27. POSSIBLE VOLCANOLOGIC EXPLANATIONS FOR THE ORIGIN OF FLAT-TOPPED SEAMOUNTS AND RIDGES IN THE LINE ISLANDS AND MID-PACIFIC MOUNTAINS

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Six flat-topped seamounts and ridges were dredged on SIO Expedition 7 TOW, Leg 6 (E.L. Winterer and the late E.C. Allison, co-chief scientists) in an effort to obtain coral, beach or stream deposits, molluscs or other evidence which would illuminate the shallow-water history and subsidence of these platforms. All of these mountains were assumed to have once been at or near sea level and beveled by stream and wave erosion to produce the characteristic guyot shape (Hess, 1946; Hamilton, 1956). Surprisingly, no materials supporting such an erosional history were recovered in any of the dredge hauls in spite of dredging across the main breaks in slope of the summits where corals and island shelf deposits would be expected. Instead, volcanic rocks erupted under water (aquagene tuffs), associated with phosphatized planktonic foraminifer sands, and manganese oxide crusts were dredged. This indicates either that the level summits formed entirely under water or that post-subsidence volcanism was common on volcanoes of the Line Islands chain. The discussion below presents alternatives to the erosional planation theory of guyot formation, where evidence for such erosion is lacking. It must be emphasized that none of the seamounts have been sampled extensively enough to preclude an erosional episode in their history. But the interpretations given below are based on all the available evidence rather than on the simple fact of a volcano's shape.

The bathymetry and materials dredged from two seamounts (one at 158°W, 9°30′N; the other at 163°W, 9°30′N) suggest that submarine caldera collapse shaped the volcanoes (Natland et al., 1972). Figures 1 and 2 show the bathymetry of these seamounts and the locations of the dredge hauls. The westernmost seamount, contoured without sediments, has a central depression surrounded by higher ridges, also shown in the cross-sections of Figures 3 and 4. The dredge station on this seamount was at the base of one of these summit ridges and recovered a large quantity of hyaloclastite breccias encasing lithic clasts of an unusual amphibole-bearing potassic nephelinite (Natland, this volume, analysis 129-2, Table 2). The central depression of this peak has the form of a central caldera. A cross-section without vertical exaggeration (Figure 5) reveals how very nearly flat-topped this seamount is.

The second seamount (Figure 2) is a twin guyot with each peak mantled and flattened by sediments. The sediment cap on the western summit is thinner than on its twin and appears to be bounded on the north by a series of small pinnacles of about 100 meters relief. The dredge station on the west side of this peak is at about the same depth as the bases of these pinnacles. It recovered aquagene tuffs with isolated pillow lobes enclosed in

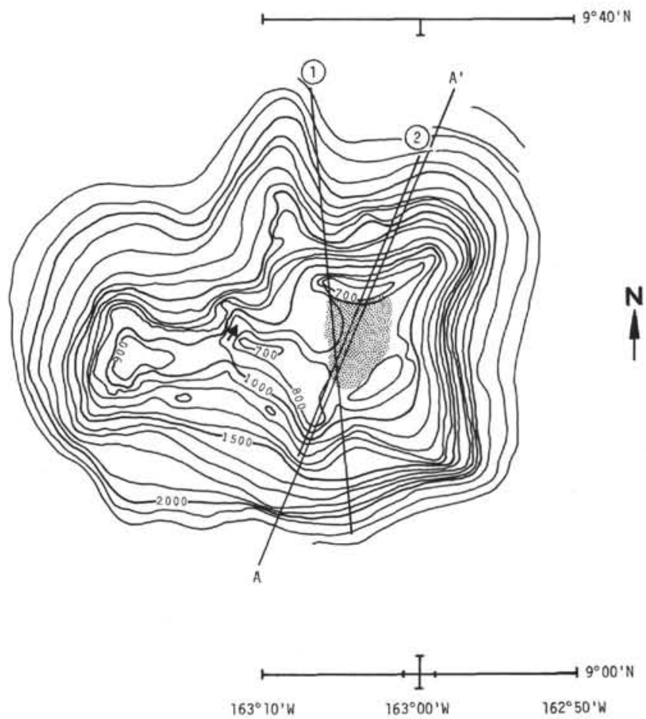

Figure 1. *Seamount 9° 30′N, 163° W, showing small summit ridges around sediment cap (stippled) that may fill in a summit caldera. Depths in fathoms to volcanic basement, not to surface of sediment cap.*

hyaloclastites. The lava is hawaiite in composition (Natland, this volume, analysis 128-1, Table 3) which usually erupts as small viscous domes or flows in island occurrences. This suggests that the pinnacles are small volcanic cones and favors a volcanic origin for the shape of this peak and its twin. Complete infilling of collapse features similar to the structures of the seamount shown in Figure 1 could explain the shape of the twin guyots of Figure 2. Cross-sections of the twin guyot are shown in Figures 6 and 7. Pelagic sediments overlying aquagene tuffs would provide the final leveling. The alkalic volcanics are reasonable candidates for intra-caldera eruptives and could presumably fill collapse features on seamounts. The seamount tops, being 20-25 km in diameter, could contain calderas 12-15 km in diameter, of a size similar to known collapse features on oceanic islands (Kauai, Hawaii, Macdonald and Abbott, 1972; Tutuila, American Samoa, Stearns, 1944; Upolu, Western Samoa, Natland, 1974).

Aquagene tuffs were also dredged from a guyot at 8°20′N, 164°22′W. This guyot was not surveyed, but available track lines (Figure 8) show no small ridges or

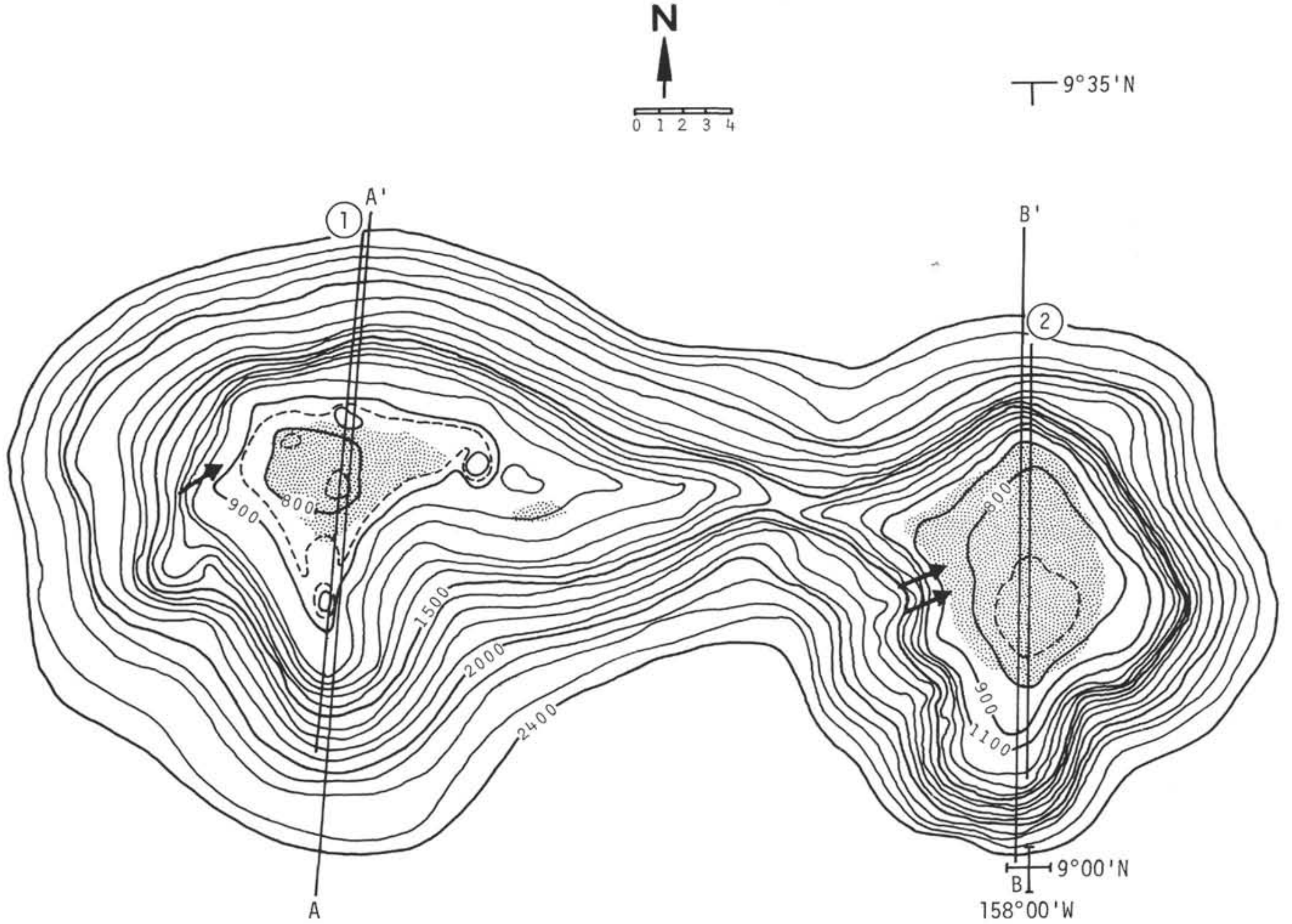

Figure 2. *Twin seamount (guyot) at 9°20'N, 158°W showing sediment cap (stippled) and small summit pinnacles on western peak. Depths in fathoms to tops of sediment caps. Volcanic basement depths beneath sediment caps uncertain because of possible chert layers concealing basement.*

pinnacles suggesting a collapse feature at the summit. The guyot is close to DSDP Site 165, where graded sandstones and volcanic conglomerates eroded from a nearby shallow-water source were cored. The source is undoubtedly this seamount (Winterer, Ewing, et al., 1973). Post-subsidence volcanism is therefore suggested. The rock type dredged, an alkalic basalt (or olivine-poor basanitoid, Natland, this volume, analysis 130-2, Table 3), is a typical post-caldera or post-erosional island eruptive and thus could well have erupted on this volcano after erosional truncation. Jackson and Schlanger (this volume) infer from the Line Islands drill sites of Legs 17 and 33 that an episode of epeirogenic uplift and volcanism occurred in the Line Islands region 85-90 m.y. ago. The typical lavas erupted at this time are basanites, nephelinites, and potassic nephelinites such as those drilled at Site 165 and dredged from the seamounts shown in Figures 2 and 8. The accompanying uplift carried Line Islands seamounts above sea level for the first time, since no coral or erosional debris cored on Legs 17 or 33 is older than about this age, even though the chain itself may in part be as old as 124 m.y. (Ozima and Saito, 1974). If the seamount at 8°20'N (Figure 8) was leveled by erosion at about this time, then it can be considered a sea-level indicator. The guyots of Figures 1 and 4, which may have formed by infilling of collapsed calderas, have breaks in slope about 300 fathoms deeper (1 sec = 400 fathoms on Figures 1 and 2). If the top of the eroded volcano can be used as a regional sea-level indicator, then the deeper guyots could not have been carried above sea level during the uplift. This assumes, of course, that uplift and later subsidence were uniform. This is probably reasonable for the seamount shown in Figure 1, which is not far from the inferred erosional guyot and from which similar nephelinite-type lavas have been dredged. However, the twin guyot to the east is off the main Line Islands ridges. But it is aligned parallel to ridges of the Line cross trend, which are inferred by Winterer (this volume) to have formed at the time of the regional Line Islands uplift, 85-90 m.y. ago, and its summit is deeper than the top of the eroded guyot that dates from this time.

Aquagene tuffs were also dredged from two ridges between 5° and 6°N at about 161°W (Figures 9 and 10). The dredge locations are near the bases of pelagic sediment caps which are the main cause of the flatness of the two ridges. The lavas at station 122 are among the extremely undersaturated potassic mafic lavas which

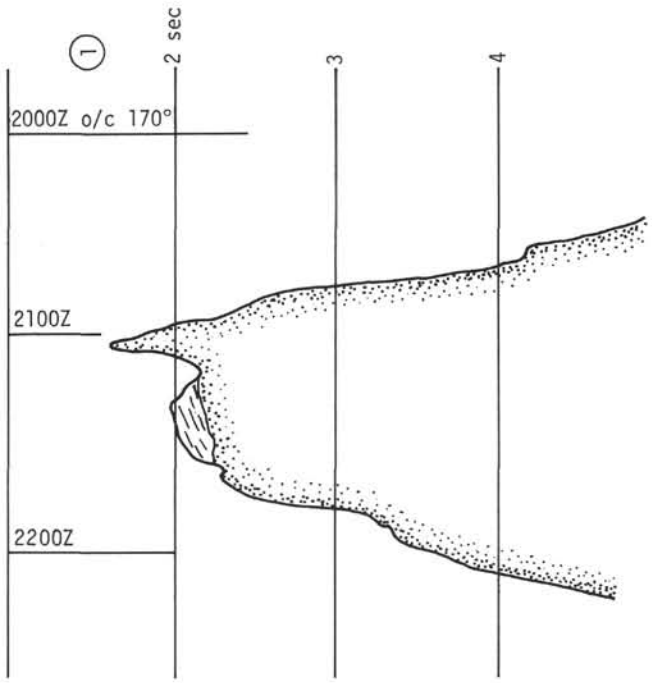

Figure 3. *Tracing of airgun profile across the seamount of Figure 1 (Crossing 2). Vertical exaggeration about 15.5:1.*

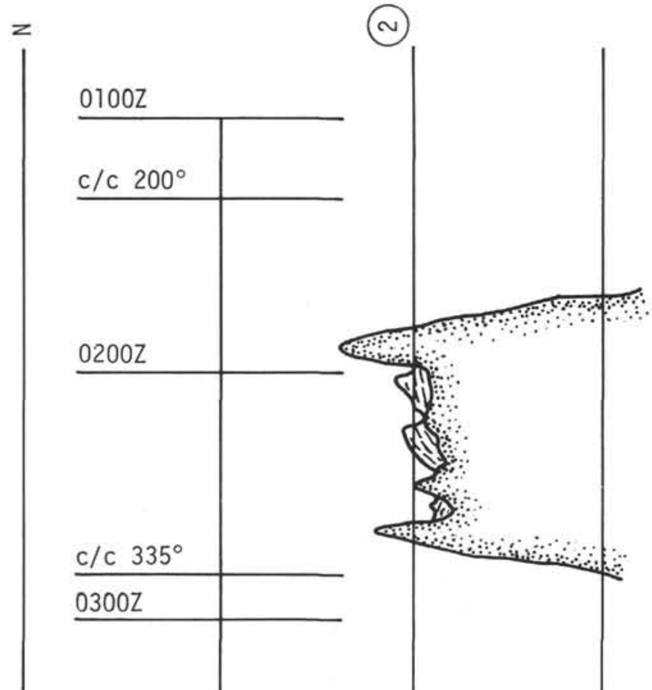

Figure 4. *Tracing of airgun profile across the seamount of Figure 1 (Crossing 2). Vertical exaggeration about 15.5:1.*

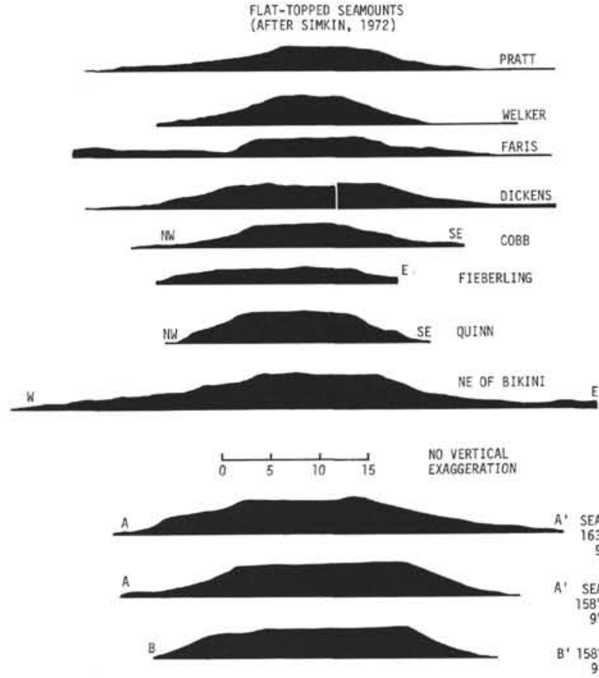

Figure 5. *The seamounts of Figures 1 and 4 without vertical exaggeration compared with other Pacific guyots, from Simkin (1972).*

characterize the west-northwest-oriented cross-trend ridges of the Line Islands chain (Natland, this volume, analysis 122-1, Table 2). The limited survey undertaken before and after dredging suggests that this ridge also trends west-northwest. Less than 1° north and east of this ridge, however, is the second ridge which has a more northerly trend and is about 200 fathoms deeper. Alkalic basalts similar to Hawaiian or Samoan post-caldera or late pre-caldera lavas were obtained at dredge station 123 (Natland, this volume, analysis 123-15, Table 3). These basalts could represent the late cappings of the initial north-northwest-trending Line Islands ridges, and the nephelinites of station 122 the outpourings of a younger set of ridges, the Line cross trend. This would explain both the difference in orientation and the difference in summit depth of the two ridges, consistent with the interpretation that the cross-trend ridges are younger than the north-northwest-trending main Line Islands ridges. However, this is a region of complex interaction of north-northwest and west-northwest-trending topographic belts, and there may be local factors influencing the orientations of portions of ridge crests.

Neither the sharp breaks in slope of erosional guyots nor possible collapse structures are present on either of these two ridges although both are located in a region of present-day atolls. They are large enough, if either was ever at sea level, for permanent reefs to have developed and to have survived to the present day as they have on neighboring atolls. It is plausible that these ridges developed their level summits by infilling of troughs between parallel, closely spaced rows of volcanoes, or by repeated eruptions along a zone of closely spaced dikes, analogous to the rift zones of Hawaiian shield volcanoes, such as the Kilauea rift (Fiske and Jackson, 1972).

The final guyot dredged on Expedition 7 TOW, Leg 6 was Horizon Guyot, one of the easternmost ridges of the Mid-Pacific Mountains (Figure 11). It trends roughly

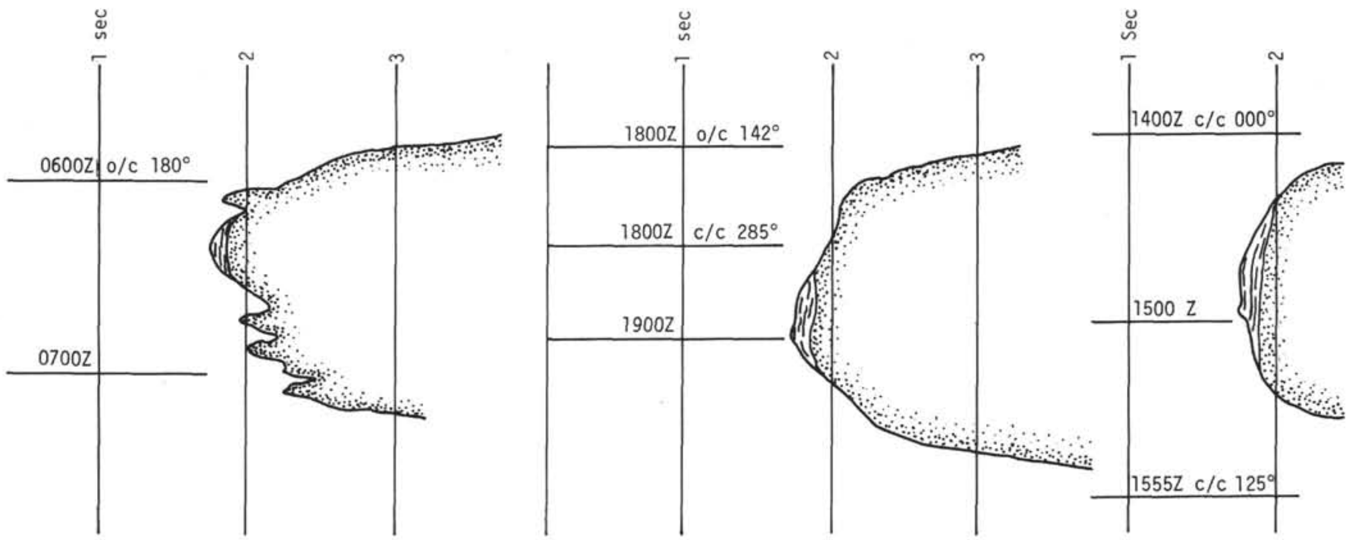

Figure 6. *Tracing of airgun profile across the western peak of the twin guyot (Crossing 1). "Basement" beneath sediment cap may be chert. Note small pinnacles of probable volcanic origin. Vertical exaggeration about 16:1.*

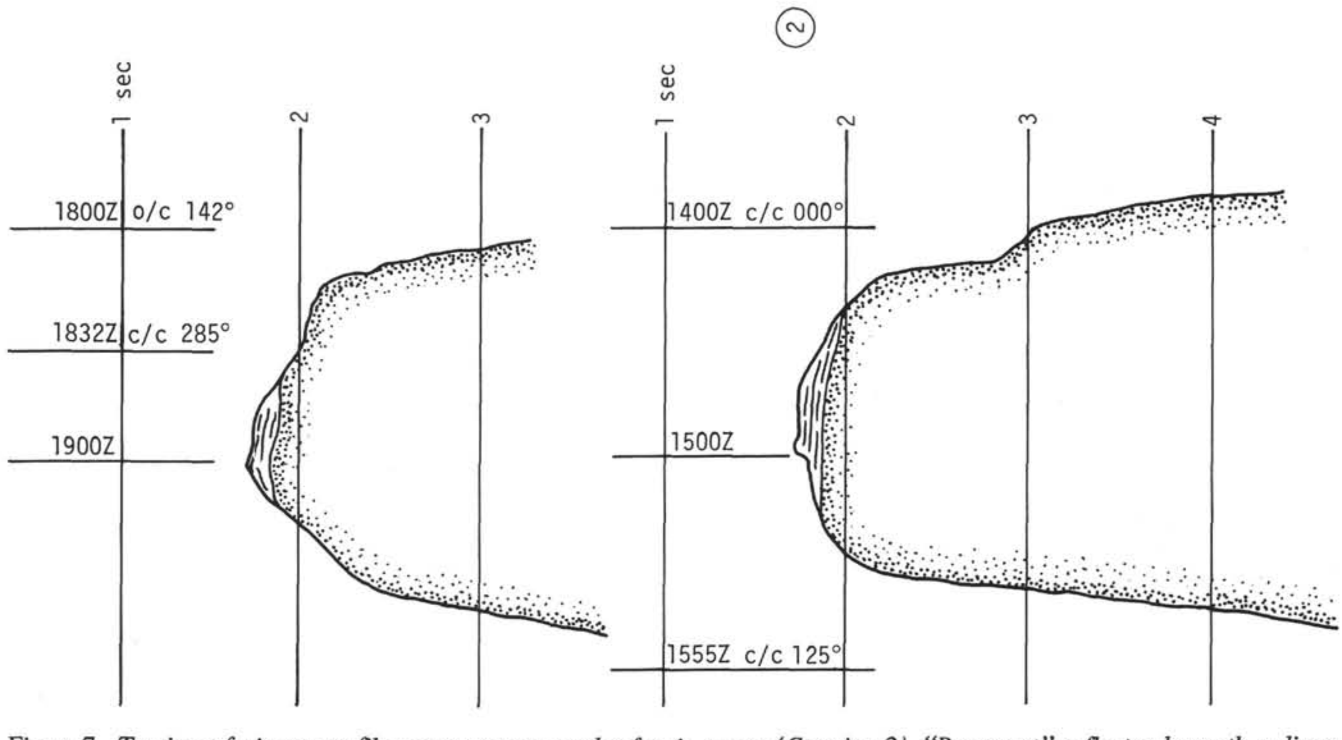

Figure 7. *Tracing of airgun profile across eastern peak of twin guyot (Crossing 2). "Basement" reflector beneath sediment cap may be chert. The irregular bathmetry of the sediment cap appears to be due to a small basement knoll, which is possibly volcanic. Actual volcanic basement thus is probably somewhat irregular.*

northeast and is the terminus of the north-northwest-trending ridges of the Line Islands chain from which trachytes and phonolites were dredged (Natland, this volume, analyses 137-1, 137-11, 142-1, Table 3). Volcanism probably lasted until about 105 m.y. ago on Horizon Guyot (Winterer, Ewing, et al., 1973) making it at least partly younger than the 124 m.y. old trachytes of the nearest dredge station (142) on the Line Islands ridges (18°N, 169°W).

Horizon Guyot is enormous compared with the guyots so far described. It is a double guyot with an intervening saddle. Together, the two summits comprise a nearly flat-topped feature over 300 km long and up to 70 km wide. Four dredge hauls across the breaks in slope of Horizon Guyot failed to produce evidence for erosional leveling (two reported in Hamilton, 1956; two in Lonsdale et al., 1972, including 7 TOW 6 Station 143). Lonsdale et al. presented the results of a deep-tow survey of the pelagic sediment cap of Horizon Guyot, which in fact lends the summit its flatness. They described flights of flat volcanic terraces on the north side of the guyot which have been exhumed from beneath the

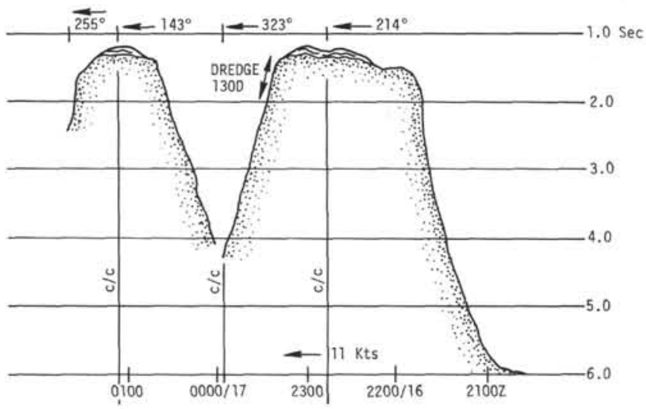

Figure 8. *Tracing of airgun profile of a sediment-capped guyot at 8°20'N, 164°22'W. Vertical exaggeration approximately 16:1. The dredge station, 130-D, recovered aquagene tuffs, but DSDP Site 165 penetrated shallow-water erosional debris from this seamount (Winterer, Ewing, et al., 1973).*

sediment cap by submarine erosion. The terraces descend in steps of about 50 meters from the base of the sediment cap to the main break in slope. These were inferred to be constructional submarine volcanic landforms, possibly the fronts of submarine volcanic flows or lahars.

Shallow-water fossils and subaerial plant remains were cored at DSDP Site 171 in the saddle between Horizon Guyot's two platforms and were inferred to have been transported there from one or both of the nearby flat summits (Winterer, Ewing, et al., 1973). This prompted Newman and Ladd (1973) to criticize the interpretation of Lonsdale et al. that the primary shape of Horizon Guyot is volcanic-constructional in origin. I have inspected all the dredge hauls from Horizon Guyot and agree with Lonsdale et al. that the volcanics dredged reached their in situ positions under water. All are fragmental pillow lavas and aquagene tuffs. I do not agree that the volcanic terraces on the north side of the summit are submarine lahars, but they may be individual breccia flow units of the type illustrated in Figure 12, or possibly small fault scarps. The lavas of the four dredge hauls are either tholeiitic basalts (based on identification of pigeonite in thin section; Natland's section *in* Heezan et al., 1973) or alkalic basalts (Natland, this volume, analysis MP-25-2F-2, Table 3) which should erupt relatively passively under water to form flow units of the type in Figure 12).

Because of its great size, Horizon Guyot must have coalesced from several vents. It appears to be nearly as old as the subjacent sea floor (possibly 110-115 m.y., based on results at DSDP Site 171, Winterer, Ewing, et al., 1973; see also Winterer, this volume, fig. 13-15), and presumably, therefore, built near an oceanic ridge crest. Olivine-plagioclase tholeiitic basalts are the predominant lavas dredged or cored from Horizon Guyot, including some with oceanic tholeiitic affinities (Bass et al., 1973). Olivine-plagioclase tholeiitic basalts are

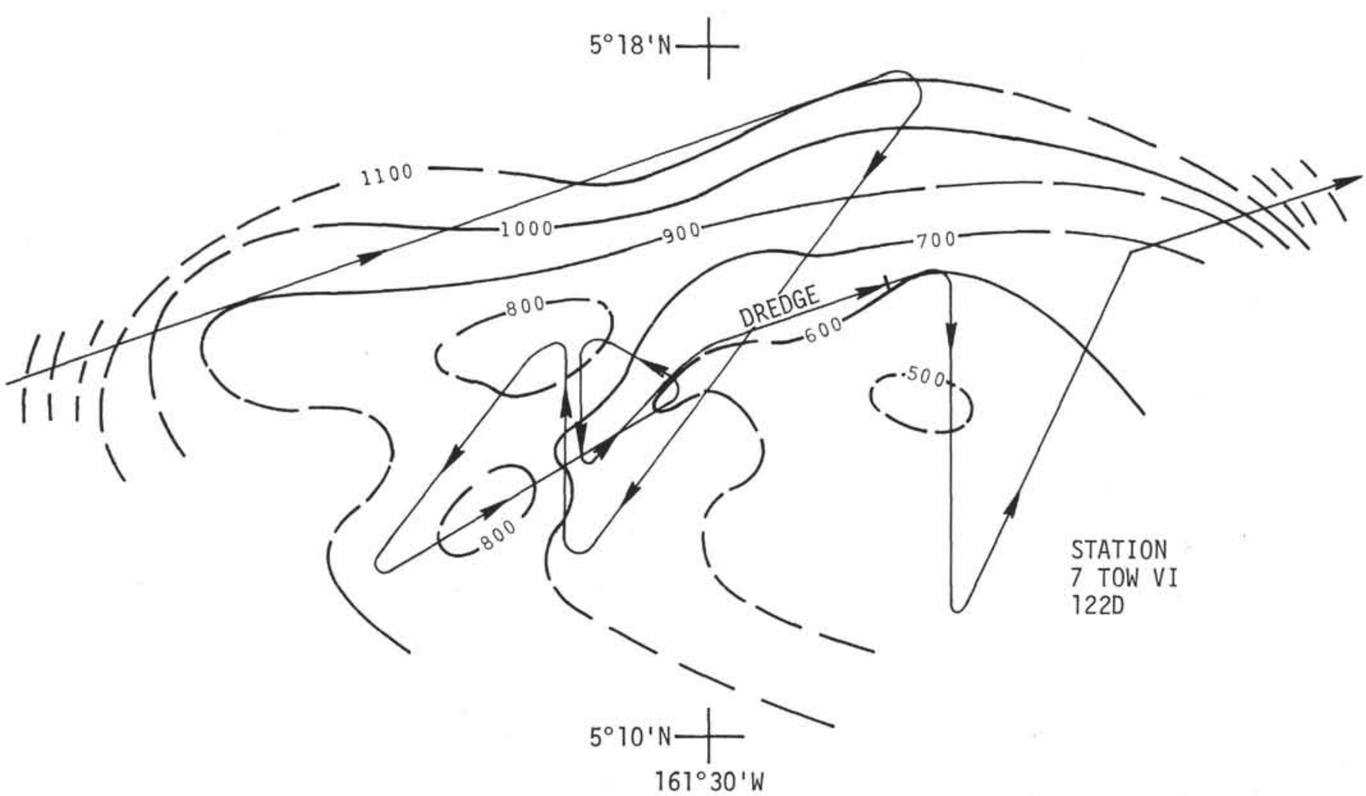

Figure 9. *Sketch of bathmetry of a flat-topped ridge at 5°15'N, 161°30'W. The west-northwest trend of the ridge suggests that it dates from the time of the Line cross-trend (about 85 m.y.) Potassic nephelinites were dredges from this ridge, also suggesting the ridge formed at the time of cross-trend volcanism.*

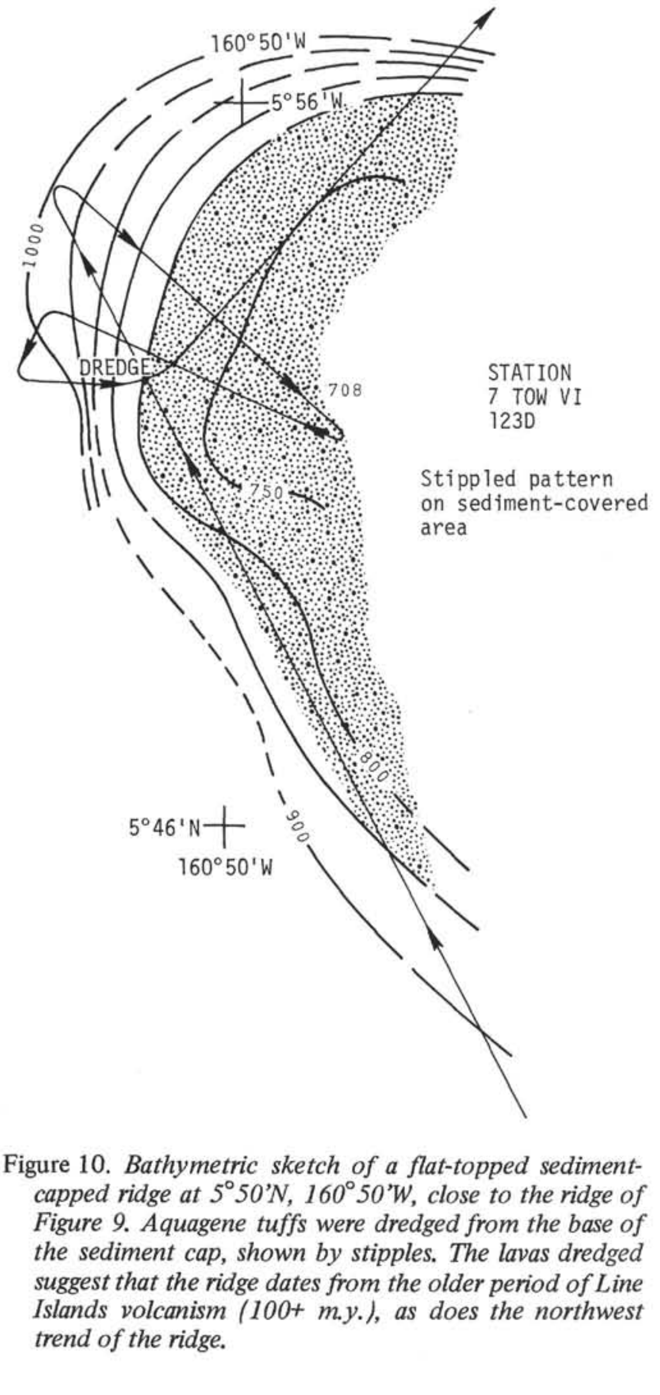

Figure 10. *Bathymetric sketch of a flat-topped sediment-capped ridge at 5°50'N, 160°50'W, close to the ridge of Figure 9. Aquagene tuffs were dredged from the base of the sediment cap, shown by stipples. The lavas dredged suggest that the ridge dates from the older period of Line Islands volcanism (100+ m.y.), as does the northwest trend of the ridge.*

typically found on active volcanic islands near ridge crests (Galápagos, Iceland, and others; McBirney and Williams, 1968) and which are inferred to have a shallow melt source (35 km or less, Kay et al., 1972). They differ from the predominantly olivine-phyric Hawaiian basalts which appear to have a source at least 60 km deep (Eaton and Murata, 1960).

The Galápagos Islands are of interest in connection with Horizon Guyot because they are a cluster of relatively small, closely spaced volcanoes built virtually atop the Galápagos spreading center. The islands rise above a large, shallow platform built from the coalescence of lavas from these separate vents. The islands form less than 20% of the area of this platform, which is usually less than 100 fathoms deep (Figure 13). Flows erupt from the central vents or from a trellis of rift zones connecting the separate volcanoes (McBirney and Williams, 1968), insuring an even distribution of lava over a broad area of the Galápagos platform. Simkin (1972) has described the tendency of lavas to erupt at the least elevated portions of caldera ring faults on Galápagos central vents, repeatedly emerging at the points of least superincumbent load and thus maintaining a uniform elevation of cauldron rims. A similar mechanism may extend to the rift zones, insuring that no excessive pile of lava will build up at any one place on the platform. This mechanism is favored by the development of an interconnected mosaic of rift zones and magma pockets at shallow crustal levels which would respond sensitively to any excess crustal load. Such a network might be expected near ridge crests where an abundant supply of magma melted at shallow depths is available. Such a network is not likely beneath volcanoes built on old, thick, cold portions of lithospheric plates. There, Hawaiian-type shield volcanoes, characterized by massive outpourings from single vents and parasitic rift zones, result.

Nordlie (1973) has described the morphologic development of Galápagos volcanoes from submarine to subaerial structures. Initially, flows are fluid enough to build dome-shaped structures under water with slopes up to 10° and no particular break in slope. Once sea level is breached, subaerial flows built flat platforms out over the submarine domes, terminating in rather steep, submerged breaks in slope (up to 26°). The depths of the breaks in slope are never more than 200 meters. Between the breaks in slope and the island shore lines are constructional volcanic shelves, very nearly flat. They form the major portion of the Galápagos platform and have coalesced from a dozen or more volcanoes.

Horizon Guyot probably originated in an analogous manner. A few small islands combined to produce a large, flat platform built of lava flows that extended relatively great distances under water, or erupted directly from submerged portions of the rift zones connecting the larger magma chambers beneath the small islands. This would explain the abundance of aquagene tuffs at the breaks in slope of Horizon Guyot's two platforms. The small islands would have produced little erosional debris or shallow-water fossils, and much of this material may be buried by lava flows or the present sediment cap, assuming that most of the islands were located near the centers of the platforms. Erosional processes may thus have had a minimal role in producing the flat top of Horizon Guyot, although the break in slope may be a good sea-level indicator, if the Galápagos platform is a viable analog. An island the size of the entire platform never existed. If it had, then the break in slope would most likely be either at the edge of a coral bank or a constructional sedimentary shelf similar to those normally surrounding large, deeply incised islands. Aquagene tuffs of the primary (tholeiitic) stage of volcanism would be extremely unlikely materials to recover from the break in slope of such a large submerged island.

In conclusion, the existence of a flat summit on a seamount or large submarine platform is by itself insuf-

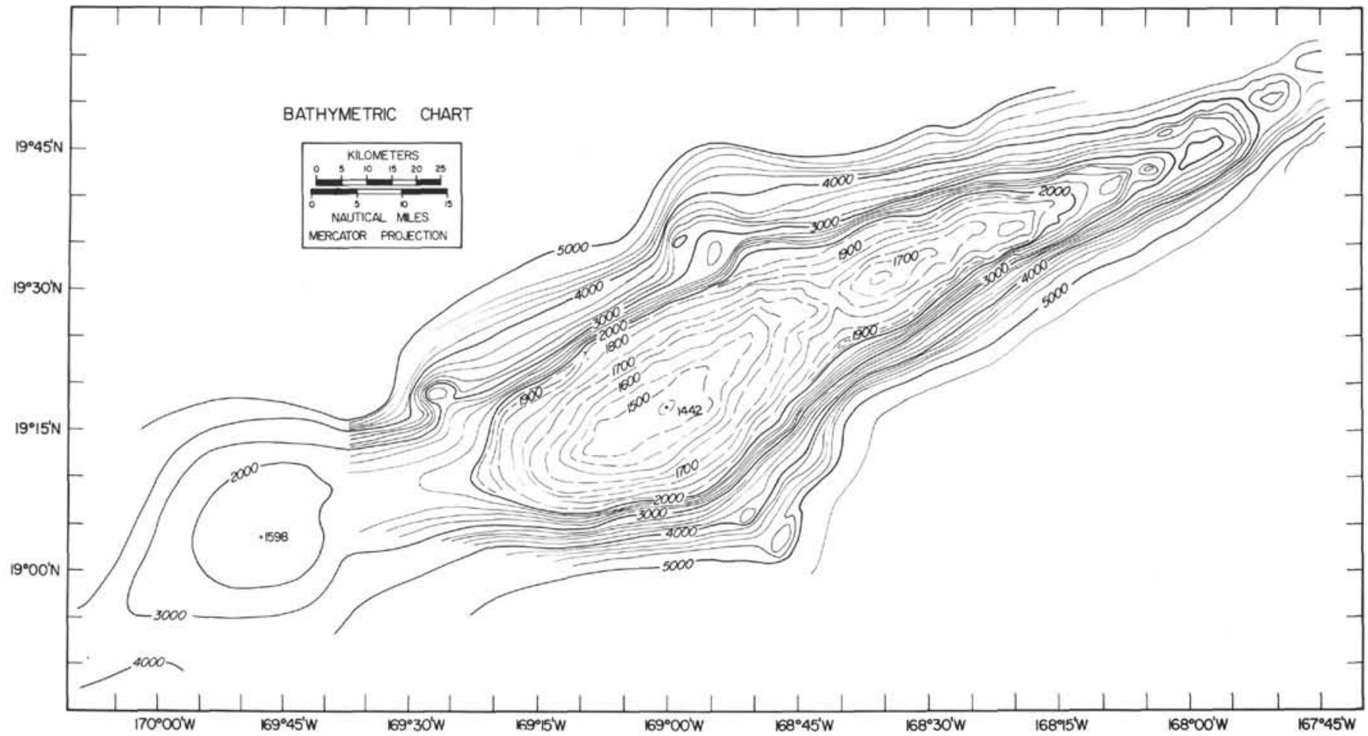

Figure 11. *Horizon Guyot bathymetry, depths in corrected meters from Lonsdale et al. (1972). Inset shows conversion from "uncorrected fathoms" (nominal sound velocity of 800 fathoms per sec) to "corrected meters" (sound velocity profile calculated from temperature and salinity measured in a hydrocast at 19°58'N, 169°59'W).*

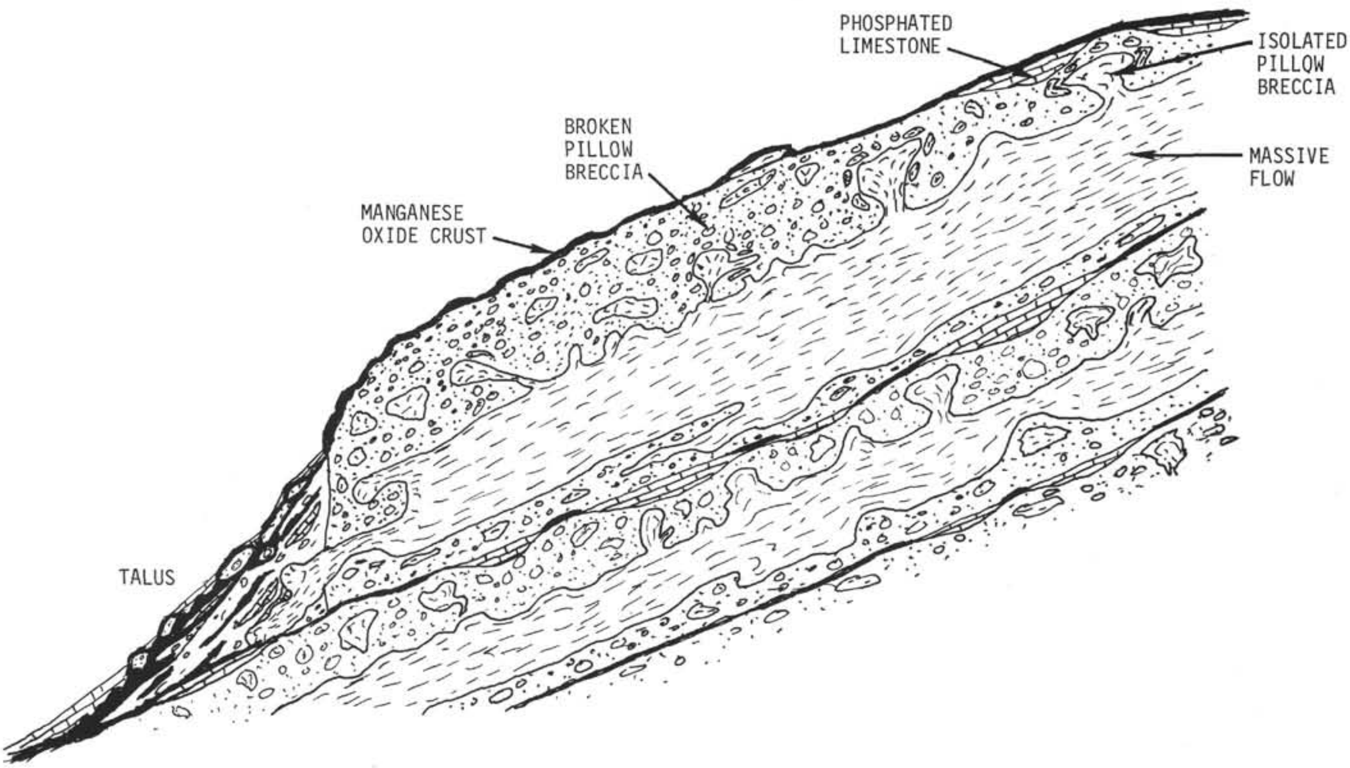

Figure 12. *Cross-section through an idealized series of aquagene tuffs, showing the relationship between flows, isolated pillow breccias and broken pillow breccias. The talus-strewn front of a single such flow may represent volcanic terraces dredged on the north edge of the summit of the main Horizon Guyot ridge (Lonsdale et al., 1972).*

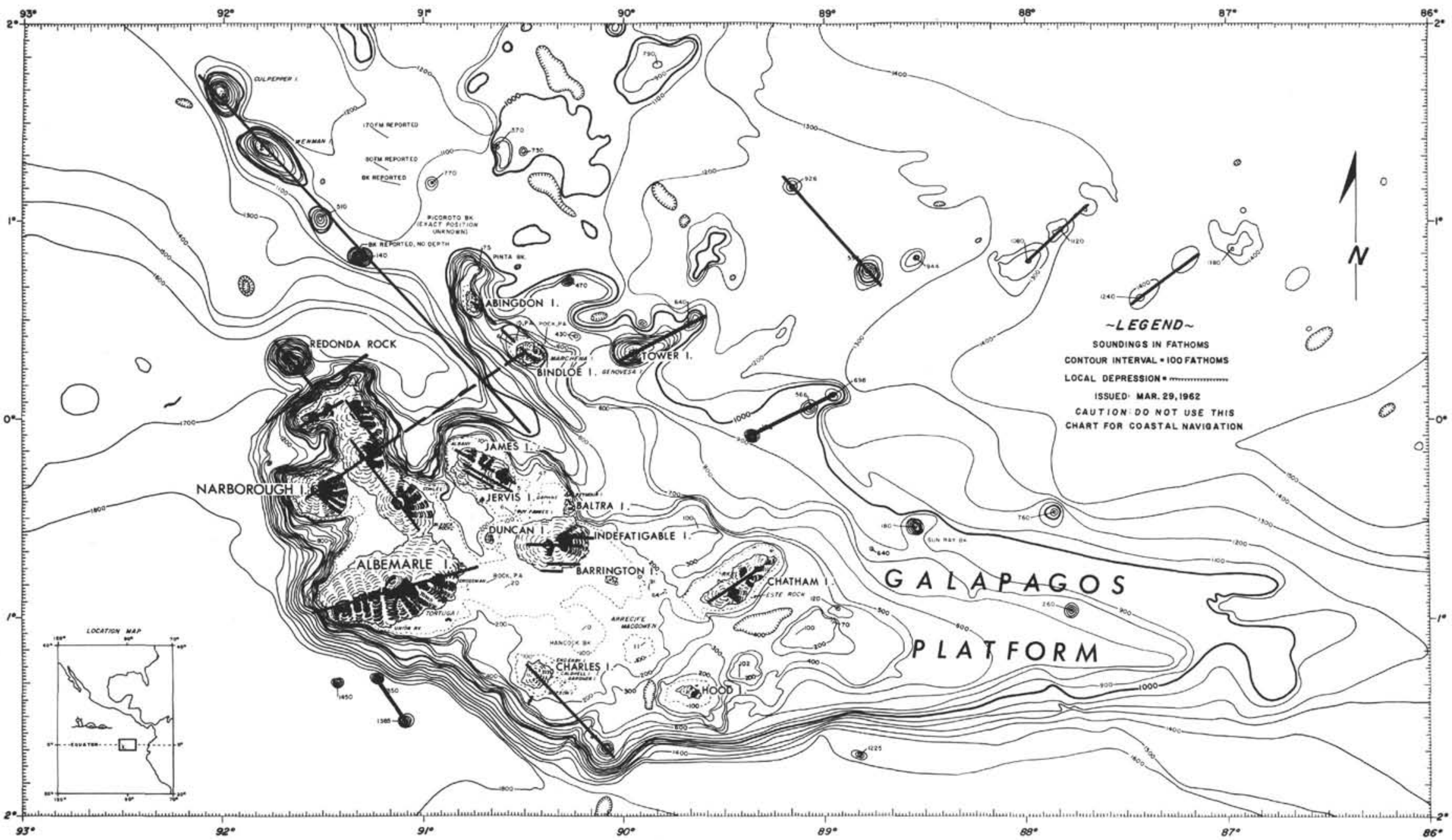

Figure 13. *Galapagos Platform. Bathymetry base prepared by U.S. Bureau of Commercial Fisheries and the University of California Institute of Marine Resources (after Chase, 1962). Fracture pattern of the archipelago (solid lines) from McBirney and Williams (1968). Is inferred to extend throughout the platform which is more than 80% submerged. Such a platform may develop into a large, flat-topped seamount such as Horizon Guyot.*

ficient proof that wave and stream erosion were the main reason for the guyot shape. Volcanologic factors (which can be inferred directly from dredge hauls and indirectly from the petrology of the dredged lavas), regional geology (based on other dredge hauls and DSDP sites), and the age of the subjacent oceanic crust must be considered. Although no definitive proof can be presented that any of the guyots discussed here formed entirely under water, it is hoped that the explanations given best represent the available data, and that the mechanisms proposed are viable alternatives to the wave planation hypothesis that can be applied and tested more thoroughly in the future.

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