41. SYNTHESIS OF GEOLOGICAL AND GEOPHYSICAL DATA IN A 1° SQUARE AREA AROUND SITE 356, LEG 39 DSDP

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ABSTRACT

Site 356, in the southern Brazilian margin, is located on the northern flank of São Paulo ridge. This ridge, composed of mafic rocks, is an expression of an east-west trending fracture zone which delineates the southern limit of the São Paulo Plateau. Gravity and magnetic anomalies parallel the east-west structural trend of this fracture zone.

Piston cores show that whereas on one hand hemipelagic sediments have accumulated in the continental rise to the south, the plateau itself at present receives dominantly pelagic sediments. The southward flowing North Atlantic Deep Water sweeps the main surface of the plateau. On the other hand, the northeastward-flowing Antarctic Bottom Water flows at the base of the plateau and is deflected to the east by the São Paulo ridge. On the basis of measured time difference between the deepest reflector drilled at Site 356 and a still deeper feature seen on a nearby profile (here suggested as possibly the igneous basement), we speculate that the drilling terminated 100 meters or so above the basement.

INTRODUCTION

The São Paulo Plateau is a marginal plateau located in the southwest Atlantic Ocean (Figure 1). Various studies in the area have indicated the presence of a thick evaporitic layer with associated diapiric structures (Baccar, 1970; Leyden and Nunes, 1972; Leyden et al., 1976; Leyden, 1976). However, when these studies were completed, the thickness, lithology, and ages of various units in the sedimentary column of the plateau were unknown. Furthermore, the relationship of the sedimentary column on the plateau with the stratigraphy of the adjacent coastal basin—the Santos Basin (Figure 1)—was also not known. Hence, the origin and development of the plateau during the early evolution of South Atlantic could only be speculated upon.

The research vessels of Lamont-Doherty Geological Observatory have surveyed the area since the early 1960's. Cruises made by R/V *Conrad* in 1972 and 1973 and by R/V *Vema* in 1974 attempted to map the extent of these diapiric structures and to sample possible basement outcrops at the southern edge of the plateau. On the basis of these surveys a drill site was proposed at the southeastern edge of the plateau in an area where large diapiric structures were absent and where a complete stratigraphic section of the plateau was expected to exist within the drilling capability of D/V *Glomar Challenger*. Subsequently, Site 356 was drilled at lat 28°17.22'S and long 41°05.28'W during Leg 39 (see Site 356 chapter, this volume).

This paper discusses the geological and geophysical data within a 1° square area around the drill site bounded by 28° and 29°S latitudes, and 40°30' and 41°30'W longitudes (Figure 2). A regional synthesis for the origin and evolution of the plateau is presented elsewhere in this volume (Kumar et al., this volume).

MORPHOLOGY

The bathymetric contours for the survey area are shown in Figure 2. The main surface of the São Paulo Plateau is shown in the northern part of this map. The 3000-meter contours denote the relatively sediment-free crest of the east-west trending São Paulo ridge (Figure 1). The 3250-meter contour to the west of the drill site represents a local closed depression on the northern flank of the ridge.

The São Paulo ridge has a very steep southern flank. A deep trough parallels the ridge to its south. The axial portion of this trough is delineated by the 4250-meter contour, and the relief from the crest of the ridge to the trough on its south is of the order of 1250 meters. South of the trough, the sea floor rises to an average depth of 3850 meters where it merges with the continental rise.

The microphysiography and morphology of the area has been interpreted through an analysis of 3.5-kHz echograms. Large irregular overlapping hyperbolae (echo type 1) indicate a very rough bottom in the São Paulo ridge area (Figures 3, 4). Echo type 2 (Figures 3, 4) is defined by a prolonged echo with no subbottom reflector. It indicates a slightly irregular sea floor and represents the surface of the sediment column that has

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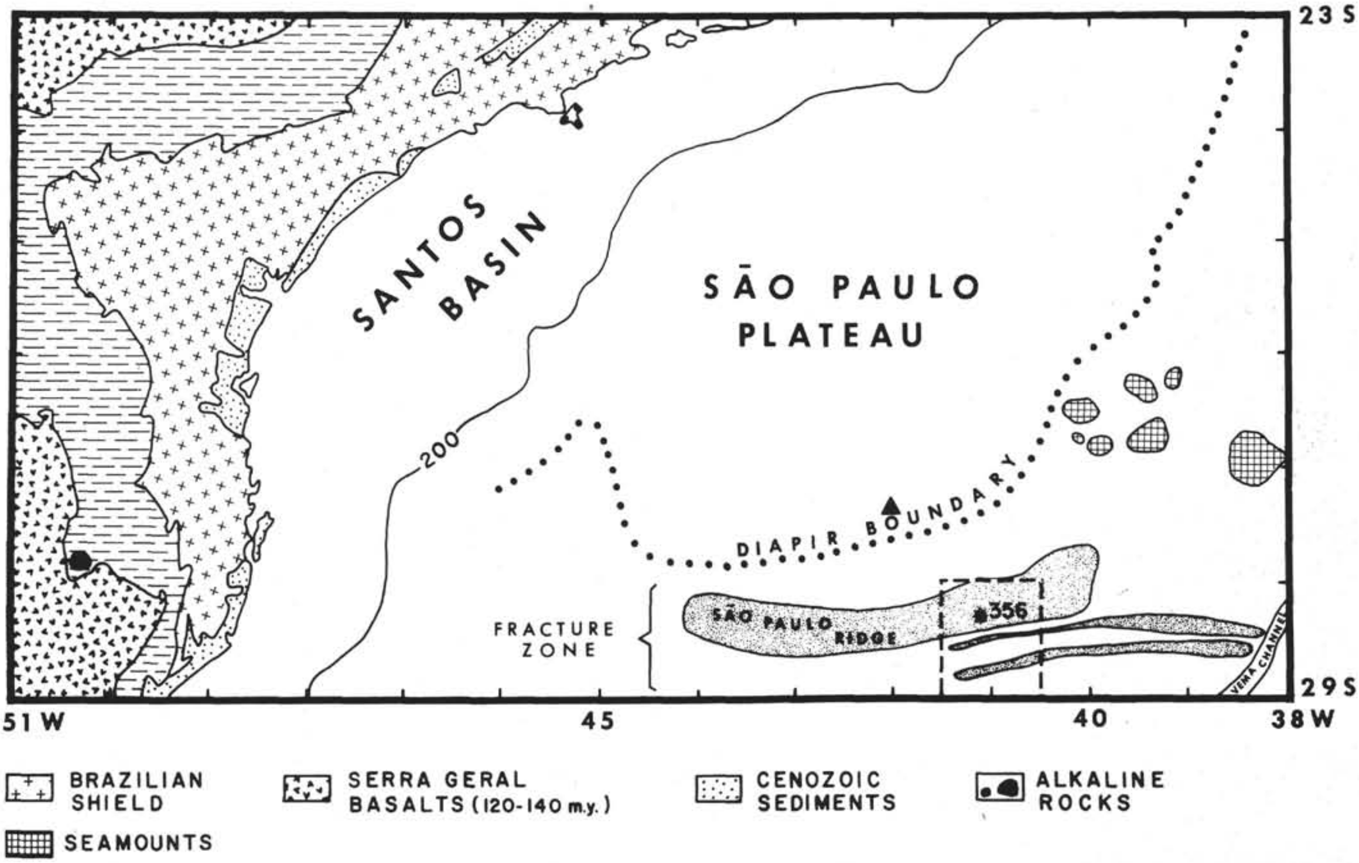

Figure 1. *Regional setting and location of the survey area (dashed square). Star marks the location of Site 356. Land geology from the Geologic Map of Brazil (1971). Offshore features from Kumar et al. (this volume). Triangle marks the location of Figure 6C.*

covered the northern flank of the São Paulo ridge. The trough that parallels the São Paulo ridge is represented by a flat and prolonged echo with no subbottom reflectors (echo type 3, Figures 3, 4). Small areas of echo type 3 are also seen on the crest of the São Paulo ridge, representing the smooth surface produced by the pelagic sediments filling its irregularities. South of the trough, the bottom is represented by a wavy echo with parallel subbottom reflectors (echo type 4, Figures 3, 4). This echo occurs only in those areas which are deeper than the plateau. The undulating sea floor of echo type 4 may represent erosion/deposition by bottom currents. Large ripple-like features are also seen at the base of the plateau in profile AA′ (Figure 5). Bottom photographs at the southern flank of the ridge Figure 6A, B, location on Figure 3) show ripple marks and scouring caused by an easterly current. These facts suggest that the morphology of echo type 4 may have resulted from the action of the Antarctic Bottom Water (AABW) which flows only at the base of the plateau (Damuth and Hayes, in press). This northeastward-flowing water is probably deflected eastward against the southern flank of the São Paulo ridge and may also have scoured the paralleling trough located at its base. In contrast, a southwest-flowing current appears to sweep the main surface of the plateau as indicated by bottom photographs (Figure 6C, location on Figure 1) from a station located slightly to the north of survey area at 27°25′S and 41°59.9′W. Bottom potential temperature indicates that this current is probably caused by southward-flowing North Atlantic Deep Water (NADW) which flows at shallower depths than the AABW (Damuth and Hayes, in press).

CORING AND DREDGING

Two piston cores were obtained in the survey area (Figure 3). One of these was taken on the São Paulo ridge (RC16-134) and contains 528 cm of interbedded layers of pelagic foraminiferal ooze and foraminiferal marl ooze. The other (V16-189) was taken on the continental rise south of the São Paulo Plateau and contains 913 cm of fine clay with interspersed manganese micronodules and has a low carbonate content. As mentioned earlier, the AABW seems to erode/deposit sediments to the south of the plateau. The relative concentration of manganese nodules in the sediments (Goodell et al., 1971; Payne and Conolly, 1972) may be another indication of this bottom-current activity.

The only data on the composition of the São Paulo ridge come from a dredge station (located on Figure 3) and a basalt pebble found in Unit 5 at Site 356 (Fodor et al., this volume). Mafic rocks (basalt, metabasalt, diabase) were recovered from this ridge at the eastern of the two dredge stations shown in Figure 3. The material

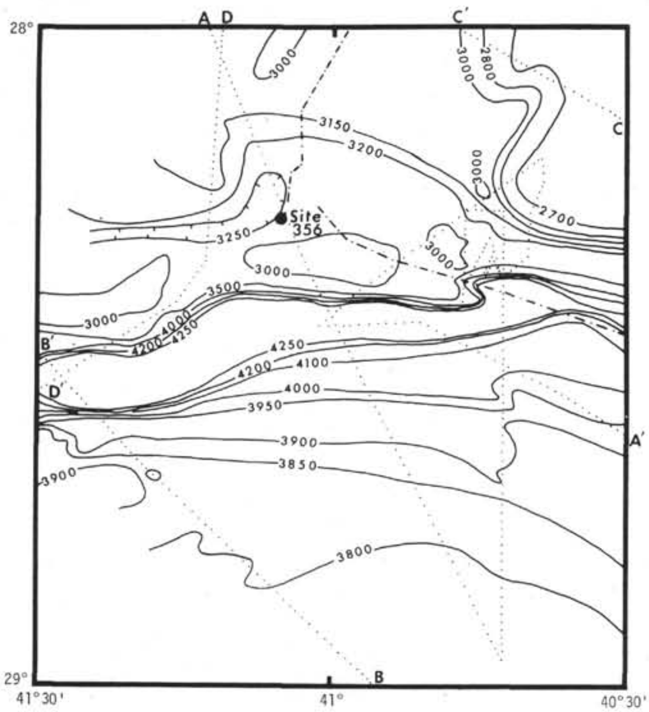

Figure 2. *Bathymetry in uncorrected meters of the survey area around Site 356. L-DGO tracks shown by dotted lines and the R/V* Glomar Challenger *(Leg 39) track shown by dashed-and-dotted line.*

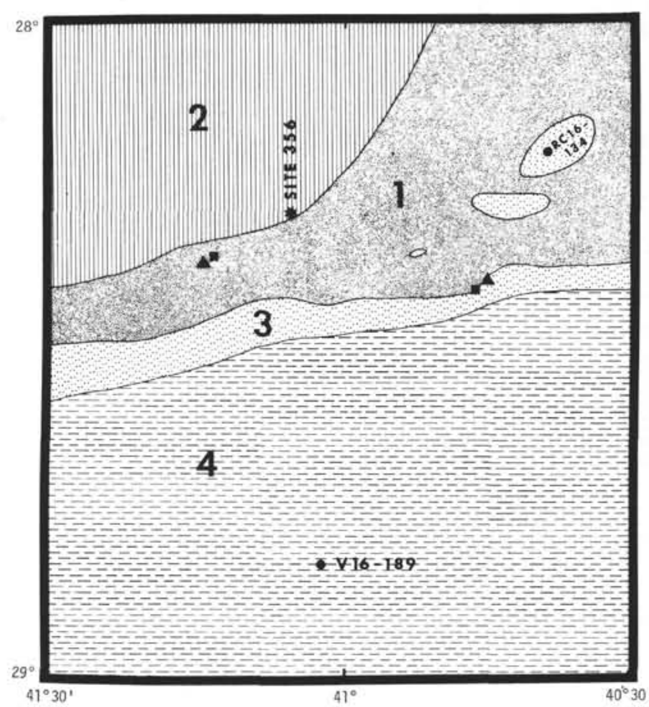

Figure 3. *Echo-character map of the survey area. Cores (dots), dredges (squares), and bottom-camera stations (triangles), located within the area are marked. Examples of individual echo types marked by numbers 1 through 4 shown in Figure 4.*

recovered from the western station was too weathered to provide any useful information. Talus composed of large blocks at the base of the southern flank of São Paulo ridge is seen in bottom photographs (Figure 6D).

SEISMIC DATA

The seismic-reflection profiles from the survey area (Figure 5, tracks shown in Figure 2), were used to construct an isopach map (Figure 7). Because the basement could not be followed in the northern part of the survey area, the isopachs there represent only the minimum sediment thickness (Figure 5).

The region between the 0.0 and 0.1 sec isopachs approximately represents the crestal portion of the São Paulo ridge where the basement either outcrops, or where it is covered with less than 0.1 sec (two-way travel time) of sediment. Whereas the southern flank of the São Paulo ridge is very steep and sediment free, the northern flank is buried by the sedimentary sequence of the São Paulo Plateau.

The axial portion of the trough that parallels the São Paulo ridge to its south is approximately delineated by the 1.0-sec contours. The southern boundary of the trough is marked by a basement high which is buried under 0.6 sec (two-way travel time) of sediment cover. South of this buried high follows a buried trough and another buried high. As discussed by Kumar et al. (this volume) the entire sequence constituted by the São Paulo ridge, the trough to the south, a buried high, a buried trough, and another buried high (Figure 7), appears to define a fracture zone. This fracture zone marks the southern boundary of the São Paulo Plateau and can be traced farther to the east, marking also the northern boundary of the Rio Grande Rise (Kumar et al., this volume).

Although we do not have a definite control for predicting the depth to basement in the vicinity of Site 356, an estimate is attempted here. Profile AA′ (Figure 5) was used as the reference profile for the drill site. As is shown in the enlarged and interpreted part of the profile AA′ (Figure 5), the deepest irregular seismic reflector at 0.75 sec subbottom under the point marked as "projected location Site 356," was expected to represent the igneous basement. The approach profile for the site (from 09:30 hr, 16 November 1974 to the drill site, see chapter on underway geophysics, this volume) is almost coincident with the traced part of profile AA′ and also showed the deepest reflector at 0.75 sec subbottom. However, the drilling results showed that the 0.75 sec reflector correlates with the top of Albian limestones in which the site terminated. We speculate that the reflector at 0.75 sec subbottom in the left part of the traced profile (marked with an arrow) maintains its subbottom depth up to the drill site and the drilling terminated just below this reflector. The same reflector is also seen at a similar subbottom depth in profile DD′ (Figure 5, also marked by an arrow). To the left of the projected site location, a possible basement feature is seen at 0.85 sec subbottom. If our assumptions are correct then at least in the vicinity of the drill site the igneous basement might be approximately 0.1 sec (or 100 m using an average velocity of 2km/sec) below the Albian reflector. However, because the basement surface

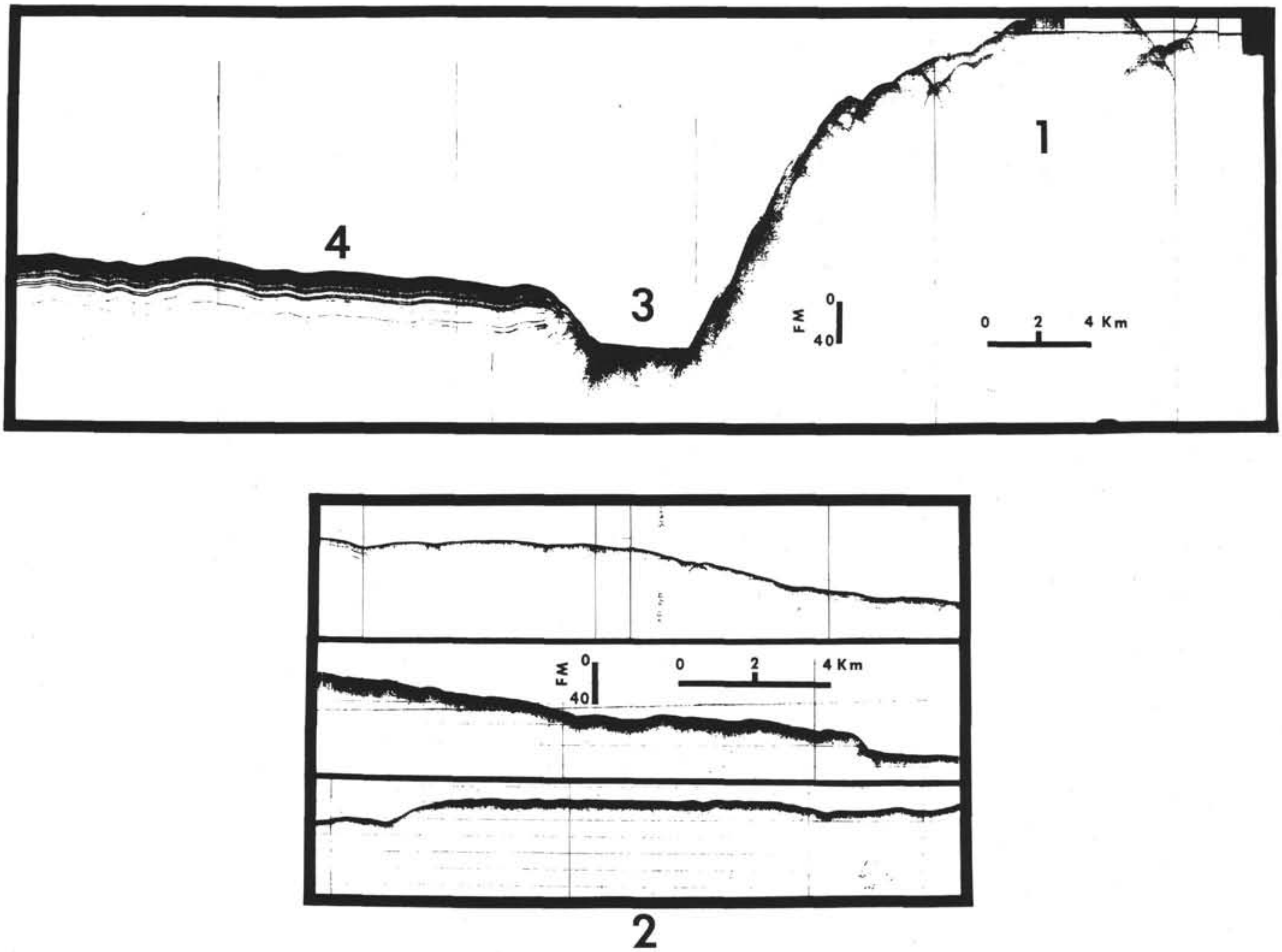

Figure 4. *Examples of echo types 1 through 4 mapped in Figure 3.*

is highly irregular, it is difficult to estimate its depth directly under the drilled location.

Two sonobuoys, 74V24 and 75V24 (Figure 7), were recorded in the survey area. The seismic sections at each station are shown as bar graphs on Figure 7. The velocities of 4.5 and 4.4 km/sec under the sediment layer may correlate with layer 2B, whereas the velocities of 5.9 and 6.4 km/sec may correlate with layer 2C (Houtz and Ewing, 1976). The seismic sections measured through these two sonobuoys thus suggest a typically oceanic crust south of the São Paulo ridge. Although sonobuoy station 75 is located within the fracture zone which marks the southern boundary of the São Paulo Plateau, and station 74 is located to the south of it, the velocities and thickness of measured layers at the two stations are very similar.

GRAVITY AND MAGNETICS

The free-air gravity anomalies for the survey area is shown in Figure 8. The total range of the anomalies within the area is of the order of 65 mgal. The contours of the free-air anomaly generally conform with the bathymetric contours. The area of positive anomalies coincides with the area of most shallow topography, and the area of largest negative anomalies coincides with the deepest regions. The anomalies gradually decrease northward from the ridge to the main surface of the plateau. They decrease abruptly across the southern flank of the São Paulo ridge; the minimum anomalies (-55 mgal) are located in the trough to the south of the ridge. The anomalies increase again south of the trough.

The regional magnetic anomaly pattern over the São Paulo Plateau is complex (Cande and Rabinowitz, in preparation). In the survey area, the total intensity residual magnetic anomalies (Figure 9) show a maximum of 500 gammas and a minimum of -350 gammas. The overall trend of the magnetic anomalies follows that of local gravity anomalies and topography, as well as that of basement structure as indicated by the isopach map of Figure 7.

CONCLUSIONS

1. The São Paulo ridge marks the southern limit of the São Paulo Plateau and is a prominent expression of an east-west trending fracture zone. Oceanic velocities were measured within the survey area at two sonobuoy stations located to the south of the ridge.

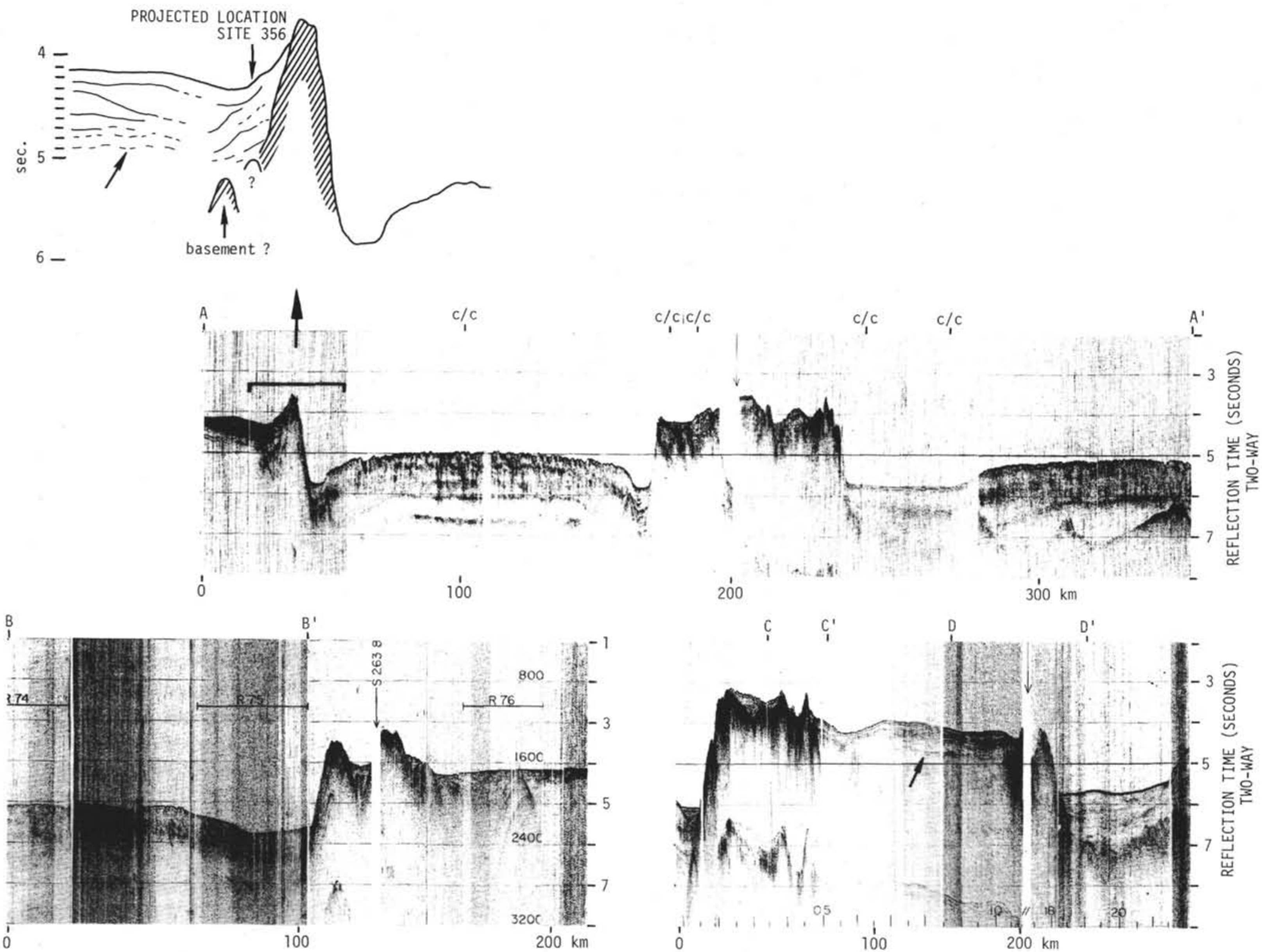

Figure 5. *Examples of seismic-profiler records from the survey area. Profiles marked AA', BB', CC', and DD' located in Figure 2. Projected location of Site 356 marked on the interpreted part of profile AA'. Vertical exaggeration is between 1:12 and 1:25. D/V* Glomar Challenger *profile within this area is from 0930 hr on 16, November 1974 to 2350 hr on 22, November 1974 (shown in Neprochnov, Underway Data, this volume).*

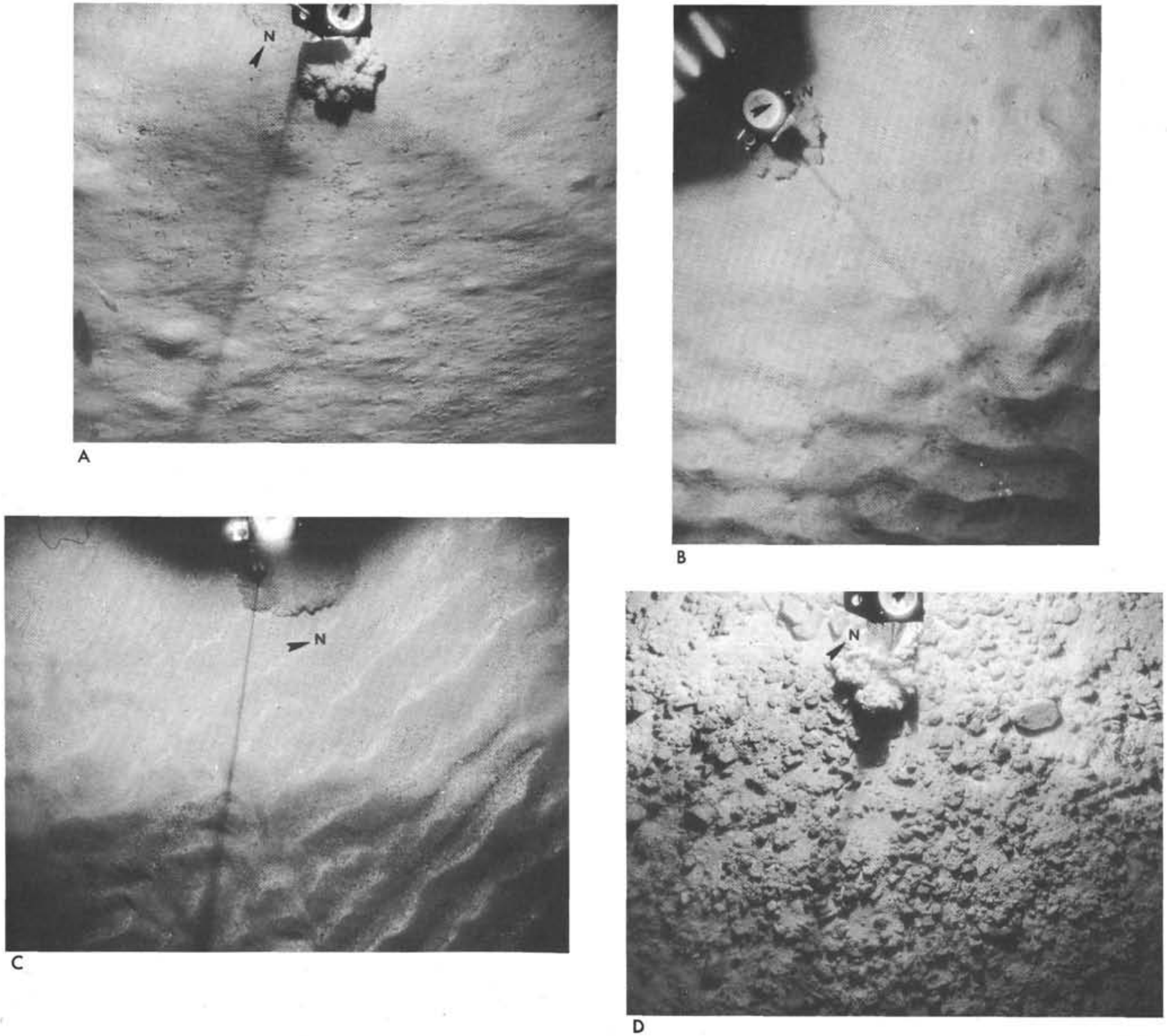

Figure 6. *Bottom photographs from the survey area and vicinity. (A) located on Figure 3 (black triangle) at lat 28°25′S and long 40°45′W, depth: 3550 meters, shows scour marks and current lineations indicating a current flowing from SW to NE. (B) located on Figure 3 at lat 28°21′S and long 41°12′W, depth: 3200 meters, shows asymmetric ripples indicating a current flowing from NW to SE. (C) located on Figure 1 at lat 27°25.2′S and long 41°59.9′W, depth: 2920 meters, shows asymmetric ripples indicating a current flowing from NE to SW. (D) location same as Figure 6a, showing blocky talus at the base of the southern flank of São Paulo ridge.*

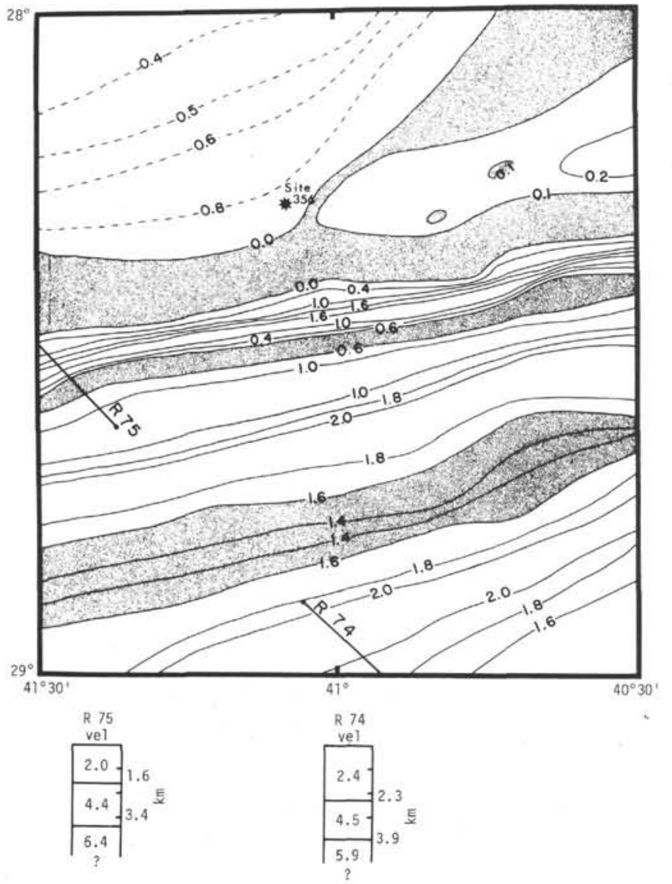

Figure 7. *Isopach map of the survey area in seconds (two-way travel time). Shaded areas represent the sediment-free part of the São Paulo ridge and two buried highs to the south. Sonobuoys station R74 (L-DGO #74V24) and R75 (L-DGO #75V24) shown by straight lines (located on profile BB', Figure 5). Structural sections measured at each station shown as bar graphs, velocities in km/sec.*

2. Site 356 is located on the sediment-covered, gentler northern flank of the São Paulo ridge. On the basis of our seismic data we suggest that at least in the vicinity of the drill site the igneous basement might be located 100 meters or so below the deepest reflector drilled at Site 356. The total sediment thickness in the survey area ranges from nearly zero to nearly 2.0 sec (two-way travel time).

3. The north-flowing Antarctic Bottom Water flows at depths too great to flow on the main surface of the plateau; it flows only along its base. It is deflected to the east by the São Paulo ridge. Although the trough that parallels the ridge is located in a structurally low area, its surface morphology has been derived from erosion by the Antarctic Bottom Water. The rippled morphology of the sea floor to the south of the trough has also resulted from the activity of the Antarctic Bottom Water.

4. The south-flowing North Atlantic Deep Water flows over the main surface of the São Paulo Plateau. It flows too sluggishly to generate large ripples and sand waves as are seen on the continental rise to the south, but causes minor erosion/deposition at the sea floor.

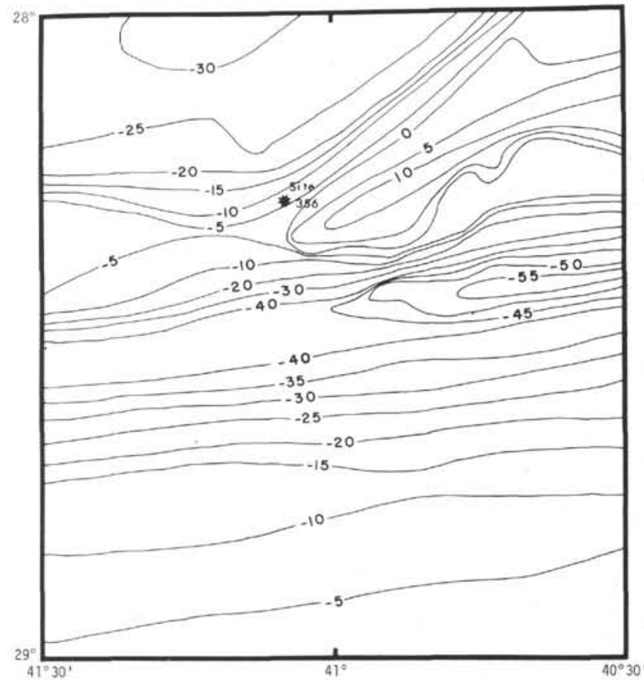

Figure 8. *Free-air gravity anomalies in the survey area contoured at 5-mgal intervals.*

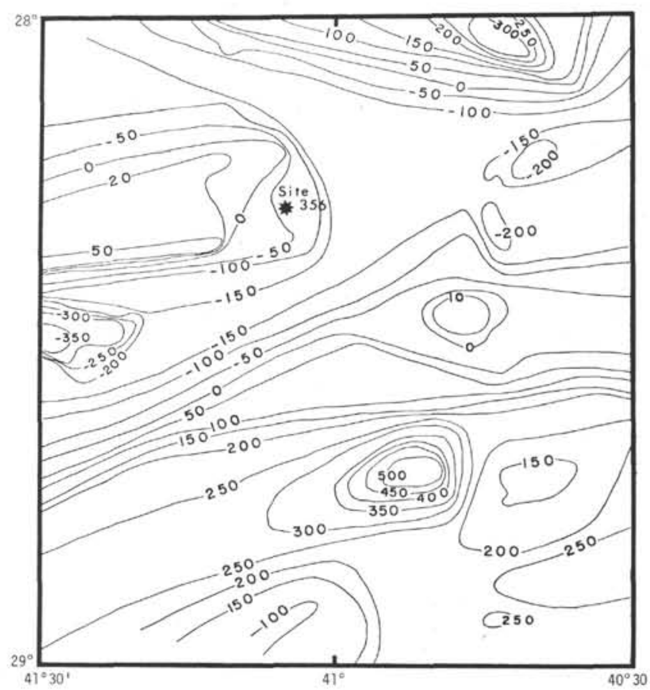

Figure 9. *Total intensity residual magnetic anomalies in the survey area contoured at an interval of 50 gammas and at a smaller interval in some parts.*

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