12. CORRELATION OF SEISMIC REFLECTORS

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INTRODUCTION

At all sites drilled on Leg 21 vertical reflection profiles were shot using the *Glomar Challenger's* 30 cu in airgun and sonobouy receivers. At Site 203 two sonobuoys malfunctioned and no record was obtained, but data from all other sites (204-210), combined with the nearly continuous coring carried out at each site, have provided a reasonably detailed picture of the nature of reflective horizons. In several instances (especially Sites 206 and 210) the correlations have shown earlier interpretations of the geology based solely on reflection profiling to be quite incorrect.

The individual sonobuoy records are presented here with annotations from shipboard work. It was found during drilling that "typical" sediment velocities (e.g., 1500 m/sec for the upper 2-300 m of sediment) provided quite acceptable estimates of depth for guiding the sampling programs. The sonic velocities measured on cores in the shipboard lab now permit depth determinations to be refined. Limits on the depth determinations arise principally from measurements on the original records, wavelength considerations, and interference patterns. Measurements are easily made to 0.01 sec using a Gerber expandable scale, and may be occasionally interpolated to 0.001 sec. This gives general accuracies of ± 7.5 meters. A sediment velocity error of 100 m/sec (a typical range of variation in a "uniform" section) adds to this by only ± 0.5 meters. If such an error existed throughout a 300-meter section, the error would be ± 25 meters; however, it is felt that this does not occur. This range of error is also that encountered due to in situ versus lab temperature and pressure effects on velocity and no corrections made for these factors. Wavelengths of the seismic pulse at these sediment velocities average 10 meters (150 Hz center frequency at 1500 m/sec), but for the lowest frequencies recorded (10-50 Hz) and velocities deeper in the section (2000-3000 m/sec) may be as great as 300 meters, and resolution is limited accordingly. The effect of the multiple signals of the bubble pulse from the airgun is such that overlap occurs at or before one wavelength separation of reflecting horizons. As spacing changes, destructive phase interference may mask reflectors separated by intervals of $(2n+1)\lambda/4$ ($n\lambda/2$ if there is a velocity decrease at the lower reflector). Constructive interference occurs for the inverse of these spacings and impedance changes and can result in spurious and nonuniform strengthening of reflectors or incorrect apparent spacing of reflectors. Some of thesy problems can be seen in the model studies of Woods (1956). Thus the records are most correctly regarded as an interference pattern rather than a simple representation of geologic structure. It is interesting, however, that practice shows the range ± 10 meters to be normally obtained when correlations may be established. The major problem then is that patterns do not always represent similar geology and that not all reflectors observed represent real features of the sediment column.

Sonic velocities were measured onboard the *Glomar Challenger* with a Hamilton frame unit, and density/porosity values were derived from the GRAPE records. Thermal conductivity was measured when heat flow measurements were taken in the hole (see Physical Property sections for each site for data). Reflections occur where acoustic impedance (sonic velocity × density) changes in the section. In the sediments cored, velocity and density discontinuities generally coincide as a result of overburden compaction, and at greater depths, cementation. Because GRAPE measurements are continuous, they often show density maxima in intervals over which velocity data have been averaged, and these points may appear as reflectors. Such boundaries may easily be time transgressive and more a function of sedimentation rates than biostratigraphy. In recording the sonobuoy records, a variety of filter settings was used to investigate the effect of frequency (or wavelength) on the reflected signal. This influence derives from the reflector spacing (constructive or destructive phase interference) and variable attenuation of different wavelengths. The latter is generally of less importance for the frequency variations used. Tables 1 to 7 present summaries of reflector depths, sedimentological, and lithologic properties against depth below ocean floor. A time scale (round-trip travel time) adjusted on the basis of sediment velocities is also shown. The velocities are averages for intervals of relatively uniform values, and individual measurements may vary by ± 100 m/sec or more.

SITES

Site 204 is on a section of relatively undisturbed crust near the western margin of the Pacific plate. The acoustic basement on underway profiles is a broad band up to 0.1 sec thick which slopes to the west (Figure 1). On the sonobuoy profile (Figure 2) the acoustic basement is seen as a series of reflectors overlain by a generally transparent section containing one moderately strong reflector. Velocities in the clay sections were measured at an average of 1483 m/sec throughout the section. Reflector 1 at 47.5 meters marks the change from silty clay to glass shard ash. A second transition from the ash to a clay at 70 meters is near the calculated depth for Reflector 2 at 0.09 sec. At 0.14 sec (103 m) acoustic basement was found to be a tuffaceous sandstone and conglomerate, with velocities increasing abruptly to 2643 m/sec. The drilling was terminated at 150 meters due to low drilling rate and the absence of fossils. The deepest of the reflectors forming the acoustic basement horizon are at or below 315 meters (at 2643 m/sec). There is a correlation at 129 meters of one of these reflectors with the top of the vitric tuff, although no pronounced change in acoustic velocity is observed at the

TABLE 1
Site 204 Correlations

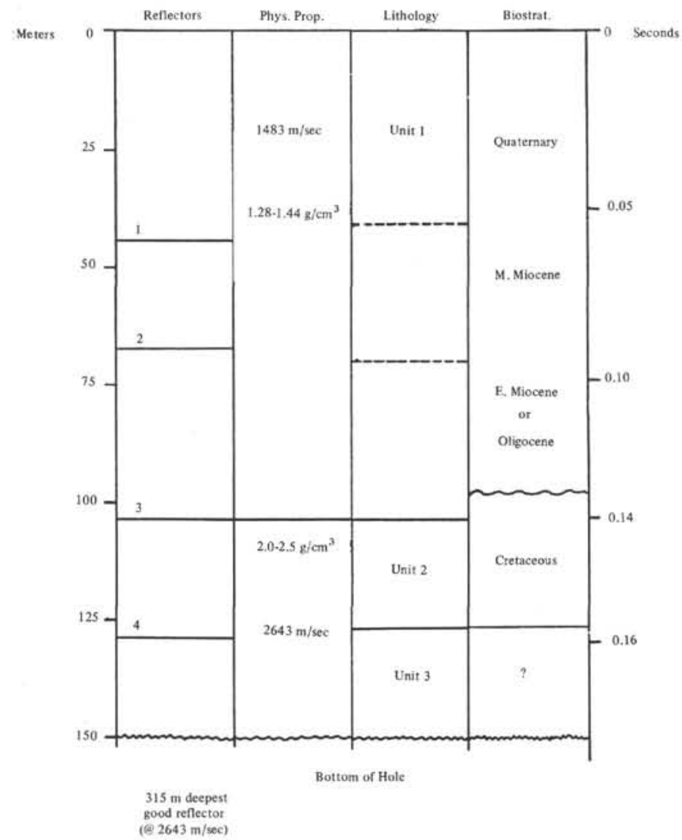
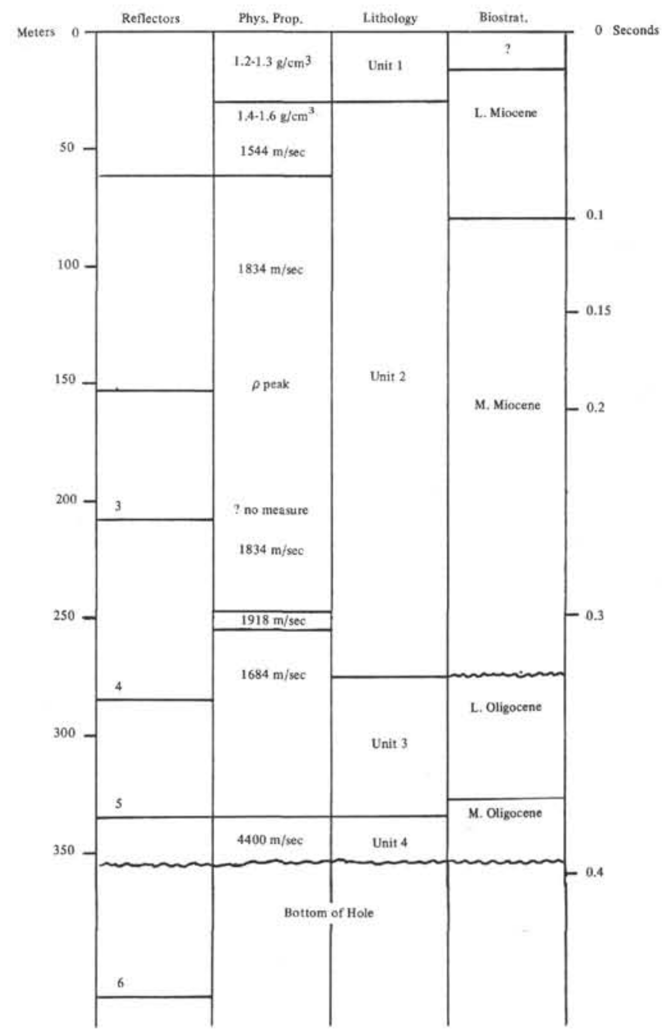


TABLE 2
Site 205 Correlations



break. This suggests that the numerous reflectors below this depth may be real, rather than reverberation, and makes estimates of depth to the top of the second layer very difficult.

Site 205 was selected near the eastern edge of the flattest portion of the South Fiji Basin. Near the site several small basement intrusions occur at the change in slope between the basin and the sediment blanket coming from the Lau Ridge. Occasionally these are expressed as low hills. The underway record (Figure 3) shows a very thin transparent section above a section of acoustically well stratified material. A broader transparent zone beneath this lies immediately above a weak acoustic basement (0.39-0.49 sec). The sonobuoy profile (Figure 4) shows a series of reflectors above an acoustic basement at 0.49 sec (Reflector 5). This reflector is very clear on the record at 10 to 40 Hz, but when higher frequencies (40-80 or 160 Hz) were used, a series of returns appears above this level almost obscuring the breaks. Table 2 presents correlations down the hole.

Reflector 1 at 62 meters coincides with a velocity increase of 300 m/sec and is clear at low and high frequencies. This lies entirely within lithologic Unit 2 at a velocity discontinuity. Reflector 2 at 154 meters is only clear when frequencies above 80 Hz are recorded and is represented by peaks in the velocity, density, and thermal conductivity profiles down the hole, although no general lithologic change occurs at that level. A third reflector at 209 meters (0.24 sec) is also clearly seen on 40 to 160 Hz portions of the record. No major lithologic changes occur here, and a gap in the physical property measurements prevents correlation with small excursions.

The change at 275 meters from the ash of Unit 2 to the chalks of Unit 3 is near a faint reflector at 0.33 sec—about 285 meters. An interesting situation is created by the slightly higher velocity (1918 m/sec) in the interval 250 to 255 meters followed by the substantially lower velocity of 1684 m/sec from 255 to 335 meters. These velocity changes do not appear as reflectors on the sonobuoy trace, although they suggest a signal should be prominent at 0.30 sec where only vague indications exist on the profiles at 40 to 160 Hz. In such instances it may be that cancellation of signals from adjacent reflectors is possible—the depth from the 1918/1684 m/sec surface to the top of Unit 3 is about 1.5 wavelengths (although this varies by a factor of 4 in the range recorded). The high over low velocity structure would produce a phase change opposite to a low/high surface so that ($n\lambda/2$) should be the appropriate spacing for destructive interference. The top of Unit 4 (basalt and limestone) is marked by a velocity increase to 4400 m/sec and correlates

TABLE 3
Site 206 Correlations

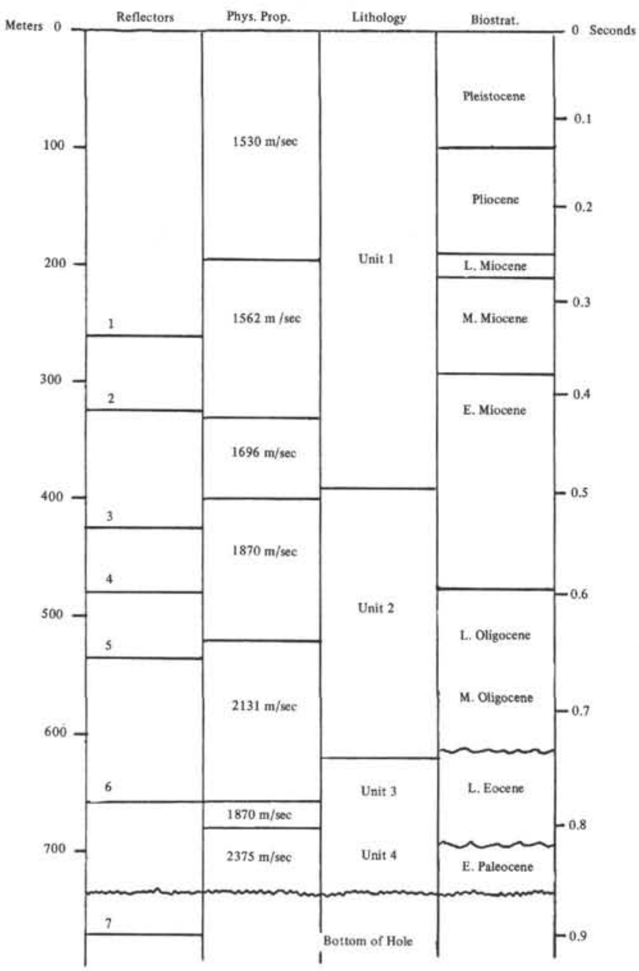
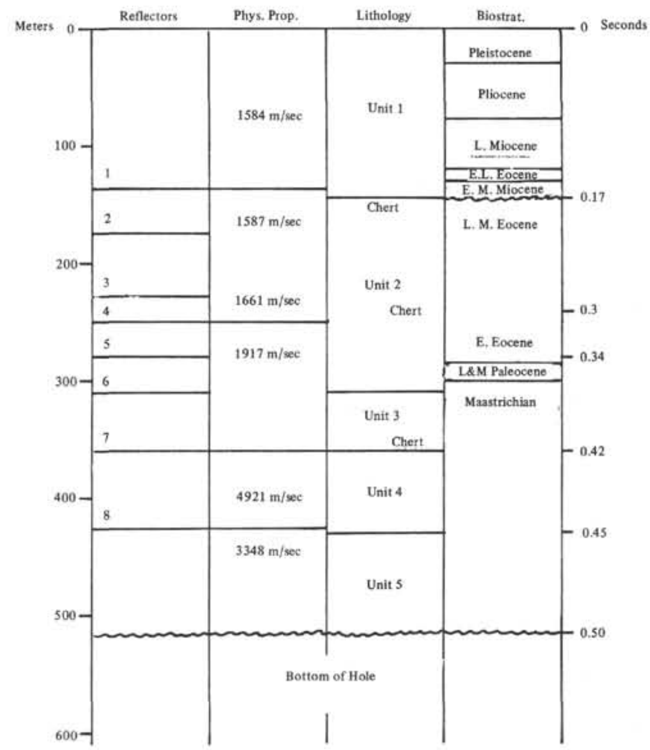


TABLE 4
Site 207 Correlations



exactly with Reflector 5 using the overlying velocities. This reflector is faintly visible at 10 to 40 Hz, and is clearly present at all other frequencies. The strong reflective horizon at 0.49 sec (perhaps 550 m depth) suggests oceanic second layer and supports the contention that Hole 205 terminated in an intrusive sill.

Site 206 in the New Caledonia Basin presents major discrepancies between stratigraphic boundaries and reflectors, as well as between geophysical interpretation and geologic structure. The site survey and approach tracks show (Figure 5) an acoustically stratified basin fill of rather well defined dimensions with an intrusive structure from a deep transparent horizon. This was initially interpreted as basin turbidites on earlier pelagic material. The on-site profile is shown in Figure 6. Drilling and quasi continuous coring showed the entire section penetrated (nearly 0.9 sec-711 m) to be rather uniform pelagic sediments with no sign of terrigenous contribution via turbidites. The regional unconformity (see Leg Summary and Conclusions) occurs at this site at 620 meters, but is not marked as a reflecting horizon. Table 3 presents correlations for this site.

Reflectors 2, 5, and 6 coincide closely with velocity discontinuities (1562 to 1696 m/sec; 1870 to 2131 m/sec; and 2131 to 1870 m/sec, respectively). Reflector 5 also marks marks the Late Oligocene/Middle Oligocene boundary. None of the other biostratigraphic boundaries and none of the lithostratigraphic boundaries are marked by reflectors. Two velocity discontinuities–one of 200 m/sec (1696/1870 m/sec) and one of 500 m/sec (1870/2375 m/sec)–are not seen in the record, probably again due to phase interference and masking. A displaced section of nearly 40 meters of Paleocene and Cretaceous material also does not produce a signal on the profiles.

Reflector 4 appears to be the top of the "transparent" layer of the site surveys which suggests a possible Late Oligocene event as a disturbing influence on the sediments below, although this is quite a tenuous conclusion.

The possible basement at 0.9 sec was not reached by drilling, but on the 10 to 40 Hz record there is a suggestion of reflectors as deep as 1.2 sec so that the depth to basement is conjectural. The displaced older sediments near the base of the hole suggest that the possibly thicker fill may be material slumped from the adjacent highs–perhaps during Eocene deepening of the basin.

Reflectors 4 to 6 show up strongly at all frequencies recorded, while Reflectors 1 to 3 are best delineated at frequencies of 160 Hz or above. The lack of coincidence of reflectors with structure as at other sites (e.g., Site 210) suggests that local or regional tracing of reflectors as time lines in structural interpretation can be misleading.

The presence of displaced material within the section defined as acoustically transparent which forms the bulk of the adjacent hill suggests that the lack of reflectivity may be a function of internal disruption of the sediment during

TABLE 5
Site 208 Correlations

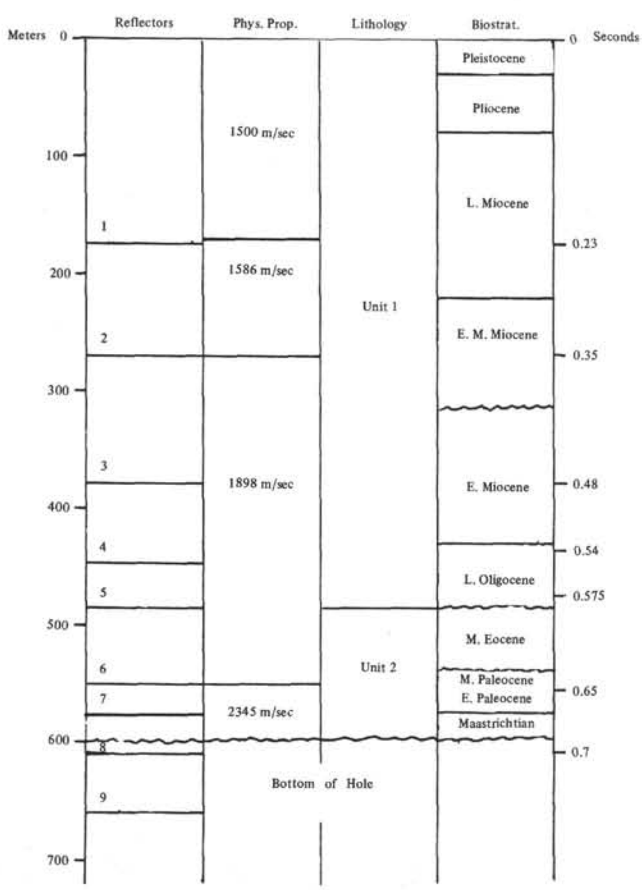
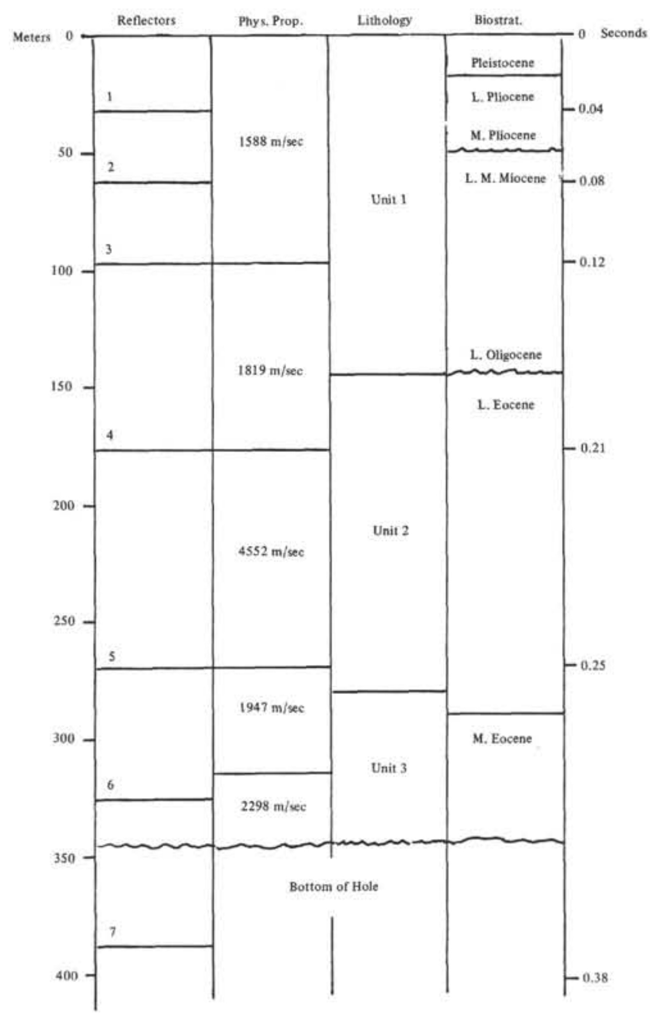


TABLE 6
Site 209 Correlations



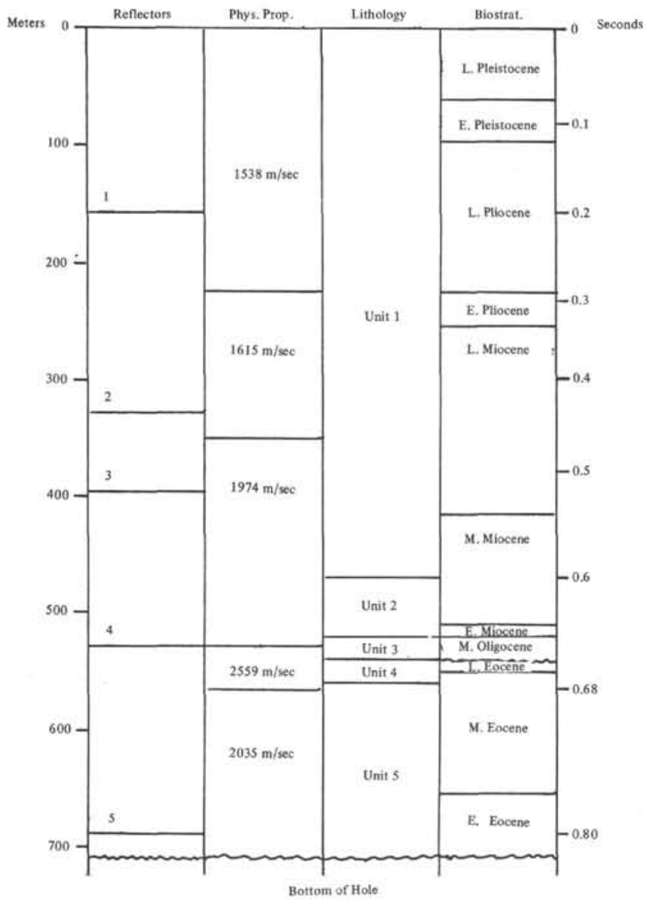
a period of tectonism within the basin. This possibility was suggested earlier on the basis of site survey data and will be explored more fully elsewhere. It does appear, however, that the New Caledonia Basin may well have undergone compression during early or mid-Tertiary with resultant folding of some basin structures and perhaps some structures on the eastern slope of the Lord Howe Rise.

Site 207 on the southern Lord Howe Rise is near the top of a basement high (Figure 7). Reflectors converge onto this structure (with some deeper ones being truncated) and can be clearly correlated with boundaries within the section. The sonobuoy profile (Figure 8) and the correlation chart (Table 4) show the local structure. Principal boundaries marked by reflectors are: The Eocene/Oligocene regional unconformity (Reflector 1) at 135 meter (0.17 sec). In this section there is a displaced section of Early Late Eocene (118-120 m) above a 14-meter section of Early Middle Miocene (128-142 m) which rests on the unconformity. Immediately below the unconformity a chert stringer was encountered (143 m). There is a very small change in average velocity (and acoustic impedance) at the depth calculated for the reflector (134.6 m), and any of the above boundaries fall within extreme confidence limits of the depth calculations. Since this is one of only two sites (out of five) at which a reflector marks the unconformity, it is unfortunate that the picture cannot be further clarified, but it would appear most likely that the chert was responsible. This boundary also marks the transition between lithologic Units 1 and 2.

The Unit 2/Unit 3 boundary (310 m) is marked by Reflector 6 (0.37 sec). This is the top of the silty claystone, but not a point of marked change in sonic velocity, although a density maximum does occur at 305 meters. The Unit 3/Unit 4 boundary—the top of rhyolite— is also marked (Reflector 7). This is a pronounced velocity jump from 1917 m/sec to 4921 m/sec at 360 meters. The Unit 4/Unit 5 boundary which is lithologically a transition from a brecciated appearance in Unit 4 to a flow appearance in Unit 5 is marked by Reflector 8 (0.45 sec).

Reflectors 3 and 4 mark velocity increases (1587 to 1661 m/sec and 1661 to 1917 m/sec, respectively) within Unit 2. A chert interval also occurs at the depth of Reflector 4. Reflectors 2 and 5 also are within Unit 2 and are at or near zones where the induration op the cores increased sufficiently to be remarked by sedimentologists onboard while opening the cores. Acoustic basement on the underway profiles is the top of the rhyolite—Unit 4. The reflectors, in this instance, can be usefully traced to local

TABLE 7
Site 210 Correlations



geologic structures to provide bench marks for interpretations of structural history.

Site 208 is on the northern end of the Lord Howe Rise (Figure 9) and is the only other site (with 207) at which the regional unconformity is clearly marked by a reflector (Reflector 5, 0.575 sec). This reflector appears to truncate some layers to the east and west of the site and supports the hypothesis of an erosional origin for the unconformity. Reflectors are present on the sonobuoy profile (Figure 10) at least 0.2 sec below underway acoustic basement and at least 60 meters below the bottom of the hole so that the nature of true basement cannot be determined. Only two lithologic units are present, and their boundary at 490 meters is marked by Reflector 5 which is also the regional unconformity. Correlations are presented in Table 5.

Reflectors 1, 2, and 6 coincide with increases in sonic velocity in the cores–from 1500 m/sec to 1586 m/sec to 1898 m/sec to 2345 m/sec. Reflector 2 also corresponds with the Late Middle Miocene/Middle Middle Miocene boundary, and Reflector 6 with the Middle/Early Paleocene boundary. Reflector 7 marks the Cretaceous/Tertiary boundary. Other reflectors–3 and 4–are not obviously related to any stratigraphic or physical transitions, and Reflectors 8 and 9 were below the depth of the hole.

Reflectors at Site 209 on the Queensland Plateau are not as well known as those at other sites due to the poor core recovery in the coarse sediments encountered and the variations in velocity with sediment type. This places a great deal of uncertainty on velocity averages and boundaries. The underway seismic profiles (Figure 11) are marked by a definite basement reflector which rises at the site to 0.38 sec (Reflector 7) and a strong intermediate reflector at 0.25 sec (Reflector 5). The 0.25-sec reflector is the "unconformity" or "erosional" surface described by Ewing et al. (1970) which crops out on the edge of the plateau near the 2000-meter contour. The on-site sonobuoy profile is shown in Figure 12, and Table 6 presents the derived correlations. Velocity boundaries have been placed roughly at midpoints between depths of measured velocities. On this basis Reflectors 1 and 2 are not related to observed changes, while Reflectors 3 and 4 mark the velocity increases of 1588 to 1819 m/sec and 1819 to 4552 m/sec. Since only three measurements are available in the interval of high velocities below Reflector 4 (5799, 4823, and 3035 m/sec), an average is difficult to accept, but does produce a reflector depth for Reflector 5 which coincides with the Late Eocene/Late Middle Eocene boundary at 270 meters. This is the depth of a velocity decrease to 1947 m/sec and marks the lowest level of chert stringers in Unit 2. Thus, geophysical interpretations must be redrawn to recognize the nature of this reflector. Mass movement of sediments above the chert has exposed the reflector, but is post-depositional rather than another interval of nondeposition. The regional unconformity is present at this site near 145 m–the top of Unit 2– but the interval 90 to 180 meters is unsampled. Reflector 3 at 100 m may mark the break but this is conjectural. In using the velocities available, Reflector 6 falls at 328 meters, 20 meters below the top of Unit 3. There is a small increase in acoustic impedance at this depth.

Site 210 provided one of the most interesting contrasts of geophysical interpretation with geological structure. At this site only one of five reflectors coincides with observed physical or stratigraphic breaks. The site was continuously cored to 90 meters depth, and thereafter every other 9 meters was cored. Even combining the maximum seismic uncertainty with a possible 9-meter error in an uncored horizon boundary does not give sufficient scope to approach a fit for the unrelated reflectors, and it seems obvious that this is exactly what they are.

Underway records to the site and from the site survey (Figure 13) show acoustically stratified and transparent horizons horizontally overlying a rough basement reflector. These were interpreted as abyssal plain turbidites and pelagic oozes overlying basaltic basement.

Figure 14 shows the on-site profile, and Table 7 presents the correlations proposed. Reflectors 1, 2, and 3 occur within the 480-meter thick turbidite sequence of Unit 1. Throughout this unit layers of nanno ooze several centimeters (average 8.5 cm) thick occur. These are generally more highly lithified than the turbidite intervals, and it may be that phase correlation of reflections from several of these are responsible for the recorded signals while interference obscures reflections from the physical property breaks. Reflector 3 is associated with an increase in frequency of occurrence of these beds.

Reflector 4 clearly marks the top of Unit 3–lithified tan nanno chalks. There is also a marked sonic velocity increase

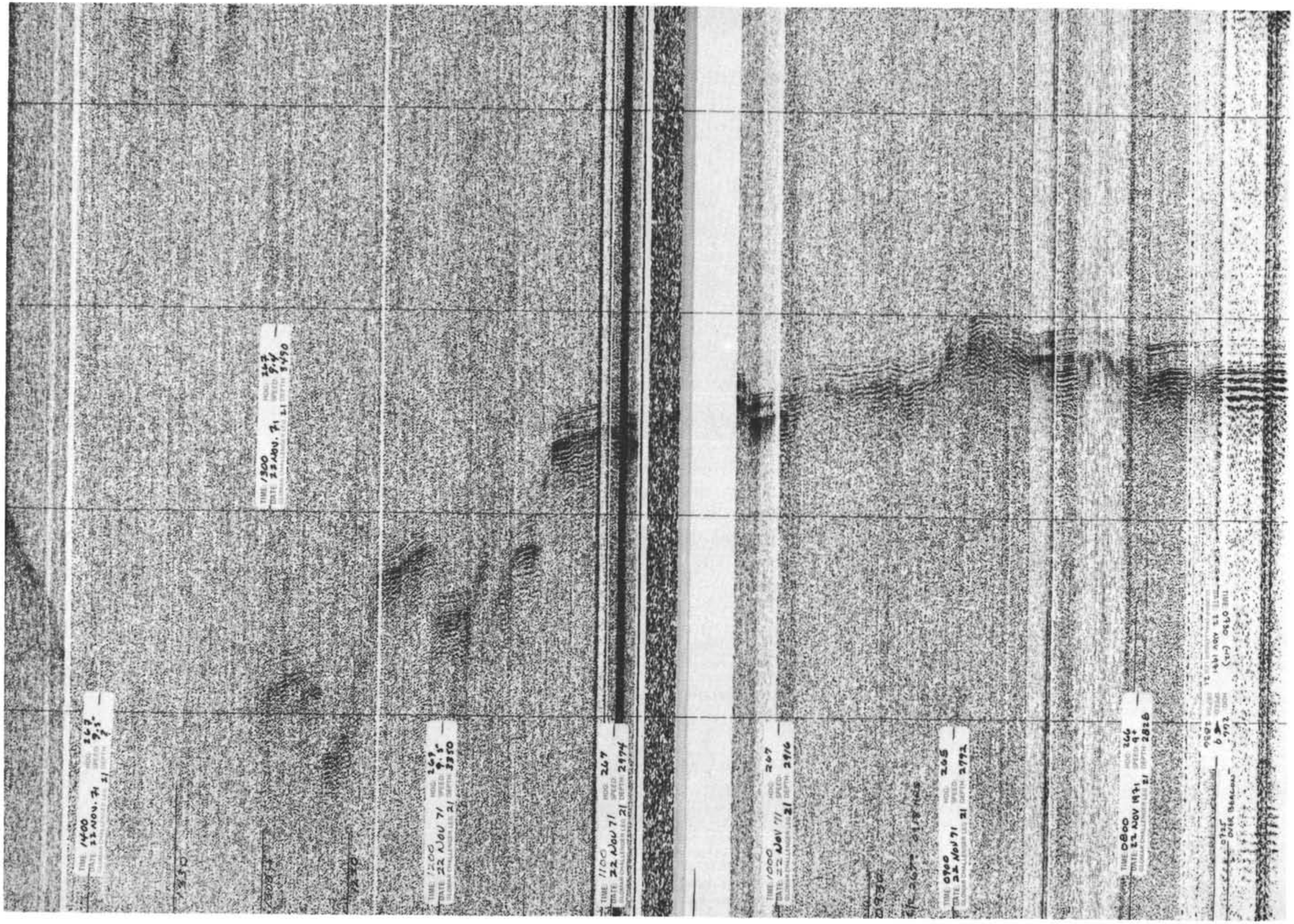


Figure 1. *Profile to Tonga Trench from 204 (GC).*

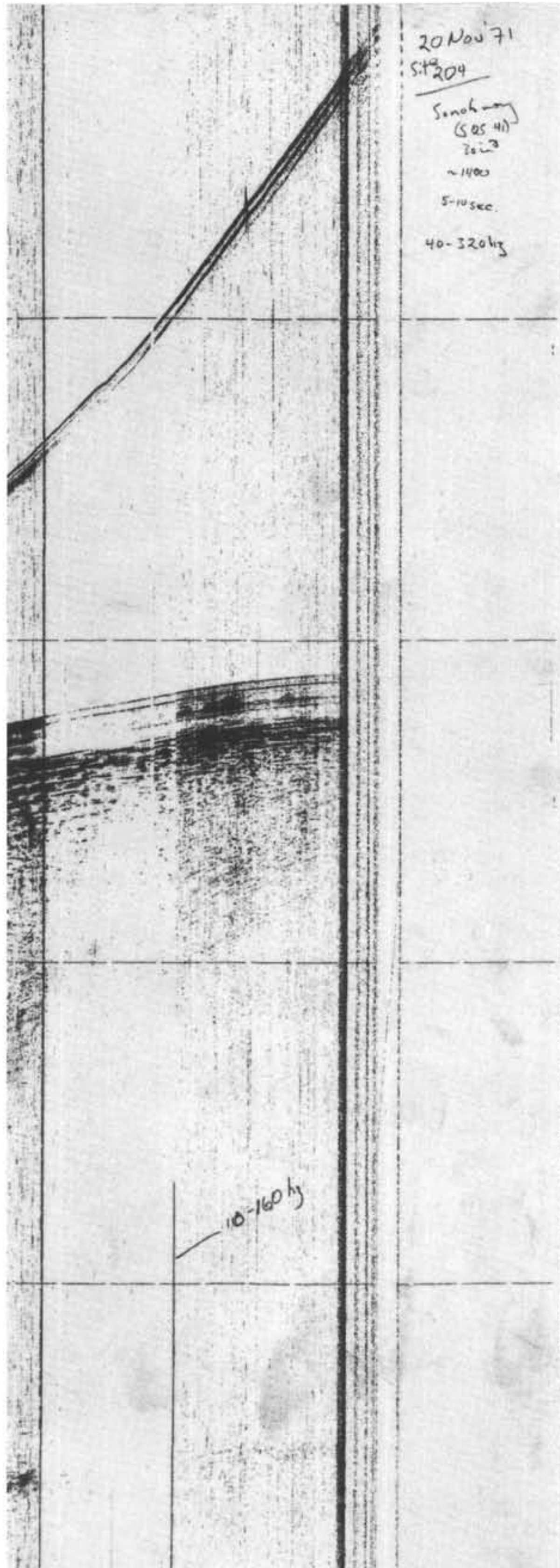


Figure 2. *204 Sonobuoy.*

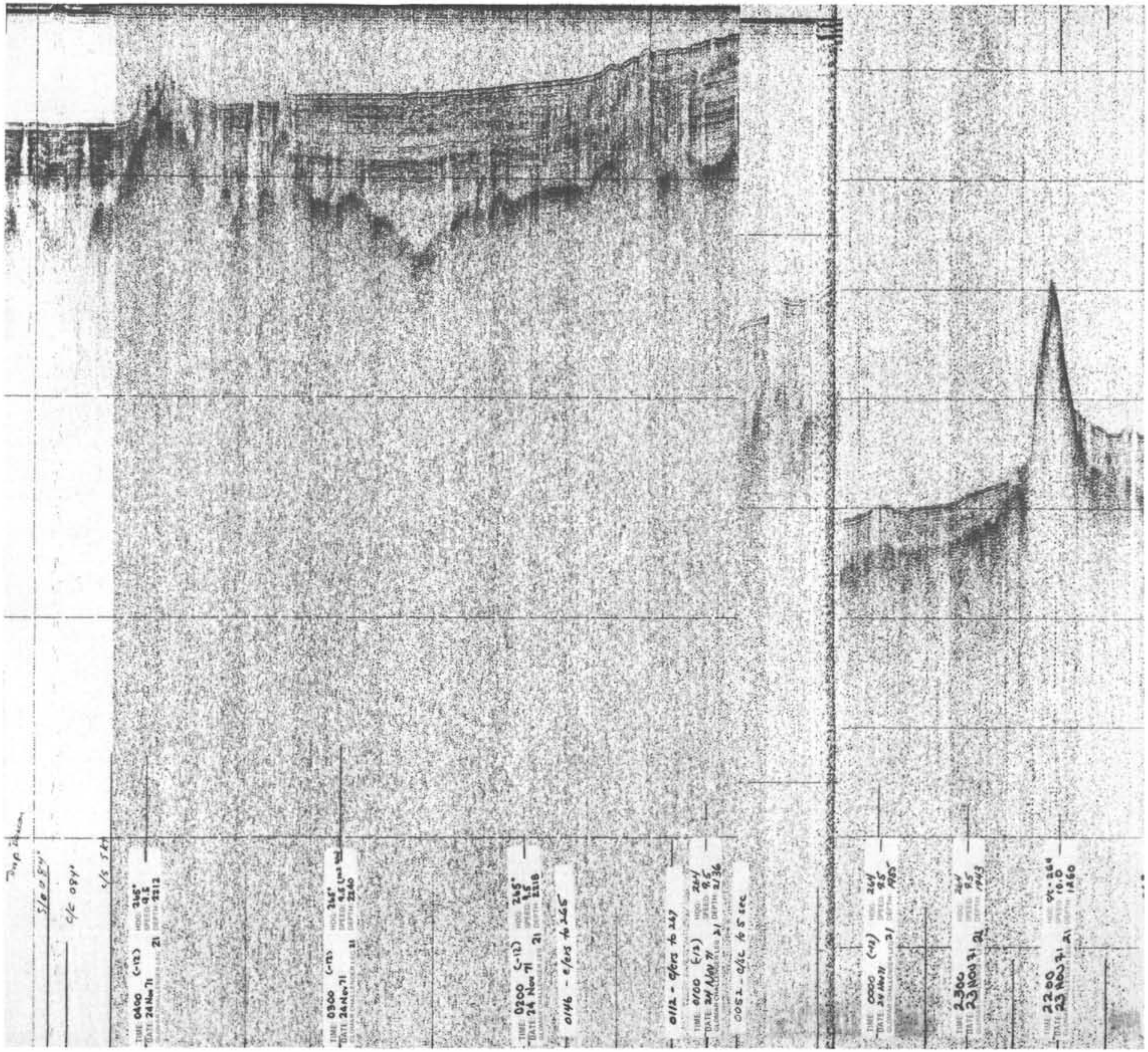


Figure 3. *Profile to 205 (GC) South Fiji Basin.*

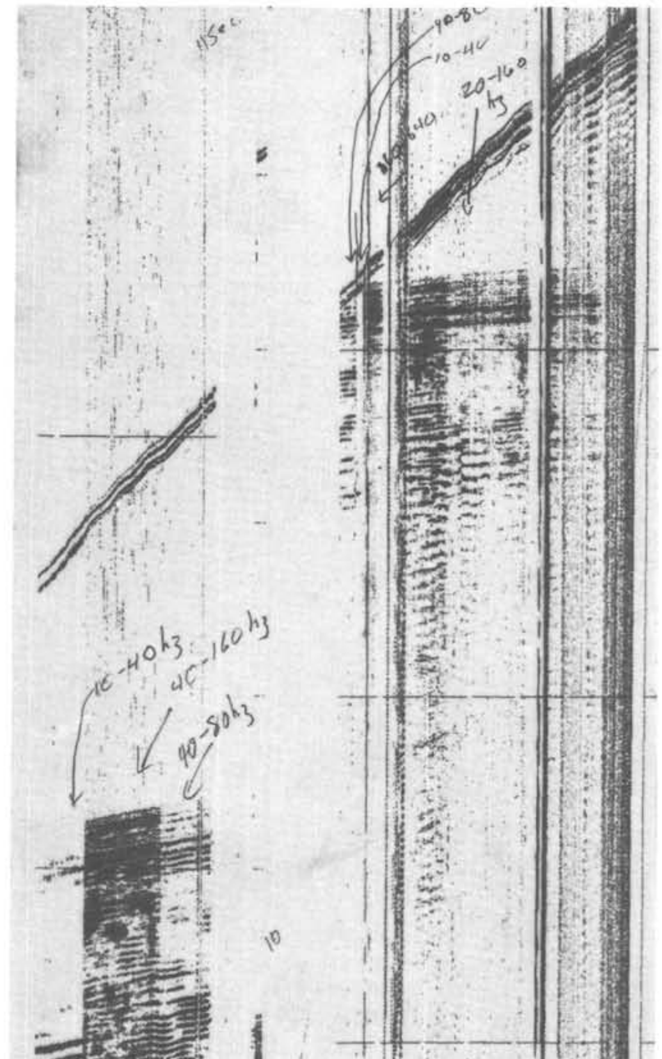


Figure 4. *205 Sonobuoy.*

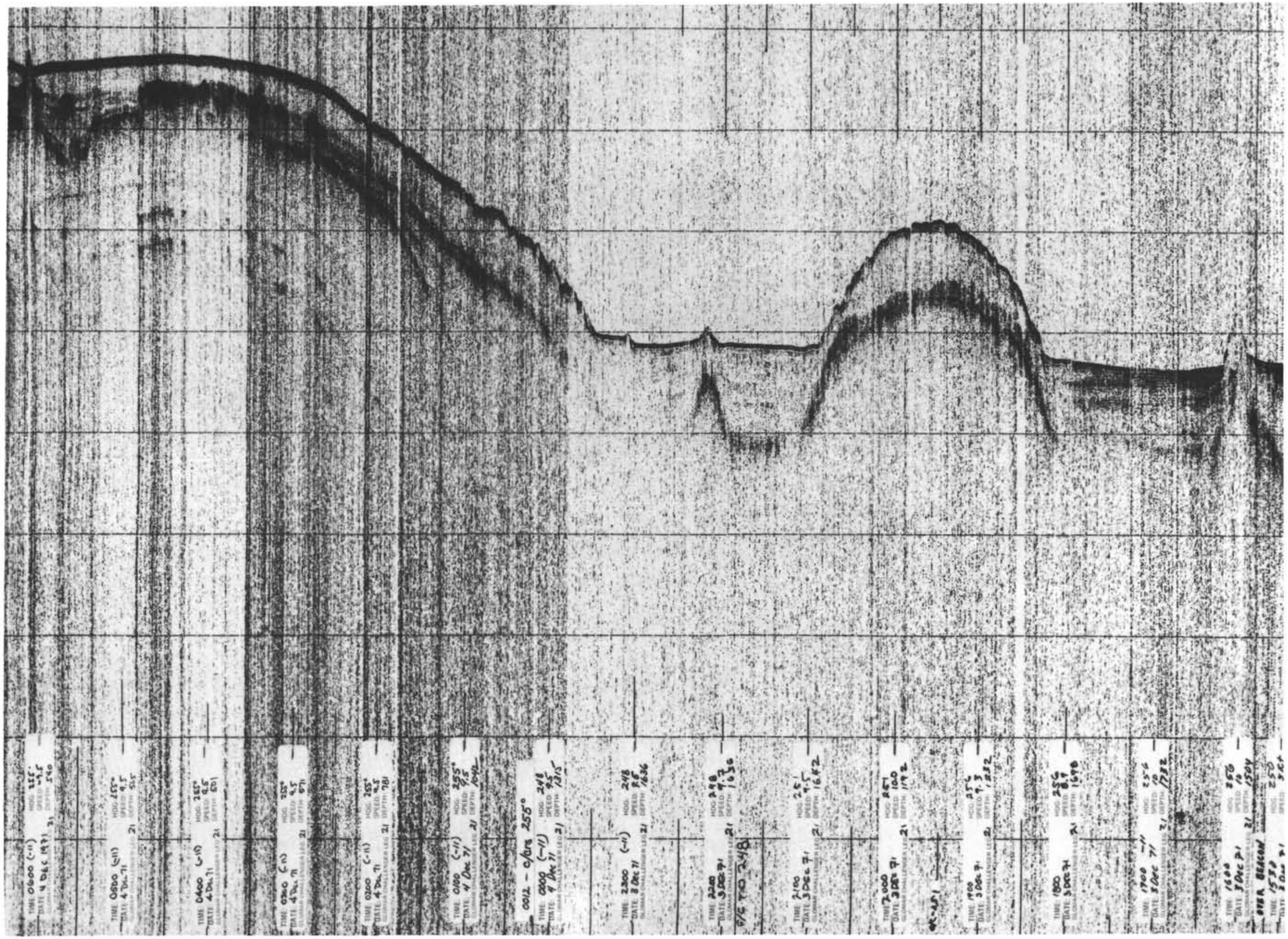


Figure 5. *Profile to 206 (GC) New Caledonia Basin.*

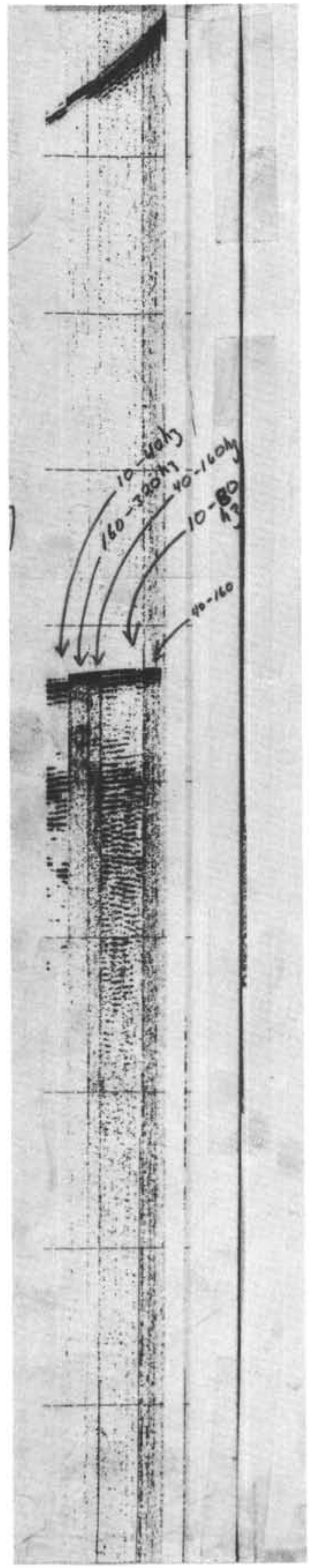


Figure 6. *206 Sonobuoy.*

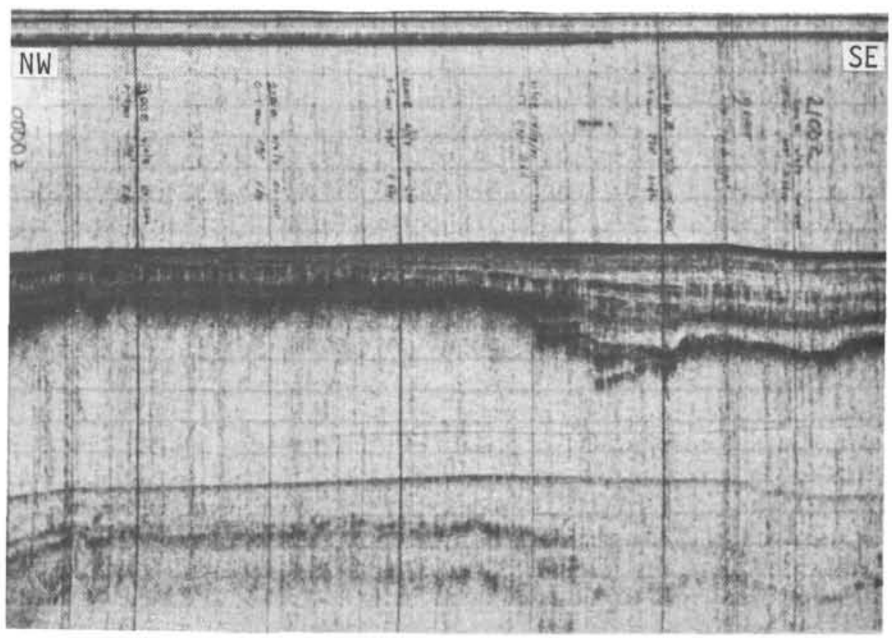


Figure 7. *Approach to 207-Site Survey–Southern Lord Howe Rise.*

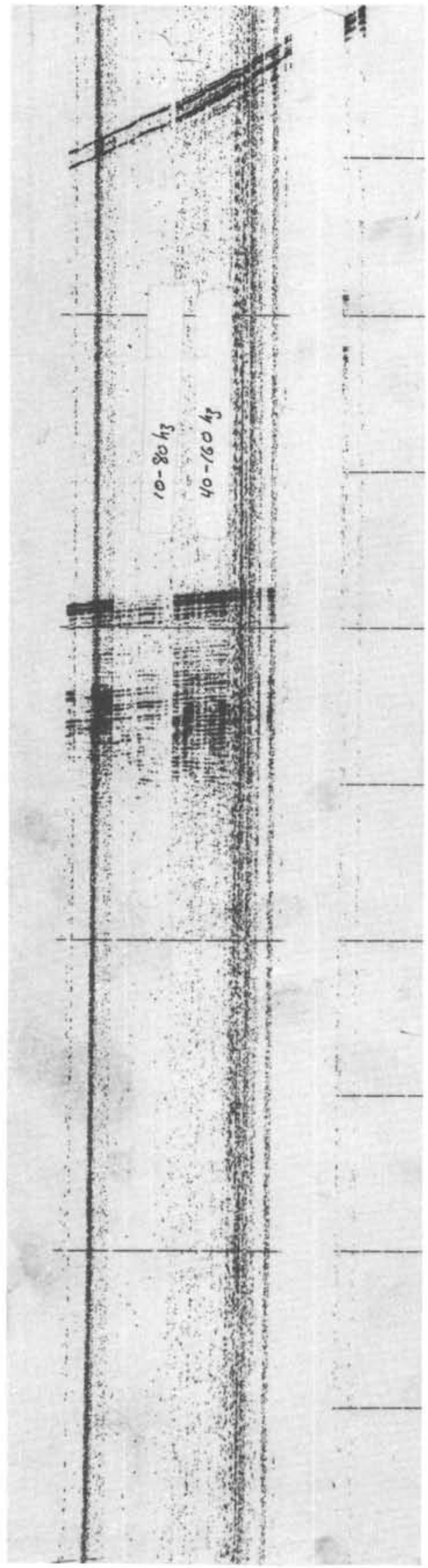


Figure 8. *207 Sonobuoy.*

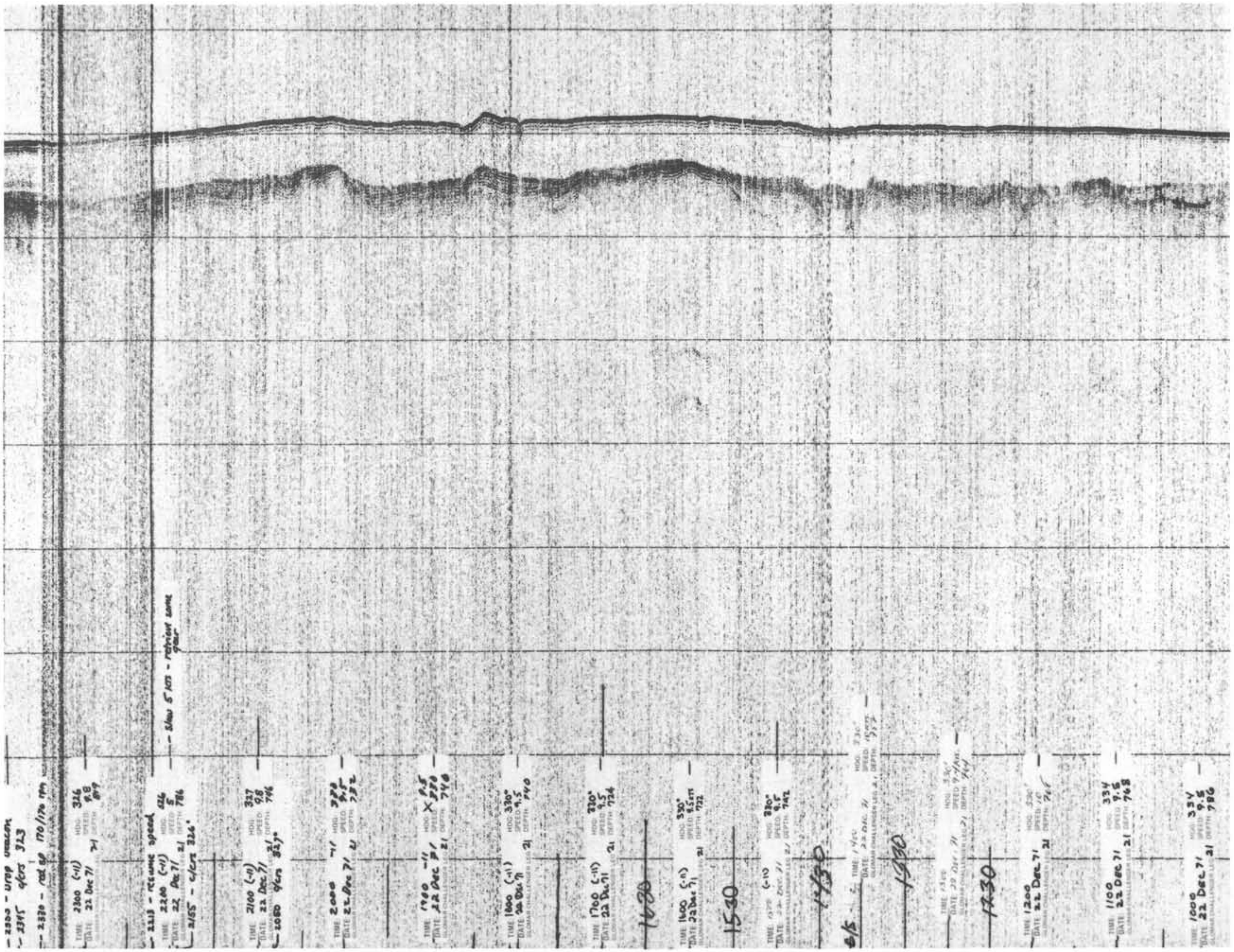


Figure 9. *Approach to 208 (GC) Northern Lord Howe Rise.*

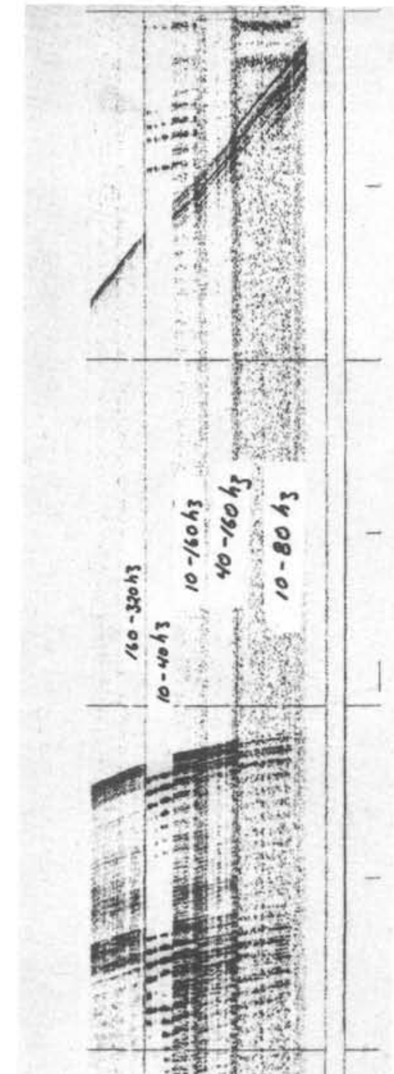


Figure 10. *208 Sonobuoy.*

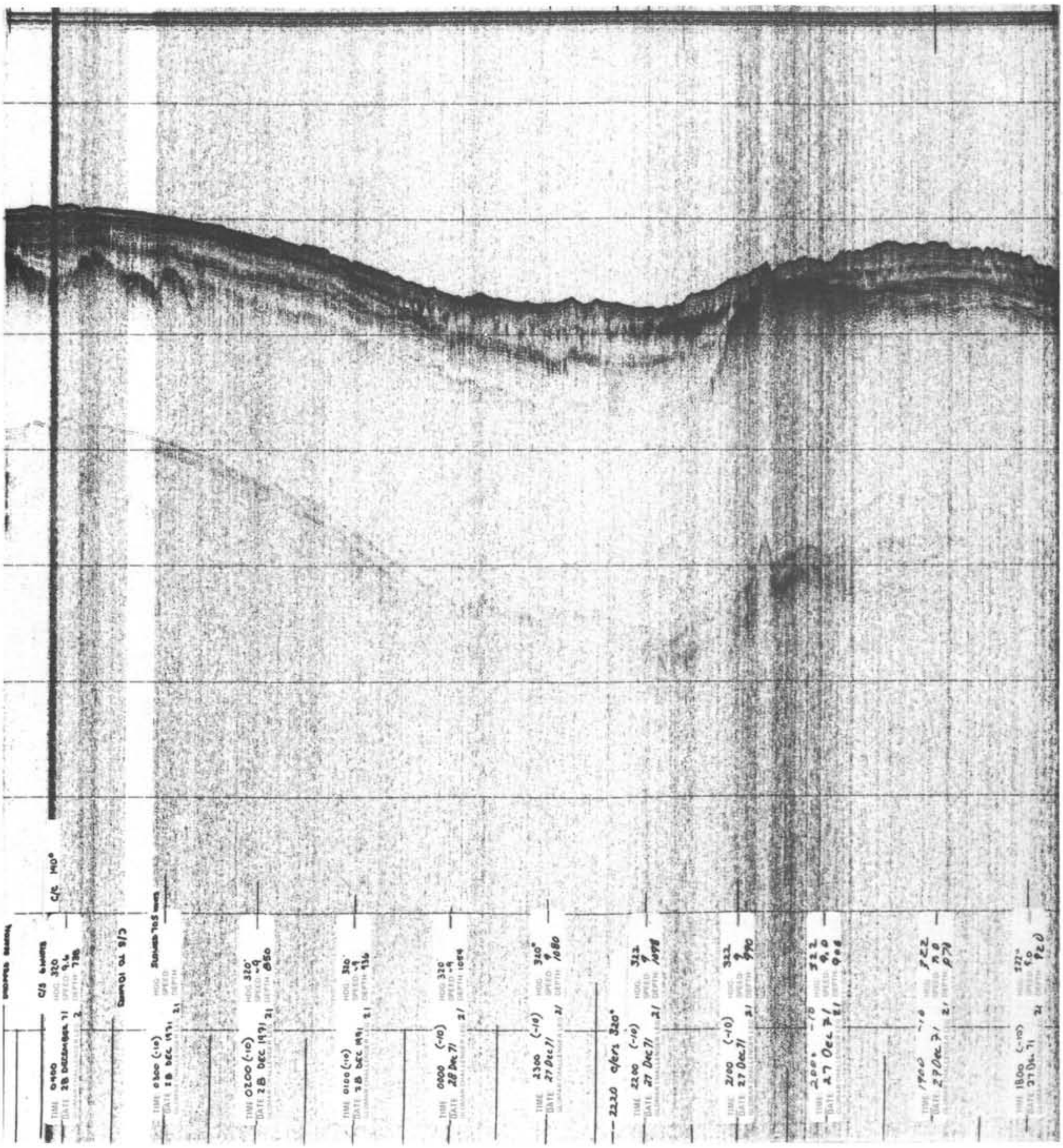


Figure 11. *Approach to 209 (GC) Queensland Plateau.*

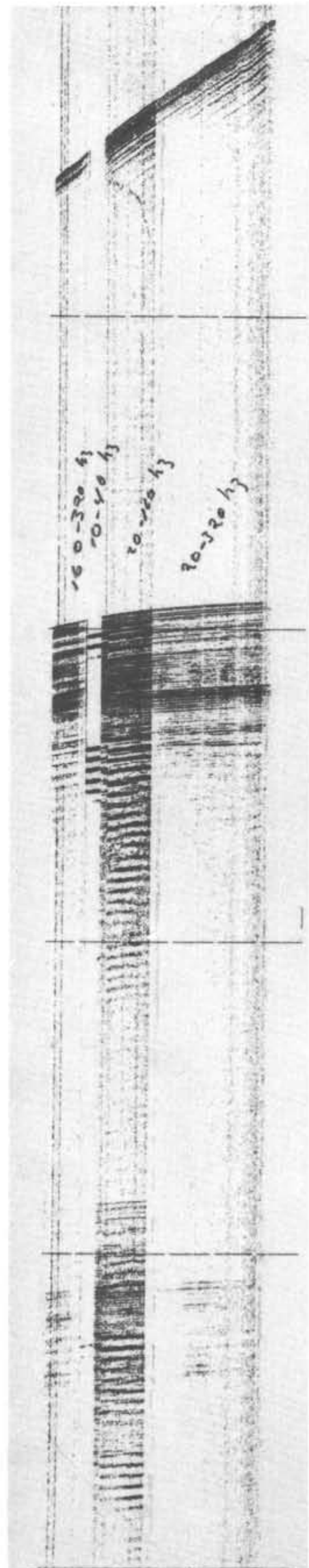


Figure 12. *209 Sonobuoy.*

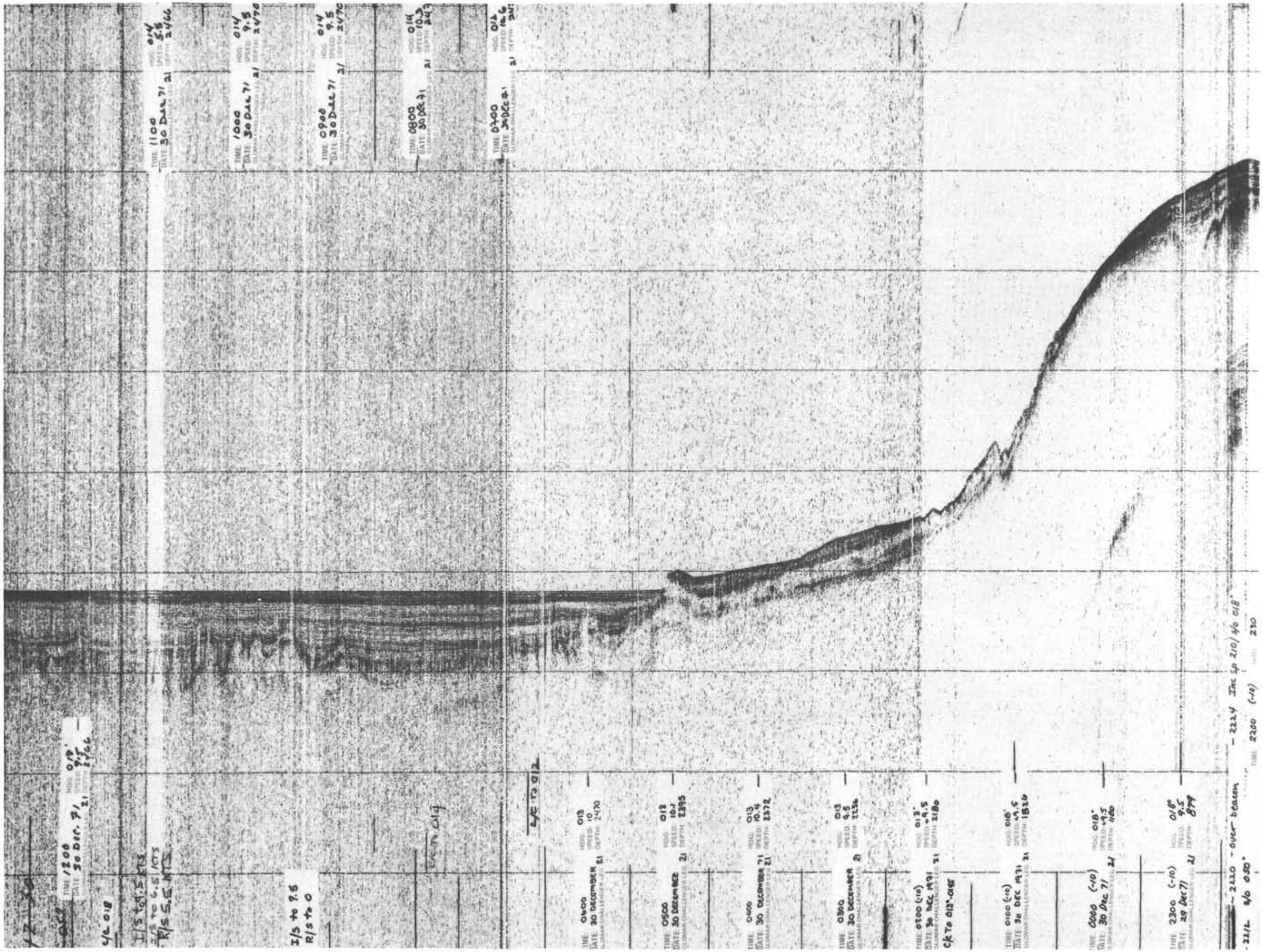


Figure 13. *Profile from 209 to 210 (GC) Coral Sea Abyssal Plain.*

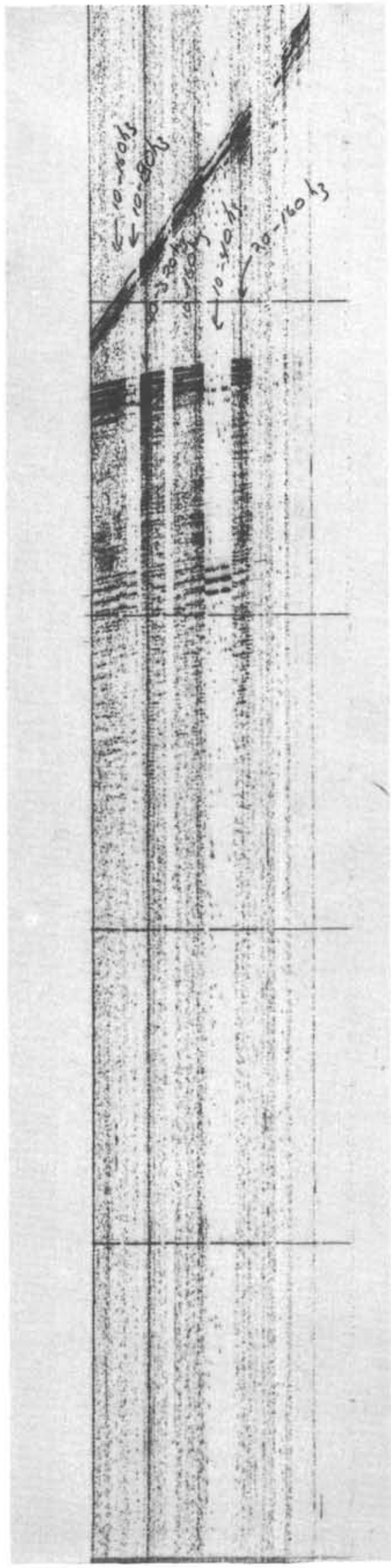


Figure 14. *210 Sonobuoy.*

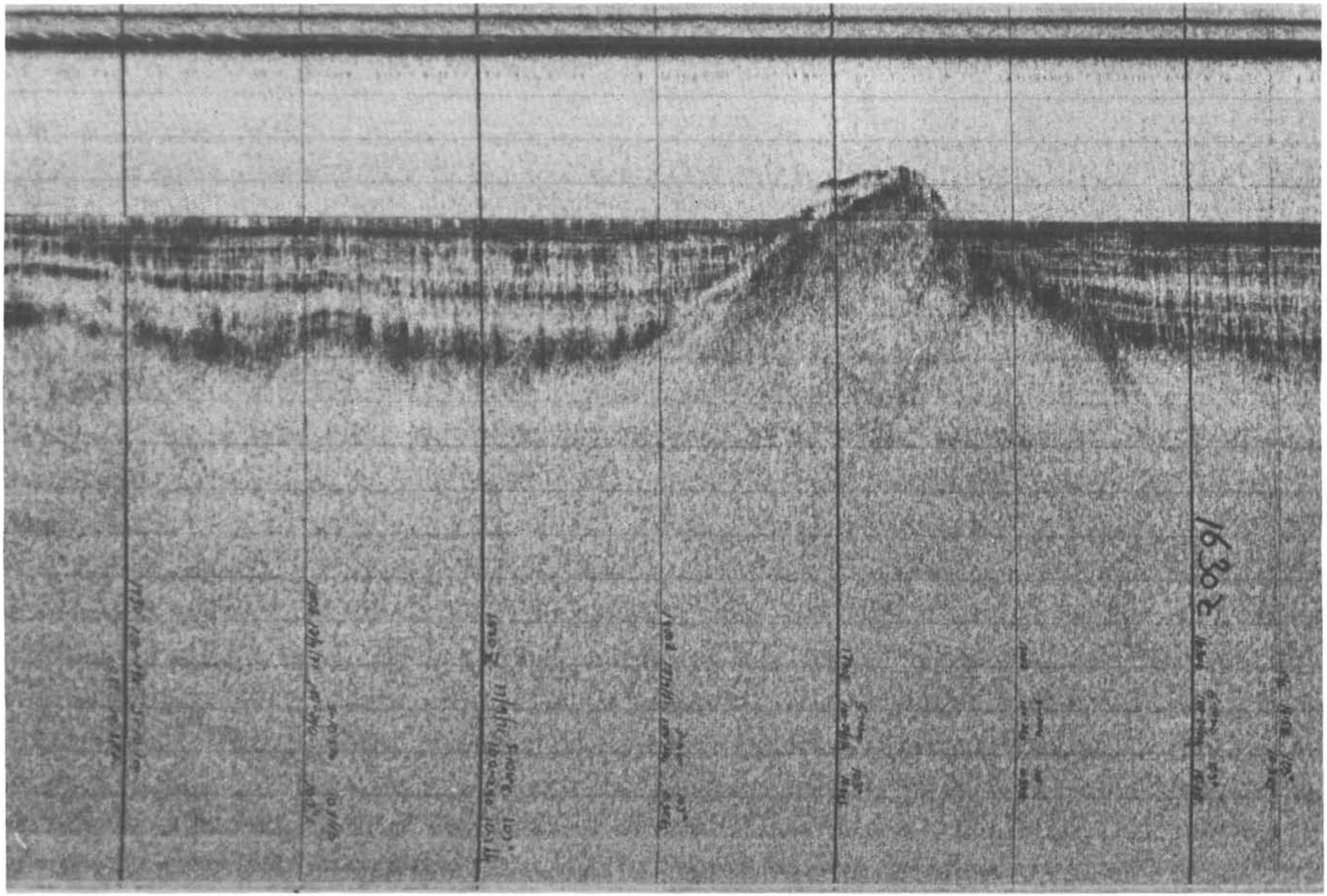


Figure 15. *Kana Keoki profile over structure near 210. Coral Sea Abyssal Plain.*

into this unit (1974 to 2559 m/sec). This reflector appears in underway records as acoustic basement except at very low speeds when Reflector 5 is present. These two reflectors are the rough surface thought to be basalt, but are obviously within the sediment section. The roughness of the horizons hints at earlier tectonic influences on an existing basin floor. The clays of Unit 2 are not apparent in the seismic records. The regional unconformity is present at 540 meters and is not marked by a reflector. Velocity changes at 523 meters (top of Unit 3, Reflector 4) and at 565 meters (no reflector) bracket the unconformity. No distinct acoustic basement is present on the sonobuoy profile.

The distinction of stratified and transparent acoustic horizons is not seen in the cores. Rather, the presence or absence of reflectors appears to be a function of phase relations in the reflected signals, and no major "transparent" or pelagic intervals exist in the section above the rough surfaces.

On an uplifted section to the east of the site, the seismic profile shows the lower rough transparent section uplifted with the basin fill ponded against it (Figure 15). This area is a very good candidate for future drilling to establish the age and early history of the Coral Sea Basin.

CONCLUSIONS

The nearly continuous coring carried out on Leg 21 has demonstrated a wide variation in the degree of correlation possible between acoustic reflectors and stratigraphic and/or physical changes in the sediments. Major changes in acoustic impedance, at times marking major unconformities in the sedimentary sequence, may not appear on seismic profiles due to interval spacing and interference. In other cases it is possible to establish regional interpretation on the basis of reflectors which do represent erosional surfaces and lithostratigraphic boundaries. Except where unconformities are present, biostratigraphic horizons are not usefully defined. Time transgressive lithostratigraphies are the most usefully defined horizons. These problems must be accepted in all geologic interpretations of geophysical data.

REFERENCES

Woods, J. P., 1956. The composition of reflections: Geophysics, vol. XXI, p. 261-277.