UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GLORIA STUDY OF THE EXCLUSIVE ECONOMIC ZONE OFF ALASKA -- SOUTHERN BERING SEA (BOWERS BASIN) INITIAL REPORT FOR CRUISE F1-87-BS

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by

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OPEN-FILE REPORT

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This report is preliminary and has not been reviewed for conformity with Geological Survey editorial standards and stratigraphic nomenclature. Any use of trade names is for descriptive purposes only and does not imply endorsement by the USGS.

THE EEZ-SCAN 87 PROGRAM

The EEZ-SCAN program is a cooperative research project between the U.S. Geological Survey (USGS) and the British Institute of Oceanographic Sciences (IOS). The major objective of the EEZ-SCAN program is reconnaissance mapping of the United States exclusive economic zone using the long-range side-scan sonar, GLORIA. The GLORIA instrument provides continuous sonographs that give an areal "photograph" of the sea floor.

The cruise was conducted aboard the British ship M/V FARNELLA with a complement of U.S. and U.K. scientists and technical support staff. In addition to GLORIA data, continuous geophysical measurements were made. These included two-channel seismic-reflection (160 cu. in. air-gun source), gravity, magnetic gradiometer, and two sets of high-resolution bathymetric data (using 3.5 kHz and 10 kHz transducers). Expendable bathythermographs were also deployed.

The area of the Bering Sea surveyed on cruise F1-87-BS included Bowers Basin, Bowers Ridge, and the southwestern part of the Aleutian Basin (Figures 1 and 2). A small area south of Attu, Agattu, Shemya, and Buldir Islands (western Aleutian Islands) was also surveyed. The cruise was highly successful and more than 8500 km of GLORIA and geophysical data were collected during the 24 working days at sea.

CRUISE NARRATIVE

The cruise departed Dutch Harbor, Unalaska Island ($55^{o}51'$N, $165^{o}36'$W) on June 28. USGS staff included Alan Cooper, Ralph Hunter, John Chin, Guy Cochrane, Byron Ruppel, and Rick Vail. IOS personnel were Quentin Huggett, Malcolm Harris, Emma Woodward, Andy Harris, Peter Mason, and Steve Whittle.

The ship spent 2 days in transit to the working area on the east side of Bowers Ridge. For the next 13 days, seas were nearly flat and routine survey work over Bowers Ridge and Bowers Basin was run at survey speeds averaging 8.5-9.0 kts. The weather deteriorated and operations had to be halted for 1.5 days. Work then resumed along NW-SE transects extending from the Aleutian Basin across Bowers Ridge and into Bowers Basin. At the end of three weeks, the GLORIA fish was pulled aboard briefly for inspection and minor repairs.

The Bering Sea survey, consisting of this and three previous cruises, was completed on July 23. The ship then commenced operations on the south side of the Aleutian Ridge. Shortly thereafter, stormy weather and an electrical failure in the GLORIA cable necessitated a 12-hour layover in the lee of Attu Island for repairs. Because of continued bad weather, the ship transited directly to Adak arriving on July 26, one day ahead of schedule.

EQUIPMENT SYSTEMS

GLORIA side-scan sonar

The GLORIA system operated well throughout the Bering Sea survey. The vehicle was recovered twice for repairs during the survey, but on neither occasion was survey time lost because these events coincided either with bad weather or 100% overlapping coverage where the data were not needed. At first, minor problems were encountered with gain settings between the port and starboard transducers causing unbalanced records. This was rectified on the second survey day. During the first bad weather, the yaw filter began to corrupt the data, thus the filter was not used during the last half of the cruise.

Low-level noise appeared on the starboard side of the data after two-thirds of the survey had been completed. When the vehicle was recovered, the source of the noise was found to be a loose cable flapping against the transducer array. At this time, the tow cable was found to be damaged. A decision was made to relaunch the vehicle without a 12-hour delay to replace the cable, to take advantage of good weather. The end of the Bering Sea survey, our primary objective, was only two days away. The cable lasted until one hour after the Bering Sea survey had been completed, at which time the conductors in the tow cable failed and the vehicle had to be hauled in. Storm conditions precluded further GLORIA operations.

Navigation

The principal navigation systems were GPS satellite, transit satellite, and LORAN C (hyperbolic mode). A new track-following computer system, developed by USGS personnel, was installed and resulted in significantly straighter tracklines than on previous cruises. The system computed ship position every few seconds from either GPS or LORAN C and compared actual position with the desired track. A video display in the pilot house allowed watch-personnel to adjust ship heading to keep the ship on the desired track. The system worked exceptionally well during the 12 to 14 hours per day of GPS satellite coverage. Early in the cruise, the LORAN C interface to the computer system failed. Consequently, standard ship navigation procedures were followed during non-GPS satellite times. The absolute position error was less than 500 m and probably within 50 m during GPS satellite times.

Bathymetry

The Raytheon 3.5 kHz (with IOS-built correlator) and the Mufax PES 10 kHz bathymetry systems worked well throughout the cruise, giving maximum sub sea-floor penetrations on the abyssal plain of about 60 m and 10 m, respectively. Clear indications of different sea-floor materials were observed as changes in amplitude of returning echoes on the 3.5 kHz, as well as GLORIA, records. Higher resolution scan rates (0.5 and 0.25 sec) were used over the abyssal plain and indicated that the sea floor is covered by an acoustically semi-transparent layer up to several meters thick.

Seismic reflection

Analog seismic-reflection data from the two-channel Geomechanique streamer were digitized and recorded on magnetic tape at a 4 msec rate using a USGS-designed MASSCOMP recording system. MASSCOMP performed well throughout the cruise, with only momentary data loss due to intermittent tape recorder problems. The dual-channel streamer and 160 cu. in. airgun source recorded identifiable reflection events to sub-sea-floor times of up to 4.5 sec, at ship speeds of about 8.5 kts. Although the seismic records appeared to have somewhat greater noise levels than the 1986 Bering Sea cruises (using the same equipment), the depth extent of useful seismic data was the same as before. Down time was limited to only a few hours during the survey for routine gun changes.

Gravity

For the 1987 field season, the LaCoste and Romberg seagravimeter S-53 was moved from its previous location, one deck lower, to the main lab. The meter operated continuously and reliably throughout the cruise. Data were degraded only during periods of heavy weather, when the noise level of the analog gravity measurements increased by 2-3 mgal. Base ties were made at Dutch Harbor and Adak.

Magnetics

A Geometrics G801n magnetic gradiometer system was employed for the duration of the cruise. Difficulties were encountered with the towing system throughout the initial two-thirds of the cruise. The gradiometer data were noisy during this period owing to water leaking into the towing cable and into the slave (forward) sensor. Two attempts were made to repair water leaks into the slave sensor; however, the leaks could not be stopped. The 10-year-old cable was also found to be water saturated, and consequently the cable was discarded. The first replacement cable, which had been used extensively the previous year, also had problems owing to an intermittent short (broken wire?) in the cable. After one sensor had failed and the noise on the other sensor became excessive, a second replacement cable was constructed and installed. The third, and new, cable performed well with noise levels generally less than 3 gamma for the remainder of the cruise.

Expendable bathythermograph - XBT

Nearly 40 XBTs were recorded at sites throughout the survey area. Results were variable depending upon whether the XBT wire snagged in other towed equipment. Temperature-depth measurements were attained to 450 meters, the maximum depth of the T-6 probe, on only a few occasions. Mostly, the measurements were terminated at 100 to 150 meter depths because of wire-fouling problems. The XBT data were routinely transmitted to NOAA via satellite. The XBTs and computer-controlled recording system were provided by NOAA.

PRELIMINARY SCIENTIFIC RESULTS

During the cruise, several phases of compilation and analysis of GLORIA and geophysical data were accomplished. The successes in these endeavors are directly attributable to the sophisticated shipboard computer and photographic facilities as well as the excellent cooperation of USGS and IOS staff. The initial compilations included:

- two mosaics of GLORIA sonographs covering the survey area
- preliminary interpretation overlay of geomorphic and sedimentary features on GLORIA mosaics
- preliminary isopach map of total sedimentary thickness in the survey area
- preliminary structure contour map on basement for the survey area
- preliminary magnetic anomaly map of the Bering Sea, incorporating data from all four Bering Sea GLORIA cruises
- preliminary free-air gravity anomaly map of the Bering Sea, incorporating data from all four Bering Sea cruises.
- preliminary map of surface and subsurface structural features of the survey area
- small-scale photographic copies of all seismic-reflection profiles recorded during the survey
- profile plots of free-air gravity, magnetic anomaly, and bathymetry for all reduced-scale seismic-reflection profiles
- preliminary line drawings of select seismic-reflection profiles
- final map-plots of navigation, bathymetry, magnetic anomaly, and gravity anomaly data for the survey area at several scales
- this Open-File cruise report.

The following sections describe highlights of the preliminary cruise results organized by the geomorphic provinces surveyed during the cruise: a) the north flank of the western sector of the Aleutian Ridge, b) Bowers Ridge crest and flanks adjoining Bowers Basin, c) Bowers Basin, and d) the southwestern part of the Aleutian Basin (Figures 1 and 2). A few nearshore areas on the south side of the western Aleutian Ridge were also surveyed during the cruise. The preliminary results from these areas will appear in later cruise reports for 1987 (F2-87-AA and F3-87-AA).

Western sector of Aleutian Ridge

GLORIA and other data indicate that the nearly flat crest of the western Aleutian Ridge is incised in places by isolated, late Cenozoic, extensional bathymetric depressions. An example, Buldir depression lying directly east of Buldir Island (Figure 3), has a flat floor pierced by circular volcanic structures. The nearby north flank of the Aleutian Ridge, east of Buldir Island, is characterized by dendritic canyons. These canyons carry sediment and debris flows directly down the flank to the abyssal basin floor, where the sediment is dispersed only about 50 km basinward as deep-sea fan deposits (Figure 3).

Farther west, the Aleutian Ridge flank steepens and is characterized by a series of 50-150-km-long, linear, bathymetric scarps that extend to the western end of the survey area. An example of a distinct 100-km-long linear scarp, probably an active fault along mid-slope adjacent to Shemya Island, is shown in Figure 4. Here, prominent canyons are not found on the steep scarp and only small and local debris flows rest at the base of the slope. Seismic-reflection data indicate up to 5 km of sedimentary section beneath the base of the slope, suggesting that most sediment here is not derived from the adjacent ridge.

Bowers Ridge crest and western flank

Bowers Ridge is a large, asymmetric, arcuate bathymetric ridge that is probably an early Tertiary and younger volcanic arc. The crest of the ridge is segmented into flat-topped elongate blocks lying in 200-600 m water depth. This eroded crestal platform plunges westward as a chain of basement ridges that separate the strata of the Aleutian and Bowers basins. Bowers Ridge was believed to be inactive owing to its aseismic character and deep, flat crestal platform. GLORIA, geophysical, and previous DSDP drilling data show, however, that some areas of the ridge crest and flank have been uplifted and locally intruded in at least Pleistocene and possibly younger times.

GLORIA images show several, isolated, circular features, probably submarine volcanoes, along the crest and on the flanks of Bowers Ridge (Figure 5). These features are small (diameter of 1 km), symmetric bathymetric knolls (with magnetic anomalies) standing above an otherwise flat or gently sloping sea floor. A large concentration of small circular features also lies on top of a major E-W trending basement antiform beneath the flanks of Bowers Ridge (1500 m water depth; Figure 5). These circular features look like the small submarine volcanoes that pierce the flat sea floor beneath the platform areas of the seismically active Aleutian Ridge, between Little Sitkin and Semisopochnoi islands (Figure 6).

Large (10-km-wide) submarine volcanoes occur beneath two areas of Bowers Ridge. One volcanic structure overlies a basement antiform beneath the western ridge-flank (Figure 7). This structure lies in 2000 m water depth and is 220 km north of the active volcanoes of the Aleutian Ridge. The other submarine volcano lies midway along the narrow, western extension of Bowers Ridge in 3000-3900 m water depths (Figure 8). The large and small volcanic structures beneath Bowers Ridge suggest active tectonism is occurring at the ridge crest and flanks.

GLORIA data show that the western flank of Bowers Ridge (WBR) is morphologially different from the northern flank of the Aleutian Ridge (NAR). There are three main differences:
1) Gullies and canyons - The WBR is devoid of gullies and canyons. Two canyon-like conduits run down the slope, but are straight, wide features that are entirely fed by areas of slumping (eg Figure 4). One of these conduits has undergone extensive lateral migration. Some small abandoned channels are buried within 20-30 m of the sea floor. By contrast, the NAR is cut by a myriad of steep gullies which coalesce in a classic dendritic pattern to produce larger canyons.
2) Fans - Bowers Basin only has two small submarine fans and both of these have formed from canyons running off the NAR. The WBR has no distinct fan-like deposits where it meets the Bowers abyssal plain.
3) Slumps - The WBR is characterized by massive slump bodies delineated by distinct headwall scarps (Figure 4). The area of slumping in Figure 4 is about 60 km by 20 km. Within this area, a coherent, rotated slump-block (marked by high-reflectivity) is 2 km by 10 km and has a back-tilted sea floor. By contrast, the NAR shows no slump features in GLORIA data.

GLORIA data from other parts of the world's oceans show gullying to be the commonest mass-wasting process for submarine slopes. The WBR is an anomalous region with regard to sediment erosion and transport processes. Several explanations are possible:
1) Uplift - the area may be undergoing uplift that would oversteepen the slopes and cause massive failure.
2) Sediment type - the area is known to be draped by several hundred meters of pelagic diatomaceous ooze that may be less stable than the volcaniclastic sediments on the NAR.
3) Currents - strong currents occur across the crest of Bowers Ridge. These currents may carry terrigenous debris down the steep canyons on the north and east flanks of the ridge, away from Bowers Basin where pelagic deposition dominates.

Uplift of pelagic-dominated strata is likely the main cause for the distinct character of the WBR. Currents alone cannot explain the differences between the WBR and NAR, because non-deposition could not explain the WBR oversteepened slopes. Uplift would account not only for the slumping but also for the abandoment of channels, now buried on the WBR. Many slumps have sharp, fresh-looking scarps (Figures 4 and 7) that would surely be degraded if the sediment were incompetent and uplift was not not recent. Seismic profiles across some of these scarps indicate upbowing of a uniformly thick young sedimentary section. Also, a 'stable state' of gullies, canyons, and fans would be likely along WBR if uplift were not recent. We propose, therefore that the uplift is relatively recent (eg Pleistocene and possibly younger).

Bowers Basin

Bowers Basin abyssal plain is a nearly flat, bathymetrically-featureless area underlain by about 3-5 km of flat-lying strata covering a layered basement that dips gently to the southwest. In GLORIA images, the plain is non-reflective over most of the area, as exemplified by the dark regions southeast of the submarine volcano in Figure 8. Only the eastern and southeastern parts of the basin show variations in sea floor reflectivity, typical of areas of sediment gravity-flow deposition (Figure 3). Deeply buried strata within the abyssal sedimentary section continue up the flanks of Bowers Ridge, where they onlap against basement or underlying layers. In general, the abyssal Bowers Basin appears to have been a tectonically stable region throughout Neogene and into Paleogene time.

Aleutian Basin

The Aleutian Basin is a flat, featureless, abyssal plain that dips gently south toward Bowers Ridge. In the southwestern part of the basin, the sedimentary section is about 2-4 km thick in an area marked by a province of 50-100-km-long basement ridges trending NE-SW. About 100 km north of Bowers Ridge, the basement ridges end and the basement surface ramps downward to sub-sea-floor depths of nearly 10 km at the foot of Bowers Ridge.

GLORIA images over this part of the Aleutian Basin show either non-reflective areas or zones of interference patterns (Figure 9, discussed below). The GLORIA data, however, may mimic the deep basement structure in a subtle fashion. Interference patterns are generally found in areas where the near-sea-floor strata have been gently arched with up to 10 m of relief. The arching appears to result from either differential sediment compaction above the basement ridge crests or from overpressuring and doming of the strata above VAMPs, which are commonly found throughout the basement ridge province. Consequently, interference patterns appear to mark areas of basement relief. Broad 1-2 m sea floor undulations, caused by uplifts over the sub-sea-floor features, cannot be identified on GLORIA images - only the associated interference patterns are apparent.

GLORIA study of interference patterns

During the 1987 cruise, a 4 hour segment of a 1986 GLORIA trackline was resurveyed to determine the persistence and origin of unusual interference patterns observed in the 1986 data. The wide-spread interference patterns appear as alternating light and dark sinuous bands that roughly parallel the ships track and that increase in width away from nadir, directly below the ship. The interference patterns observed in 1986 could apparently be correlated across some 30-km-spaced ship tracks. The resulting pattern was a coherent, but geologically improbable, set of reflectance signals.

The patterns were initially believed to be caused by sound channels or other layering in the water column. Later comparison of seismic and GLORIA records suggested a correlation between subsurface features and the GLORIA interference patterns. The resurvey was done to look more closely at subsurface features and see if the same GLORIA interference pattern could be reproduced one year later.

The 1987 survey showed an interference pattern nearly identical to that observed in 1986. A second 1987 track, diverging from the 1986 track, also showed a similar pattern that was slightly bent. A third 1987 track perpendicular to the 1986 track showed no trace of an interference pattern, even though the pattern should have fallen within the GLORIA receiving window.

The patterns appear to correlate with sub-sea-floor features within the upper 10-15 meters of the sedimentary section, seen in the 1987 high-resolution bathymetric data (see above). The interference patterns are common in the Aleutian Basin (Figure 9, where 1-2 km of basement relief occurs, but, the patterns are rare in Bowers Basin, where the basement is regionally flat. The few places where interference patterns occur in Bowers Basin (Figure 10) are characterized by VAMPs and small diapirs. The acoustic mechanism responsible for the banded patterns is still unknown and under study.

SUMMARY

GLORIA and geophysical survey operations were highly successful, with more than 8500 km of trackline data collected. In addition to voluminous data collection, several preliminary geological and geophysical maps and compilations were completed during the cruise.

Preliminary shipboard analysis of GLORIA and geophysical data across the Aleutian and Bowers Ridges clearly show that these areas are actively being degraded by slumps, debris flows, submarine slides, and likely bottom currents. The erosion of these areas is being expedited by tectonic uplift leading to unstable, over-steepened slopes. The apparent youthfulness of sea-floor scarps, submarine volcanoes, and basement ridges beneath the crest and flanks of Bowers Ridge suggests that Bowers Ridge is presently being uplifted, as well as eroded. In contrast, the abyssal basin areas of the Bowers and southwestern Aleutian Basin appear to be tectonically stable and receiving mostly pelagic sediments.

ACKNOWLEDGMENTS

We thank the officers and crew of the R/V FARNELLA for their cooperation. Sue Hunt and Steve Wallace of the USGS Marine Operations group provided outstanding logistic support. We appreciate the cooperation of the U.S. Navy in extending cordial access to their facilities at Adak, Alaka.

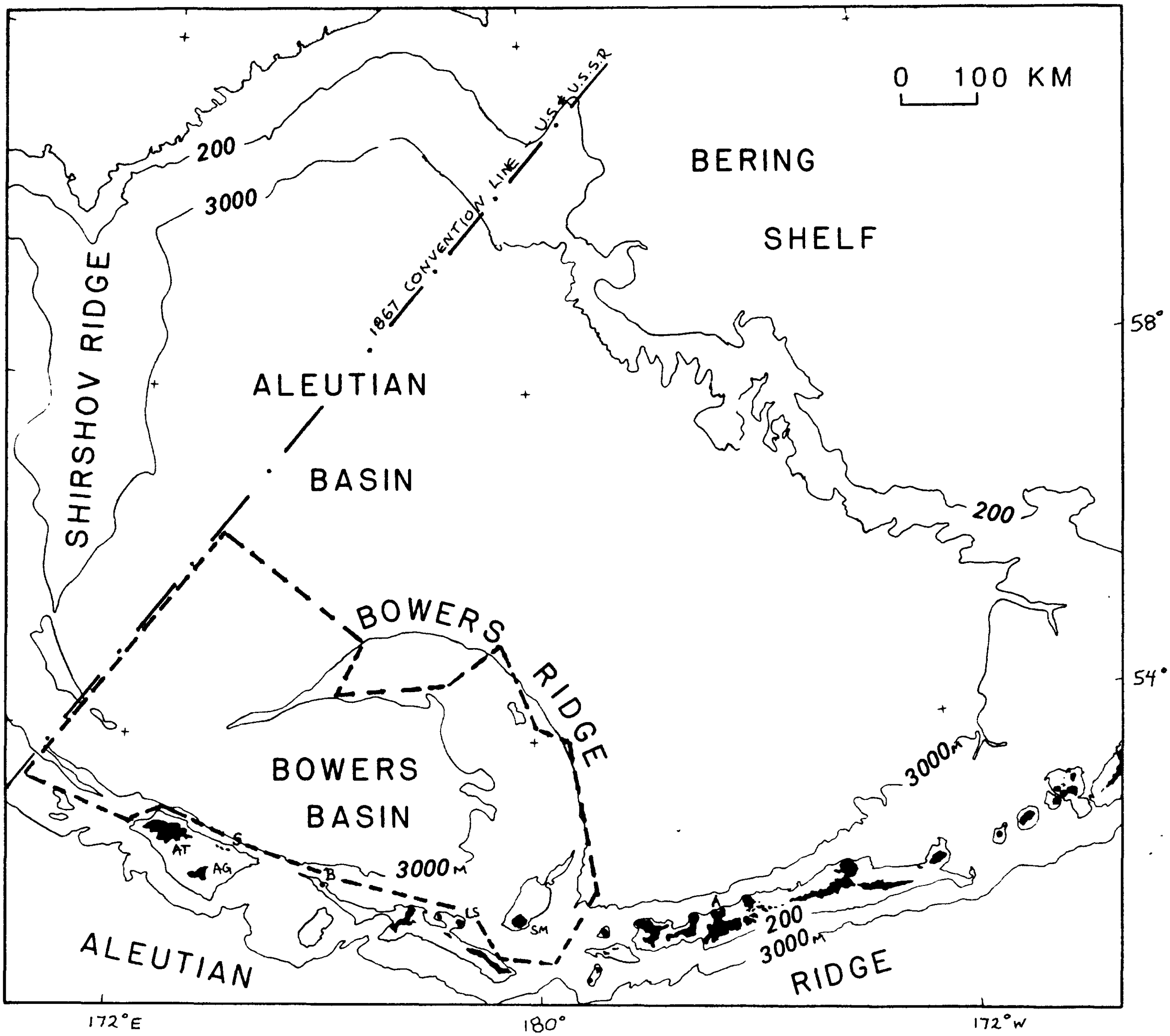

Figure 1: Index map of the southern Bering Sea. Dashed lines show survey area for cruise F1-87-BS. Abbreviations are: A-Adak Island; AG-Agattu Island; AT-Attu Island; B-Buldir Island; LS-Little Sitkin Island; S-Shemya Island; SM-Semisopochnoi Island. Albers Equal Area projection.

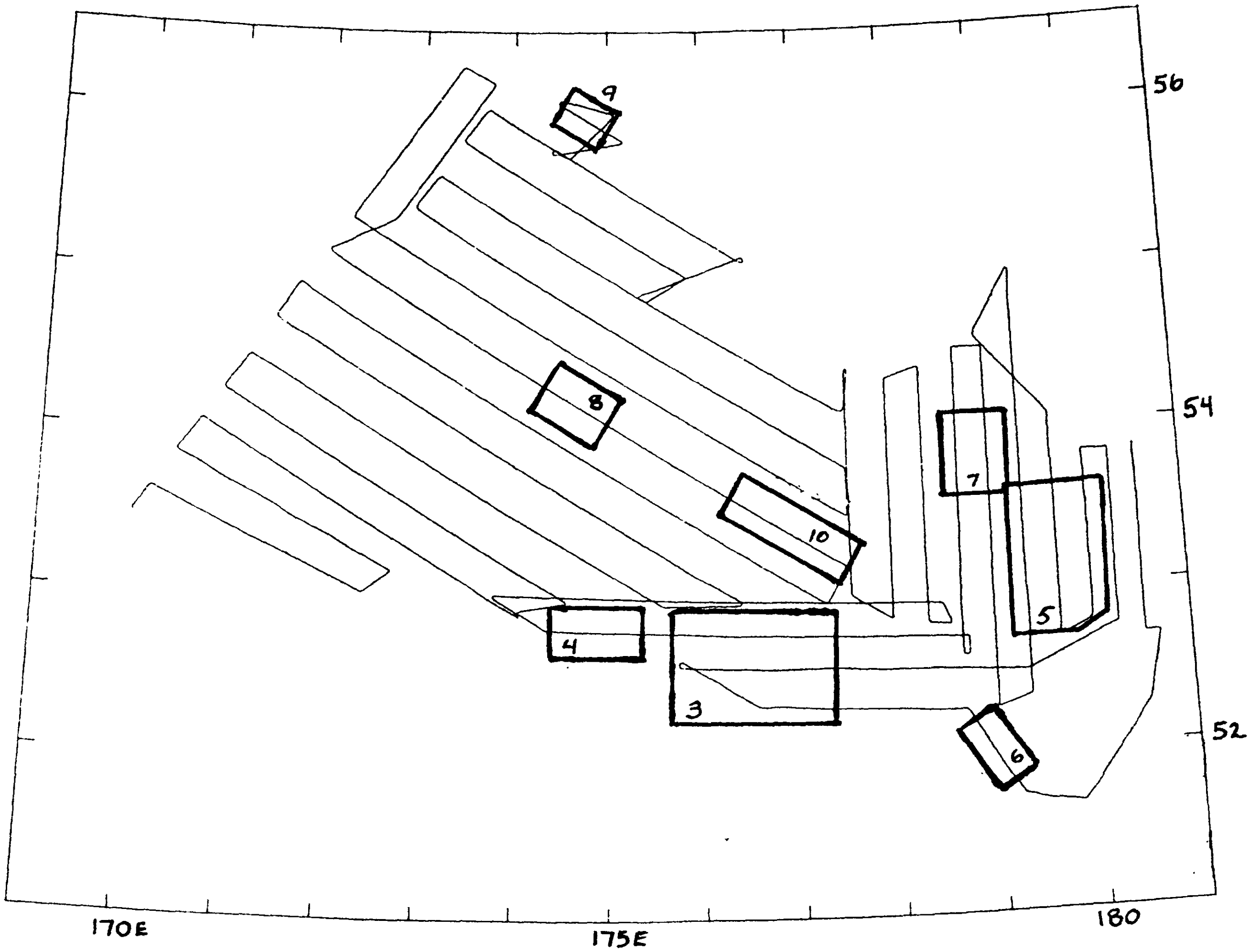

Figure 2: Map showing tracklines for cruise F1-87-BS. Numbered boxes show locations of Figures 3 to 10. See Figure 1 for location.

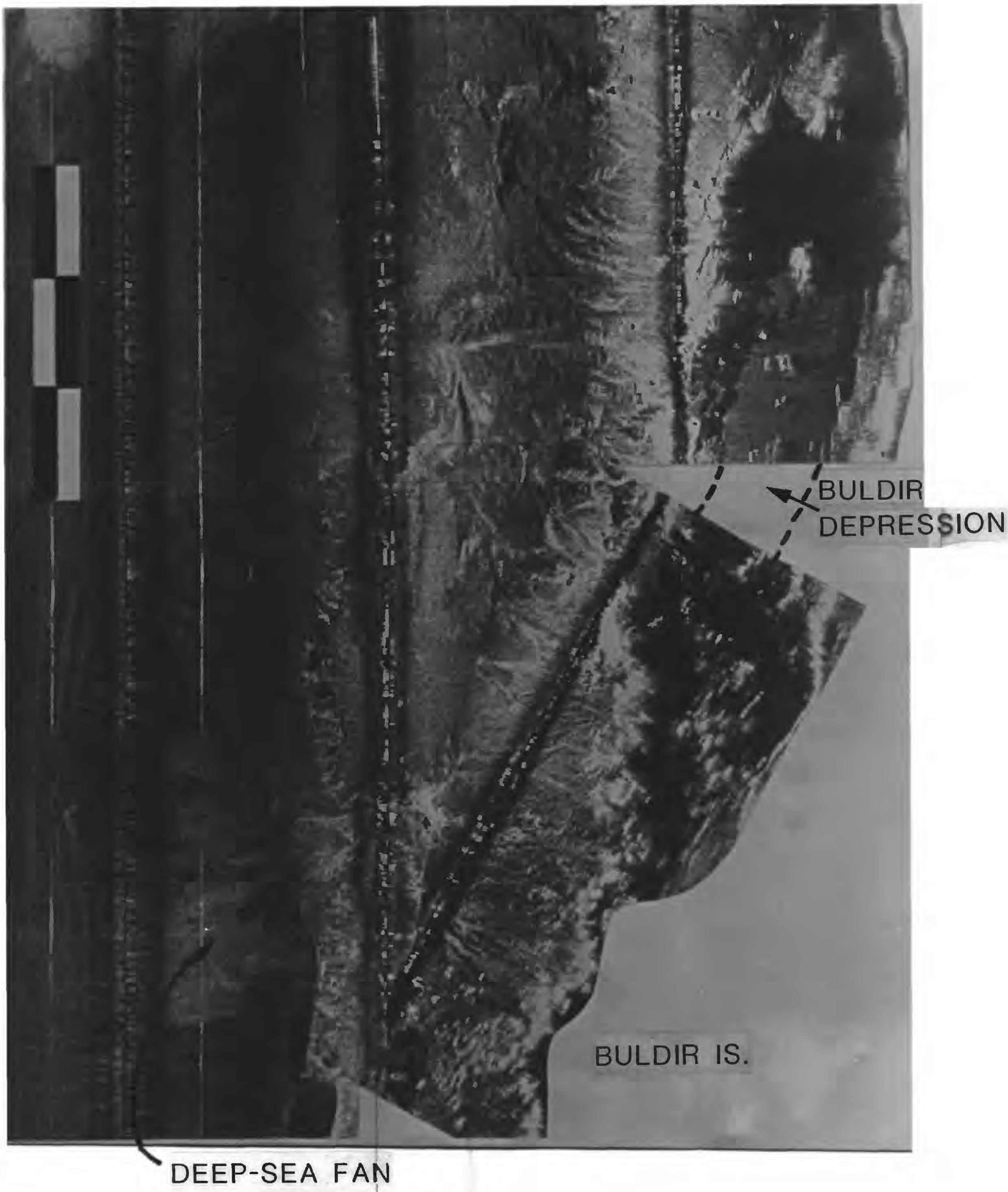

Figure 3: Mosaic of GLORIA sonographs (pass nos. 6,7,8,9, and 27) across the north flank of the Aleutian Ridge showing an extensional bathymetric depression (Buldir Depression) on the ridge crest as well as typical small canyons and gullies of the north ridge-flank. One system of small canyons has deposited a small deep-sea fan at the base of the ridge flank. The heavy black lines marked by coarse grained block patterns are the ship's track. White areas are those with high reflectivity and dark areas have low reflectivity. Scale bar is 30 km long. Top of sonograph is to east. See Figures 1 and 2 for location.

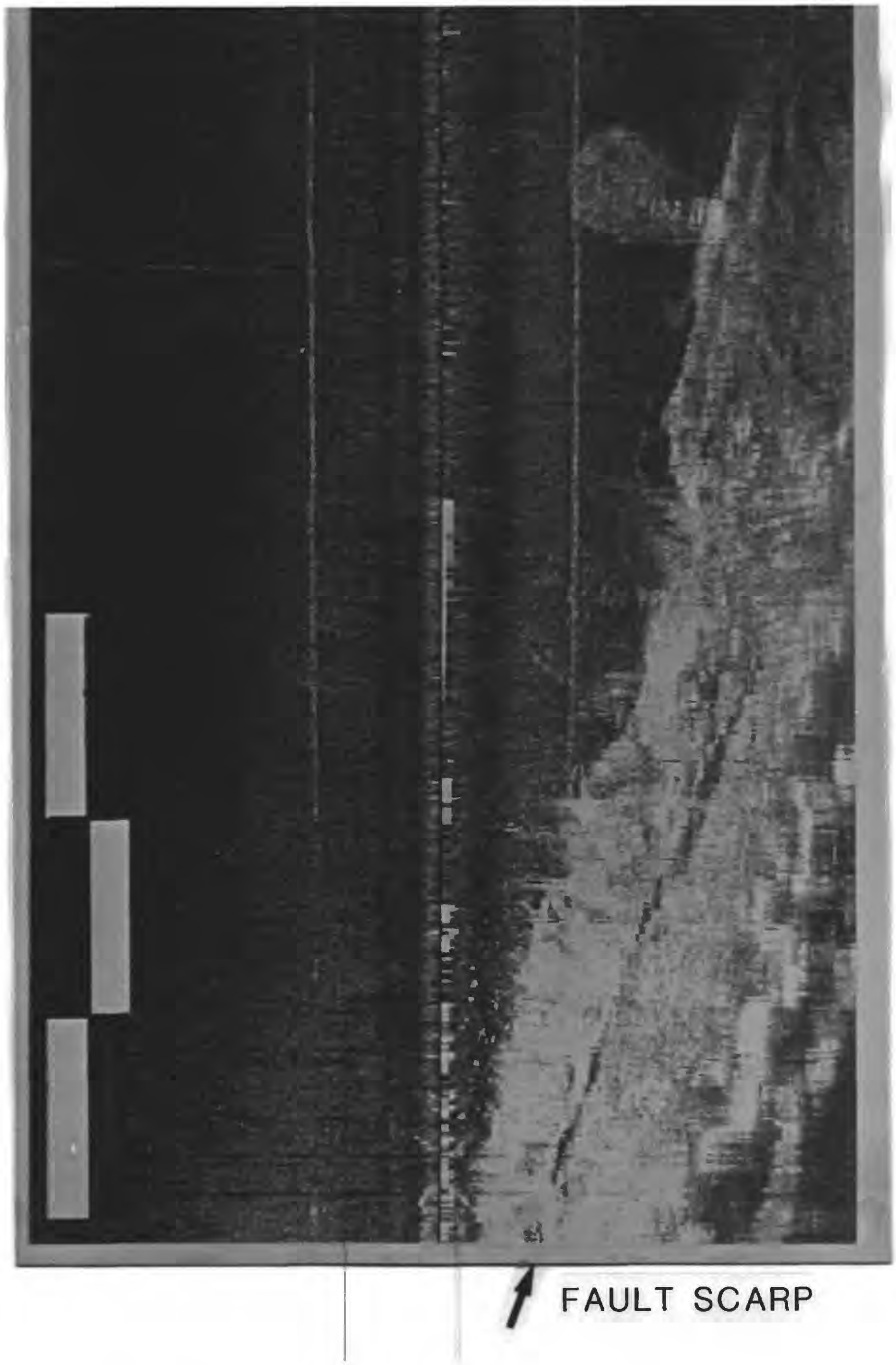

Figure 4: GLORIA sonograph (pass no. 27) along the steep north flank of the Aleutian Ridge between Buldir and Shemya islands showing a segment of the 90-km-long fault scarp underlying the ridge flank. A small debris flow can be seen on the abyssal plain at the base of the slope. Scale bar is 30 km long. Top of sonograph is to east. See Figures 1 and 2 for location.

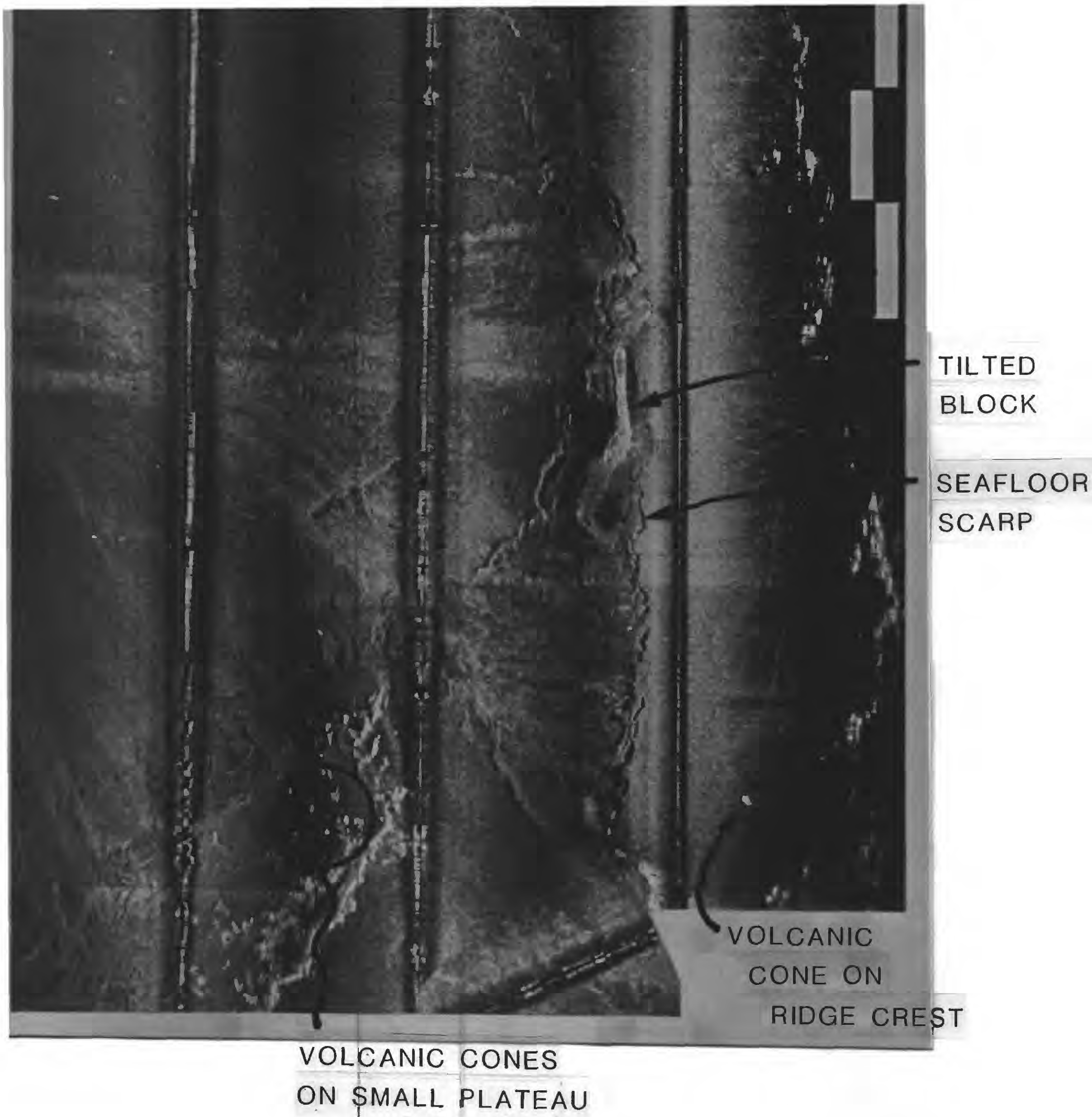

Figure 5: Mosaic of GLORIA sonographs (pass nos. 12,13,14,18 and 19) showing a small volcanic cone(?) on Bowers Ridge crest and several cones on a small plateau on the western flank of the ridge. The sonograph also depicts a 60-km-long series of sea-floor scarps that mark the heads of major slumps down the ridge flank. The light-colored (high-reflectivity) areas are revealed as valley-filling, acoustically transparent layers with irregular upper surfaces on the 3.5 kHz bathymetric records; these deposits are interpreted to be debris flows formed when the slump masses lost coherence during their downslope movement. The narrow, linear, bright band adjacent to the scarp is a back-tilted block of intact sea floor. Scale bar is 30 km long. Top of sonograph is to north. See Figure 1 and 2 for location.

Figure 6: GLORIA sonograph (pass no. 4) across the crest of the Aleutian Ridge between Semisopochnoi and Little Sitkin Islands showing numerous small volcanic cones resting on the nearly flat, eroded crest of the ridge. Scale bar is 30 km long. Top of sonograph is to northwest. See Figures 1 and 2 for location.

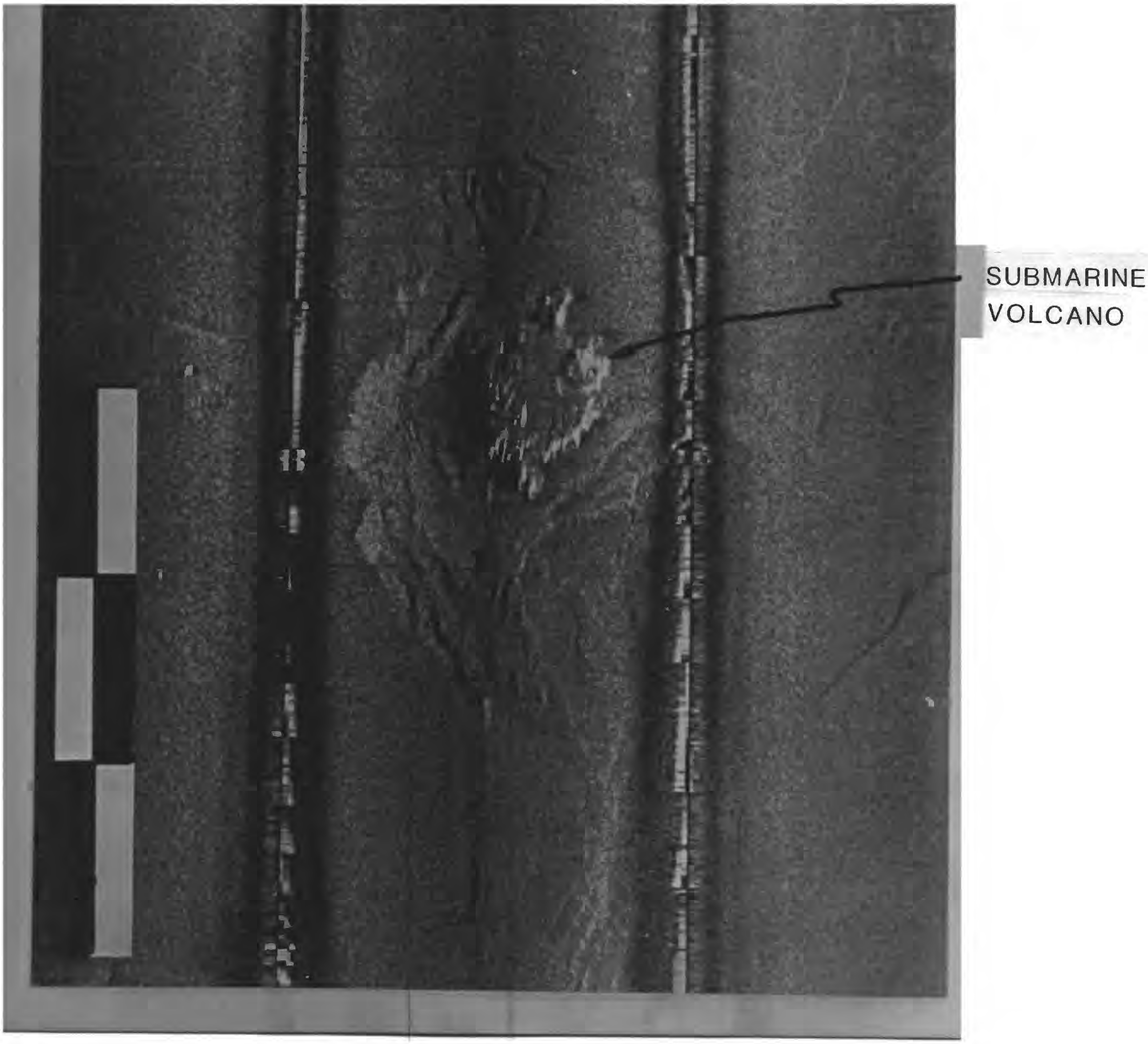

Figure 7: Mosaic of GLORIA sonographs (pass nos. 21 and 23) showing a large submarine volcano on the flanks of Bowers Ridge. The volcano rests on a basement antiform that is uplifting the sedimentary section, probably causing the numerous sea-floor scarps of sedimentary slump bodies especially around the submarine volcano. Scale bar is 30 km long. Top of sonograph is to north. See Figures 1 and 2 for location.

Figure 8: GLORIA sonograph (pass no. 65) showing a large submarine volcano lying in about 3500 m of water along the western extension of Bowers Ridge. The cone rests close to uplifted areas of the sea floor at the nearby ridge crest and next to the featureless and non-reflective Bowers abyssal-basin floor. Scale bar is 30 km long. Top of sonograph is to northwest. See Figures 1 and 2 for location.

Figure 9: GLORIA sonograph (pass no. 43) showing example of interference pattern in the Aleutian Basin. Here, the abrupt start of the banded pattern correlates with the initial sub-sea-floor shallowing of a 10-m-deep horizon. Scale bar is 30 km long. Top of sonograph is to northwest. See Figures 1 and 2 for location.

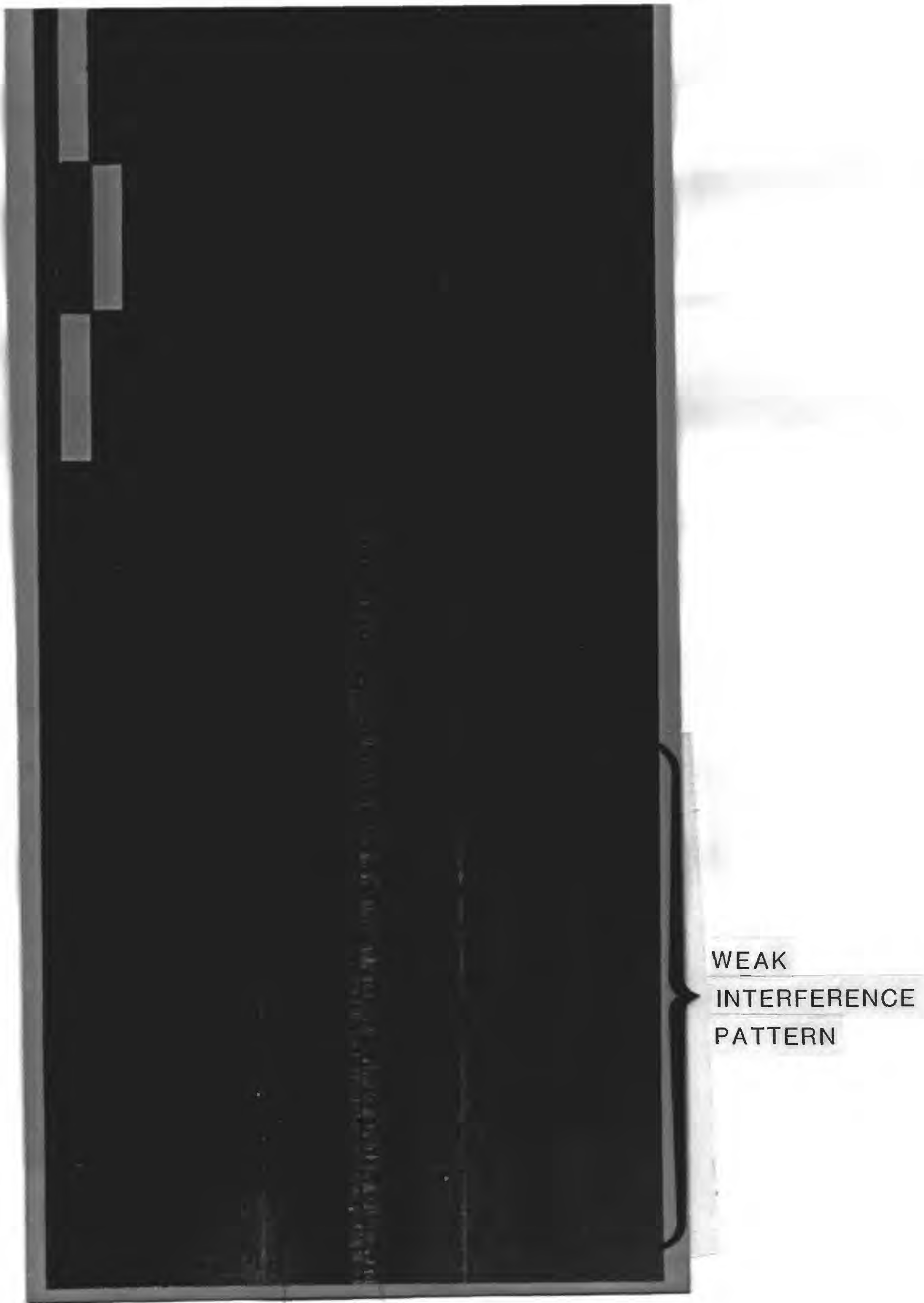

Figure 10: GLORIA sonograph (pass no. 67) showing example of interference pattern in Bowers Basin. The pattern begins near the seaward (NW) edge of a sub-sea-floor zone of VAMPs and small diapirs. The pattern also lies in the transition zone between sea-floor materials that are characterized by low reflectivity (to the NW) and high reflectivity (to the SE) on the regional GLORIA imagery. Scale bar is 30 km long. Top of sonograph is to northwest. See Figures 1 and 2 for location.