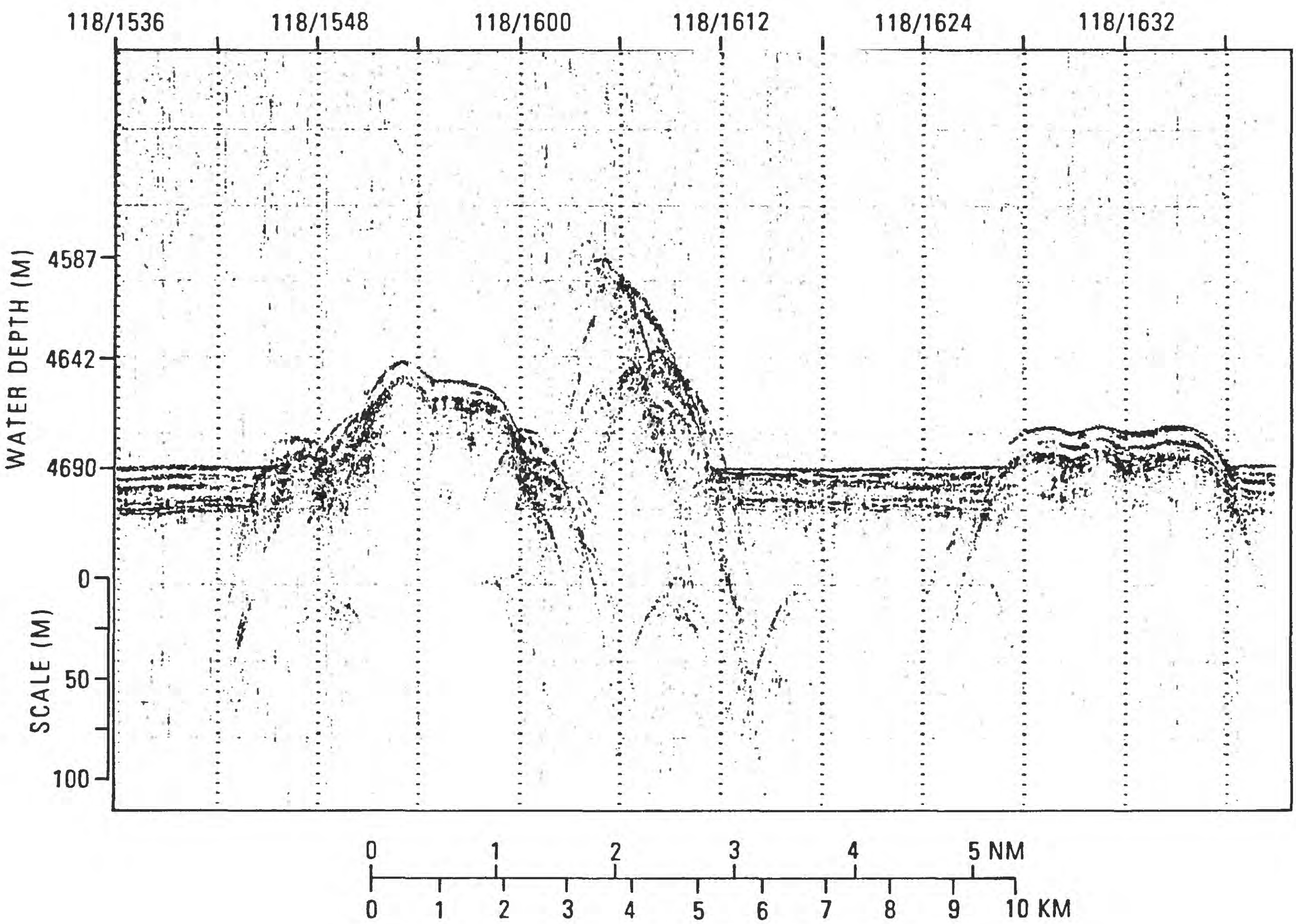


Figure 14

APPENDIX 1: EQUIPMENT SETTINGS AND COMMENTS

F5-88-HW

1. 3.5 kHz system

LSR (Recorder)	MODE	Continuous
	PAPER	150 lines/inch
	SWEEP	1 second
	PROGRAM	As required
	GAIN	Variable
	CONTRAST	Mid-range
	THRESHOLD	Low to mid-range
PTR Transceiver	GAIN	9 low (fixed; ramp control not active)
	POWER	0 db
	PULSE WIDTH	Controls not active
IOS Correlator	OUTPUT LEVEL	4
	ATTENUATOR	11.5

Fish depth compensation is set at 15 m. Instructions for the time and cruise id are in the manual provided.

2. 10 kHz System

MUFAX RECORDER	ATTENUATOR	-6 (-12, -18 if needed)
	PULSE LENGTH	2.8 msec (5 if needed)
	TIME MARKS	6 min intervals
	FISH DEPTH	6 m (controls 6 x 1)
	GATING INT	6 sweeps
	SCALE	2 sec
	SCALE	1500m/
	PROGRAM	Edge or center key; allows scale changes of 1 sec intervals
	TVG	Can be used to suppress the outgoing pulse

Note: The TVG is normally on when GATING is on and vice versa.

3. Seismic reflection system (two channel)

Sound source	AIR GUN	160 in^3
Receiver	2 CHANNEL	50 m active sections
LSR(Receiver)	DISPLAY	Normal
	STYLUS SCAN	2 sec
	PAPER	120 line/inch
	MEMORY SWEEP	6 sec
	FILTER	In
	POLARITY	+
	GAIN	4 to 5
	CONTRAST	-30
	THRESHOLD	5 (FWC as needed)
Krohn-Hite Filter		20-80 Hz

Amplifier — Not a seismic unit (ours was not functioning properly). We used a simple oscilloscope differential amplifier AM 502).

MASSCOMP	RECORD LENGTH	6 sec
	GAIN (prefilter)	0 db
	GAIN (postfilter)	6, 12, or 18 db depending upon water depth and seafloor reflectivity.
	DELAY	Variable

4. Gravimeter — Standard operation; watchstander only checks gravity and spring tension values on the hour and marks the paper record with time, course, speed once an hour as part of the routine log entry. All adjustments or changes to operation is handled by the electronics tech or the designated navigator.

5. Magnetometer — Standard operation; watchstander checks field value on the hour; logging procedures and equipment changes are the same as for other potential field data.

6. XBT — One XBT probe every day between 1300 and 1500 local. The NOAA recording unit has complete instructions for launching, plotting, and transmitting the data. Use a T-7 (750 m) probe about once a week and T-4 or T-6 (450 m) otherwise.

APPENDIX 2: Summary of GLORIA Passes For F5-88-HW

TAPE	FILE	PASS	START TIME	FINISH TIME	COMMENTS
8	1	1	0011/099	0559/099	NO ERRORS
8	2	2	0600/099	1159/099	NO ERRORS
8	3	3	1200/099	1759/099	NO ERRORS
8	4	4	1800/099	2359/099	NO ERRORS
8	5	5	0000/100	0559/100	NO ERRORS
8	6	6	0600/100	1159/100	NO ERRORS
8	7	7	1200/100	1759/100	NO ERRORS
8	8	8	1800/100	2359/100	NO ERRORS
8	9	9	0000/101	0559/101	NO ERRORS
8	10	10	0600/101	1159/101	NO ERRORS
8	11	11	1200/101	1759/101	NO ERRORS
8	12	12	1800/101	2359/101	NO ERRORS
8	13	13	0000/102	0559/102	NO ERRORS
8	14	14	0600/102	1159/102	NO ERRORS
8	15	15	1200/102	1759/102	NO ERRORS
8	16	16	1800/102	2359/102	NO ERRORS
9	1	17	0000/103	0559/103	NO ERRORS
9	2	18	0600/103	1159/103	NO ERRORS
9	3	19	1200/103	1759/103	NO ERRORS
9	4	20	1800/103	2359/103	NO ERRORS
9	5	21	0000/104	0559/104	NO ERRORS
9	6	22	0600/104	1159/104	NO ERRORS
9	7	23	1200/104	1759/104	NO ERRORS
9	8	24	1800/104	2359/104	NO ERRORS
9	9	25	0000/105	0059/105	NO ERRORS
9	10	26	0600/105	1159/105	NO ERRORS
9	11	27	1200/105	1759/105	NO ERRORS
9	12	28	1800/105	2359/105	NO ERRORS
9	13	29	0000/106	0059/106	NO ERRORS
9	14	30	0600/106	1159/106	NO ERRORS
9	15	31	1200/106	1759/106	NO ERRORS
9	16	32	1800/106	2359/106	NO ERRORS
10	1	33	0000/107	0559/107	NO ERRORS
10	2	34	0600/107	1159/107	NO ERRORS
10	3	35	1200/107	1759/107	NO ERRORS
10	4	36	1800/107	2359/107	NO ERRORS
10	5	37	0000/108	0059/108	NO ERRORS
10	6	38	0600/108	1759/108	NO ERRORS
10	7	39	1200/108	1759/108	NO ERRORS
10	8	40	1800/108	2359/108	NO ERRORS
10	9	41	0000/109	0559/109	NO ERRORS
10	10	42	0600/109	1159/109	NO ERRORS
10	11	43	1200/109	1759/109	NO ERRORS
10	12	44	1800/109	2359/109	NO ERRORS
10	13	45	0000/110	0559/110	NO ERRORS
10	14	46	0600/110	1159/110	NO ERRORS
10	15	47	1200/110	1759/110	NO ERRORS
10	16	48	1800/110	2359/110	NO ERRORS
11	1	49	0000/111	0559/111	NO ERRORS
11	2	50	0600/111	1159/111	NO ERRORS

11	3	51	1200/111	1759/111	NO ERRORS
11	4	52	1800/111	2359/111	NO ERRORS
11	5	53	0000/112	0559/112	NO ERRORS
11	6	54	0600/112	1159/111	NO ERRORS
11	7	55	1200/112	1759/112	NO ERRORS
11	8	56	1800/112	2359/112	NO ERRORS
11	9	57	0000/113	0559/113	NO ERRORS
11	10	58	0600/113	1159/113	NO ERRORS
11	11	59	1200/113	1759/113	NO ERRORS
11	12	60	1800/113	2359/113	NO ERRORS
11	13	61	0000/114	0559/114	NO ERRORS
11	14	62	0600/114	1159/114	NO ERRORS
11	15	63	1200/114	1759/114	NO ERRORS
11	16	64	1800/114	2359/114	NO ERRORS
12	1	65	000/115	0559/115	NO ERRORS
12	2	66	0600/115	1159/115	NO ERRORS
12	3	67	1200/115	1759/115	NO ERRORS
12	4	68	1800/115	2359/115	NO ERRORS
12	5	69	0000/116	0059/116	NO ERRORS
12	6	70	0600/116	1159/116	NO ERRORS
12	7	71	1200/116	1759/116	NO ERRORS
12	8	72	1800/116	2359/116	NO ERRORS
12	9	73	0000/117	0559/117	NO ERRORS
12	10	74	0600/117	1159/117	NO ERRORS
12	11	75	1200/117	1759/117	NO ERRORS
12	12	76	1800/117	2359/117	NO ERRORS
12	13	77	0000/118	0559/118	NO ERRORS
12	14	78	0600/118	1159/118	NO ERRORS
12	15	79	1200/118	1759/118	NO ERRORS
12	16	80	1800/118	2359/118	NO ERRORS
13	1	81	0000/119	0559/119	NO ERRORS
13	2	82	0600/119	1159/119	NO ERRORS
13	3	83	1200/119	1759/119	NO ERRORS
13	4	84	1800/119	2359/119	NO ERRORS
13	5	85	0000/120	0559/121	NO ERRORS
13	6	86	0600/120	1159/120	NO ERRORS
13	7	87	1200/120	1759/120	NO ERRORS
13	8	88	1800/120	2359/120	NO ERRORS
13	9	89	0000/121	0059/120	NO ERRORS
13	10	90	0600/121	1159/121	NO ERRORS
13	11	91	1200/121	1759/121	NO ERRORS
13	12	92	1800/121	2359/121	NO ERRORS
13	13	93	0000/122	0559/122	NO ERRORS
13	14	94	0600/122	1159/122	NO ERRORS
13	15	95	1200/122	1759/122	NO ERRORS
13	16	96	1800/122	2359/122	NO ERRORS
13	17	97	0000/123	0325/123	NO ERRORS