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DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Preliminary Cruise Report,

Hawaiian GLORIA Leg 2,

F6-86-HW,

November 1986

by

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INTRODUCTION

This cruise was the second leg of a multi-year program to survey the Hawaiian Ridge Exclusive Economic Zone (EEZ) using the long-range side-looking sonar GLORIA. The objective is to produce an atlas that displays geologic and morphologic characters of the seafloor as a first step toward evaluation of the economic potential and other possible uses of the EEZ. The Hawaiian Ridge is the fifth major segment of the U.S. EEZ in which GLORIA studies have been initiated; the others are: the western U.S. off Washington, Oregon, and California; the Gulf of Mexico and Caribbean; the Atlantic margin of the East Coast; and the Bering Sea-Aleutian-southwestern Alaskan margin. At this time, only the West Coast survey data are complete and published in atlas form (EEZ SCAN 84 Scientific Staff, 1986).

The Hawaiian Ridge survey will require approximately one year of GLORIA surveying. At the present time, only about seven months of survey time have been scheduled because of a shift of nearly 3 months' activity to the East Coast area. The Hawaiian surveys are generally scheduled for the winter and early spring when the weather in the other areas prevents effective mapping. Thus, as presently scheduled, the Hawaiian Ridge effort will extend through 1990. Publication of an atlas of the data is expected to follow promptly after completion of the EEZ survey around the major islands of the State of Hawaii.

Leg 1 of the Hawaiian Ridge survey was conducted from 13 October to 3 November 1986 (Holmes et al, 1987). Their study area was in the EEZ north and east of the Island of Hawaii. Leg 2 joined the Leg 1 survey along a trackline that bears 140° from the summit of Kilauea Volcano on the south coast of the island and extends to the southeastern limit of the EEZ (Figs. 1 and 2). The Leg 2 work extended the area covered to 222 km (120 n. mi.) southwest of South Point on Hawaii, paralleling the trackline pattern established during the first leg. We also completed the imaging of the slopes of the island on the north and northwest sides. In addition to the GLORIA data, standard cruise operations include: seismic-reflection profiling 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.

OPERATIONS

The GLORIA surveys are conducted from the M/V FARNELLA, a converted freezer trawler under lease to the U.S. Geological Survey through the Institute of Oceanographic Sciences (IOS) in Wormley, England. The FARNELLA arrived in Hilo, Hawaii, on 3 November at the end of the Leg 1 survey. During two days in Hilo, there was a complete changeover of both IOS and USGS personnel. The only major equipment problem from the first leg, the loss of the gravimetry as a result of a power-supply failure, which in turn led to problems with other components, was corrected during the port call. Operational quirks related to the geophysical systems in use were outlined in the cruise report from Leg 1 (Holmes et al, 1987). After review of this report, a training session for the Leg 2 watchstanders was given on 4 November to smooth their transition to shipboard activities.

The GLORIA surveying responsibilities are split between IOS and USGS personnel. The IOS participants are responsible for all operations involving GLORIA, as well as for all deck operations and maintenance of the air-gun seismic-reflection system and the 3.5- and 10-kHz profiling systems. The USGS personnel are responsible for all aspects of the gravimeter and gradiometer operations and for wachstanding duties for everything except GLORIA and the navigation system. The co-chief scientists from the USGS and IOS are jointly responsible for general survey planning and construction of two sets of field mosaics of the GLORIA data.

The tabulations below review the scientific personnel, the schedule of field operations, and a review of the status of equipment throughout the Leg 2 operations. A special comment on navigational problems concludes this review.

Scientific Party for F6-86-HW (Leg 2)

U.S. Geological Survey

Gutmacher, Christina	Geologist
Holland, Lynn	Geologist
Lipman, Peter	Co-chief scientist
Normark, William	Co-chief scientist
Thede, Joanne	Geophysicist
Vaughn, Jim	Electronic technician

Institute of Oceanographic Sciences, United Kingdom

Bishop, Derek	GLORIA supervisor
Cherriman, John	Electronics technician
Clarke, Jim	Electronics technician
Jacobs, Colin	Geologist/photographer
Whittle, Steve	Mechanical technician
Wilson, John	Co-chief scientist

National Environmental Research Council/Research Vessel Services (U.K.)

Cooper, Ed	Computer support
Sherwood, John	Computer support

Visiting Scientist (Peter Cook University, Australia)

Johnson, David	Geologist

Schedule of Field Operations, F6-86-HW

The following list begins with day of the year/Greenwich Mean Time (GMT) for the starting point of each survey segment. For conversion to local time, note that day 309 is 5 November and that the local Hawaiian time is 10 hours behind GMT, e.g., 1900 GMT is 0900 local. Figure 1 is a track-chart summary to provide a geographic reference for the various stages of the survey. Figure 2 provides the geographic references used in the schedule review.

1. 309/1900 Depart Hilo, Hawaii.

2. 310/0408 Begin underway watchkeeping; all gear has been deployed and is operational. Begin westerly line through the Alenuihaha Channel along south side; this line together with an early line from the Leg 1 survey completes imaging of this deep-water pass between Hawaii and Maui.

3. 310/1000 Begin survey of the submarine slopes of Hawaii from Kohala south to Mauna Loa.

4. 312/0200 Begin survey inshore around South Point and continue east to complete the imaging of Loihi Seamount that was begun during Leg 1.

5. 312/2100 Start the standard deep-water trackline pattern that trends 122° with a spacing of 30 km (16 n. mi.). This continues the main survey grid initiated during the first leg. These initial lines extend from the base of the island slope south of the Kilauea Volcano out to the southeastern limit of the EEZ (Fig. 1). The northern end of some of these lines has a slight dogleg to allow us to complete mapping west of the island.

6. 319/0900 Break from the normal survey pattern to image the Cross Seamount group. The northern part of this group trends northeast-southwest. The summit of Cross seamount is less than 400 m below sea level, and at least five of the seamounts, including the rest of the group immediately south, have summits within 1050 m of sea level. The shallow-water depths of the features require closer line spacings than the 30 km deep-water grid.

7. 320/1900 Resume surveying along the southeast-trending standard trackline pattern.

8. 327/1857 Break survey early in Line 27 because the tow cable for GLORIA is damaged. The fourth sensor, giving the heading of the GLORIA vehicle, failed at 1845, necessitating the end of line. Ship alternately hoves to and steams around the termination of the survey line while repairs are attempted. Refer to the equipment review for more details.

9. 328/0800 Begin a survey using all underway geophysical equipment to provide tielines across the GLORIA tracklines.

10. 329/1056 Begin recording GLORIA data again for a short survey west of the Alenuihaha Channel and north of the Cross Seamount group. About 14 hours are available for this work.

Equipment Review: Comments and Operational Log

This review is to highlight the problems encountered and subsequent data gaps with the various systems. Standard operational procedures were covered by the F5-86-HW (Leg 1) cruise report (Holmes et al, 1987), and we include their summary as Appendix 1. Each system, except for GLORIA, is reviewed separately, generally in order from most reliable to most troublesome. Complete reviews of the trouble-shooting and repairs for each system are available in the technicians' logbooks.

Gravity Meter

The 15 v Sorenson power supply in the gravity meter that failed during the Leg 1 operations was replaced in Hilo prior to our departure. The system was operational by the afternoon of 3 November and was checked on 4 November by the representative from LaCoste and Romberg. The Leg 1 personnel felt that the meter failure during their leg was the result of overheating in the room where both the meter and the recording systems are located. They suggested a temporary solution to the overheating problem by changing the air flow through the compartment where the meter is housed. During our cruise, the gravity meter operated without problems or any interruption in data collection.

In addition, a gravity tie was established at the dock in Hilo. A second gravity tie was also available from the dock in Honolulu where the Leg 1 cruise started and Leg 2 ended. The land-tie values are:

Honolulu 286/1645

International gravity at meter: 978926.8 mgal

Hilo 308/1920

International gravity at meter: 978864.3 mgal

10-kHz Echo-Sounding System

The 10-kHz bathymetric profiling system uses a towed vehicle that was deployed at the start of the survey. No tow-vehicle maintenance was required, and the system operated continuously with the exception of three short periods for minor repairs to the recorder.

Time down	Time on line	Reason
313/0430	313/0453	Paper-feed failure
316/1433	316/1510	Paper take-up linkage slipping
319/2216	319/2313	General R & R

3.5-kHz High-Resolution Profiling System

The 3.5-kHz reflection-profiling system had operated erratically during the Leg 1 cruise, with record quality reported to range from good to poor. No repairs or modifications were attempted in Hilo. The 3.5-kHz system uses a towed vehicle similar to that used for the 10-kHz system. Both vehicles are the responsibility of the IOS personnel.

The 3.5-kHz system operated reasonably well for the first day of Leg 2. Then the system began to record random noise that continued to increase in strength until the noise dominated the record in deeper water areas. In addition, the "gray" background noise increased with time--a problem encountered during the first leg. A change of tow vehicles eliminated the random-noise problem. The record contrast, however, remained poor despite a change in the printer amplifier as had been tried by the Leg 1 group. A change of the high-voltage power transistor solved the contrast problem.

Time down	Time on line	Reason
313/0910	313/0954	Noisy tow vehicle
313/1946	313/2048	Excessive gray background
317/0935	317/1018	Deteriorating record

Two-Channel Seismic Reflection System

The seismic-reflection system uses a 2,600 cm^3 (160 cu. in.) air-gun sound source and a two-channel streamer, whose total length including stabilizing drag line is 750 m. The two active sections are each 50 m long and are towed between 400 and 500 m behind the sound source. The signals are recorded on a MASSCOMP digitizing system, and one channel is displayed on a line scan recorder (LSR) paper recorder with memory.

We followed the suggestions from the previous leg to set the operational parameters for the seismic-reflection system (Holmes et al, 1987). Basically, this included a record length of 6 seconds, firing the air gun every 10 sec., and using the memory capability of the LSR to print the field copy with a constant orientation (west and north ends of profiles will be on the left side of each profile) and to reduce the vertical exaggeration of the profiles by printing each trace three times. We also followed their advice to clean the LSR on a regular basis to avoid a paper-feed problem that had plagued the earlier cruise.

The advice given was good, and, as a result, we were able to operate with no down time caused by the recording system. Thorough cleaning of the LSR every two days during change of paper rolls was adequate. All down time with this system was from repeated failure of the air-hose packages when small leaks developed; the cause of the leaks is undetermined.

Time down	Time on line	Reason
311/2033	311/2219	Air leak
312/2004	312/2113	Air leak
313/0117	313/0232	Air leak
313/0408	313/0438	Air leak
313/1456	313/1558	Air leak
313/1629	313/1734	Air leak
315/0227	315/0321	Air leak
317/1825	317/1918	Scheduled gun change
322/1819	322/1904	Scheduled gun change
327/1857	328/0800	Scheduled gun change and GLORIA repair
329/0950	329/1049	Launch GLORIA

NOTE: The last scheduled air-gun change coincided with the failure of the GLORIA tow cable. The air gun was not redeployed until it was clear that the GLORIA vehicle would be out of operation for at least 24 hours.

Magnetometer/Gradiometer System

This system was operated in the gradiometer mode during Leg 2. The logging and recording systems functioned normally throughout the cruise. Two major failures with the sensors, however, resulted in a little over two days of no operation during the period when GLORIA was functioning.

The first problem involved the slave sensor, which developed a very noisy signal over a two-day period. The problem was traced to the winch slip ring and cable assembly on deck, not in the sensor or tow cable. The slip ring was bypassed and other deck connectors were checked and cleaned. This eliminated the noise, and operation with the gradiometer was resumed.

The second problem was with the master sensor when the signal turned to noise only. Upon recovery of the system, the master sensor was found to be flooded with sea water. Repair and reassembly fully corrected the problems, and the gradiometer remained operational until the GLORIA vehicle had to be retrieved. The last data gap was during the re-launch of GLORIA on the last day of the survey.

Time down	Time on line	Reason
317/1826	318/2000	Bad slip ring
321/2320	323/0217	Flooded master sensor
327/1857	328/0818	Off for GLORIA repairs
329/0952	329/1107	Launch GLORIA

Expendable Bathythermograph System

Expendable bathythermograph probes (XBT's) were deployed at least once each day. The purpose was to measure the thickness of the surface mixed layer and the temperature profile within the thermocline zone. Three problems were encountered during the XBT deploymemts: (1) the lead cable to the launcher is so short that the XBT's must be taken on the starboard side. As was known from the earlier GLORIA cruises this year, this restriction in launch site on the ship leads to many of the XBT's fouling in the air gun, which is towed from the same side of the vessel; (2) because of equipment malfunction the data were not transmitted to NOAA as was the plan; this also was a problem on earlier legs; and (3) at the start of Leg 2, we got intermittent records from those XBT's that apparently did not foul on the air gun. A broken wire inside the XBT launcher was found to be the cause of this problem, and after appropriate repairs, the percentage of successful XBT stations improved.

Because the XBT system is not continuously in operation, only the successful stations are recorded below. Positions for the stations are recorded in the data logs. Where the record length is listed as "partial," we assume that the probe wire fouled on the air gun.

Day	XBT depth rating	Record length
311	250 m (T-10 probe)	Partial
311	900 m (T-7 probe)	Partial
314	900 m	Partial
315	900 m	Full
316	900 m	Full
317	900 m	Partial
319	900 m	Partial
321	900 m	Full
323	900 m	Partial
323	900 m	Full
325	900 m	Partial
326	900 m	Full
327	900 m	Full
329	900 m	Full
330	900 m	Full

GLORIA Side-Scan Sonar System

The operation of the GLORIA system is covered in extensive log forms by the IOS personnel and will not be elaborated upon here. A copy of the pass (one pass equals 6 hours of GLORIA data) record and number of files of GLORIA data is attached as Appendix 2. The GLORIA vehicle operated continuously from about 0400 on day 310 until the failure of a key conductor in the tow cable at 1845 on day 327. The winds and seas during this leg caused both navigation problems, which are covered later, and problems in towing the GLORIA vehicle, especially on the southeastward traverses. The outbound (southeastward) runs caused a fair degree of pitching of the vessel. As a result, the GLORIA vehicle was pitching and yawing and this caused some data dropouts. The continued jerking motion on the tow cable led to a series of breaks in individual conductors within the tow cable. The first breaks occurred nearly 3 days before the operation had to be suspended when the heading information from the vehicle was lost. All breaks occurred on southeastward traverses.

Day/time	GLORIA sensor lost
324/1620	Temperature sensor
325/0239	Roll indicator
325/0651	Pitch indicator
325/0845	Power to depth indicator
327/1845	Compass readings erratic
327/1900	Data logging terminated
329/1056	Resume recording after repair

Most of the time between days 325 and 327 (when no further breaks occurred), we were on a northwestward traverse with reduced pitching motion.

Replacement of the tow cable commenced immediately upon recovery of the vehicle. When the new cable was being spooled onto the reel on the launching platform, the hydraulic motor ceased to function (about 2300 on day 327). At 0915 on day 328, IOS was contacted for advice on materials to repair a distributor in the manifold of the hydraulic pump on the launcher. Repairs were effected without word back from the pump manufacturer during the next 20 hours. At 0930 on day 329, contact with IOS suggested that the GLORIA vehicle could be launched safely with the homemade parts, and the survey operations resumed at 1056/329.

Shipboard Positioning Systems

The ABC system (a non-commercial oceanographic computer system provided by IOS) is used for shipboard positioning. It collects data from various sensors, stores the data, and provides good post-processed trackline plots. Both position data and geophysical information (gravity, water depth, magnetometer/gradiometer) are handled by the ABC system, and the geophysical data can be merged with the position information to produce map and section displays. The position data for the system come from the following devices: Global Positioning System (GPS) satellite, transit satellite, LORAN-C (hyperbolic--time-difference mode only), Omega, speed log, and gyro heading. The last two are used to provide dead-reckoned positions.

The best position data is from the GPS system, but the present constellation of satellites provided us with only 8 to 10 hours coverage each day. Because the work area is adjacent to one of the LORAN-C transmitting stations, and thus outside of the area of quality coverage for the Central Pacific LORAN-C chain, our only other source of reliable position data was the transit-satellite system. The effect was to leave significant gaps in position information, as much as three hours between usable transit-satellite fixes and as much as six hours with only one reliable fix, during which time the vessel moved in unrecorded fashion in response to winds (up to 46 km/hr or 25 kt sustained) and sea-surface currents (in excess of 2.8 km/hr or 1.5 kt and highly variable throughout the work area).

The major problem with using the ABC system is that it does not provide real-time navigation for the bridge watch. Therefore, even when the best position data were being received, the information is not processed and presented in such a way that the vessel can be maintained on planned tracklines. Without GPS and LORAN-C, survey control is basically non-existent. Sinusoidal tracks with wave amplitudes of as much as 13 km (7 n. mi.) (Fig. 1) resulted in a number of gaps in the side-looking sonar images. During the periods without GPS data, adjustments in heading by the bridge watch after nearly every transit-satellite position was received produced a trackline with more curves than straight-line segments (unless one approximates the track by a large number of very short segments. The net result is that the mosaic of the side-looking sonar images has a large number of distortions that probably cannot be corrected during later processing.

Appendix 3 includes a discussion of several other problems encountered in trying to make the mosaic of GLORIA images onboard the FARNELLA.

THE MAIN CONCLUSION IS THAT A DIFFERENT POSITIONING/NAVIGATION SYSTEM OR MAJOR MODIFICATION OF THE EXISTING SYSTEM IS REQUIRED BEFORE ANY FURTHER SURVEYING WITH GLORIA IS ATTEMPTED AROUND THE MAIN ISLAND AREA. Farther to the northwest along the Hawaiian Ridge, the Central Pacific LORAN-C coverage should greatly improve trackline control.

PRELIMINARY SUMMARY OF SCIENTIFIC RESULTS

Hawaii Leg 2 (F6-86-HW) focused on the southern and southwestern flanks of the island of Hawaii, and adjacent portions of the Hawaiian Deep and Rise, out to the 200-mile limit of the EEZ (Fig. 1). The geologic setting of the Hawaiian Ridge and associated structures are summarized in the cruise report for the preceding leg (Holmes et al, 1987) and accordingly will not be repeated here. Preliminary on-ship interpretations were to focus ideas generated during the cruise, permit comparisons with other GLORIA legs, and guide future work. Because the shipboard processing of the GLORIA images was incapable of subduing the high reflectivity of some key features on the relatively steep slopes of the volcanoes, and only limited comparisons were made with accompanying bathymetric and seismic data, some interpretations presented here may require revision (see Appendix 3). These interpretations are also handicapped by lack of shipboard access to published literature on Hawaii. Much of the description and interpretation, especially for the Alika slide, also can be improved and sharpened by further study of the acoustic and seismic-reflection profiles obtained in the 1978 R/V S.P. LEE cruise.

Flanks of the Island of Hawaii

Leg 2 surveyed the submarine west flank of the island of Hawaii from the Loihi area, around the southwest sides of Mauna Loa, Hualalai, and Kohala Volcanoes, to Upolo Point (Fig. 2). Among the most prominent features of the island flanks are some of the largest submarine landslides ever observed as has been suggested from earlier work (Moore, 1964; Normark et al, 1979). Nomenclature used by us for these slides generally follows that reviewed by Moore (1977) and includes (in order from the most coherent to most fluidized downslope movement) fault-bounded block slumps, morphologically complex rock slides, and fluidized debris slides. Another striking feature of the GLORIA data is imaging the actual shoreline in many areas. In contrast to most geologically older areas, shallow-water wave-cut shelves are poorly developed around most of the island.

Alika Slide

A large region of submarine slumping on the south Kona flank of Mauna Loa was initially inferred in the middle 1970's (Lipman, 1980) from the atypically steep on-land slopes (up to 7°), even though all on-land slump structures are now covered by younger lavas. Slump and slide features were detected as far as 80 km west of the shoreline and named the Alika slide, based on bathymetric and seismic profiling during a 1978 R/V S.P. LEE cruise (Normark et al, 1979). The GLORIA images indicate that the Alika Slide is larger and more morphologically complex than previously recognized; they provide clear evidence that the slide was a geologically rapid event, involving mass flowage, rather than a prolonged or repetitive sequence of slump or creep events (Fig. 3).

The Alika slide covers a roughly rectilinear region about 55 x 80 km across, with a total area of about 4,000 km^2. A minimum total volume for the slide, assuming an average thickness of only 50 m, the smallest-scale feature detected on the GLORIA images, would be 200 km^3. At least two closely related phases of movement can be distinguished on the sonar images. Initial failure led to westward-directed transport; at some later time, the upper part of the slumping mass broke out laterally to form a large secondary lobe that moved northward.

Slide Deposits

For each phase of the Alika slide, five major deposit types can be distinguished: (1) upper break-away slumps, (2) middle smooth debris-flow deposits, (3) lower hummocky debris-slide deposits, (4) fringing zones of isolated slide blocks, and (5) outer turbidite apron.

(1) Breakaway slumps.--The slide heads in an area of steep subaerial and submarine slopes (averaging 8-20°) on the west flank of Mauna Loa that is characterized by normal fault scarps, generally concave to the west in trace and with some scarps showing at least several hundred meters minimum displacement down in seaward directions. One of these scarps is the on-land Kealakekua fault that had historic movement during the 1950 Kona earthquake. Another major fault, at a depth of about 2,000 m, is inferred from bathymetry, and many smaller fault scarps were recognized on the upper 2 km of the underwater slope in this area during submersible studies in the late 1970's (Fornari et al, 1980). These features define a block-slump terrane, similar to but smaller than the subaerial and submarine Hilina system on the south flank of Kilauea Volcano and presently less active. Much of the steep south Kona flank of Mauna Loa is believed to represent prehistoric oversteepening by such block slumps that have been subsequently largely covered by historic and late prehistoric lavas erupted from the southwest rift zone of Mauna Loa.

(2) Middle smooth debris-slide deposits.--The upper 20 km of the mapped slide deposit, to a water depth of about 4,000 m, is characterized by a smooth, relatively featureless surface on the GLORIA images that was also observed on the 1978 profiles. This is a zone of deposition, rather than a continuation of the source breakaway, as shown by the westward deflection of bathymetric contours and the role of this zone as a source for the phase-2 portion of the slide.

(3) Lower hummocky debris-slide deposits.--The most widespread and distinctive facies of the slide is a lower region of closely spaced hummocky mounds (Fig. 4). Individual mounds are typically a few hundred meters across and average 20-100 m high, as measured from 3.5-kHz profiles. The mounds are probably subequant in shape, even though they have an elongate appearance on the GLORIA records. This stretching is an artifact of the imaging that results from beam spreading and the high reflectivity of the steep-sided mounds, as demonstrated by the invariable parallelism of an apparent elongation of features to the ship track. The hummocky zone is similar in morphology to many subaerial rockfall landslides and provides conclusive evidence of catastrophic failure and geologically rapid emplacement of the Alika slide. This morphology and emplacement mechanism is in contrast to the block-slump failure related to large normal faults of the Hilina system on Kilauea Volcano, or slow steady creep such as suggested for the morphology of

the adjacent Papau Seamount slide mass (Fornari et al, 1979).

(4) Fringing zone of isolated slide blocks.--Downslope, the zone of closely spaced hummocks merges gradationally with a peripheral zone of scattered large mounds that have skidded beyond the margins of massive slide material. Some of these blocks, especially those associated with the first phase of sliding, are as much as 1 km across and 100-200 m high, as measured on 3.5-kHz records. The reflection profiles are highly distinctive across this zone because of numerous hyperbolic echos generated by detached blocks to the sides of the ship track. In outer parts of this zone, individual blocks may be separated by as much as 3-4 km of seemingly undisturbed sediment on the floor of the Hawaiian Deep. For the phase-1 slide area, the isolated slide blocks traveled across the axis of the Hawaiian Deep and extend 5 to 10 km up the gentle lower slope of the Hawaiian Arch.

(5) Outer turbidite apron.--Much of the flat sedimented axis of the Hawaiian Deep in this area is characterized by sediment that is weakly reflective and relatively acoustically opaque. Similar sediments fill areas between the detached glide blocks of the fringing zone of the slide and pockets within the hummocky zone, as determined from the air-gun seismic data. This sediment is interpreted as volcanogenic turbidites that settled from flows generated during rapid emplacement of the slide masses.

Movement Kinematics

Motion of the Alika slide, documented by distributions of the deposit types and by broad bathymetric features of the overall slide deposit, is shown by arrows on Figure 3. The initial phase of the slide moved about 80 km due west from a breakaway zone headed on the steep west flank of Mauna Loa, near the Kealakekua fault. Anomalously steep underwater slopes, averaging 15-20° and locally approaching vertical as viewed from a submersible in 1976 (Fornari et al, 1980), extend to 2,500 m depth, at which level the contours bulge westward indicating upper limits of major deposition of slide material. Lower parts of the slide area consist of hummocky ground, with the possible exception of an equant low hill of relatively featureless material about 12-km across near the northern margin of the phase-1 slide. This may constitute a remnant of bedrock, earlier slide material, or a large relatively coherent mass rafted downslope during the phase-1 slide. The fringing zone of detached blocks is especially wide, as much as 20 km, and maximum block size is large, indicating catastrophic failure and rapid emplacement. Westward convexity of the bulge in bathymetric contours indicates that the bulk of the deposit was deposited during this phase.

A second phase of sliding was initiated by failure of the thickest accumulation of the phase-1 deposit and appears to head at a depth of about 4,000 m. Additional material from the shallower block-slump area may also have been mobilized. This secondary slide mass moved northward 55-60 km down less steep, lower slopes of Mauna Loa, also to about 4,600 m water depth. The direction of movement and failure area is defined by a prominent broad depositional lobe 40-50 km long and 10-12 km wide, bounded by scarp-like lateral flow margins 20-50 m high that make prominent linear sonar reflectors. The breakaway zone is probably indicated by a relatively featureless zone within the upper reach of the leveed trough, at a depth of 4,000-4,200 m, bounded on both sides by scattered mounds that are interpreted to represent attenuated remnants of the phase-1 hummocky material. Mounds of the phase-2 hummocky zone are smaller than in phase-1 deposits, and the fringing zone of detached blocks is narrower, indicating less energetic emplacement compatible with the lesser gravitation head.

The scale and morphology of the Alika slide is strikingly similar to some subaerial debris flows, generated by gravitational failure of flanks of andesitic arc volcanoes, despite their contrasting underwater and on-land settings (Mount St. Helens; Mt. Shasta; Bandai, Japan; Mt. Egmont, NZ, etc.). Although larger and farther-travelled than any known subaerial debris-avalanche slide deposits, relations between collapse height and travel distance for the Alika slide merge with those of the largest subaerial deposits, indicating an only slightly lower apparent coefficient of friction (see Ui, 1983; Ui et al, 1986a). Seemingly, the decreased gravitational acceleration for slide debris in water, as contrasted with air, is more than compensated by lubrication effects in the aqueous medium. For subaerial debris avalanches, greater mobility of volcanic debris avalanches than nonvolcanic landslides has been analogously related to presence of more fluids in the volcanic environment (Ui, 1983), perhaps from melting of snow and ice derived from upper levels of the volcanic edifices.

Longitudinal profiles of the Alika slide are also within ranges of those for many subaerial slides, implying rapid flow velocities and brief emplacement times that may be analogous to those observed at subaerial debris avalanches such as Mount St. Helens in 1980 or calculated for representative deposits by Ui et al (1986a, fig. 7). Notably, the slopes of the Hawaiian Deep over which lower portions of the Alika slide traveled are no gentler than those for some large subaerial debris avalanches such as that from ancestral Mount Shasta, which traveled at least 42 km beyond the base of the volcano on a slope that was only about 5 m/km (Crandell et al, 1984). The slope traversed by the lower 50 km of the Alika slide (phase 2), beyond the base of the island of Hawaii, averaged more than 10 m/km, and only approached 5 m/km over the lowermost 20 km of the slide area.

Mechanisms for generating the characteristic hummocky topography by fragmentation and abrasion during flowage (Ui et al, 1986b; Ui and Glicken, 1986) may also be applicable to the Alika slide. Progressive generation of a fine-grained matrix is particularly important during downslope movement; this fine-grained component is relatively mobile during emplacement and flows away from the larger blocks leaving the hummocky topography behind. More detailed morphologic studies of the hummocky terrain of the Alika slide by bottom photography and/or high resolution sonar could provide important constraints on emplacement mechanisms.

The striking, broad marginal zones of detached blocks in the Alika slide and other submarine slides around the flanks of the Hawaiian Ridge appear quantitatively different from most subaerial debris slides, although they may result from the same basic fragmentation processes during sliding. A decrease in concentration of mounds has been noted toward the terminus of the catastrophic Mount Shasta debris avalanche, the largest known subaerial volcanic slide; this decrease is attributed to lag deposition of blocks as the finer parts of the matrix drained downslope (Crandell et al, 1984; D. R. Crandell, written commun., 1986). In a subaqueous environment, such sorting processes might be more effective, and downslope segregation of the debris into block and matrix accordingly more efficient. Thus, the fringing zones of isolated blocks seem most reasonably interpreted as the distal portions of the debris slide, from which the muddy matrix segregated especially efficiently and traveled beyond the blocks as turbidity flows that deposited relatively fine-grained sediment on the seafloor out beyond the toe of the main debris slide. Gliding of discrete isolated blocks in advance of the debris slide, as inferred for some other submarine slide masses (Moore, 1977), accordingly would not be required. Coring of bottom sediment adjacent to the Alika slide is needed to test this hypothesis further.

Age

The emplacement age of the Alika slide is poorly constrained. It is the youngest major gravitational slump feature on the west side of Hawaii, perhaps the youngest slump of its size in the entire island chain. A 13,000-year-old submarine terrace, traced previously across the Kealakekua fault, indicates that this major breakaway structure has been relatively inactive since that time, despite its minor historic movement; thus, the Alika slide also predates this terrace (Moore and Fornari, 1984; Normark et al, 1978). An attractive possibility is that emplacement of the Alika slide (or the Lanai slide, see below) caused the massive tsunami deposits recognized by Moore and Moore (1984) on Lanai, for which the interpreted age is about 100,000 years b.p.

Thus far, the two phases of the Alika slide have been discussed as a successive phase of a single composite geologic event, based on their morphologic similarity and overlapping source regions. An alternative scenario, e.g., that significant geologic time separates phases 1 and 2, cannot be rigorously excluded by available data; perhaps study of the amounts and types of subsequent surface sedimentation would be informative. Relations between the block-slump terrain on the upper submarine slopes of the south Kona coast are similarly ambiguous. We interpret these as recording multiple seaward gravitational slump features, related to intrusion of dikes along the adjacent subaerial rift zones of Mauna Loa and Hualalai Volcanoes (Lipman, 1980). It seems most probable but presently unprovable that especially severe slump events along the zone of block faulting triggered the more catastrophic Alika debris slide. Comparable downslope gradations from block slumps, to debris slides, to debris flows characterize many individual subaerial landslides, both volcanic and nonvolcanic.

A final problem concerns the abundance of catastrophic debris slides that generated hummocky topography along the Kona side of Hawaii and the adjacent Lanai platform, in contrast to their apparent absence on the windward side of the island as recorded by GLORIA data during Leg 1 (Holmes et al, 1987). Particularly notable is the absence of such catastrophic slide deposits associated with the active Hilina fault system adjacent to Kilauea Volcano. Does this contrast relate to the greater size of Mauna Loa Volcano, and imply that the largest historic slump events, such as that associated with the 1975 M7.2 Kalapana earthquake (Tilling et al, 1976), were far smaller than prehistoric seismic events and associated ground failures on the Kona side of Hawaii?

Other Gravitational Slides

In addition to the Alika slide, smaller slide features were imaged widely along the west coast of the island of Hawaii. These include sizeable young landslide deposits off the west side of Ka Lae (South Point) of Mauna Loa and from the southwest portion of the Maui-Lanai platform, a large area of lobate terraced debris-slide-like material along the lower south Kona slope of Mauna Loa, and the Papau Seamount slide mass derived from the southwest flank of Kilauea.

Ka Lae Slide

This slide mass follows a channel from the upper submarine flank of Mauna Loa directly west of Ka Lae and the major Kahuku fault on its west side (Fig. 3). It is morphologically broadly similar to the Alika slide, but is shorter, narrower, and less clearly imaged by GLORIA. Total length of the slide is about 65 km, extending to a water depth of about 5,200 m. It is only 8-15 km wide, reflecting confinement within a broad channel bounded by Dana Seamount to the west and the submarine continuation of the southwest rift zone of Mauna Loa to the east (Fig. 3). The toe of the slide consists of hummocky ground, yielding a characteristically streaky sonar signature, and similar but less clearly imaged material appears to extend up channel to at least as shallow as 3,000 m depth. Several fault-like steps are indicated by reflective zones in the detachment area at about 2,000 m depth, but the main breakaway structure seems to be a larger steep slope between 500 and 1,000 m depth. Some material may have slid from the flanking Kahuku fault scarp as well. However, configuration of the breakaway may be complicated by the voluminous historic (1868, 1887) and late-prehistoric Mauna Loa flows funnelled into this area by the subaerial Kahuku fault scarp.

Lanai Slide

Morphologically similar hummocky terrane, imaged over an area of several hundred km^2 in the Kahoolawe Deep at the northwest margin of the present survey, is the terminous of another major slide area derived from steep embayments (18° slope) between 1,000 and 3,000 m water depth on the southwest flank of the Lanai platform. Only part of this slide area was imaged; southwesterly-bulging bathymetric contours at the base of the steep slopes probably mark the upper depositional limit of the slide masses. Total north-south length of the slide area is more than 100 km, and more slide terrane lies west of the imaged area.

A nearby area of scattered mounds, also at the margin of the Leg 2 survey, wraps around the north flank of Perret Seamount (Fig. 2). These mounds may constitute part of an isolated-block fringe of the Lanai slide, in which case an intervening zone containing few blocks must have been heavily sedimented. Alternatively, these blocks may have slid north from the seamount, but no breakaway source is readily apparent.

Lobate Debris Slides

A problematic but distinctive terrane along the lower southwest flank of Mauna Loa is characterized by an intricately lobate terraced morphology. These deposits are tentatively interpreted as older-assemblage gravitational debris-slide deposits, emplaced as more penetratively fluidized material than the Alika slide. As a less likely alternative, they could constitute a field of viscous lava flows related to the Cretaceous seamount cluster.

The main mass of this material occupies a northwest-trending elliptical low area along the basal southwest flank of the Mauna Loa shield. The area is 90-120 km long and about 25 km wide, mostly at water depths of 3,500-4,500 m. Overall slopes are gentle on surfaces of these deposits, without steep scarps or evidence of constructional volcanic centers other than the nearby large Cretaceous seamounts. This material is directly downslope and seemingly merges with the largest block-slump features on the Kona side of Mauna Loa, between the Alika and Ka Lae slides.

Individual lobate masses are mostly 1-5 km across. They range from subequant to highly irregular in plan. Many are marked by steep margins that are reflective on GLORIA images, and they are as much as 100-200 m high on 3.5-kHz profiles. Interiors of the lobes are commonly shadowed on the sonar images and appear flat to slightly depressed compared to the margins, resulting in a terraced appearance; some appear obscured by mantling sediment. The movement style seems to have been that of a viscous liquid, characterized by a minimum-yield threshold, modelled by a Bingham fluid. Such morphology in subaerial environments characterizes relatively fluid wet debris slides and dense mudflows.

These deposits are interpreted as fluidized debris slides downslope from major block-fault slump features of Mauna Loa's seaward flank. They involve contrasting emplacement conditions, in comparison with the Alika and similar slides, probably involving sustained periods of slower movement rather than catastrophic failure. Similar morphologies also characterize relatively viscous, slowly moving lava flows that are generally more silicic than basalt but including some basaltic aa. No unambiguous submarine basaltic flow morphology related to the Hawaiian volcanoes has such viscous flow features; an instructive contrast is with the well-defined lava field around the west base of Loihi Volcano.

Alternatively, at least some of this terrane might represent unusually viscous Cretaceous lava flows predating the Hawaiian volcanism. This seems less likely because of the lack of vent edifices associated with the lobate terraced terrane, which is characterized by low relief. Also, no comparably large areas of such terrain are (geometrically) directly associated with the Cretaceous seamounts away from the Hawaiian Ridge. One sizeable area of similar lobate terraced terrane, 15x45 km across, does occur around the south base of Jaggar Seamount, but this area also can be interpreted as debris-flow deposits.

Small areas of lobate terrane occur in isolated patches a few kilometers across, separated by as much as 150 km from the nearest seamount and associated contiguous debris apron. Most are probably remnant upper surfaces of large debris slides that are now heavily mantled by sediment, but some are difficult to distinguish from small seamount volcanoes.

Comparison with the findings of Hawaii Leg 1 and continued surveys during future Hawaii GLORIA work should help reduce uncertainties of the present interpretation.

Papau Seamount Slide Mass

This isolated mound to the northeast of Loihi images as a steep-sided, rather featureless mass. It has been previously interpreted as a sand-and-rubble slide related to the Hilina block-slump system on the south flank of Kilauea Volcano (Fornari et al, 1979). On the east flank of Papau, crescentic down-to-the-east scarps evident on the sonar images are compatible with gravitation mass movement. The bulbous character of the seamount suggests movement by slow steady creep, rather than by rapid sliding. The Papau mass appears to override the structural grain of the north rift of Loihi Seamount, suggesting relatively recent movement, perhaps continuing to the present.

Loihi Seamount

Loihi is an active submarine Hawaiian volcano, the youngest in the Hawaiian chain, as indicated by seismicity and by previously dredged samples of young tholeiitic and alkalic basalt (Moore et al, 1982).

GLORIA images clearly show south and north rift zones. The upper south rift seems to contain several pit craters or small spatter cones about 0.5 km in maximum diameter at 1,200-1,500 m water depth; these would be attractive targets for further study. The south rift bifurcates below about 2,500-m depth into southeast and subordinate south-southwest trends, studded by small constructional vents. The shorter north rift was less clearly imaged, and no vent features are evident, although a north-trending textural grain may reflect some aspect of the rift structure.

Lack of a shadow zone on images of the upper part of Loihi indicates that any summit caldera must be shallow and/or small, no more than about 1 km across, but images for the summit area are obscured by high reflectivity because of shallow water depth (>1,000 m).

A lobate lava field characterized by reflective surfaces extends southwest into the basin at depths of as much as 5,200 m, adjacent to Apuupuu Seamount. In contrast with the hummocky lavas of adjacent seamounts, the Loihi flows have insufficient relief to cast shadows on the GLORIA images and must have been highly fluid. This lava field is approximately 15x45 km across and records a period of exceptionally voluminous Loihi eruptions. A comparable lava field seems to be present on the east side of the south rift of Loihi, but it is near the limit of resolution for the most eastern line of this survey. These lava fields constitute attractive targets for bottom photography and dredge sampling, but are too deep (4,400->5,000 m) for observation from most submersibles.

Southwest Rift, Mauna Loa

The upper subaerial southwest rift has been the site of historic eruptions at 10- to 40-year intervals, but no historic activity and few late prehistoric eruptions have occurred below 500-m elevation (Lipman and Swenson, 1984). Activity on the lower rift presently seems to be impeded by the abrupt change in strike of the middle sector of the subaerial rift, and the underwater rift may have been relatively inactive during the Holocene and perhaps earlier.

Resolution on GLORIA images of features along the underwater rift is impeded by high reflectivity due to steep slopes and shallow water. Bathymetric profiles define the southern projection of the Kahuku fault, a major on-land feature that truncates the west flank of the rift underwater as well. The rift zone plunges more steeply in deep water (8-9°) than on land (about 2°), and terminates abruptly along a line between Dana and Apuupuu Seamounts (Fig. 2). These large edifices of probable Cretaceous age appear to have acted as immobile buttresses, impeding the extensional fracturing and dike injection that would have accompanied propagation of the rift farther to the south (Lipman, 1980). A reflective lava field lies at water depths of 4,200-4,600 m east of the rift, but any sizeable areas of similar lava west of the rift are poorly imaged and may be obscured by slide debris. The terrain downslope from the apparent termination of the rift was not sharply imaged, but appears characterized by irregular surfaces of considerable local relief more characteristic of gravitational-slide deposits than younger Hawaiian lavas.

Northeast Rift Zone of Hualalai

An obscure ridge that trends west-northwest for about 25 km at water depths of 900-3,000 m and merges with the south margin of the Hualalai-Kohala shelf is interpreted as a zone of eruptive vents along the submarine extension of the northwest rift zone of Hualalai Vocano (Figs. 2 and 3). Several small vent cones or craters are suggested by obscure textural irregularity on the sonar images. The entire ridge, and especially the vent cones, are highly reflective, indicating relative youth but impeding resolution on the ship-processed images. Above about 900 m water depth, the area between submarine ridge and the on-land rift zone has subdued topography, indicating either a gap in the rift zone or, more likely, cover by younger alkalic basaltic lavas associated with more scattered vents. The subaerial rift zone is similarly topographically obscure below about 500 m elevation. The more pronounced rift features in deep water suggest that these may be remnants from the earlier tholeiitic phases of Hualalai activity that are nowhere exposed on land. Dredge sampling and higher resolution imagery would be informative. To the north, the underwater segment of the rift zone abuts against the submarine flank of Kohala Volcano with a geometry similar to that of the southwest rift zone of Kilauea Volcano against Mauna Loa, supporting the edifice-buttress model of Fiske and Jackson (1972).

Hualalai-Kohala (H-K) Platform

The relatively gentle submarine platform sloping away from subaerial Hualalai and Kohala Volcanoes is interpreted as the original lower subaerial flanks of these volcanoes, which were above water at the time of formation and have subsequently subsided along with the entire Hawaiian Ridge. Slopes on the H-K platform (2-3°) are comparable to those on the lower slopes of the adjacent subaerial edifices, and are much gentler than the deeper submarine slopes (8-28°) that are interpreted as lower parts of these volcanoes that initially grew beneath the water surface. The H-K platform is broader (30-40 km) and deeper adjacent to Kohala Volcano, commensurate with its greater age. From Kawaihai to Kiholo Bays, younger lava from Mauna Kea and Mauna Loa has constructed a lava delta extending 25 km from shore to a depth of about 1,000 m that covers the upper submarine boundary between Kohala and Hualalai lavas. This lava delta is characterized by irregular reflection on sonar images; on the 3.5-kHz records, surface roughness of the young lavas, probably largely aa, is recorded as small-amplitude relief (5-10 m).

Much of the large Kohala platform is relatively featureless on the GLORIA images, in part resulting from the high and variable reflectivity in shallow water. A bathymetrically distinct north-south-trending ridge 2-4 km wide and traceable for more than 20 km, rising above 1,100 m and centrally located on the plateau west of Kohala, is more reflective than the adjacent seafloor and probably constitutes an exceptionally broad submerged barrier reef. Alternatively, it could be a relatively young lava flow, although its orientation parallel to the submerged shoreline seems inappropriate. A prominent sinuous ledge just downslope at about 1,200 m is more certainly a subsided reef or shoreline. This probable barrier reef would be an attractive target for dredging, and a submersible study would be especially feasible because of the shallow water depth (1,000 m) and sheltered location in the lee of the island of Hawaii.

Western Volcano

GLORIA images of an isolated edifice, which is partly buried by rocks of the H-K platform, show that it is a discrete volcano of reflective lava, resembling other Hawaiian volcanic slopes more than the known Cretaceous seamounts. Reflective lava flows from this volcano extend to a depth of 3,100 m on the north side, riding over volcanogenic sediments in the lower Alenuihaha Channel. Several satellitic vent cones, as much as 1 km across, appear faintly evident on its upper slopes. Their appearance seems similar to that on alkalic cones of mature Hawaiian volcanoes such as Mauna Kea or Kohala, and the location is reasonable for a mature volcano on the Loa trend between Hualalai and Kahoolawe. Alternatively but less likely, this "west volcano" could be a Cretaceous seamount, but these seem less strongly reflective and lack the satellitic cones. Dredging and/or submersible study would be rewarding.

This volcano is buried by lavas of the Kohala platform, indicating a greater age. A bathymetrically well-defined break in slope at 2,900-2,400 m depth may mark the base of a dominantly alkalic cap on a tholeiitic base; alternatively, this could mark the deeply submerged shoreline at the time of dominant activity, subsequently dropped as a result of general subsidence of the Hawaiian Ridge.

Alenuihaha Channel (Kahoolawe Trough)

This pronounced submarine canyon between Kohala and East Maui Volcanoes is 90 km long, 20-30 km wide where steep sided, and up to 2 km deep (Fig. 2). It superficially resembles an erosional feature--a highly improbable possibility in light of its great size and depth. The limited initial cruise trackline along the south flank of this channel provided good images of the opposite slope, where three reflective steps seem best interpreted as submerged shorelines or coral reefs at depths of 1,000-1,200 m as interpreted by Moore (1987) and Moore and Fornari (1984). The main valley bottom contains reflective young-appearing lava, probably from Maui, to about 3,000 m depth. Less reflective featureless bottom at greater depth that yields multiple acoustic reflections on 3.5-kHz records is probably mixed volcanogenic and pelagic sediment. Both the existing bathymetry and the GLORIA images indicate that the valley sides are primary depositional slopes of the adjacent volcanoes, little modified by erosion. The sinuous subparallel slopes of the opposing volcanoes indicate some sort of mutual interference between the concurrently growing edifices, as inferred previously more generally for Hawaiian volcanoes by Fiske and Jackson (1972).

Cretaceous Seafloor

Topographically subdued Cretaceous seafloor is well preserved southeast of the island of Hawaii, variably obscured by sediment cover. In places, faint variations in reflectivity suggest the presence of large lobate sheet flows of fluid basalt without sizeable initial relief, but most such variations are widely obscured by sediment cover.

The most striking feature of the seafloor is a N10-20°W structural grain, defined by linear ridges and valleys inherited from extensional faulting along the Cretaceous spreading-center ridge (Fig. 5A). Relief on the present fault scarps is commonly 20-50 m, rarely as much as 100 m. Variable sediment fill of the valleys precludes precise estimates of offset, but the terrain seems less rugged than on GLORIA images of the Gorda and Juan de Fuca Ridges, suggesting more rapid spreading. 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 toward the larger faults. With more detailed analysis, the fault spacing and relief might permit more precise estimates for seafloor spreading rates during the Cretaceous magnetically quiet interval.

Seamounts

Hundreds of seamounts, ranging in diameter from less than 2 km to as much as 40 km, stud the Cretaceous seafloor south and west of the island of Hawaii. The largest rise as much as 4 km from seafloor depths of 4,500-5,000 m to within a few hundred meters of the ocean surface. Most are distributed irregularly, but some are in linear arrays following several trends, including the seafloor structural grain, the Molokai Fracture Zone, the trend of the

Hawaiian Ridge, and some directions seemingly unrelated to major adjacent structures. Sonar images of many of the large seamounts are difficult to interpret in detail because of the large size, relatively steep slopes (10-15°), and shallow tops of these volcanoes, but many features of their lower slopes are well displayed. In order to image upper slopes of the large seamounts, survey tracks had to be run across the lower flanks; this, however, yields no useful GLORIA image directly below the track and gives weak reflectance on the downslope flank and boundary with the adjacent seafloor. Seamount dimensions cited here are from Chase et al (1981), except where otherwise indicated.

Large Seamounts

The largest seamounts in the vicinity of the Hawaiian Ridge--those greater than 20 km in diameter and rising more than 2 km above the seafloor--mostly cluster in an area about 250 km across just west of Hawaii that has been covered by the Leg 2 survey (Figs. 2 and 6). Many of these are named after pioneering geologists of the Hawaiian Islands (Cross, Dana, Dutton, Jaggar, etc.); others are named after Navy ships (Swordfish, Indianapolis, Pensacola).

These seamounts range in shape from equant cones as much as 40 km in diameter (Cross) to elliptical ridges as much as 60 km long (Ellis, McCall) (Fig. 6). Volumes of single seamount volcanoes are as much as 500 km^3 (Cross, Apuupuu). Some seamounts seem to be composites of several volcanoes (Pensacola, Dana, Apuupuu). Only the shallowest seamount of the group (Cross) has a flat guyot top; it is 5-6 km across at a present water depth of 350 m. Slopes on many of the large seamounts are as much as 12-14° with vertical relief of several kilometers; slopes of 15° or more on a few seamounts are breakaway scarps for rockslides. Despite their size, none of the large seamounts has been shown to contain a summit caldera.

Many of the larger seamounts have linear ridge crests that are morphologically similar to the rift zones on Hawaiian volcanoes, although few possible vent features are discernible on the GLORIA images. Likely candidates are a row of about 6 vent-like knobs, each 1-2 km in diameter that cap the elongate ridge crest on the west flank of Dana Seamount. The multiple summits of McCall Seamount also are likely discrete vents, although this ridge crest is shadowed on the sonar images. Many of the subequant seamounts appear to have three subequally developed rift zones, extending radially from the summit at about 120° angles (Swordfish, Pensacola, Washington). Interference between adjacent volcanoes commonly favors development of rifts in a younger volcano parallel to slopes of the existing edifice and result in suppression of one rift direction, as documented for volcanoes of the Hawaiian Ridge (Fiske and Jackson, 1972). This model suggests sequential growth of several of the seamounts. For example, the north and east rifts of Washington Seamount straddle the southwest rift of Ellis, suggesting younger development. Several of the elongate seamounts (Ellis, McCall, Perret) are not obviously influenced by adjacent edifices, however, despite predictions of the edifices model. The north-northeast alignment of these volcanic ridges suggests eruption from basement fissures, even though this trend is not evident on adjacent seafloor structures.

Several types of deposits interpreted to result from gravitational sliding are associated with the large seamounts. The strikingly steep and dissected northeast side of a large unnamed seamount at 154°W, 17°30'N seems to have resulted from a sector failure that produced a rockslide of chaotic semi-coherent blocks as much as 2-3 km across on the lower slopes. A significant interpretive problem at this seamount and elsewhere is to determine whether the knobs clustered around bases of the major seamounts are slide debris, satellitic vents, or both. Whereas the hills at the northeast base of this seamount seem likely to be debris from the disrupted slope above, similar steep-sided hills adjacent to the southwest flank have no obvious slide source upslope (although much of the upper slope is obscured beneath the nadir of the sonar beam). This seamount would be an informative target for more detailed bathymetry, bottom photography, and higher resolution sonar.

Debris aprons of similar rock-slide and more lobate debris-slide character form platforms several hundred meters high and 5-20 km wide surrounding many of the cones (Fig. 6). Where most clearly imaged (Cross, Swordfish, Washington), individual lobes are terraced and 2-5 km across, indicating a source from higher on the volcano. On 3.5-kHz records, individual lobe fronts are 50-200 m high, similar to but smaller than the debris-slide deposits at the base of the Hawaiian Ridge (Fig. 5B). The debris slides are only weakly reflective with a mantle of thick sediment, as shown by a 3.5-kHz profile, and may have formed contemporaneously with volcanism during the Cretaceous.

Atypically steep slopes on the southeast sides of Cross and Washington Seamounts seem to be the sources of debris fans of finely reflective material that extends 15-20 km down the flanks of these volcanoes (Fig. 6). The highly reflective character of the debris, which resembles a subaerial talus cone on GLORIA images, suggests relatively recent formation. Although the talus fans might be alternatively interpreted as relatively recent lava flows based on their reflectivity, their flame-like terminations differ from typical lobate margins of basaltic lavas. In addition, recent reactivation of a Cretaceous volcano seems improbable.

A better candidate for relatively young lava adjacent to a large seamount, and perhaps erupted from its flank, is an irregular area 15 km across of reflective rough bedrock on gentle slopes on the east side of Pensacola Seamount (Fig. 6). This lava field is characterized by surface roughness, without detectable sediment cover on the 3.5-kHz record. Dredging and bottom photography would help to evaluate the presence of post-Cretaceous volcanism in this area.

Small Seamounts

Small seamounts seem irregularly scattered across the Leg 2 survey area. Contiguous areas as large as 10,000 km^2 can lack discernible seamounts (>1-2 km in diameter), while tens of seamounts are clustered within a few hundred km^2 in adjacent terrain. Seamounts smaller than about 5 km in diameter tend to have nearly circular outlines, relatively steep reflective sides, and flattened less-reflective tops--thus forming typical basaltic shields. Some have discernible small summit cones and craters (0.5-1 km diameter), but others do not. For many, the images are inadequate for confident interpretation. Larger seamounts (5-10 km diameter) tend to be more irregular in plan, and high reflectivity of their flanks makes detailed morphologic observation less certain. Many of these occur in overlapping clusters.

Young-Appearing Basalt on the Hawaiian Rise

Reflective basalt fields of low topographic relief lie in several places along the inner flank of the Hawaiian Rise, suggesting volcanism more recent than the Cretaceous seafloor. These rocks are characterized by surface roughness, similar to young basalt on the flanks of Hawaii, as shown by small-scale hyperbolic reflections on the 3.5-kHz profiles. Thus, their high sonar reflectivity cannot simply be a matter of smoother surfaces than adjacent seafloor; rather it must reflect a lack of thick sediment.

The lava field on the east flank of Pensacola Seamount has already been mentioned. In addition, reflective basalt that is overlain by little or no sedimentary cover was imaged at 156°W, 17°15'N, where three irregular lobes of lava radiate up to 20 km from an obscure, centrally-located vent source (Fig. 7). These flows are central within a somewhat less reflective larger area of rough-textured lava, at least 50 km across, that obscures the seafloor structural grain. This is another inviting target for dredge sampling and bottom photography.

Sediments

Pelagic and volcanogenic sediment blankets the volcanic basement to varying thickness as a function of age and proximity to source. Sediment thickness ranges from zero over young volcanic rocks to at least 150 m in the Hawaiian Deep, adjacent to flanks of the volcanic islands. Thick sediment is expressed by weakly reflective material on the sonar images; acoustic echo-sounder and air-gun seismic-reflection profiles provide additional information on thickness and lithologic variation.

Bottom types are divided into four groups to provide a preliminary framework for more detailed evaluation: (1) rough bedrock bottoms, (2) smoothly reflective slopes, (3) acoustically opaque basin sediments, and (4) acoustically transparent basin sediments.

(1) Rough bedrock bottoms, marked by weak acoustic returns and hyperbolic reflections, are interpreted as indicating only limited sediment cover over young lava. Intense hyperbolic reflections are associated with hummocky submarine landslide deposits.

(2) Smoothly reflecting slopes are thought to indicate coarse volcanic debris on the flanks of Hawaii and thin sediment cover over some older lava on the island flank and Cretaceous seamounts.

(3) Flat-lying sediment in basin areas that is acoustically opaque on the 3.5-kHz and air-gun seismic records is interpreted as indicating relatively coarse volcanogenic sediments derived from Hawaii.

(4) Flat-lying sediment that yields multiple subbottom reflections is interpreted as pelagic and fine-grained volcanogenic sediment. Penetration was rarely more than about 20 m on the 3.5-kHz records, but penetration locally of more than 0.1 sec. on the air-gun records suggests as much as 100 m of sediment along the axis of the Hawaiian Deep.

Increased sonar reflectivity of sedimentary cover toward Hawaii, reported by Leg 1 for the windward side of the island and interpreted as indicating coarsening of near-source material, does not seem to be present on our sonar mosaic. Further interpretation of this relation awaits comparison between data of the two legs. East of the Hawaiian Deep, secondary reflectors gradually appear on the 3.5-kHz profiles out beyond where the seafloor structural grain first becomes evident. Sediment ponded in the more distinct grabens between abyssal hills shows multiple reflectors to depths of as much as 30 m at the eastern margin of the survey. These areas of relatively thick sediment are less reflective on the sonar images than the more thinly sediment-draped horsts.

Regional Structure

In addition to the volcanic structures on the flanks of the island of Hawaii and the Cretaceous seafloor, the sonar images provide new evidence of regional features seemingly related to development of the Hawaiian Ridge. Most notable is a complex fault zone extending at least 150 km southeast from near Palmer Seamount (Fig. 2) to a large seamount cluster and relatively young-appearing basalt fields near the crest of the Hawaiian Rise.

This zone, here informally called the Palmer fault zone, is parallel to the Hawaiian Ridge, but offset about 75 km to the south, merging with the axis of the Hawaiian Deep at its north terminus. It thus forms a southwest boundary of the propagating southeasterly nose of the Hawaiian Ridge. The fault zone seems to have been unable to propogate through the seamount cluster at its northwest end; it converges with the structural grain of the Cretaceous seafloor at its southeast end.

In detail, the Palmer fault zone consists of en-echelon west-stepping fault segments, 20-40 km long, that strike N40-50°W and step westward toward the north. Most are dropped down to the northeast, although a few small scarps have opposing displacements (Fig. 8). Along the middle sector of the fault zone, the general northwest trend is accommodated by a saw-tooth pattern of alternating short fault segments (2-3 km long), alternately trending N70-80°E and N10-20°W, without any through-going northwest-trending faults. The north-trending segments are reactivated segments of the Cretaceous seafloor faults; displacements on these segments decrease conspicuously beyond about 5 km of the fault zone. (Displacements on the faults are difficult to estimate reliably because the ship track was nearly parallel to them, and because of sediment accumulation on the downthrown sides.) Bathymetric contours suggest 100-200 m total displacement across the fault zone where well defined southeast of Palmer Seamount. At the southeastern terminus of the fault zone, the strike swings to N20-30°W, gradually merging with the seafloor structure, and displacements diminish.

Sediment cover is relatively thick on the northeast side of the fault zone within the Hawaiian Deep, thus obscuring the structural grain of the Cretaceous seafloor. In contrast, to the southwest of the fault zone the seafloor grain is especially clear on the sonar images, probably because sediment has tended to move across the fault scarps to accumulate to the north.

CONCLUSION

The operation and science review presented here are preliminary and intended to give a simple overview of the major geologic features imaged with GLORIA. This report will be superceded by an atlas that will present all GLORIA images (after substantial processing and enhancement) and accompanying geophysical data.

REFERENCES CITED

Chase, T. E., Miller, C. P., Seekins, B. A., Normark, W. R., Gutmacher, C. E., Wilde, P., and Young, J. D., 1981, Topography of the southern Hawaiian Islands: U.S. Geol. Survey Open-File Report 81-120, 3 sheets.

Crandell, D. R., Miller, C. D., Christainsen, R. L., Glicken, H. X., and Newhall, C. G., 1984, Catastrophic debris avalanche from ancestral Mount Shasta Volcano, California: Geology, v. 12, p. 143-146.

EEZ SCAN 84 Scientific Staff, 1986, Atlas of the Exclusive Economic Zone, western conterminous United States: U.S. Geol. Survey Misc. Investigation Series I-1792, 152 p.

Fiske, R. S., and Jackson, E. D., 1972, Orientation and growth of Hawaiian volcanic rifts: the effect of regional structure and gravitational stresses: Royal Soc. London Proc., v. 329, p. 299-326.

Fornari, D. J., Moore, J. G., and Calk, L., 1979, A large submarine sand-rubble flow on Kilauea Volcano, Hawaii: Jour. Volc. Geotherm. Res., v. 5, p. 239-256.

Fornari, D. J., Lockwood, J. P., Lipman, P. W., Rawson, M., and Malahoff, A., 1980, Submarine volcanic features west of Kealakekua Bay, Hawaii: Jour. Volc. Geotherm. Res., v. 7, p. 323-337.

Holmes, M. L., Moore, J. G., Holcomb, R. T., Belderson, R. H., 1987, Preliminary cruise report, Research Vessel FARNELLA, Windward Hawaii, F5-86-HW: U.S. Geol. Survey Open-File Report 87-XXX, XX p.

Lipman, P. W., 1980, The southwest rift zone of Mauna Loa Volcano, Hawaii: Implications for structural evolution of Hawaiian volcanoes: Amer. Jour. Sci., v. 280A, p. 752-776.

Lipman, P. W., and Swenson, A., 1984, Geologic map of the southwest rift zone, Mauna Loa Volcano, Hawaii: U.S. Geol. Survey Misc. Invest. Map I-1323.

Moore, D. G., 1977, Submarine slides, <u>in</u> B. Voight, ed., Rockslides and Avalanches, Vol. 1, Natural Phenomena, Elsevier, p. 563-604.

Moore, J. G., 1964, Giant submarine landslides on the Hawaiian Ridge: U.S. Geol. Survey Prof. Paper 501D, p. D95-D98.

Moore, J. G., 1987, Subsidence of the Hawaiian Ridge: U.S. Geol. Survey Prof. Paper 1350, p.85-100.

Moore, J. G., and Fornari, D. J., 1984, Drowned reefs as indicators of the rate of subsidence of the Island of Hawaii: Jour. Geol., v. 92, p. 752-759.

Moore, J. G., and Moore, G. W., 1984, Deposit from a giant wave on the island of Lanai, Hawaii: Science, v. 26, p. 1312-1315.

Moore, J. G., Clague, D. A., and Normark, W. R., 1982, Diverse basalt types from Loihi Seamount, Hawaii: Geology, v. 10, p. 88-92.

Normark, W. R., Lipman, P. W., Lockwood, J. P., and Moore, J. G., 1978, Bathymetric and geologic map of Kealakekua Bay, Hawaii: U.S. Geol. Survey Misc. Field Studies Map MF-986.

Normark, W. R., Lipman, P. W., and Moore, J. G., 1979, Regional slump structures on the west flank of Mauna Loa volcano, Hawaii (abs.): Program, Hawaii Symposium on Intraplate Volcanism and Submarine Volcanism, July 16-22, Hilo, Hawaii, p. 72.

Tilling, R. I., Koyanagi, R. Y., Lipman, P. W., Lockwood, J. P., Moore, J. G., and Swanson, D. A., 1976, Earthquake and related catastrophic events, Island of Hawaii, November 29, 1975: A preliminary report: U.S. Geol. Survey Circular 740, 33 p.

Ui, T., 1983, Volcanic dry avalanche deposits--Identification and comparison with nonvolcanic debris stream deposits: Jour. Volc. Geothermal Res., v. 18, p. 135-150.

Ui, T., and Glicken, H., 1986, Internal structural variations in debris avalanche deposits from ancestral Mount Shasta, California, USA: Bull. Volc., v. 48, p. 189-194.

Ui, T., Yamato, H., and Suzuki-Kamata, K., 1986a, Characterization of debris avalanche deposits in Japan: Jour. Volc. Geothermal Res., v. 29, p. 231-243.

Ui, T., Kawachi, S., and Neal, V. E., 1986b, Fragmentation of debris avalanche during flowage: Evidence from the Pungarehu Formation, Mount Egmont, New Zealand: Jour. Volc. Geotherm. Res., v. 27, p. 255-264.

Wilde, P., Chase, T. E., Normark, W. R., Thomas, J. A., and Young, J. D., 1980, Oceanographic data off southern Hawaiian Islands: Lawrence Berkeley Lab. Earth Science Div. Publ. 359.

FIGURE CAPTIONS

Figure 1. Track chart for F6-86-HW, showing location of Figures 4, 5A and B, 7, and 8.

Figure 2. Major geographic features of the Hawaiian Islands showing location of northwest portion of area covered by GLORIA Leg F6-86-HW (heavy dashed line). Areas shown on Figures 3 and 6 are outlined. From Wilde et al (1980).

Figure 3. Interpreted geology of the Alika slide and adjacent flanks of the island of Hawaii. Heavy arrows indicate movement during successive phases of the slide.

Figure 4. Sonar image of the north terminus of Alika slide, within Hawaiian Deep, banked against the southwest flank of Hualalai Volcano. Outward decrease in density of hummocks marks gradation from debris slide into zone of isolated detached blocks. Apparent elongation of hummocks is artifact of sonar imaging.

Figure 5. Representative 3.5-kHz profiles of typical features. (A) North-northwest-trending horst-graben structure of Cretaceous seafloor (18°N, 155°15'W). (B) Toe of lobate debris slide, south of Jaggar Seamount.

Figure 6. Interpreted geology of large seamount cluster southwest of Hawaii showing large flanking aprons of lobate debris-slide deposits (stipple pattern) and inferred volcanic rift zones (railway-track pattern). SM, Seamount.

Figure 7. Sonar image of young-appearing basalt field on flank of Hawaiian Rise at 17°15'N, 155°45'W. Three irregular lobes of brightly reflective lava extend outward from a central vent; east lobe bifurcates around a high area, surrounding a kipuka (window) of older seafloor.

Figure 8. Sonar image of part of Palmer fault zone. This segment is a well-defined graben about 10 km across, with highly reflective boundary faults on each side. Horst-graben structure of Cretaceous seafloor is reactivated along southwest side of image, resulting in a sawtooth pattern.

APPENDIX I: EQUIPMENT SETTINGS AND COMMENTS

F5-86-HW - M/V FARNELLA

(from Holmes et al, 1987)

3.5-kHz SYSTEM

LSR (Recorder)	MODE - Continuous PAPER - 100 lpi SWEEP - 1 sec. PROGRAM - As required GAIN - 12 to 2 o'clock CONTRAST - Mid THRESHOLD - CCW
PTR Transceiver	GAIN - 6-8 POWER - 0 db PULSE WIDTH - Controls not active
IOS Correlator	OUTPUT LEVEL - 4-5 ATTENUATOR - 11.5

Instructions for annotator are in the manual. Fish depth compensation is 15 m.

10-kHz SYSTEM

MUFAX Recorder	ATTENUATOR - -6 to -18 as required TIME MARKS - 6 min. PULSE LENGTH - 2.8 to 5 FISH DEPTH - 6 X 2 M GATING SELECT - 6 FATHOMS METERS - Meters TRIGGER (Left/Centre) - As required for scale changes TVG - Use to suppress outgoing pulse GATING - Use to "see" bottom through the outgoing pulse

The TVG is normally off when GATING is on and vice versa.

SEISMIC-REFLECTION SYSTEM

LSR (Recorder)	DISPLAY - Normal STYLUS SCAN - 2 sec. PAPER - 120 lpi MEMORY SWEEP - 6 sec. FILTER - out POLARITY - + GAIN - 12 to 2 o'clock CONTRAST - -30 THRESHOLD - 2

Krohn-Hite Filter	15-70 Hz
Mod. 450 Amplifier	FILTER - 10 to 10,000 Hz GAIN - 40 db
BNC Delay Generator	As required for DWD in 2-sec. increments
HP 3968A Tape Rcdr.	TAPE SPEED - 15/16 ips Tapes last about 6 hours 15 minutes
MASSCOMP	GAINS - Prefilter 0, Postfilter 18

MAGNETOMETER/GRADIOMETER

Soltec Recorder	CHART SPEED - 40 cm/hr
Junction Box	AV SELECTOR - 4 min.

MINI-MANUAL FOR MASSCOMP

END OF LINE

1. Type (CNTL) C.

2. The program will stop and the active drive will rewind, LOAD light will come on, and UNLOAD light will blink.

3. Press UNLOAD, open door, pull out tape, remove write ring.

4. Slide new tape into drive, close door, press LOAD.

5. When WRT EN TEST light and LOAD light are steady, press ON LINE.

START OF LINE

1. Type "newline" (note the quotes) and answer the menu questions. The Cruise ID and Record Length--6 sec.--will always stay the same.

2. To start program running, type /dev/lp (CR).

3. Set postfilter gains to 18 by typing g 1 a 18 (CR), wait one shot then type g 2 a 18 (CR). Check printer to see if it accepted the command.

TAPE CHANGES DURING A LINE

The Cipher drives will switch automatically, and the drive with the full tape will rewind and take itself offline. Keep a close watch on this because new tape must be inserted ASAP. You have less than 5 minutes before an error message comes on the printer, "tape drive not on line." Follow tape change procedures under END OF LINE section above.

DEEP-WATER DELAY

The BNC box affects only the LSR and the wiggle trace monitor. MASSCOMP must also be told of DWD by typing w n (CR), where n = DWD in seconds.

MISCELLANEOUS

1. Tapes last about 8 hours.

2. Clean drive after every other tape.

3. If printer shows potential overload on Channel 2, reset gain as described above under START OF LINE.

4. System will not allow line changes to be made "on the fly," and stopping the tape automatically dumps it. You have to make the choice whether to put only a few minutes or hours on a tape or to continue recording with the wrong line number.

5. The MASSCOMP keyboard is live. It only takes a soft touch to ruin your day.

APPENDIX 2

PASS #	START TIME	FINISH TIME	FILE #	TAPE #	COMMENTS	RECORDS
1	0205/310	0800/310	1	29	Starts at Line 11	710
2	0800/310	1400/310	2	29	Error Line 9	720
3	1400/310	2000/310	3	29		720
4	2000/310	0200/311	4	29		720
5	0200/311	0800/311	5	29		720
6	0800/311	1400/311	6	29		720
7	1400/311	2000/311	7	29		720
8	2000/311	0200/312	8	29		720
9	0200/312	0800/312	9	29		720
10	0800/312	1400/312	10	29		720
11	1400/312	2000/312	11	29		720
12	2000/312	0200/313	12	29		720
13	0200/313	0800/313	13	29		720
14	0800/313	1400/313	14	29		720
15	1400/313	2000/313	15	29		720
16	2000/313	0200/314	16	29	Error Line 48	720
17	0200/314	0800/314	1	30		720
18	0800/314	1400/314	2	30		720
19	1400/314	2000/314	3	30	Error Lines 385, 395	720
20	2000/314	0200/315	4	30		720
21	0200/315	0800/315	5	30		720
22	0800/315	1400/315	6	30		720
23	1400/315	2000/315	7	30		720
24	2000/315	0200/316	8	30		720
25	0200/316	0800/316	9	30		720
26	0800/316	1400/316	10	30		720
27	1400/316	2000/316	11	30		720
28	2000/316	0200/317	12	30		720
29	0200/317	0800/317	13	30		720
30	0800/317	1400/317	14	30		720
31	1400/317	2000/317	15	30		720
32	2000/317	0200/318	16	30		720
33	0200/318	0800/318	1	31		720
34	0800/318	1400/318	2	31		720
35	1400/318	2000/318	3	31		720
36	2000/318	0200/319	4	31		720
37	0200/319	0800/319	5	31		720
38	0800/319	1400/319	6	31		720
39	1400/319	2000/319	7	31		720
40	2000/319	0200/320	8	31	Line 255 missing	719
41	0200/320	0800/320	9	31		720
42	0800/320	1400/320	10	31		720
43	1400/320	2000/320	11	31		720
44	2000/320	0200/321	12	31		720
45	0200/321	0800/321	13	31		720
46	0800/321	1400/321	14	31	Error Line 71	720
47	1400/321	2000/321	15	31		720

48	2000/321	0200/322	16	31		720
49	0200/322	0800/322	1	32		720
50	0800/322	1400/322	2	32		720
51	1400/322	2000/322	3	32		720
52	2000/322	0200/323	4	32		720
53	0200/323	0800/323	5	32	Line 255 missing	719
54	0800/323	1400/323	6	32		720
55	1400/323	2000/323	7	32		720
56	2000/323	0200/324	8	32		720
57	0200/324	0800/324	9	32		720
58	0800/324	1400/324	10	32		720
59	1400/324	2000/324	11	32		720
60	2000/324	0200/325	12	32		720
61	0200/325	0800/325	13	32		720
62	0800/325	1400/325	14	32		720
63	1400/325	2000/325	15	32		720
64	2000/325	0200/326	16	32		720
65	0200/326	0800/326	1	33		720
66	0800/326	1400/326	2	33		720
67	1400/326	2000/326	3	33		720
68	2000/326	0200/327	4	33		720
69	0200/327	0800/327	5	33		720
70	0800/327	1400/327	6	33		720
71	1400/327	1900/327	7	33	GLORIA cable failed	600
72	1056/329	1600/329	8	33	GLORIA on line again	611
73	1600/329	2200/329	9	33		720
74	2200/329	0148/330	10	33	Logging terminated	457

APPENDIX 3: INTERPRETIVE PROBLEMS

A variety of position uncertainties and image-degradation situations caused significant problems in interpreting the GLORIA data for this leg.

Navigation problems similar to those encountered during the previous Hawaii leg required dead reckoning for as much as several hours and caused track excursions of as much as 13 km (7 n. mi.) Strong surface-water currents and sustained trade winds of up to 46 km/hr (25 kt) required steering as much as 15° into the wind/current from the actual track. Crosscurrents were particularly severe in the lee of Ka Lae, the south point of the island of Hawaii, and the field of Cretaceous seamounts in this area. Because the GLORIA instrument presumably tracks with the ship, especially when the crab angle is caused by ocean currents, location errors are potentially large in the far field if the images are mosaicked perpendicular to the plotted navigation course. At a 15° crab angle, an object at 10 km distance will be 2.5 km from its apparent imaged location. Attempts to correct for this by slicing and rotating segments of images result in overlaps, gaps, and visual disruption. When the track line is also uncertain due to navigation problems, construction of a best-fit mosaic becomes an appropriate task for a master collage artist.

Resolution of the GLORIA images was at times limited for several reasons. The steep flanks and shallow portions of the volcanoes were commonly highly reflective and washed out in the ship-processed images; hopefully, this limitation can be subdued by more thorough processing in Menlo Park. More seriously, large areas are streaked parallel to the ship course, especially in the distant field. This artifact gives equant hills the visually misleading appearance of ridges. The invariable parallelism of such streaks to the ship course demonstrates that they are artifacts. This problem is especially evident for hummocky landslide areas, such as the lower reaches of the Alika slide, and the flanks of some Cretaceous seamounts. We suspect that the streaking is due to pitching and yawing of the ship while sensing highly reflective steep rock surfaces near the periphery of the GLORIA beam; these may be preferentially imaged multiple times compared to more subdued and less reflective features of similar size. At other times, especially when the ship was bucking winds on southeast headings, the GLORIA image was gridded, resembling microcline twinning, presumably due to the combined effect of pitching, yawing, and rolling.

The rugged submarine terrain on volcanic edifices causes other problems. Complete coverage is unobtainable without closely spaced legs that are difficult to navigate precisely. Tracks along the flanks of volcanoes yield strongly reflective images upflank and weakly reflective images downflank for the same material, resulting in a visually misleading spurious boundary on the mosaic. The back sides of the volcanoes are shadowed, and a pass must be made on each side to obtain maximum resolution. If the passes are too close, the image is washed out; if they are farther apart, an axial shadow area remains at the crest of the volcano that can look like a summit depression and be misinterpreted as a caldera.

Other interpretive problems arise from the need to combine sonar images with seismic-reflection profiles. Because ship tracks were laid out to maximize the efficiency of sonar imaging, tracks were commonly less than optimal for profiling significant geologic features. Because no useful sonar imagery is obtained for the nadir (along the ship track), the reflection profiles provide needed data for otherwise indeterminate terrain, as well as helping characterize materials of contrasting appearance on the sonar images. Interpretation of the sonar images also benefits from the availability of detailed bathymetry (100 m contours) for some of the survey area (Chase et al, 1981). Interpretation could not be as rigorous elsewhere, and a critical element of any detailed follow-up studies would be to generate more detailed bathymetry for key study areas, especially any involving rugged topography such as the large seamounts.

Finally, the air conditioner over the drafting table (plotting room of the FARNELLA lab) drips rusty water when the ship rolls. It does wonders for GLORIA mosaics!

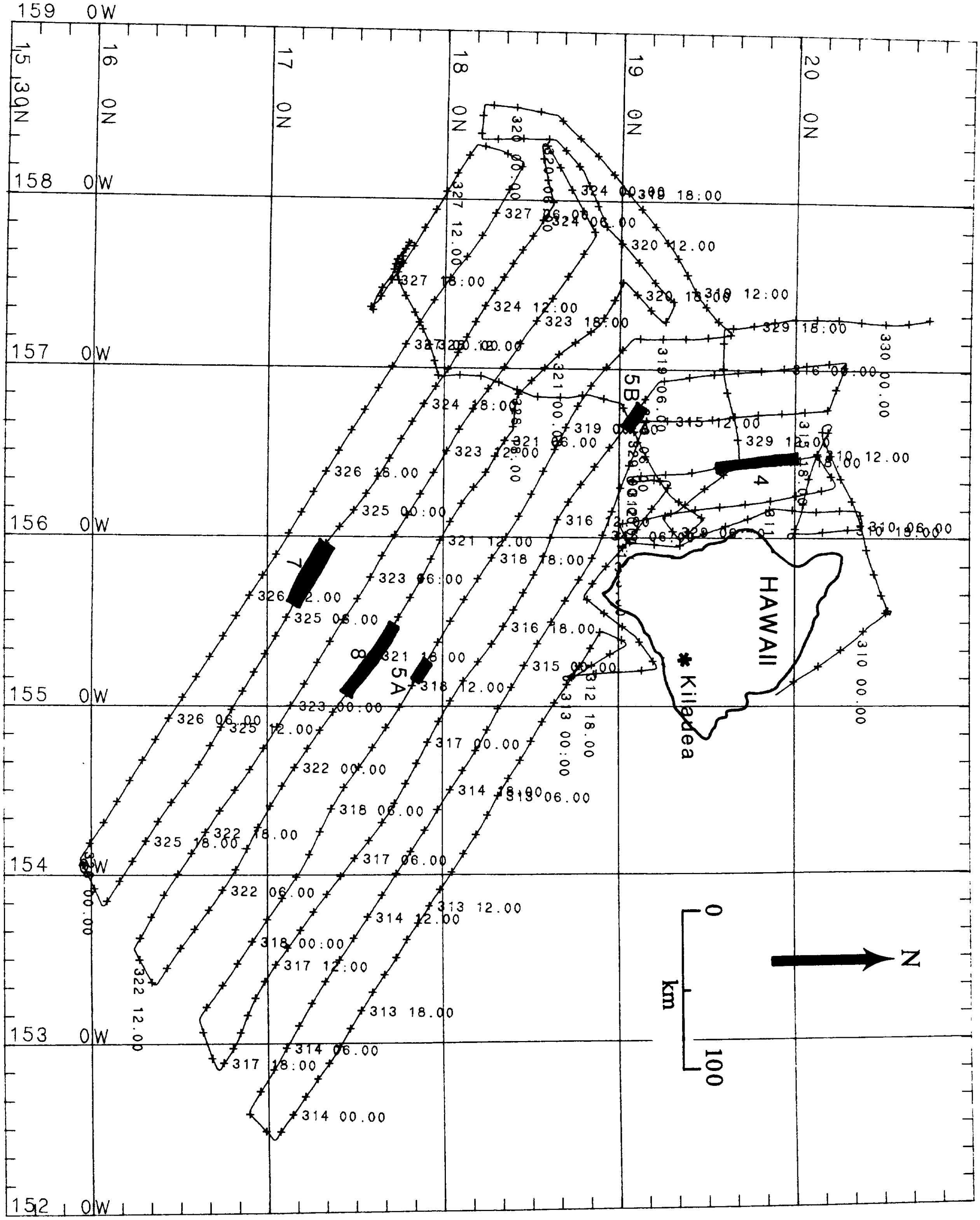
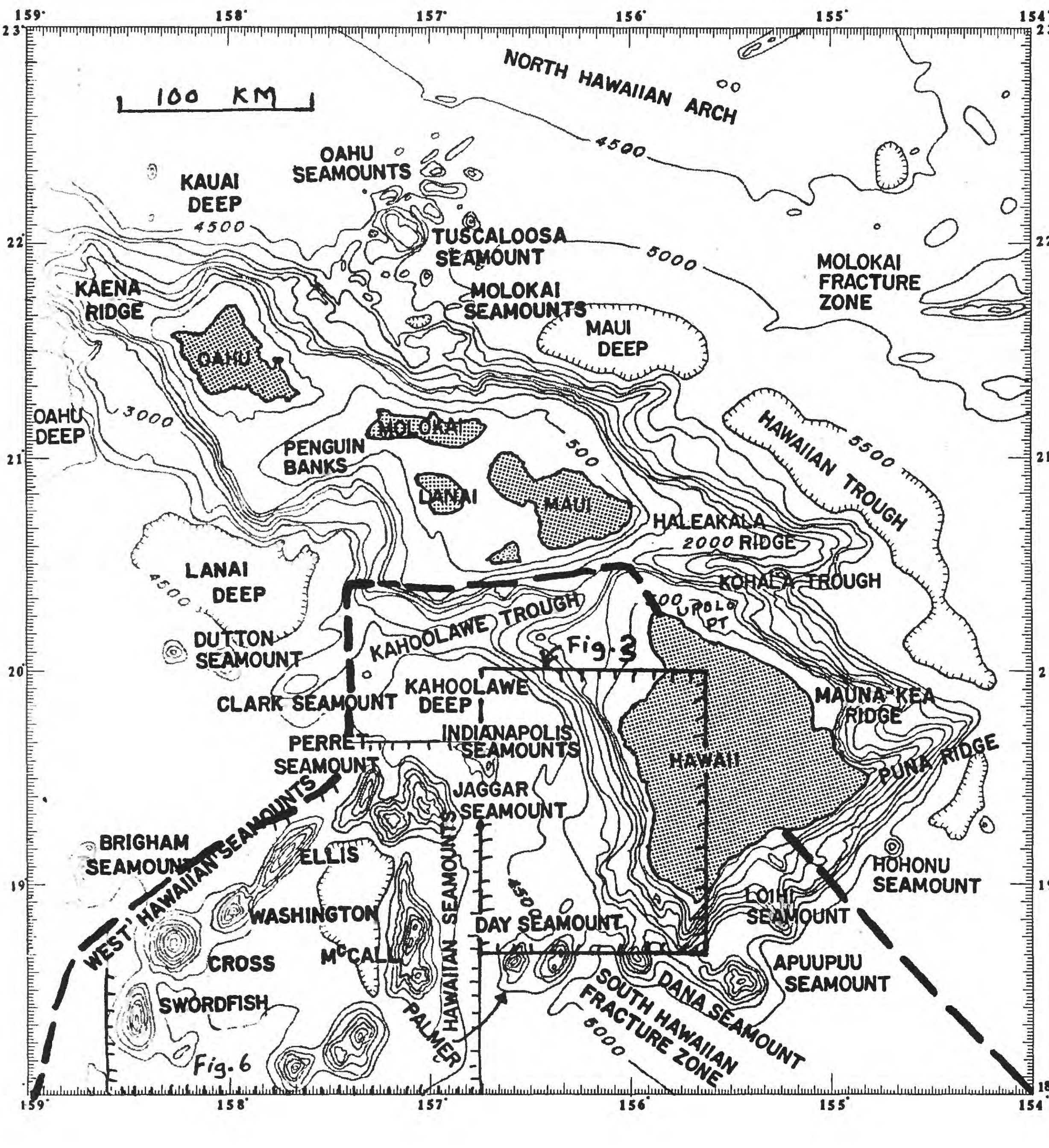
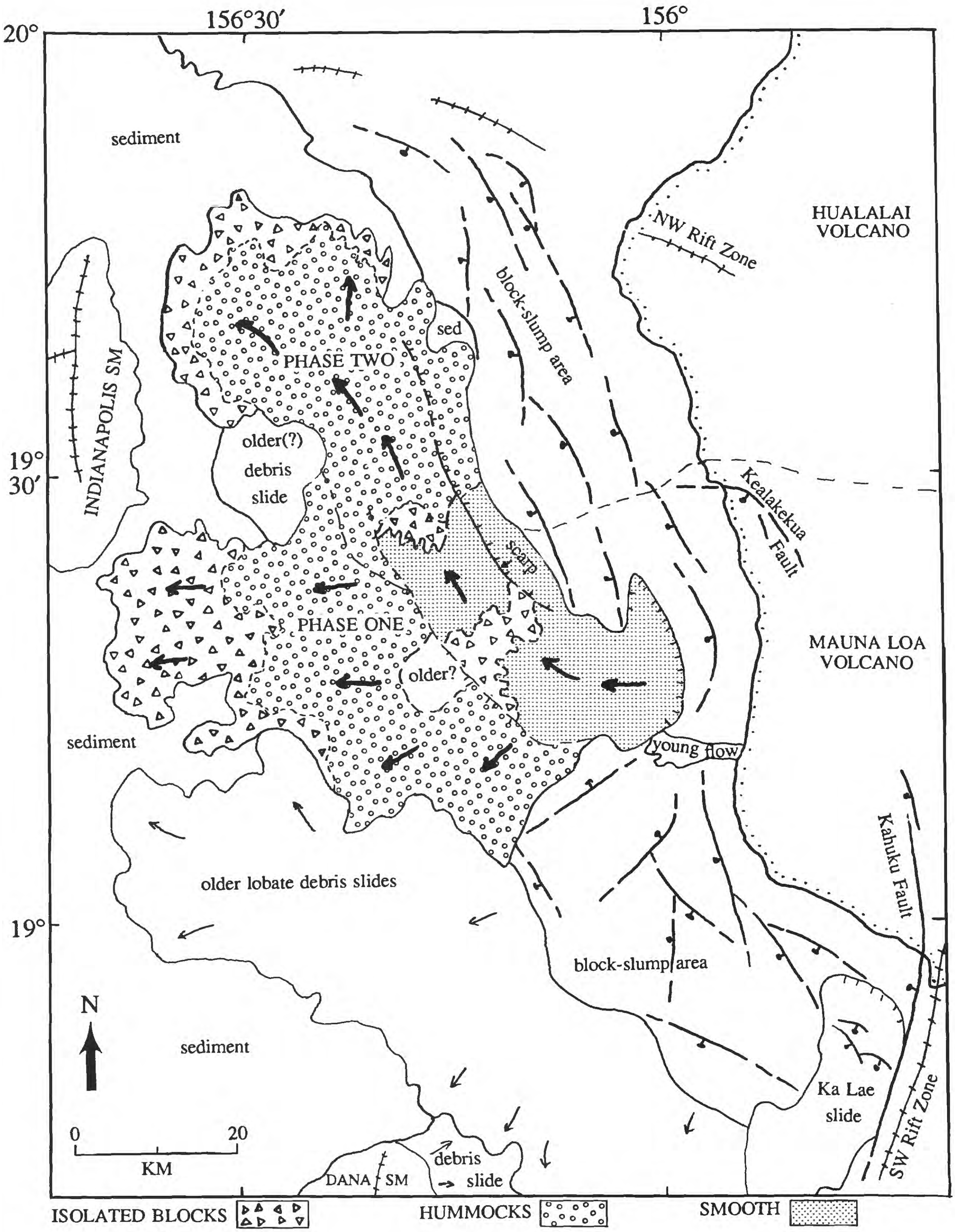

159 0W
158 0W
157 0W
156 0W
155 0W
154 0W
153 0W
152 0W
15 30N
16 0N
17 0N
18 0N
19 0N
20 0N
HAWAII
Kilauea
N
km
0
100
4
5A
5B
7
8

Figure 1



100 KM
NORTH HAWAIIAN ARCH
OAHU SEAMOUNTS
KAUAI DEEP
TUSCALOOSA SEAMOUNT
MOLOKAI FRACTURE ZONE
KAENA RIDGE
MOLOKAI SEAMOUNTS
MAUI DEEP
OAHU
OAHU DEEP
MOLOKAI
PENGUIN BANKS
HAWAIIAN TROUGH
LANAI
MAUI
HALEAKALA RIDGE
LANAI DEEP
KOHALA TROUGH
KAHOOLAWE TROUGH
DUTTON SEAMOUNT
Fig. 3
CLARK SEAMOUNT
KAHOOLAWE DEEP
MAUNA KEA RIDGE
INDIANAPOLIS SEAMOUNTS
PERRET SEAMOUNT
HAWAII
PUNA RIDGE
JAGGAR SEAMOUNT
BRIGHAM SEAMOUNT
WEST HAWAIIAN SEAMOUNTS
ELLIS
HOHONU SEAMOUNT
WASHINGTON
DAY SEAMOUNT
LOIHI SEAMOUNT
CROSS
McCALL
HAWAIIAN SEAMOUNTS
APUUPUU SEAMOUNT
SWORDFISH
DANA SEAMOUNT
SOUTH HAWAIIAN FRACTURE ZONE
PALMER
Fig. 6

Figure 2



156°30′
156°
20°
19° 30′
19°
sediment
HUALALAI VOLCANO
NW Rift Zone
block-slump area
sed
PHASE TWO
INDIANAPOLIS SM
older(?) debris slide
Kealakekua Fault
scarp
PHASE ONE
MAUNA LOA VOLCANO
older?
sediment
young flow
Kahuku Fault
older lobate debris slides
block-slump area
N
sediment
Ka Lae slide
SW Rift Zone
0
20
KM
debris slide
DANA SM
ISOLATED BLOCKS
HUMMOCKS
SMOOTH

Figure 3

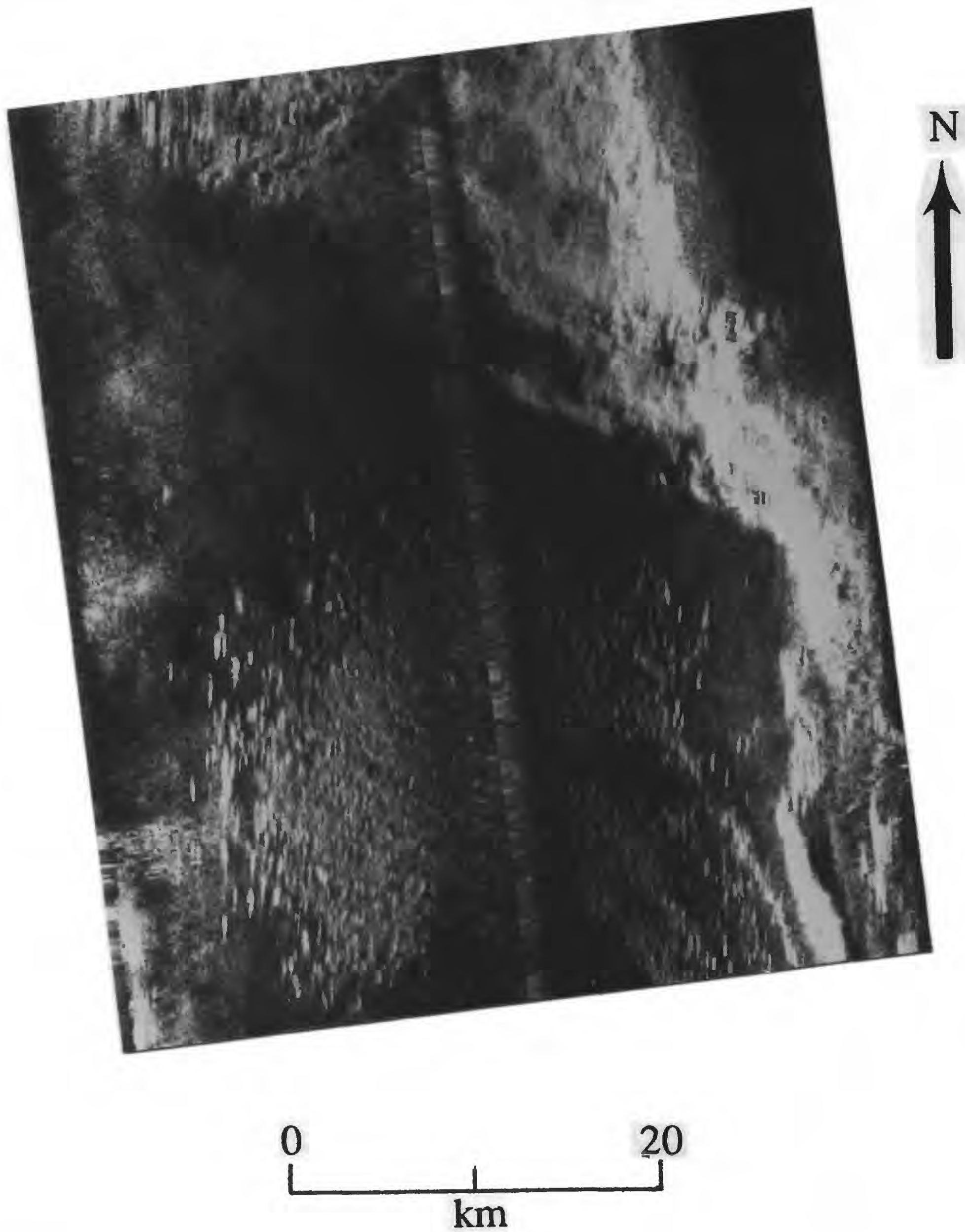


Figure 4

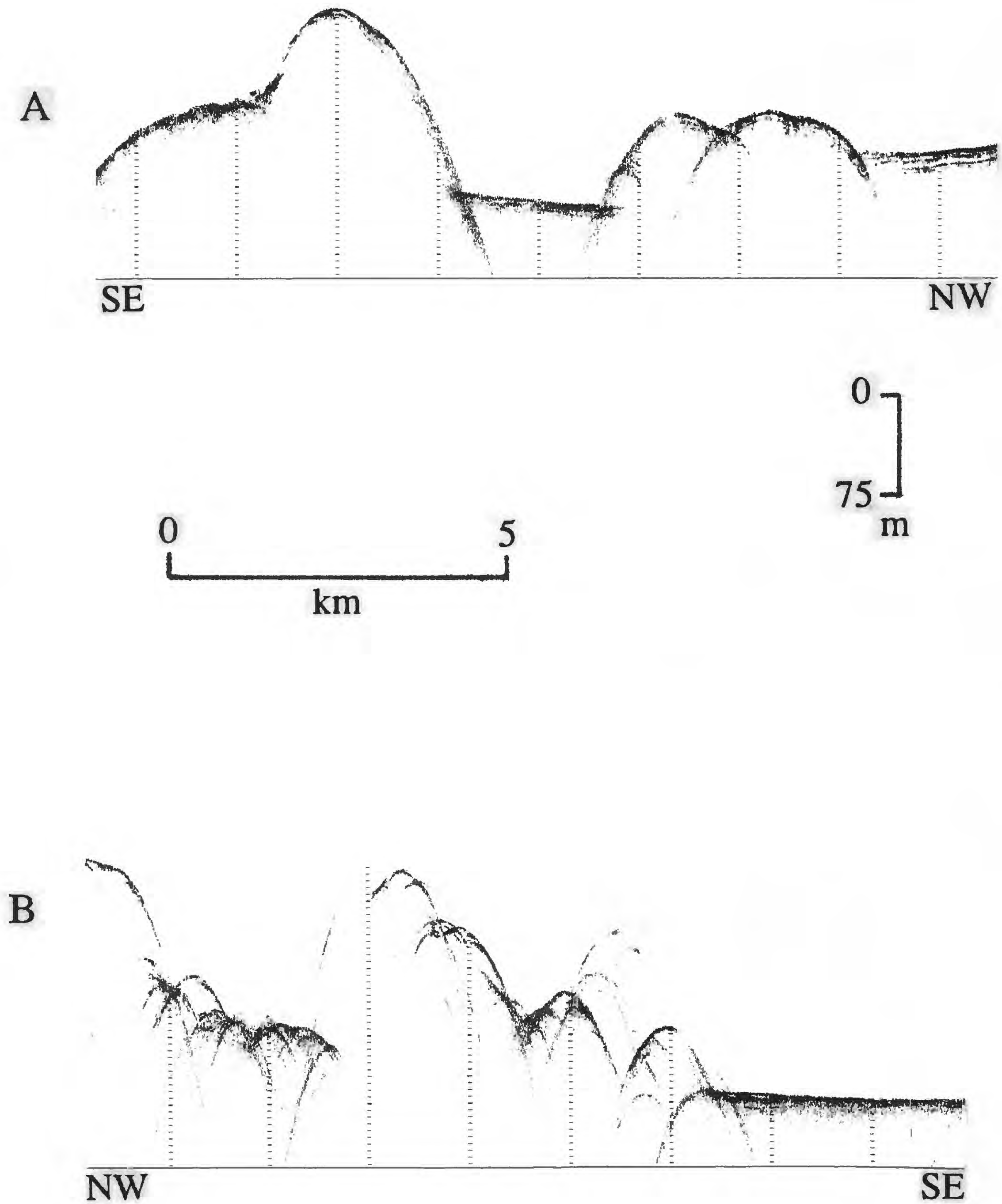
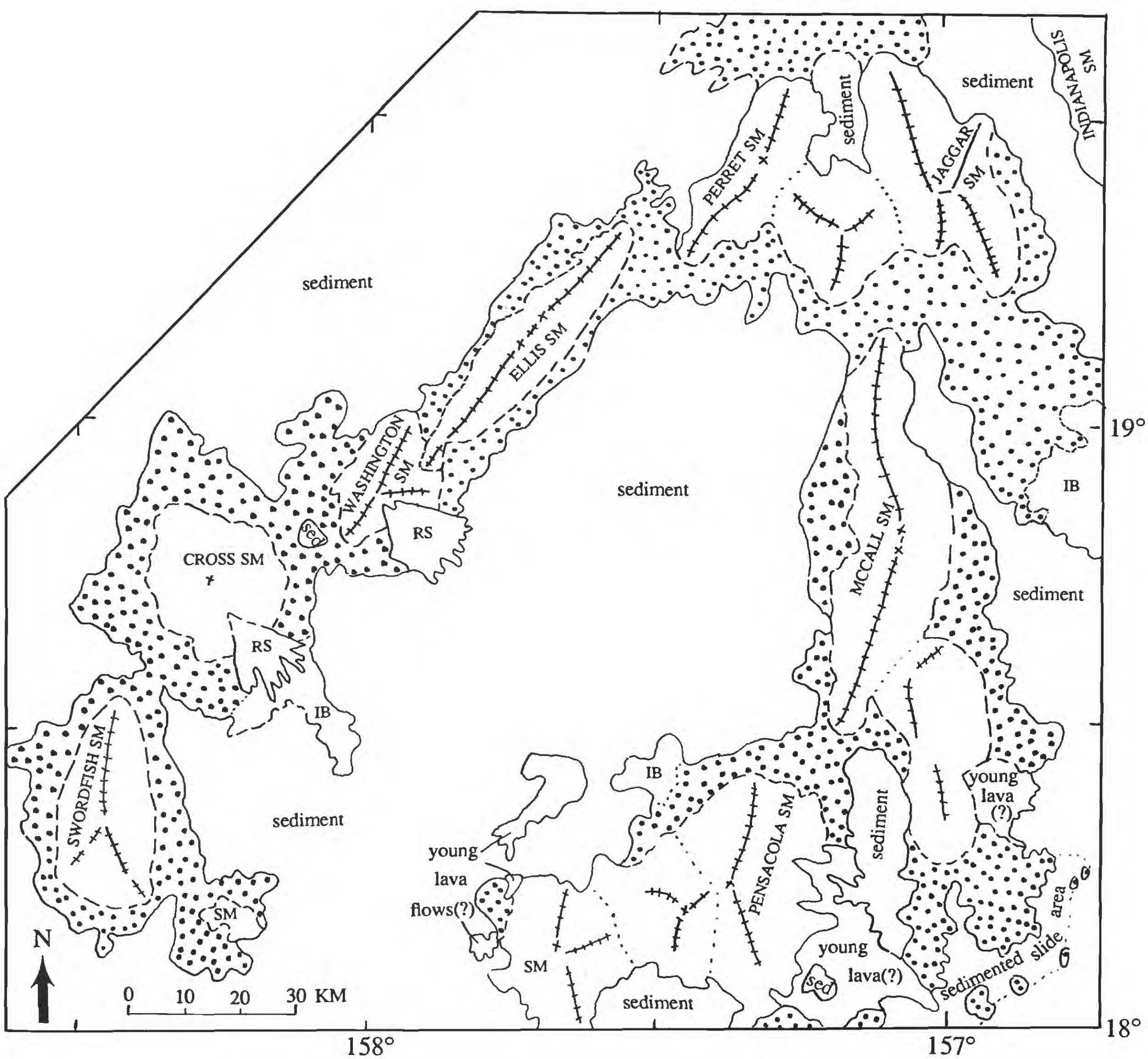


Figure 5



sediment
PERRET SM
sediment
JAGGAR SM
INDIANAPOLIS SM
ELLIS SM
WASHINGTON SM
CROSS SM
sed
RS
RS
IB
sediment
MCCALL SM
19°
IB
sediment
SWORDFISH SM
sediment
SM
IB
PENSACOLA SM
sediment
young lava (?)
young lava flows(?)
SM
sediment
young lava(?)
sed
sedimented slide area
N
0 10 20 30 KM
158°
157°
18°

Figure 6

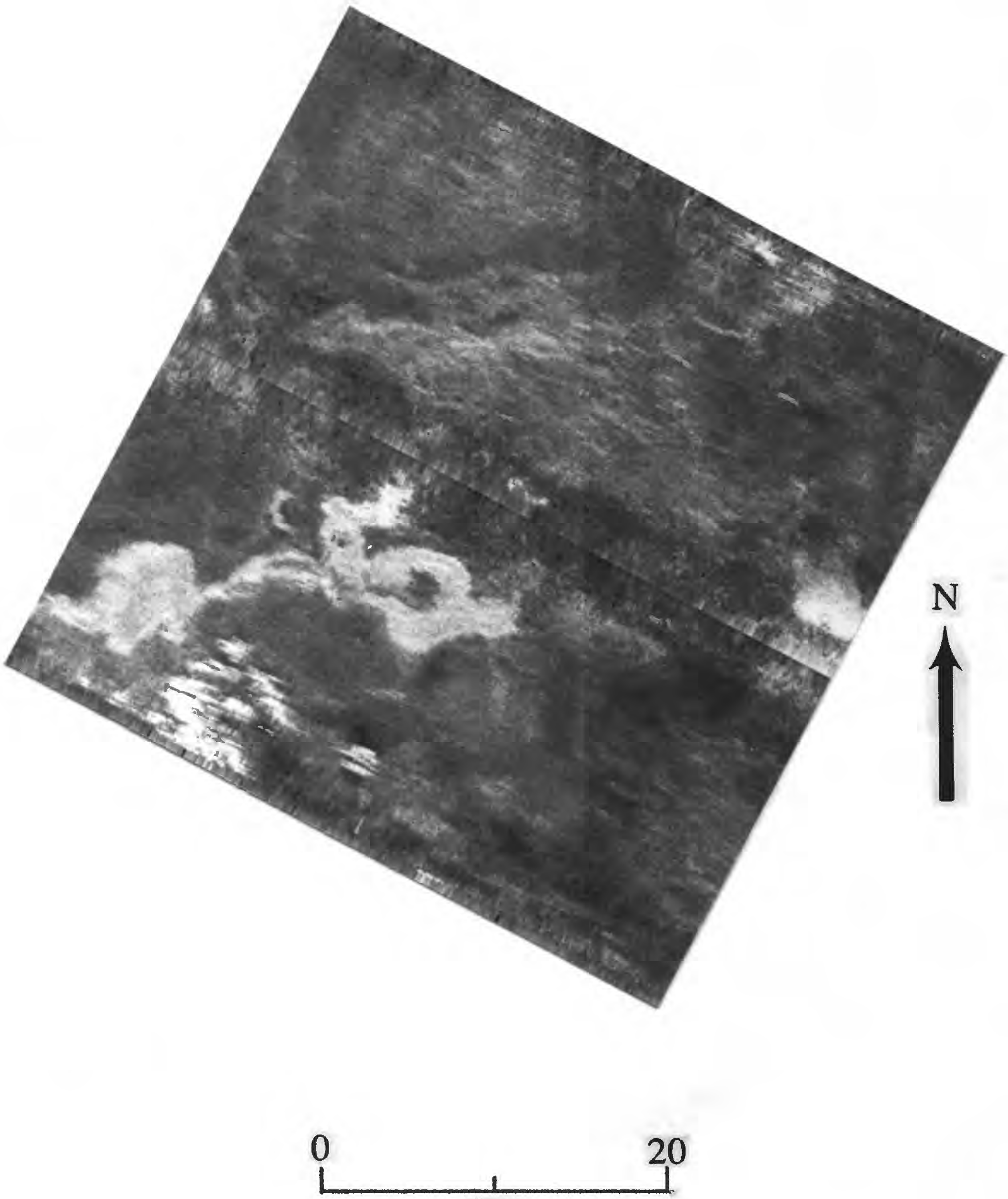


Figure 7

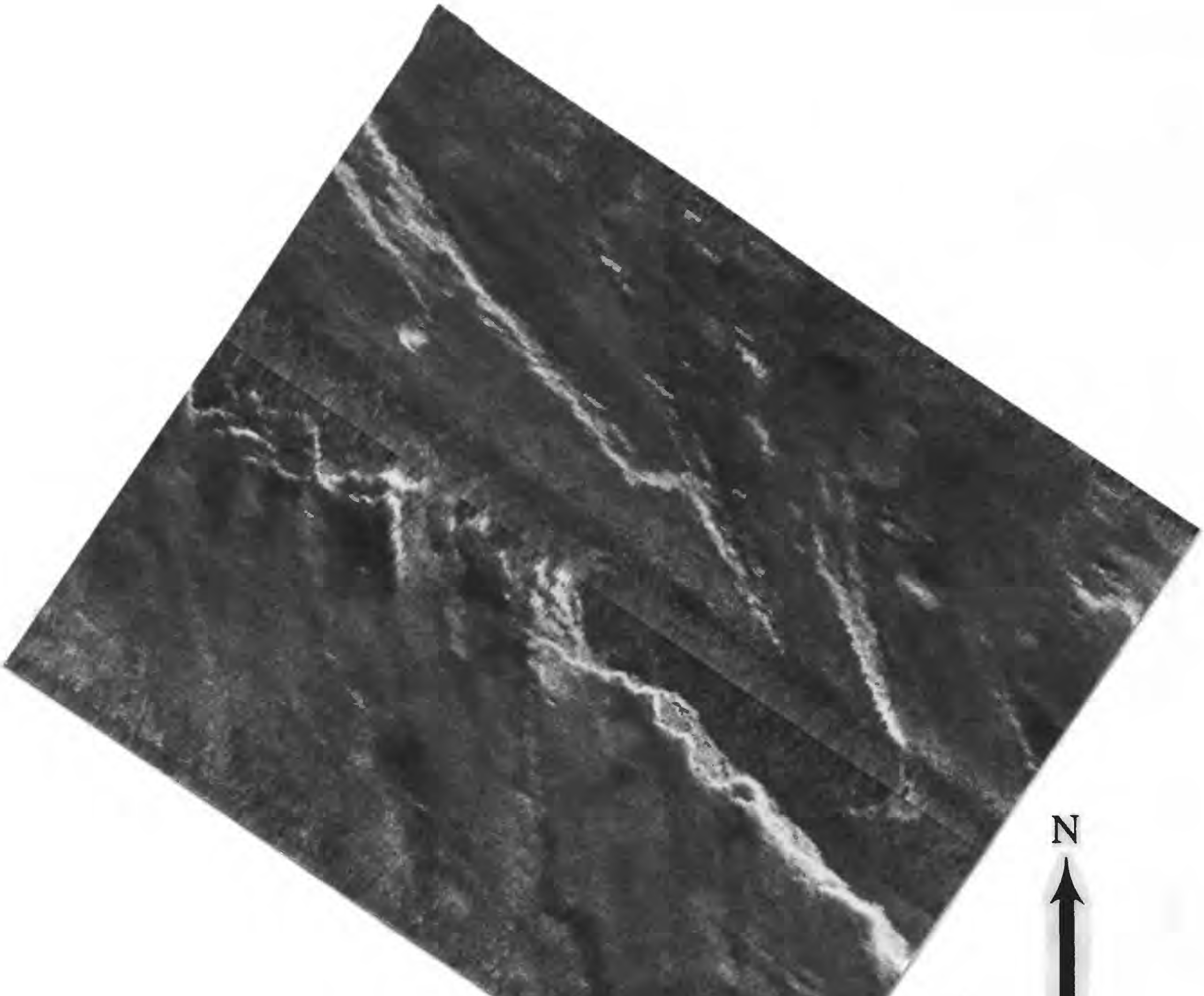


Figure 8