# 4. GLORIA SURVEY OVER COSTA RICA RIFT SITES 501, 504, AND 505[1]

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### ABSTRACT

The sea floor morphology and geology around the Costa Rica Rift sites has been mapped using the long-range side-scan sonar GLORIA. This enabled us to produce a map of basement outcrops and fault scarps. Analysis of the map shows that, in the north, around Site 505, about 17% of the sea floor is constituted by outcropping basaltic basement, and mainly northward-dipping normal fault scarps are common, occurring with a frequency of 0.2 $km^{-1}$. In contrast, the southern part of the survey area, around Sites 501 and 504, is almost devoid of basement outcrop and fault scarps, although scarps buried under sediment are still common. However, a small probable basement outcrop occurs 5 km southwest of Site 501. No other outcrops or fault scarps occur within 20 km of Sites 501 and 504.

## INTRODUCTION

GLORIA is a long-range side-scan sonar system which is ideal for mapping the regional physiographic and tectonic setting of areas subject to more-detailed investigation, such as IPOD drill sites (Searle et al., 1979). Here I report the use of this system over the Costa Rica Rift drill sites, in a site survey carried out on June 15th and 16th, 1980, during R. R. S. *Discovery* Cruise 110.

One of the major aims of the drilling was to examine the ways in which the regional heat-flow variation is determined by changes in the crustal structure and composition. It was thought likely that the direct cause of higher conductive heat flow in the southern part of the area might be the complete blanketing there of faults and fractured, permeable basement rocks by continuous overlying sediments, compared with the abundant outcropping faults and basement in the north. The main purpose of our survey, therefore, was to determine quantitatively the distribution of faults and basement outcrops in the area.

## SONAR SYSTEM AND SITE SURVEY

A technical description of the GLORIA system has been given by Somers et al. (1978). Operational methods were generally similar to those previously described (Searle, 1980, 1981). For the Costa Rica Rift survey, we used a 40-second pulse-repetition rate, and a survey speed of approximately 10 knots (5 m/s), giving a cross-range (or along-track) resolution of 200 meters at short range. The beam width was 2.7°, so that cross-range resolution decreased to about 700 meters at the maximum range obtained, 15 km. Down-range resolution was around 50 meters.

After preliminary signal processing, the data were anologue tape-recorded both with and without automatic gain control (AGC). The non-AGC recording retains the true relative amplitudes of strong signals, but fails to register low-level signals because of the limited dynamic range of the tape recorders. The AGC channel records signals of all levels, but with a non-linear distortion of signal level. This, together with the action of the correlator circuits on the 4-second-long FM pulse, gives rise to "pre-shadowing" of strong reflections. Many examples are seen in the uppermost part of Figure 1, where "shadows" appear to the north (i.e., the shipward side) of all strong reflectors.

The recorded tapes were replayed through a facsimile recorder and anamorphosed to compensate for changes in ship's speed and to make slant-range and along-track scales equal. No slant-range correction was applied automatically, but it has been applied manually to critical areas of the data mapped in Figure 3. The slant-range and horizontal scales are approximately equal at ranges of more than about 1.5 times the water depth.

The ship's track was designed to run past each drill site at a range of about 8 km and parallel to the crustal isochrons. This allowed each site to be insonified in directions looking toward and away from the spreading axis, with the site at the mid-range of sonar coverage. This is the optimum arrangement for viewing topographic and tectonic elements which strike east-west, parallel to the spreading center, which is the expected case for most sea-floor features produced at the Cocos-Nazca spreading center (Klitgord and Mudie, 1974; Allmendinger and Riis, 1979; Langseth et al., this volume).

Satellite navigation was used throughout the survey. In regions where the same feature could be recognized on two or more overlapping sonographs, the position of the track was adjusted, usually by a few hundred meters, to bring the observed positions of the feature into coincidence. It is estimated that the absolute position of the track is accurate to about half a mile; however, the relative positions of features seen on the same sonograph will be somewhat more accurate than this.

The final anamorphosed records were printed at a scale of 16 inches per degree of longitude and mounted on charts against ship's track. South- and north-looking sonographs were mounted separately. The AGC records are shown in Figures 1 and 2.

[1] Cann, J. R., Langseth, M. G., Honnorez, J., Von Herzen, R. P., White, S. M., et al., *Init. Repts. DSDP*, 69: Washington (U.S. Govt. Printing Office).

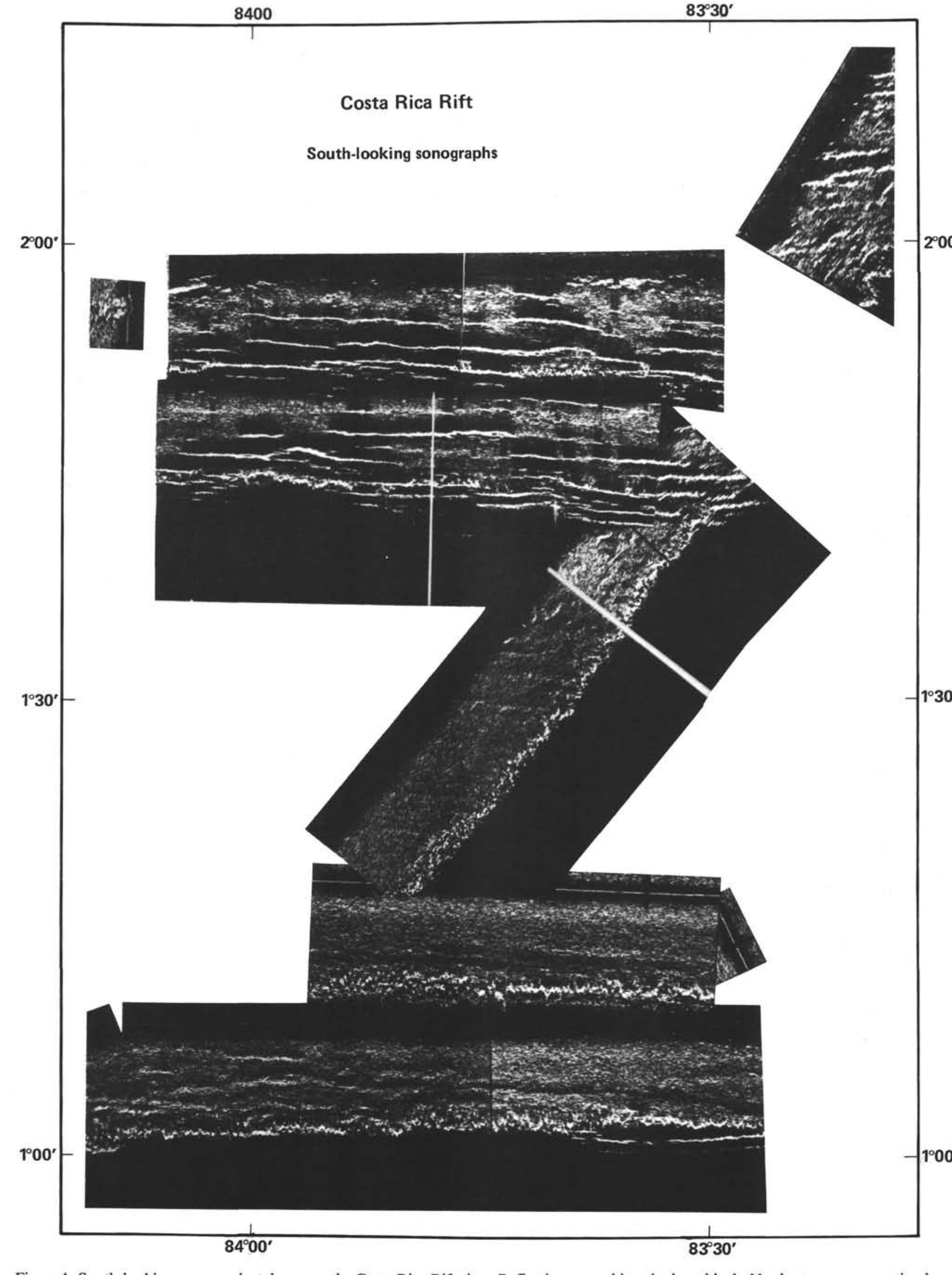


Figure 1. South-looking sonographs taken over the Costa Rica Rift sites. Reflections are white, shadows black. No slant-range correction has been applied.

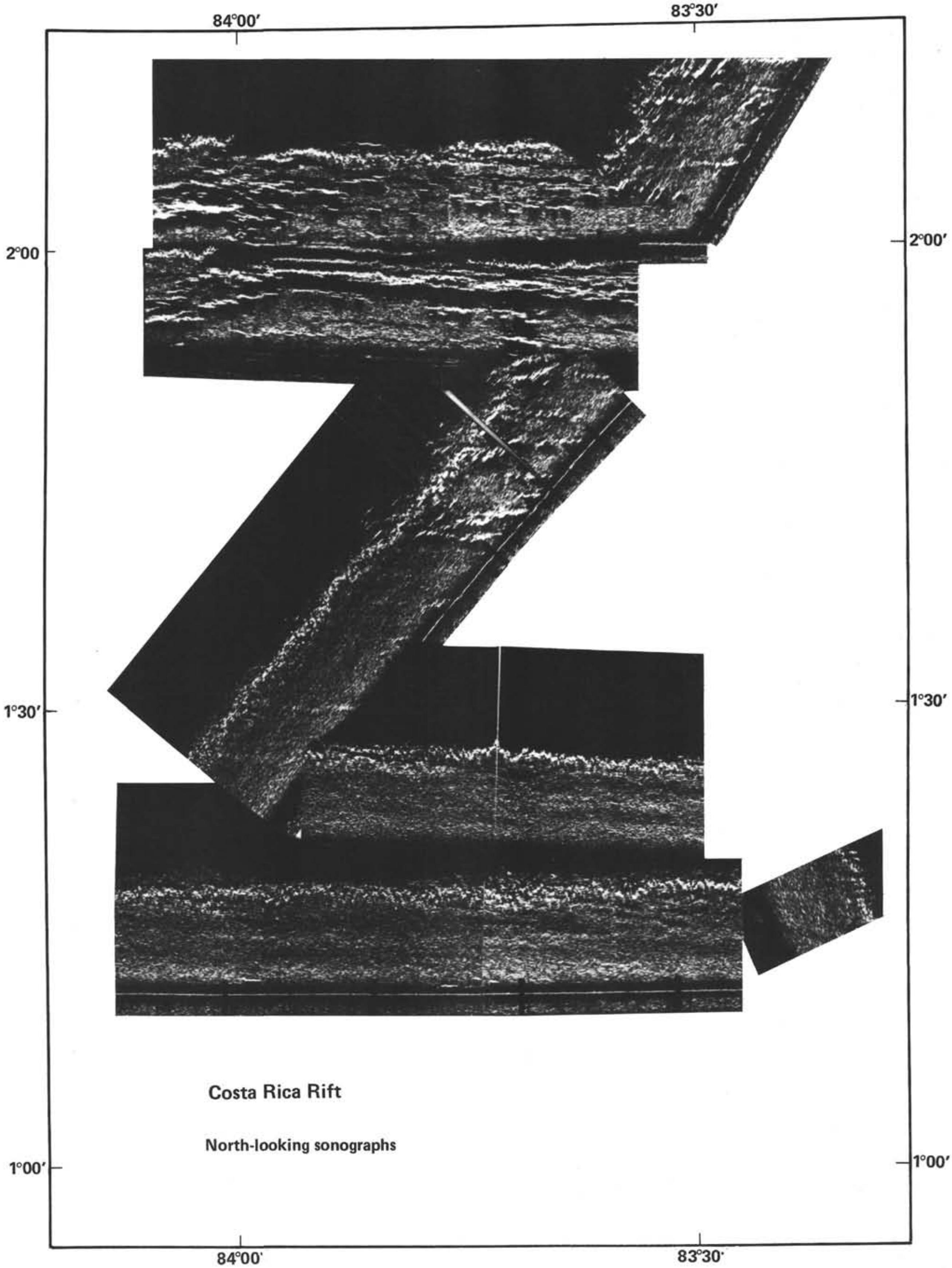


Figure 2. North-looking sonographs.

In addition to GLORIA, we also ran a conventional echo sounder, magnetometer, gravimeter, single-channel air-gun reflection system and 2-kHz sediment profiler. Data from these instruments are not reported here.

## DATA INTERPRETATION

The intensity of the signal appearing on the processed GLORIA records depends mainly on the acoustic reflectance of the sea floor. This in turn is a function of several variables, of which the most important are the angle of incidence of the sound rays, and the composition, texture, and slope of the sea-floor material. Although the ideal of uniquely identifying lithology and morphology from the sonographs is still distant, experience has shown that a broad identification of sea-floor features can be made.

Almost all very high intensity reflections come from outcrops of oceanic basement, and have been so mapped in Figure 3. Many of these high-intensity reflections are narrow, sharp, and highly linear (for example, most reflections in the northernmost part of Figure 1). Such reflectors are identified as fault scarps. Fault scarps are also deduced from narrow, linear shadows (for example, on Figure 2 at 2°05′N, 83°30′W to 83°50′W). In these cases, the direction the scarp is facing can also be inferred (toward the ship for a reflection, away from it for a shadow). When the ship's track is oblique to the strike, echoes from fault scarps appear less narrow and sharp, because the cross-beam resolution is poorer than the down-beam resolution (see, for example, the sonograph north of 2°00′N in Figure 1). In such cases, fault scarps have been identified unambiguously only where the same feature has been seen to display strong asymmetry when insonified from opposite directions, or where a shadow has been seen.

Outcrops other than along fault scarps give rise to high-intensity, but less-linear and more-diffuse reflections (e.g., the broad reflector at 1°58′N, 83°33′ to 84°02′W on Figure 2, which corresponds to the summit of the prominent ridge north of Site 505). Such outcrops may be either constructive volcanic ridges or unsedimented basement on the dip slopes of tilted fault blocks.

Finally, we see linear echoes and shadows which are much less bright and whose edges are less sharp than those identified as basement outcrops along fault scarps. These latter features are interpreted as fault scarps which have been partially covered by sediment, so that there is no basement outcrop. Langseth et al. (this volume) have reported that in the northern part of the area there are strong indications that some faulting has occurred after the deposition of the major part of the sediment cover, but we are unable to distinguish between a freshly faulted sediment scarp and a steep slope of draped sediment.

## TECTONIC SETTING OF DRILL SITES

Site 505, in the north of the survey area, is situated in a region characterized by closely spaced east–west fault scarps and basement outcrops. The scarps are up to 30 km long and spaced about 2.5 km apart in the north–south direction. Basement outcrops, mostly associated with the fault scarps, are very common, amounting to some 17% of the total sea-floor area (Table 1).

As stated above, errors in our track position may amount to several hundred meters, though the relative positions of features on a sonograph are much more precise. The positions of the drill holes at Site 505, as indicated on Figure 3, have therefore been relocated with respect to features on the sonograph to agree with the known physiographic setting of the site. Hole 505 is reported to be at the southern foot of a small ridge situated near the center of the major valley outlined by the 3500-meter contour near 1°56′N, and 505B is at the crest of that ridge at 1°55.19′N, 83°47.29′W. The GLORIA data show a 15-km-long outcrop extending eastward from very near this reported position. The small ridge on which Hole 505B is located would appear to be the westernmost, sediment-covered tip of a long ridge associated with this outcrop. At the longitude of Hole 505B, the crest of this ridge (corrected for slant-range distortion on the sonograph) is at 1°55.7′N. Hole 505B has therefore been relocated at that latitude on Figure 3, and moved slightly to the west of the western end of the outcrop. This is believed to be its correct position relative to the mapped geological features, and is about half a mile northwest of its true geographic position. This discrepancy is within the limits of our navigational accuracy. Holes 505 and 505A have been relocated in their correct relative positions with respect to Hole 505B. Hole 505A lies between 505 and 505B, and is not shown on the figure.

We can now make the following statements concerning the geological setting of the holes. Hole 505, the southernmost of the three holes at this site, lies in a sedimented valley which is uninterrupted for over 20 km to both the east and the west. The hole is 1 km north of the eastern end of a 12-km-long, sediment-covered, north-facing scarp. A more extensive system of scarps exposing basement occurs about 2.5 to 3 km south of the hole. One of these scarps extends continuously for 25 km west of the longitude of the hole; to the east, it extends, with two small breaks, up to 20 km away.

Holes 505A and 505B are near the western end of a ridge. Basement crops out extensively along the crest of the ridge for 15 km to the east of Hole 505B. The nearest outcrop must be very close by to the east (probably only a few hundred meters away—certainly less than the resolution of our underway satellite navigation). To the west of the holes, there appears to be an uninterrupted sedimented valley for 20 km. North of Hole 505B, the ridge drops away into a sedimented valley, the next feature northward being the major ridge whose foot is about 3 km away.

### SITES 501/504

The holes at these sites were drilled on a more-or-less flat, featureless sediment plain.

Figure 2 shows three small, high-intensity reflections just south of the drill site, near 1°12′N, 83°47′W. At first these reflections were all thought to represent outcrop; however, the pre-drilling site survey (Langseth et al., this volume) failed to find evidence of outcropping

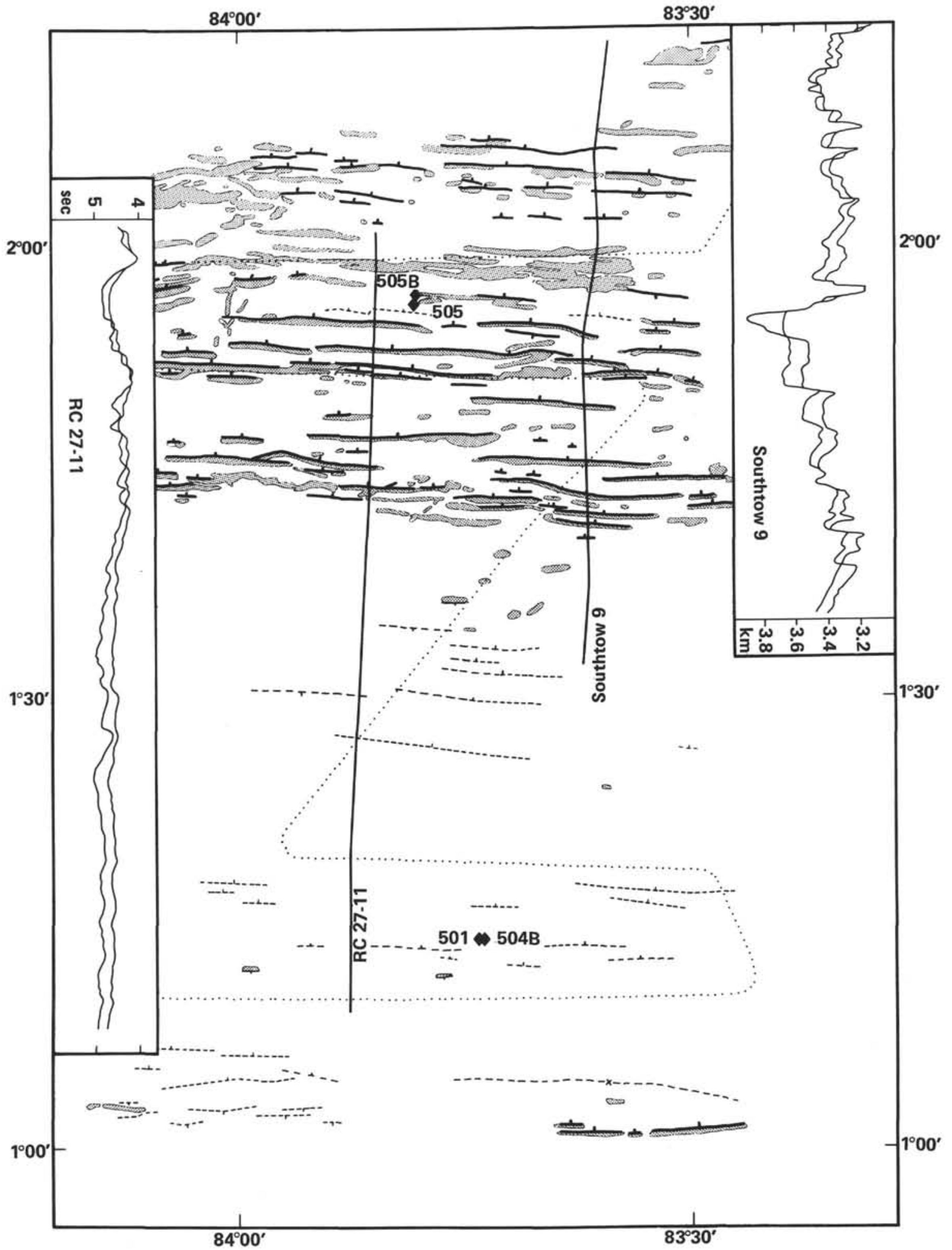


Figure 3. Regional geology of area, interpreted from Figures 1 and 2. Stippled areas represent basement outcrops; heavy lines are fault scarps, with tick on down-thrown side. Broken lines indicate relatively steep, sediment-covered slopes (possibly, but not necessarily, buried fault scarps), with tick on down-slope side; broken line with cross in center represents axis of valley in sediments; dotted line is track of *Discovery* Cruise 110; diamonds represent positions of drill sites. Positions of geological features have been adjusted to correct approximately for slant-range distortion.

Table 1. Areas of outcropping basement and lengths of exposed fault scarps within various radii around Sites 501, 504, and 505.

| Parameter | Sites 501/504 | | | Site 505 | | |
|---|---|---|---|---|---|---|
| Radius (km) | 5 | 10 | 20 | 5 | 10 | 20 |
| Total length of fault scarps (km) | 0 | 2 | 2 | 6 | 55 | 223 |
| Length/$km^2$ ($km^{-1}$) | 0 | 0.006 | 0.002 | 0.08 | 0.18 | 0.18 |
| Total area of outcrop ($km^2$) | 0 | 0.2 | 0.2 | 10.8 | 54.5 | 208.3 |
| Area of outcrop (%) | 0 | 0.06 | 0.02 | 13.8 | 17.4 | 16.6 |

basement in this area, so these features were carefully examined further. All three show up clearly only on the north-looking sonograph, where they are at a very short range (< 3 km) from the ship's track, so that they would be expected to record exceptionally strongly. In that light, their reflection intensities are probably near the borderline for classification as outcrops. As a further test, the sonographs which had been recorded without AGC were also examined, because they retain the real level of strong signals more faithfully than the AGC records. This revealed that only one (the westernmost) of this group of three reflections had a truly high intensity. It is also very narrow, suggesting a very small outcrop, probably less than 100 meters across. The outcrop strikes east-west, is about 2 km long, and lies 5 km southwest of Site 501 (Fig. 3). It probably is associated with the top of a south-facing fault scarp which is not quite covered by sediment.

Apart from this, the outcrops nearest the site are 22 km to the southeast, where basement appears to be exposed along a set of north-facing fault scarps which extend over 20 km in an east-west direction. R/V *Robert Conrad* (Cruise 21-17) passed (at 83°39′W) near the western end of this system of scarps at 0900 on 20 December 1978, crossing a north-facing basement scarp completely draped by sediment. Our data indicate that basement does crop out along this scarp to the east of the *Conrad* crossing.

Finally, two very small outcrops occur 23 km northeast and 26 km west of the site. The average nearest-neighbor distance between all four outcrops is 25 km.

Apart from the faults and outcrops mentioned above, we have no evidence for breaches of the sediment surface within a radius of at least 25 km of Sites 501/504; however, several extensive areas of graduated shadow and low-intensity reflections appear on the sonographs (particularly the south-looking ones; Fig. 1) around the site. They are considered to result from variations in the slope of sediments overlying basement ridges and valleys. They probably mark the positions of buried fault scarps in the basement, as suggested in Figure 3.

## DISCUSSION

The GLORIA survey confirms the findings of other geophysical surveys in the same area (Langseth et al., this volume), that there is a gross difference in surface morphology and degree of sediment cover between the northern and southern parts of the survey area. The change appears from our data to take place very abruptly near 1°41′N, and the zone of transition seems to be no wider than the typical 2.5 km width of a single fault block. The cause of the change is unclear, but it does seem to be related to a sudden change in basement relief. Klitgord et al. (1975) found that the spreading rate in this area increased from 26 to 38 mm/yr about 4.1 Ma. It is possible that the change in basement relief was associated with that spreading-rate change, but, if so, it is strange that higher relief should be associated with faster spreading: usually the opposite is the case.

These differences in basement outcrop and fault occurrence are believed responsible for the observed differences in conductive heat flow along a north-south transect of the survey area, by allowing greater convective heat flow in the north (Langseth et al., this volume). The GLORIA data (Fig. 3) permit precise estimates of both the area of basement outcrop and the length of exposed fault scarps (Table 1). In Table 1, estimates of these quantities within circles of radius 5, 10, and 20 km from each drill site are given. The principal sources of error in these estimates are: (1) the area of outcrop has been mapped on the basis of slant range, and will therefore in general be less than the horizontal outcrop area, except in the case of grazing incidence; (2) small (approximately 50-m width) patches of sediment within areas of outcrop will not be resolved; (3) areas thinly covered by sediment (approximately 5-m thickness?) may not be readily distinguishable from unsedimented areas. Table 1 shows that, in the north, basement outcrops over about 17% of the sea floor, and the density of fault scarps is about 0.2/km. In the south the densities are respectively 1/300 and 1/30 of these. However, it should be remembered that, because the figures for the south are based on a single small outcrop and fault scarp, they have high relative errors (approximately 100%).


## ACKNOWLEDGMENTS

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## REFERENCES


Allmendinger, R. W., and Riis, F., 1979. The Galapagos Rift at 86° W. 1. Regional morphological and structural analysis. *J. Geophys. Res.*, 84:5379-5389.

Klitgord, K. D., Huestis, S. D., Mudie, J. D., and Parker, R. L., 1975. An analysis of near-bottom magnetic anomalies: sea-floor spreading and the magnetized layer. *Geophys. J. Royal Astron. Soc.*, 43:387-424.

Klitgord, K. D., and Mudie, J. D., 1974. The Galapagos spreading centre: a near-bottom geophysical survey *Geophys. J. Royal Astron. Soc.*, 38:563-586.

Searle, R., 1980. Tectonic pattern of the Azores spreading centre and triple junction. *Earth Planet. Sci. Lett.*, 51:415-434.

________, 1981. The active part of Charlie-Gibbs Fracture Zone: a study using sonar and other geophysical techniques. *J. Geophys. Res.*, 86:243-262.

Searle, R. C., Laughton, A. S., and Loncarevic, B. D., 1979. Site survey for Site 410, an example of the use of long-range side-scan sonar (GLORIA). *In* Cann, J. R., Luyendyk, B., et al., *Init. Repts. DSDP*, 49: Washington (U.S. Govt. Printing Office), 413-418.

Somers, M. L., Carson, R. M., Revie, J. A., Edge, R. H., Barrow, B. J., and Andrews, A. G., 1978. GLORIA II—an improved long range side-scan sonar. *Proceedings IEEE/IERE Sub-Conference in Offshore Instrumentation and Communications, Oceanology International, Technical Session J:* London (B.P.S. Publications), pp. 16-24.