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Geophysical Observations between Hawaii and Australia[1]

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ABSTRACT: A 3.5 kHz high resolution profiling system and a sparker seismic system were utilized along a geophysical traverse from Hawaii to Australia. The delineated sediments range from a total lack of sediment cover on the axis of Woodlark Basin spreading center to a thick pile of biogenic debris beneath the equatorial high productivity zone. The calcareous oozes of the western Darwin Rise and Solomon Rise, the interbedded clays, silts, and volcanic debris of the Hawaiian Arch, and local sediment pockets near topographic highs are discerned by the 3.5 kHz energy source as stratified. The nonfossiliferous deep-sea lutites (red clays) and siliceous oozes in the deeper portion of the central Pacific appear as acoustically transparent sediments. Erosion and redeposition of sediments either in the recent past or at the present time are apparent on the Hawaiian Arch, near the Line Islands, in the central Pacific from 160° to 175° E, between the 2,300 and 2,400 m isobath on the Solomon Rise and along the 4,000 m isobath in the Coral Sea.

INTRODUCTION

During the summer of 1971, USNS *Bartlett* traversed the Pacific between Hawaii and Darwin en route to the Indian Ocean. Normally data from a single transit line do not warrant presentation to the scientific community. In this instance, however, the outstanding 3.5 kHz echograms and seismic reflection data raise many questions about processes occurring on the Pacific sea floor.

The 3.5 kHz echogram data were recorded, utilizing a hull-mounted EDO transducer, an ORE 5-kilowatt transceiver, and a Raytheon PSR recorder. Low frequency seismic reflection data were obtained with a 33,000 kilojoule sparker, a 100-element hydrophone streamer, and precision seismic recorders on a 4- and 10-second sweep.

Bottom Circulation

Recently, sea-floor processes of the Pacific have been investigated by Johnson (1972) and Johnson and Johnson (1970). Johnson (1972) found that bottom currents have eroded and redistributed sediments on a massive scale throughout the central equatorial Pacific. These bottom currents reflect the basic pattern of bottom circulation in the Pacific, which has been recently described by Gordon and Gerard (1970). The sole source of bottom currents is Antarctic bottom water, which Warren (1970) described as a western boundary undercurrent south of 20° S flowing northward and constrained by the Tonga-Kermadec Ridge (Fig. 1 insert). From 20° S to 16° N, the flow axis follows the 175° W meridian; thence, at 16° N it divides into two branches, the eastern passing between the Johnston and Christmas Island ridges and the western between the Marshall and Marcus-Necker ridges (Fig. 1). After traversing these passages, the flows turn northward toward the North Pacific Basin (Gordon and Gerard 1970). Edmond et al. (1971), on the basis of recent detailed data, have more accurately located the precise passages. They suggested that bottom flow to the north and east from the central basin is possible only at three locations. The major northwest link is the 200-km passage between the western flank of the Marshall Islands and the mid-Pacific mountains (20° N, 169° E) (Fig. 1 insert). To the east, the barrier of the Line Islands is breached only by the 10-km Horizon Passage at 18°08′ N, 169°11′ W just south of Horizon Guyot, and by the 40-km Clarion Passage at 12°40′ N, 165°40′ W (Fig. 1).

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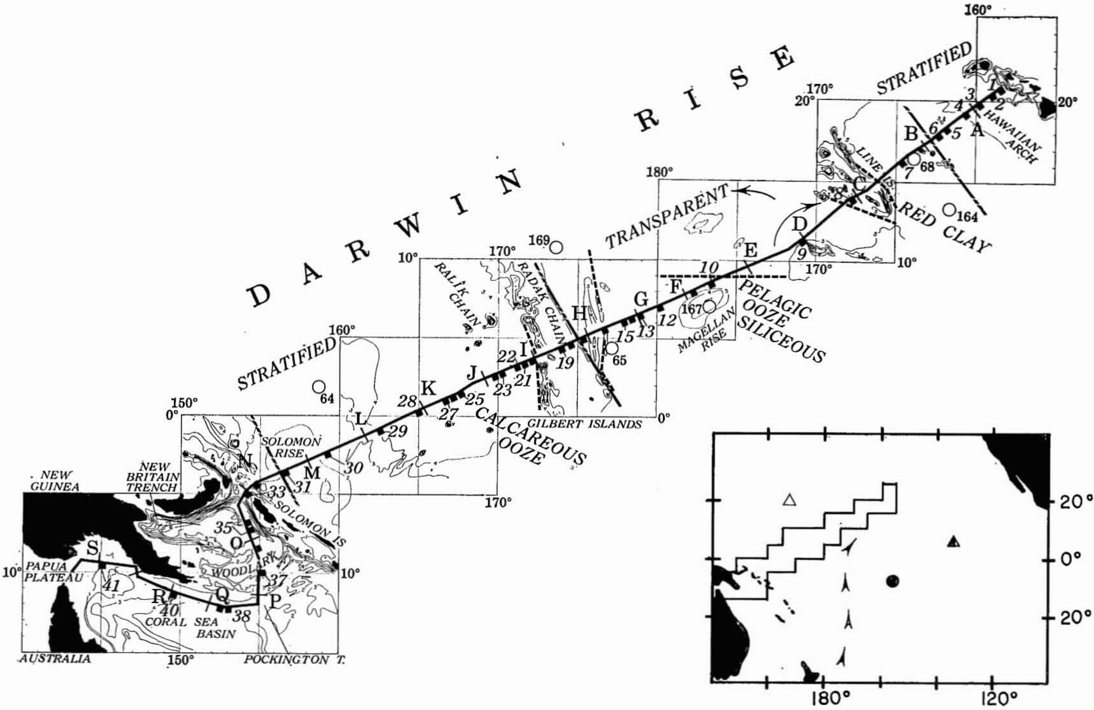

FIG. 1. Index chart of USNS *Bartlett* geophysical traverse from Hawaii to Australia. Sections of 3.5 kHz lines are indexed by a heavy line and numbering; seismic reflection sections are delineated by a cross bar and letter. Sediment types from Horn et al. (1972) are noted as well as are JOIDES drill sites by a black circle. Arrows indicate direction of bottom currents (Gordon and Gerard 1970). Depths in corrected meters from U.S. Naval Oceanographic Office 1969, 1971); Scripps Institution of Oceanography, unpublished preliminary chart of the bathymetry of the southwest Pacific; and other data from the U.S. Naval Oceanographic Office. Subbottom sediment types are noted. Insert chart shows general location. Arrows denote probable bottom circulation; filled triangle site of work by Johnson (1972); filled circle Johnson and Johnson (1970); and open triangle sill predicted by Edmond et al. (1970).

Sediments

The sediments of the equatorial Pacific have been defined by Riedel and Funnell (1964), Menard (1964), and Horn et al. (1972). Land-derived deposits include gray and gray-green silts and clays of the continental margin, along with graded sands and silts laid down by turbidity currents. Seaward dispersal of sediment in the Pacific is greatly restricted by an almost continuous line of barriers (island arcs) and deeps (trenches) at the periphery of the ocean. As a result, terrigenous deposits form a narrow band around the base of the islands and on the floor of some of the smaller basins such as the Coral Sea.

The second type of sediment is the extensive pelagic deposits. They cover three-fourths of the Pacific and include biogenic debris and red clays (brown lutites). The pelagic sediments lie in broad east-west zones that traverse the Pacific and generally coincide with major surface current systems and depths zones. The lutite is extremely uniform both laterally and vertically, with a mean particle size of less than a micron. Manganese micronodules, occasional volcanic ejecta, and fish teeth are associated with the clay. Siliceous oozes composed of radiolarian tests are found to the south of the lutite (Fig. 1). Along the equator is an 800 kilometer wide band of chalk and calcareous ooze composed primarily of the remains of foraminifera. These calcareous deposits extend from Central American to the western limit of the North Pacific Basin.

The last sediment type includes all material derived from submarine topographic highs. It generally takes the form of volcanic or carbon-

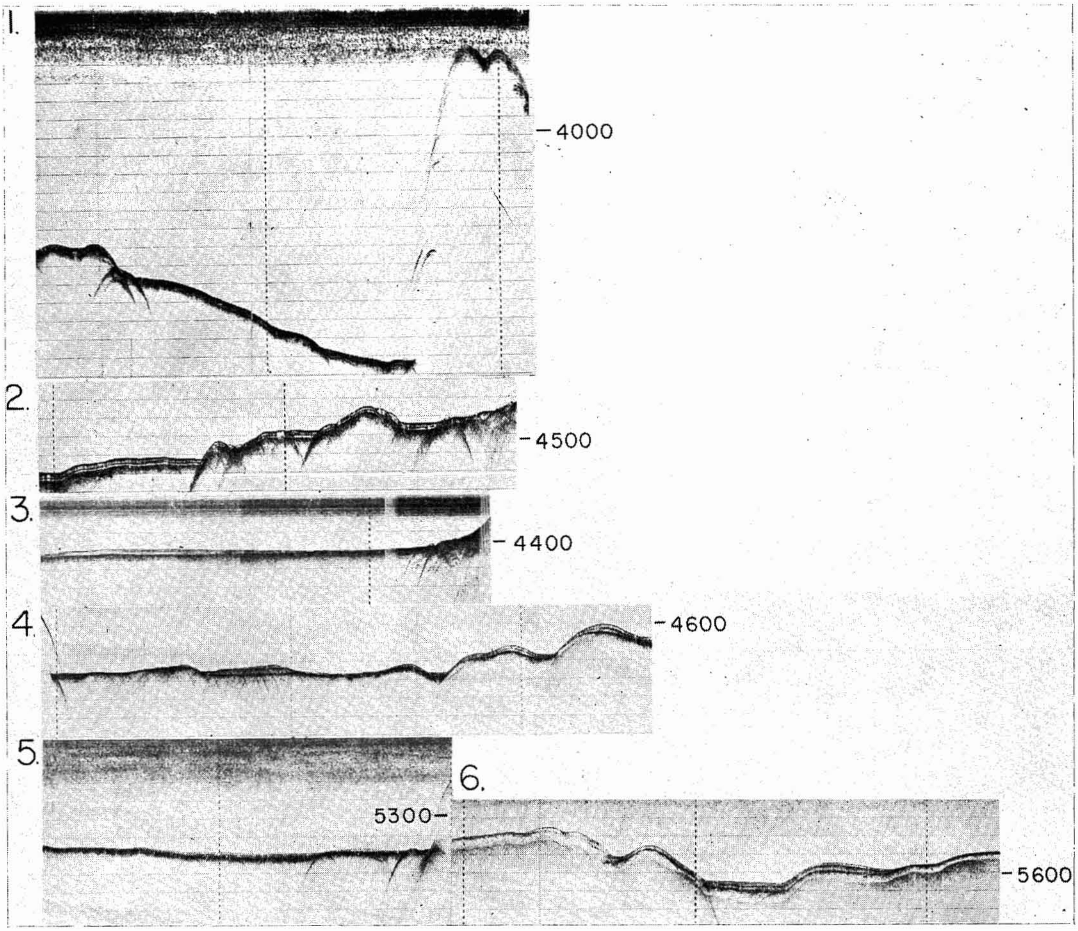

FIG. 2. Photographs of 3.5 kHz records. This is indexed on Fig. 1. Depths in corrected meters (Matthews 1939). Northeast is on right side. For scale, profile 1 is about 18 km long. Horizontal lines are in depth increments of 20 fathoms.

ate debris which has been transported downslope by normal bottom currents, slumping, or turbidity currents.

The initiating depth of dissolution of $CaCO_3$ between 45° N and 45° S in the Pacific is between 3,500 and 3,800 m (Revelle and Fairbridge 1957, Bramlette 1958, and Lisitzin 1970). Carbonate sediments are, therefore, generally confined to areas shoaler than 4,500 m. In deeper regions, the sediments are generally siliceous in low and high latitudes and are increasingly nonbiogeneous in middle latitudes. Quaternary sediments appear to be thickest near the equator, although fossiliferous Quaternary ooze extends over a wide zone between latitudes 14° N and 7° S. Reflection profiling and the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES) drilling program have shown that the equatorial sediment pattern has a north-south asymmetry and that the sediment is thickest a few degrees north of the equator. This effect can be attributed, in part, to a northward component in the motion of the Pacific plate during the Tertiary relative to the biologic equator (Winterer et al. 1969).

DATA

Sections of 3.5 kHz echograms are shown in Figs. 2, 4, 5, 6, 7, 9, and 10, which traverse the Pacific from Hawaii to the Australian continental shelf. The location of the echograms is

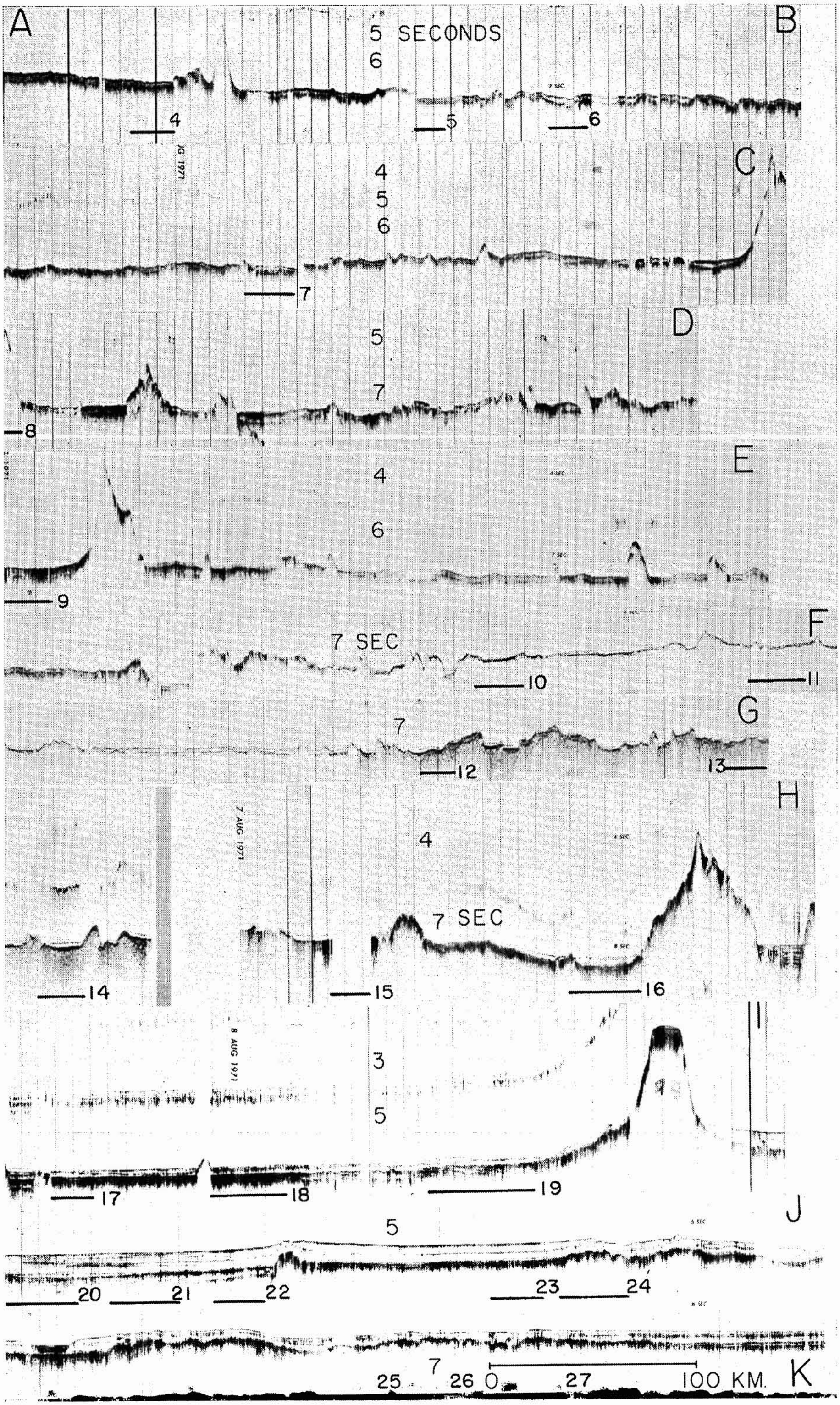

FIG. 3. Seismic reflection profiles obtained by USNS *Bartlett*. Echogram photographs are indexed along bottom. Northeast is on left side. One second of travel time is equal to approximately 1 kilometer.

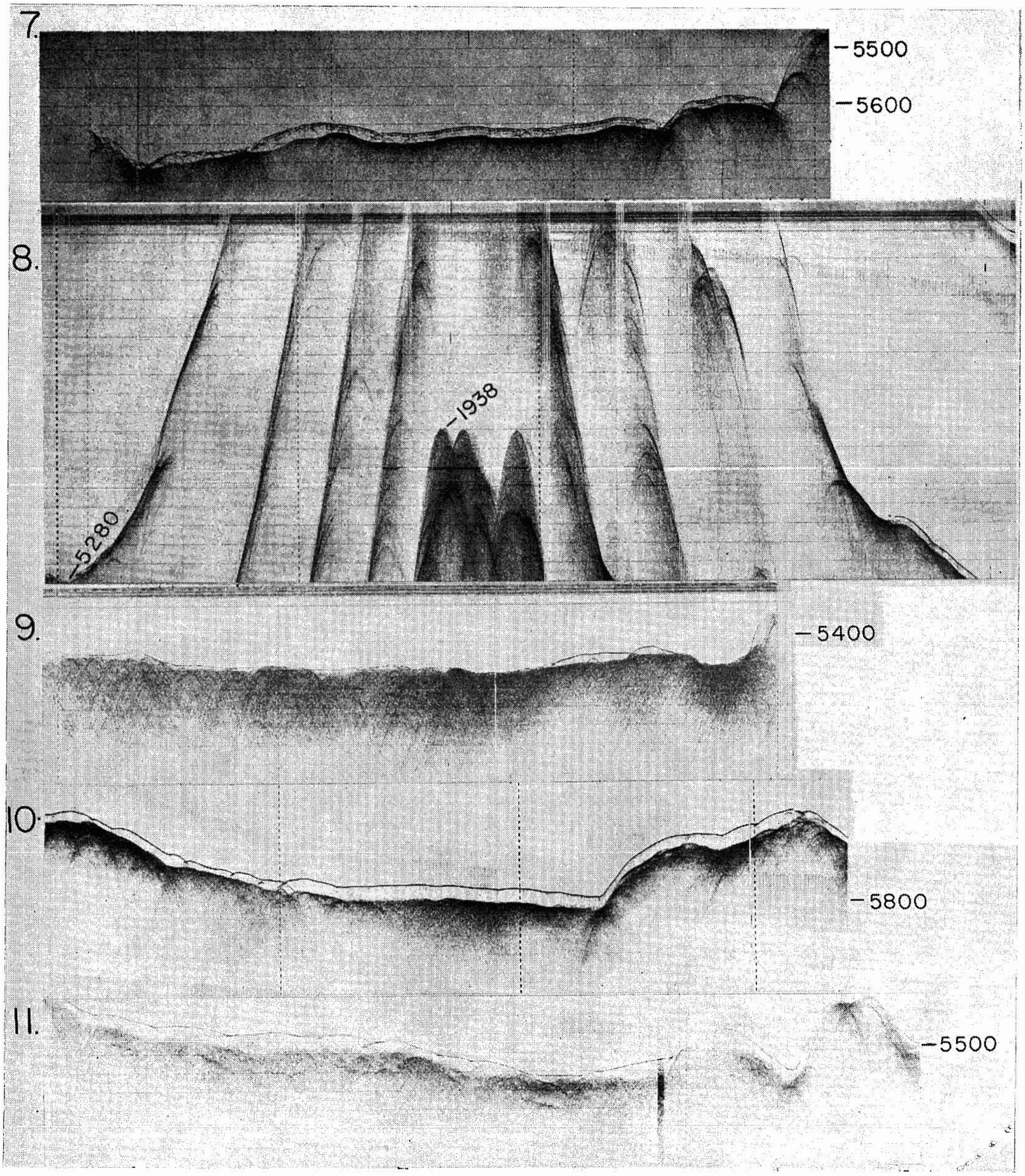

FIG. 4. Photographs of 3.5 kHz records. This is indexed on Fig. 1. Depths in corrected meters (Matthews 1939). Northeast is on right side. For scale, profile 10 is approximately 28 km. Horizontal lines are in depth increments of 20 fathoms.

indicated on the corresponding seismic reflection records (Figs. 3 and 8), as well as on Figure 1.

Hawaiian Moat and Arch

Figure 2, profile 1, extends across the bottom of the Lanai Deep southwest of Oahu (Malahoff and Woollard 1968); which, with associated deeps, forms the southern portion of the Hawaiian Moat (Menard 1964). The sea floor presents an opaque, highly reflective surface to the 3.5 kHz energy source. Cores from the Hawaiian Moat show a significant percentage of relatively coarse material emplaced by gravity

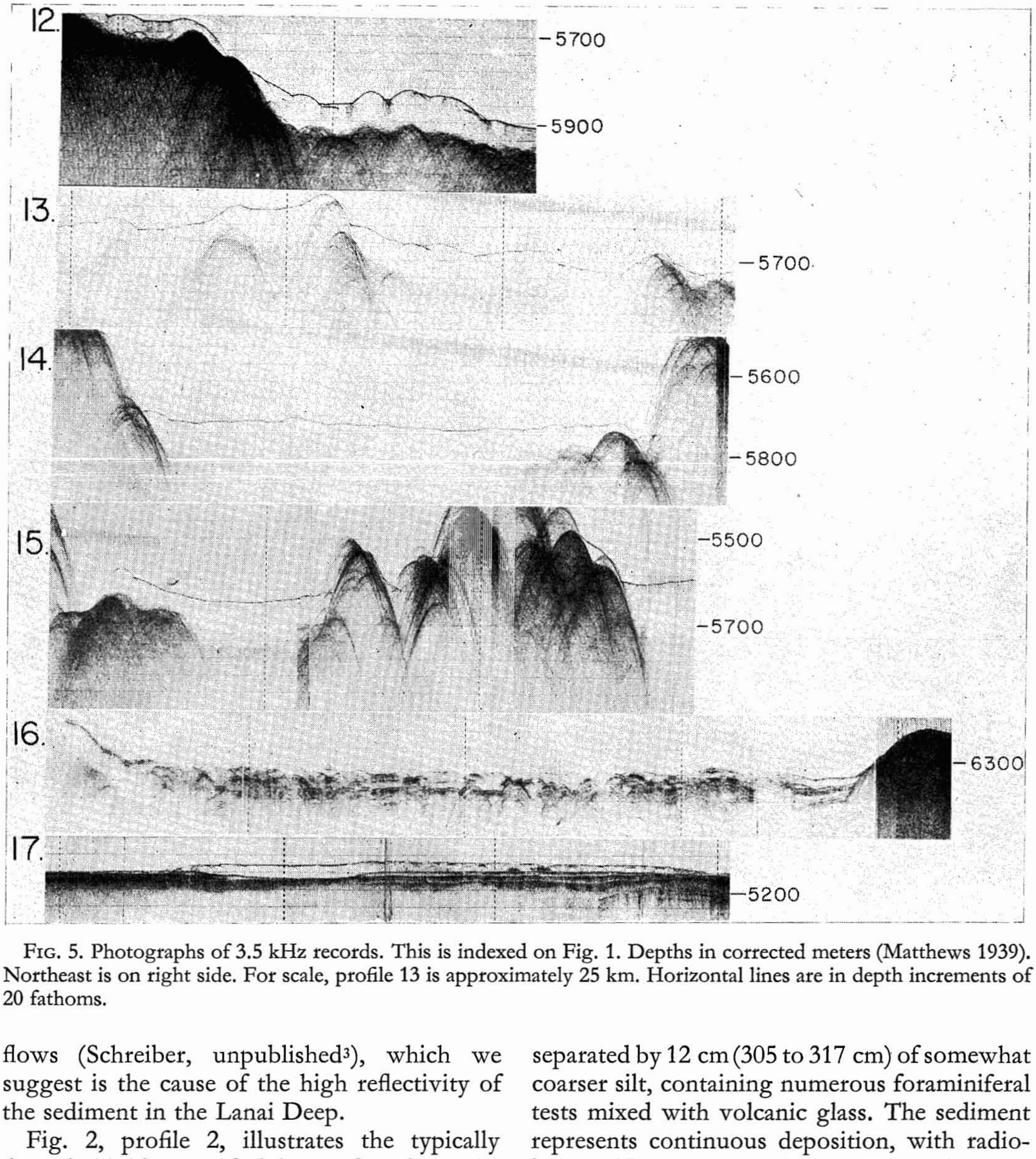

FIG. 5. Photographs of 3.5 kHz records. This is indexed on Fig. 1. Depths in corrected meters (Matthews 1939). Northeast is on right side. For scale, profile 13 is approximately 25 km. Horizontal lines are in depth increments of 20 fathoms.

flows (Schreiber, unpublished[3]), which we suggest is the cause of the high reflectivity of the sediment in the Lanai Deep.

Fig. 2, profile 2, illustrates the typically draped, highly stratified layers found on the Hawaiian Arch (Fig. 1). Schreiber (unpublished[3]) has reported on one core (BA 5-7-2) taken in 4,579 meters at 20°22′ N, 159°58′ W on the Hawaiian Arch. The core is made up of two segments of extremely porous clayey-silt, separated by 12 cm (305 to 317 cm) of somewhat coarser silt, containing numerous foraminiferal tests mixed with volcanic glass. The sediment represents continuous deposition, with radiolarian of Recent age at the top and passing into upper Pliocene by 125 to 150 cm, concomitant with a slight textural change. The thin zone (305 to 317 cm) of coarser sediment consists of vesicular, bubbled, and drawn glass fragments, some grains being altered, while others are very fresh in appearance, mixed with coarse Pliocene foraminifera tests. The latter includes 20 to 30 percent benthonic forms of shallow water origin. All of this indicates winnowing and reworking before final deposition. The sedi-

[3] "Core, sound velocimeter, hydrographic, and bottom photographic stations-cores," area V, vol. 8. Unpublished technical report SP-96-V-8 for the Marine Geophysical Survey Program, U.S. Naval Oceanographic Office.

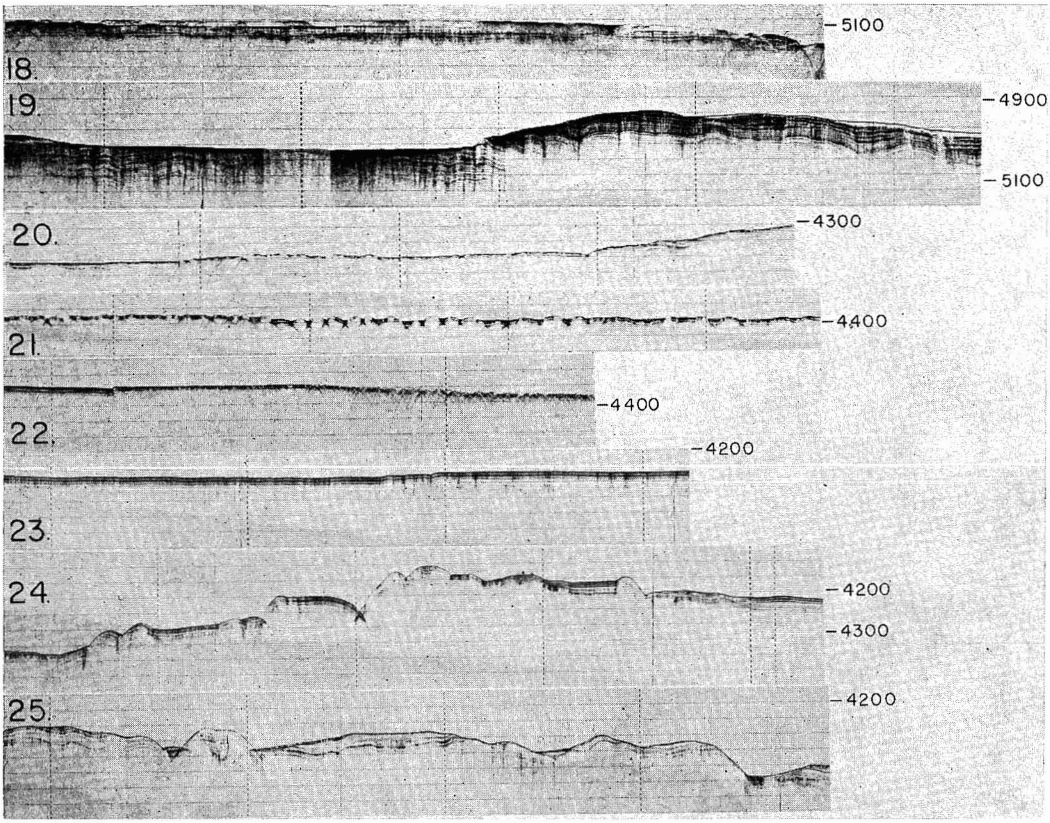

FIG. 6. Photographs of 3.5 kHz records. This is indexed on Fig. 1. Depths in corrected meters (Matthews 1939). Northeast is on right side. For scale, profile 23 is approximately 30 km. Horizontal lines are in depth increments of 20 fathoms.

ments in the lower portion (317 to 600 cm) of the core are slightly coarser than the more recent material but are uniform in texture and composition, containing occasional broken diatoms, foraminifera, and radiolarian tests.

Fig. 2 (profiles 3, 4, and 5) shows evidence of bottom currents either active or relic. In profiles 3 and 5 an opaque reflector crops out from beneath a thin (5 to 10 m) transparent layer that is due either to erosion or to nondeposition of the transparent sediment. Profile 4 traverses a region of hyperbolic patterns indicative of a corrugated sea floor which has been associated by many investigators with submarine dunes created by bottom currents (Fox et al. 1968, Schneider et al. 1967). On the right side of profile 6, Fig. 2, the buried hyperbolae overlie a strong reflector. Where not eroded, the sediment is draped and stratified like that on the Hawaiian Arch (Fig. 1). This phenomenon of erosion and redeposition by bottom currents is widespread in the Pacific. Johnson (1972) in the equatorial Pacific (Fig. 1) found angular unconformities which separated a thin upper layer of Holocene sediment from a chalk bed of Tertiary age. He interpreted the unconformity as a Pleistocene erosion surface which truncates sediments ranging in age from late Eocene to middle Miocene. Since bottom current measurements in his region of study were less than 10 cm/sec, he noted further that significant erosion probably is not taking place today but was restricted to the glacial stages of the Pleistocene.

Profile A–B, Fig. 3, is the seismic reflection line extending from the Hawaiian Arch westward. As discussed by Ewing et al. (1968), the sediments are thinner in the Pacific than in the

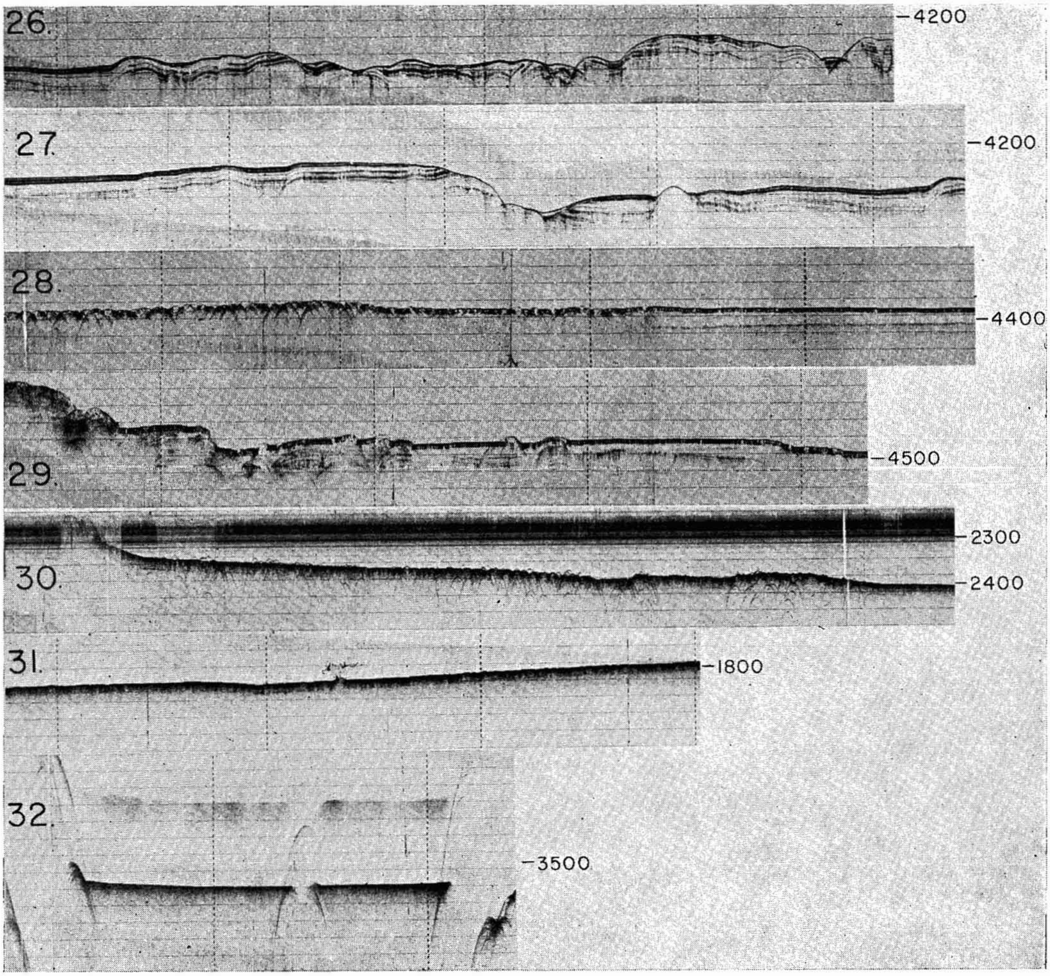

FIG. 7. Photographs of 3.5 kHz records. This is indexed on Fig. 1. Depths in corrected meters (Matthews 1939). Northeast is on right side. For scale, profile 27 is 44 km. Horizontal lines are in depth increments of 20 fathoms.

Atlantic and other oceans. This is primarily due to the ring of topographic barriers around the Pacific, the relative youth of its sea floor, and its size (Hayes and Pitman 1970). In the Pacific, a thin acoustically transparent layer is present. Its thickness ranges from 0.02 to about 1.0 sec (1 second of travel time equals approximately 1 kilometer), with thicker sequences beneath the high productivity equatorial belt. Beneath this layer is a smooth opaque layer which partially or totally obscures the rough basement relief. JOIDES drill site 164 in this region (JOIDES 1971) penetrated the opaque layer. The investigators reported that the stratigraphic column began with an acoustically very transparent layer about 50 m thick, which was very soft in its unsampled upper part and graded downward to Oligocene radiolarian oozes and brown zeolitic clay. The first cherts occurred at 50 m in the lower Oligocene and constitute the opaque reflector. JOIDES site 68 (Tracey et al. 1969) recovered a few centimeters of pelagic ooze containing mixed Quarternary, Miocene, and Eocene radiolarian overlying a middle Eocene brown clay. This certainly suggests reworking of the upper oozes by bottom currents, although the drilling process could also accomplish this. Thin indurated claystone and chert layers started about 9 meters below the sea floor and increased in number and

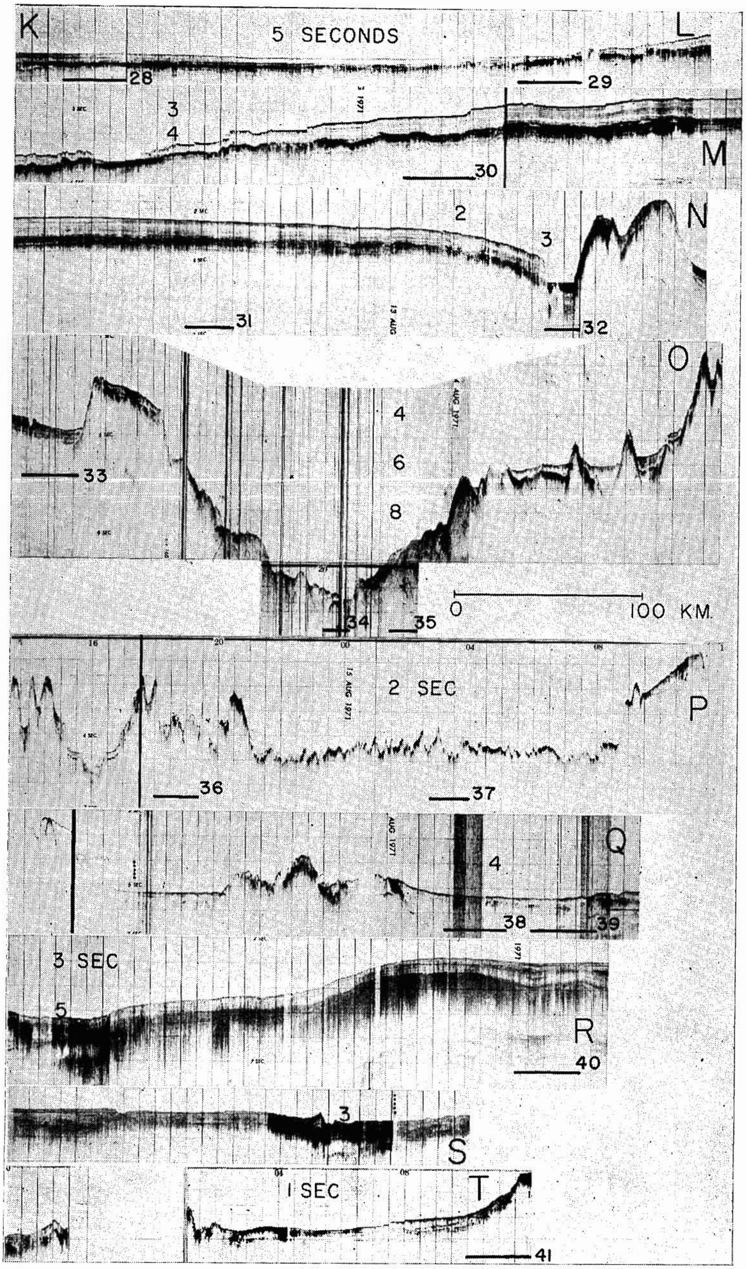

FIG. 8. Seismic reflection profiles obtained by USNS *Bartlett*. Echogram photographs are indexed along bottom. Northeast is on the left side. One second of travel time is equal to approximately 1 kilometer.

thickness below 13 meters. The first reflection layer was estimated to be at 35 to 50 meters. Tracey et al. (1969) further noted that a piston core at the SCAN site (16°25.0′ N, 164°23.5′ W) contained 2.8 meters of light brown clay overlying 6.2 meters of drier, dark brown clay. The core catcher contained stiff, very dry, brown clay, probably representing the reflector observed at 7 meters beneath the sea floor on the 3.5 kHz echogram. Profile A–B generally

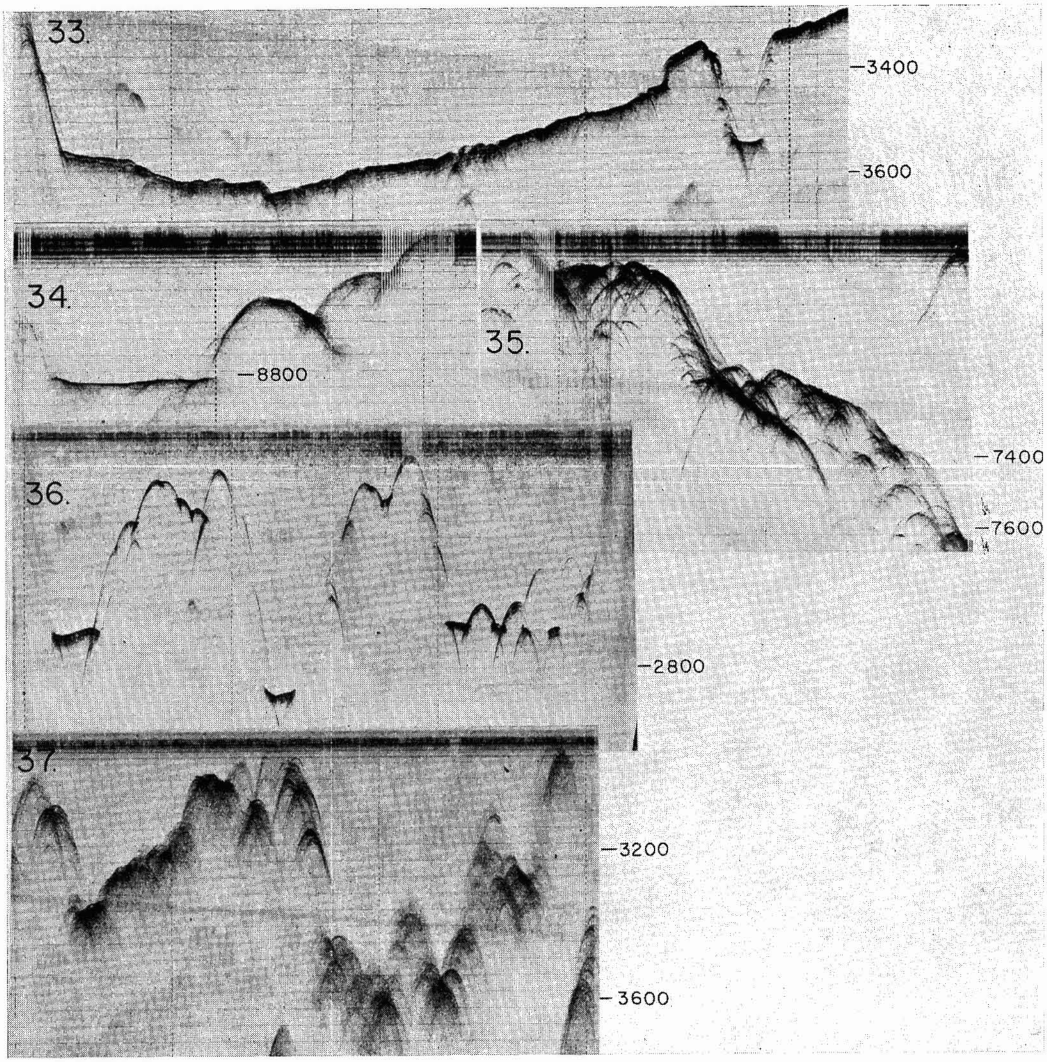

FIG. 9. Photographs of 3.5 kHz records. This is indexed on Fig. 1. Depths in corrected meters (Matthews 1939). Northeast is on right side. For scale, profile 36 is approximately 26 km. Horizontal lines are in depth increments of 20 fathoms.

exhibits less than 100 m of transparent sediment although a few sediment pockets contain up to 300 m. Profile C (Fig. 2) shows hardly any transparent sediments. In both profiles, the seismic energy does not penetrate through the opaque layer to the underlying basement. As noted in the JOIDES data, the opaque layer in this region consists of lower Oligocene–Eocene cherts and claystones. Occasional basement peaks do, however, pierce the sediment cover.

Darwin Rise

The Darwin Rise, as defined and described by Menard (1964), includes the general areas around and between Polynesia and Micronesia. In Fig. 1, it extends from the Line Islands to the Solomon Rise. As noted by Ewing et al. (1968, 1969), the transparent sediments are thin and rest on thick opaque sediments. Some stratification of the opaque layer is evident in

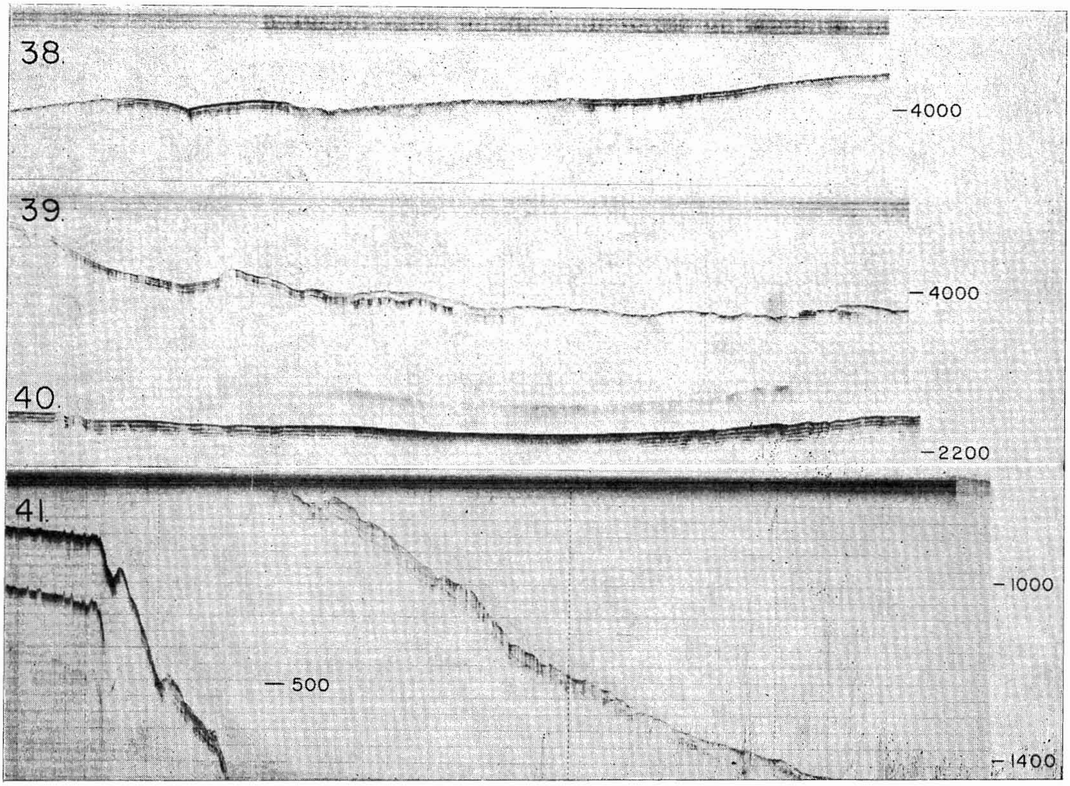

FIG. 10. Photographs of 3.5 kHz records. This is indexed on Fig. 1. Depths in corrected meters (Matthews 1939). Northeast is on right side. For scale, profile 39 is approximately 41 km. Horizontal lines are in depth increments of 20 fathoms.

profiles D–G (Fig. 3). Where crossed by *Bartlett*, the equatorial sediments are 1,500 meters thick at maximum (Fig. 3, profile J). With the exception of the equatorial region, the thickness of the transparent layer generally is less than 100 m and conforms with the isopach chart of Ewing et al. (1968). The sediments are lutites in the deeper regions; thence, as the equatorial high productivity belt (Koblentz-Mishke 1965) is approached, siliceous and calcareous oozes increase with the calcareous fraction increasing with decreasing water depth and predominating on the western portion of the Darwin Rise. As shown by typical examples (Fig. 4, profiles 9–11; and Fig. 5, profiles 12–15), the eastern Darwin Rise region is covered by a transparent layer of sediment up to 100 meters thick (profile 14), which only occasionally shows weak stratification (profile 12). Evidence for erosion near the axis of predicted bottom water flow (Gordon and Gerard 1970) is apparent in the remnant pods of transparent sediments and the hyperbolic character of the underlying opaque layer on Fig. 4, profile 9. Seamount chains (Radak, Line, and Gilbert islands) are common (Fig. 1 and Fig. 4, profile 8) striking north-northwest. Menard (1964) ascribed these to an extinct spreading axis which he named the Darwin Rise. Recent investigators such as Morgan (1972) favor a mantle plume origin, with the seamounts merely reflecting plate motion over the "hot spot."

JOIDES hole 167 on the Magellan Rise recovered a suite of calcareous sediments that ranges from Berriasian to Recent in age (JOIDES 1971). JOIDES site 65 recovered radiolarian ooze ranging from middle Eocene to Recent (Winterer et al. 1969). Below a depth of 127 meters, the ooze layers were interspersed with thin chert and turbidite layers probably associated with the nearby seamounts. Reworked radiolarian oozes were present in all samples younger than middle Eocene, indicating the presence of bottom currents.

Zeolitic clays of Tertiary age were recovered from the upper part of the sedimentary column at JOIDES site 169 (Fig. 1) located north of the *Bartlett* track. These clays overlie a unit comprising 122 m of zeolitic claystone and chert which reflect the composition of the deeper opaque layer. This lower unit ranges in age from Cenomanian or Turonian to at least Maestrichtian (JOIDES 1971).

Larson et al. (1972) studied the magnetic anomalies in the western equatorial Pacific. They interpreted the magnetic lineations to represent one flank of an early Cretaceous spreading center. Larson et al. (1972) predicted two fracture zones, one passing through point G (Fig. 1) and the other intersecting *Bartlett*'s line at 175°40′ E. As seen in profiles G and H (Fig. 3) there is no topographic or crustal evidence for the easternmost fracture zone. The most likely area would be the broad crustal trough 80 km from left edge of profile F, Fig. 3. This lies approximately 280 km east of their fracture zone. A good case can be made for the western fracture zone. At the southwest end of profile H (90 to 120 km from right edge) a deep trough and topographic high form prominent sea floor structures. The sediments on the floor of the deep delineated in profile H, Fig. 5, are highly distorted (profile 16, Fig. 5). It is uncertain if they have been affected by tectonism or bottom currents. The underlying opaque layer at a depth of 400 m does not, however, appear to be disturbed (Fig. 3, profile H). The highly stratified trough at the end of profile H adjacent to the fracture zone morphologically appears to be fault-controlled and its contained sediments show evidence of normal faulting. Coincidentally, the uppermost sediments also change at this point from transparent to the stratified equatorial layers. Locally some stratification may be associated with nearby topographic highs (Fig. 1).

Profiles 17–30 in Figs. 5–7, which cross the equatorial Pacific, strongly suggest sea floor erosion and also changes in either type or mode of transportation. The sea floor is stratified, with only occasional patches of overlying transparent sediment (profiles 17, 18, and 25). The records, especially profile 19, are strikingly similar to those presented by Johnson (1972) from the equatorial Pacific in the vicinity of 7°40′ N, 134°00′ W. He also noted that a characteristic aspect of the sedimentation pattern is its variability over distances of several kilometers or less, which he attributed to bottom currents. The variability is especially striking in profiles 18, 22, and 28. Hyperbola presumably indicative of sea floor dunes are found on the surface (profiles 21, 22, and 30), semiburied (profiles 20, 21, and 28), and completely buried (profiles 7, 18, and 20). This region from 160° to 175° E greatly extends the areal extent of sea floor upon which bottom currents have eroded and redistributed sediments as reported by Johnson (1972).

Solomon Rise and Island Arc

The Solomon Rise (sometimes referred to as the Ontong-Java Plateau) is a broad shallow arch of the sea floor. Seismic reflection records show it to be covered by approximately 900 m of conformable stratified sediment (Fig. 8, profiles L, M, and N) overlying an opaque reflector. JOIDES drill hole 64 (Fig. 1) penetrated an apparently uninterrupted sequence of highly calcareous pelagic sediments ranging in age from late middle Eocene to Recent. The moderately smooth-based seismic reflector was not reached. Winterer et al. (1969) further noted that the many reflectors traceable on the seismic reflection profiles were due mainly to alternation of indurated and less-indurated layers. The lower reaches of the Solomon Rise are apparently swept by bottom currents (profile 30, Fig. 7) between the 2,300 to 2,400 meter isobaths; alternatively slumped sediments from the nearby topographic high may have created the apparent sea floor corrugations. With the exception of the hyperbolae on profile 30, the Rise presents a fairly reflective surface with shallow stratification (20 m) in relation to the 3.5 kHz energy source. The small irregularities on the surface of the Rise seen on profile M (Fig. 8) do not appear to be faults, as only the upper layers are affected. They may represent some form of downslope creep.

Seaward of the Solomons escarpment, a small foredeep is present (Rose et al. 1968). This is seen in profile N (Fig. 8) as a grabenlike structure with over 1.5 kilometers of sediment, which appears to be faulted. The 3.5 kHz profile (Fig. 7, profile 32) consists of an opaque reflective bottom, which is assumed to be caused by a high percentage of coarse terrigenous material emplaced by various forms of gravity flows from the Solomon Island chain. Fig. 9, profile 33, crosses one submarine canyon 200 meters deep.

To the landward of the Solomon Islands is the New Britain Trench, with depths in excess of 8,800 m (Fig. 8, profile 0; and Fig. 9, profile 34). The trench has only 200 to 300 meters of sediment fill, and the walls show no discernible sedimentary cover, although profiles 34 and 35 (Fig. 9) do show some smoothing. The trench is, therefore, a geologically recent feature.

Woodlark Basin

The Woodlark Basin contains a small spreading ridge (Luyendyk et al. 1973). Profile P (Fig. 8) shows the traverse across the rough mid-ocean ridge terrain with no sediment cover in the youthful crestal region and gradually increasing sediment fill in the deeps with distance away from the axis. This can be seen in profile 36 approximately 140 km from the axis, in which intermontane valleys are filled with reflective sediment. By comparison, profile 37 in the axis of the spreading center is devoid of any sediment cover.

Coral Sea

Profiles 38 and 39 (Fig. 10) suggest that bottom circulation with sufficient force to redistribute sediments may be occurring at the 4,000 m isobath in the Coral Sea, or may have occurred in the geologically recent past. Both profiles have patches of stratified sediments interspersed with a corrugated seabed as indicated by the hyperbolic patterned sea floor which overlies the stratified sediments. Sediment fill exceeds 1.5 kilometers where *Bartlett* traversed the Coral Sea (Fig. 8, profiles Q and R). Profile R approaching New Guinea reveals about 500 m of highly stratified sediment overlying an opaque reflector which is at least 1 km thick. The topographic high at the western end appears to be related to a shoaling deeper layer. Canyons are present as expected along the line as it approaches New Guinea. The opaque sediment in the central part of profile 40 (Fig. 10) probably is the result of local drainage by gravity flows through a broad gentle channel. The normal continental rise sediments are highly stratified in this region.

Australian Continental Margin

The continental shelf terminates abruptly at the 155 m isobath (Fig. 10, profile 41). The shelf is not smooth but rather has many small elevations, which may be drowned coral reefs or erosional terraces. The continental slope is steep and shows evidence of downslope slumping, as does the adjacent continental rise.

CONCLUSIONS

The following statements can be made from these data:

1. Bottom currents are now or have in the recent past sculpted large areas of the central Pacific, stripping off the Recent sediments and leaving bare Tertiary sedimentary horizons. As noted by Johnson (1972), the most intensive current activity probably occurred in the Pleistocene. Only in the vicinity of the Line Islands (Fig. 4, profile 9) does there seem to be a possibility that present bottom currents can exceed the ± 20 cm/sec necessary to start sediment redistribution (Kuenen 1950). The conclusion by Johnson (1972) that the thin upper layer of Holocene sediments represents a Pleistocene erosion surface of Tertiary sediments is fully supported by our data. Our data extend this region from 160° to 175° E.
2. Evidence of active or recently active bottom currents is present for the Hawaiian Arch, Solomon Rise between the 2,300 and 2,400 m isobaths, and at approximately the 4,000 m isobath in the Coral Sea.
3. The interbedded pelagic oozes and volcanic debris of the Hawaiian Arch and the calcareous oozes of the equatorial belt are highly

stratified. The unfossiliferous lutites and siliceous oozes tend not to show stratification.

4. The spreading center of the Wooklark Basin is devoid of sediment in the axial region, indicating its extreme youth.

ACKNOWLEDGMENTS

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