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SUBMARINE GEOLOGY OF TWO FLAT-TOPPED NORTHEAST PACIFIC SEAMOUNTS

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ABSTRACT. Erben and Fieberling Guyots lie about 800 and 600 miles, respectively, west of San Diego, California. Their tops are largely rocky. The sparse deposits consist of a thin patchy veneer of calcareous and siliceous organic remains and small amounts of clastic mineral grains and basalt fragments derived from the underlying rocks. The rocks of Erben Guyot are encrusted with manganese dioxide. Geomorphic and petrologic evidence indicate the seamounts to be extinct basaltic volcanoes.

The drowned summit platforms of Erben Guyot (400 fathoms) and Fieberling Guyot (280 fathoms) are considered to be planes of marine abrasion cut by wave action within a few fathoms of sea level. Possible explanations are discussed for the present deeply drowned position of these truncated surfaces. It is concluded that these extinct submarine volcanoes constitute an uncompensated load on the earth's crust of such magnitude that they tend to subside slowly because of yielding of the earth's crust.

Foraminifera of Miocene age have been identified in the calcareous cement of a breccia from the Erben Guyot surface. Thus, this guyot appears to have been truncated in Miocene or earlier time.

INTRODUCTION

THE two seamounts described in this paper lie close to the great circle route from San Diego to Hawaii (fig. 1). The U. S. Navy Hydrographic Office Chart No. 0527 shows Erben Bank at 32° 50′ N and 132° 32′ W which is about 800 nautical miles west of San Diego, California. A sounding of 244 fathoms marks the summit of this seamount. This isolated feature was discovered in 1874 by the *USS Tuscarora* and the seamount was named in honor of her captain, Commander Henry Erben, USN. Additional bathymetric data about Erben Bank, consisting of some spot soundings, were obtained by the U. S. Coast and Geodetic Survey in 1929 (USC&GS Hydrographic Survey No. H-5071). Chart 0527 also shows another shoal sounding of 240 fathoms about 200 nautical miles east of Erben Bank, at 32° 24′ N, 127° 47′ W. This unnamed seamount was discovered in 1936 by the *USS Ramapo*. In 1947, the *USS Fieberling* made detailed bathymetric surveys of both of these seamounts using a continuously recording echo sounder. These surveys showed that both of these features have the shape of a truncated cone. This places them in the physiographic class of features which Hess (1946) has termed guyots. For convenience the previously unnamed seamount will be termed Fieberling Guyot. Also, inasmuch as Erben Bank is too deep to be properly termed a bank, it will be called Erben Guyot.[1]

To obtain more detailed information about flat-topped seamounts, a geological and oceanographic survey was undertaken by the writers from aboard the *USS EPCE(R) 857* of the U. S. Navy Electronics Laboratory in March 1948. During this survey the bathymetry was further investigated with a recording echo sounder, nine sea floor samples were obtained by dredges and snapper samplers, and bottom photographs were taken.

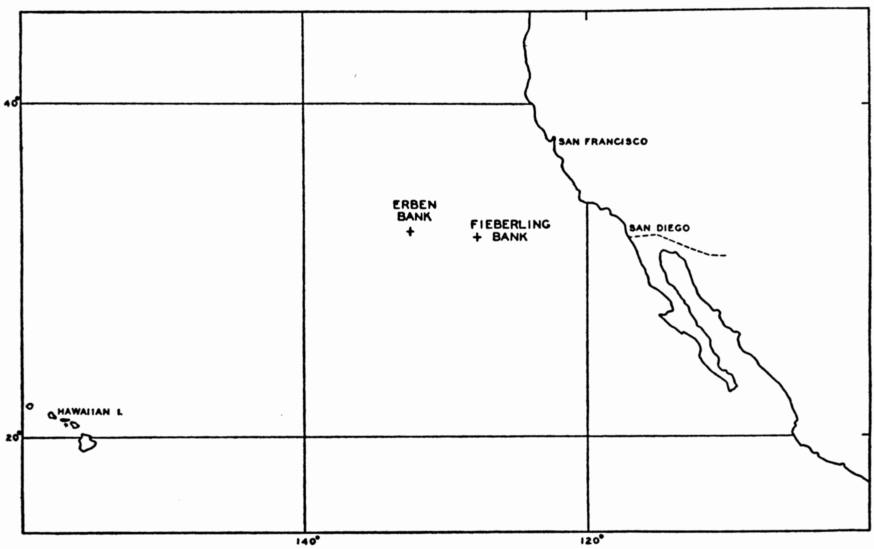

Fig. 1. Index map showing location of Erben and Fieberling Guyots.

[1] The special type of seamount termed guyots by Hess have flat tops at greater depth than the seamounts described here. However, the writers believe that these should also be termed guyots and the term bank applied only when the summit depth is less than 100 fathoms. Thus, Erben Bank will henceforth be referred to as Erben Guyot in this paper.

TOPOGRAPHY

Erben and Fieberling Guyots both rise from the abyssal ocean floor, which in this region lies at an average depth of about 2300 fathoms. Soundings obtained during the passage out from San Diego showed that level bottom extends seaward for a short distance from the continental slope off southern California, but the sea floor in the vicinity of the guyots is very irregular. The general configuration of the seamounts to a depth of 1000 fathoms is shown in figures 2, 3, and plate 1. The flanks of Fieberling Guyot have an average slope of 18 degrees; those of Erben Guyot vary between 11 degrees and 17 degrees.

Erben Guyot is characterized by a four-square mile flat surface at a depth of about 400 fathoms, from which a small peak rises to a depth of 225 fathoms. At Fieberling Guyot a five-square mile platform lies at about 280 fathoms, from which two peaks rise to 230 and 240 fathoms, respectively. The

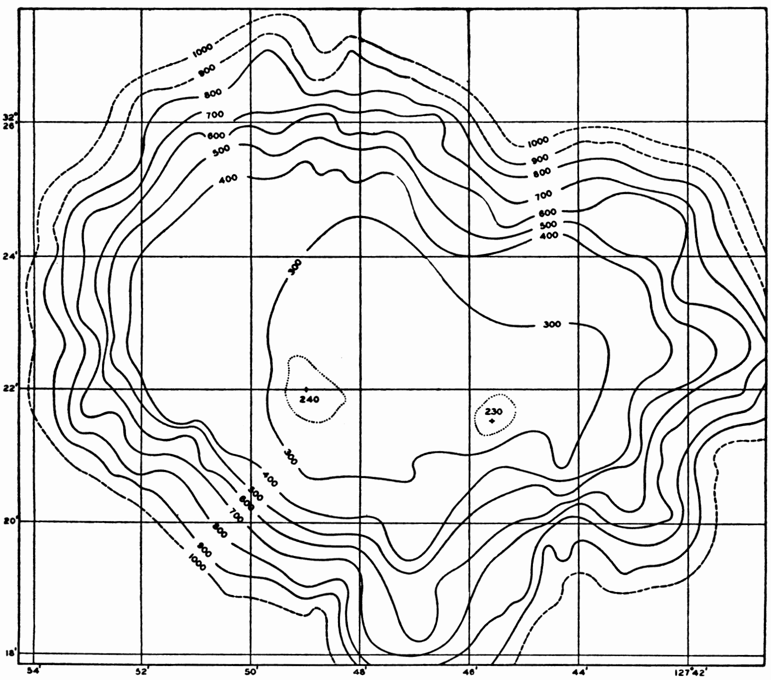

Fig. 2. Detailed topographic map of Fieberling Guyot. Contour interval 100 fathoms, except that dotted contour is 250 fathom curve. Distance between horizontal grid lines is 2 nautical miles.

sounding data are not sufficiently detailed to determine if any deep terraces or submarine canyons are cut into the flanks of these seamounts.

SEDIMENTS

General.—Information on the bottom sediments was obtained by use of a box dredge, a device mounting three snappers, and an underwater camera which trips upon contact with the bottom. The sediments from Erben and Fieberling Guyots are listed in table 1 and briefly described in table 2. Two of the four bottom photographs taken are reproduced in plate 2. Both the sampling operations and the bottom photographs show the summits to be bare, rocky, non-depositional surfaces with only occasional patches of foraminiferal sand. Great difficulty was encountered in obtaining bottom samples because of the paucity of loose detritus.

Rocks.—More than a thousand rock fragments were obtained by snappers and dredge hauls. All of the rocks are basalts or closely related types. Thin sections were prepared of one

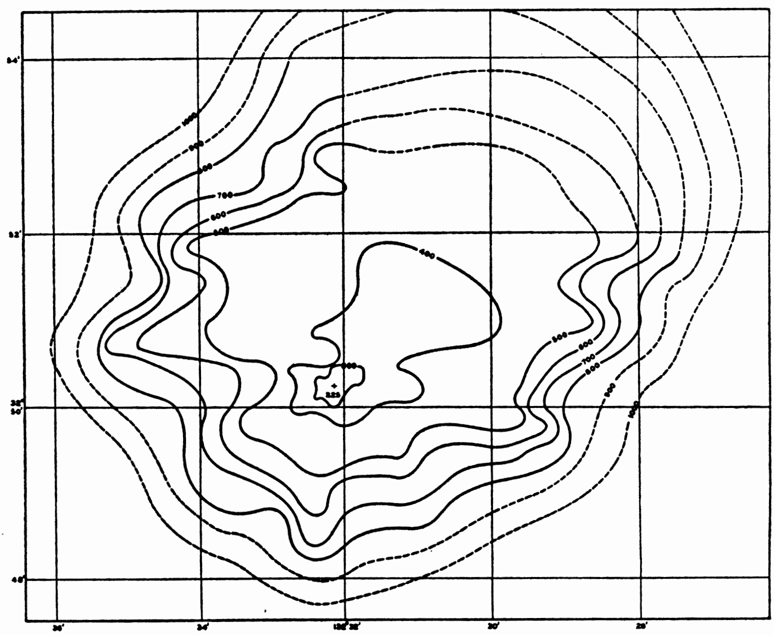

Fig. 3. Detailed topographic map of Erben Guyot. Contour interval 100 fathoms. Distance between horizontal grid lines is 2 nautical miles.

TABLE 1

Bottom Samples from Erben and Fieberling Guyots

NEL Sample No.	*Locality*	*Latitude (N.)*	*Longitude (W.)*	*Depth (Fms.)*	*Sampling Device*
662	Fieberling Guyot	32° 24′	127° 47′	273-280	Dredge
663	Fieberling Guyot	32° 24′	127° 48′	272-277	Dredge
664	Fieberling Guyot	32° 24′	127° 46′	270-280	Dredge
665	Erben Guyot	32° 51′	132° 32′	380	Snapper
666	Erben Guyot	32° 51′	132° 32′	377	Snapper
667	Erben Guyot	32° 51′	132° 32′	375	Dredge
668	Erben Guyot	32° 51′	132° 32′	375	Snapper
669	Erben Guyot	32° 51′	132° 32′	400	Snapper
670	Erben Guyot	32° 51′	132° 32′	425	Snapper

specimen from each of four dredge hauls, numbers 662, 663 and 664 from Fieberling Guyot and number 667 from Erben Guyot.

The one specimen thin-sectioned from sample 662 is a typical olivine basalt, with phenocrysts of plagioclase up to nearly one cm. in length, and rarer, smaller ones of altered olivine. These are scattered in a sub-ophitic or intersertal groundmass of plagioclase laths, granular augite and magnetite, and a little interstitial glass devitrified to a mixture of chlorite and other minerals. All of the olivine is altered to iddingsite (?) or iron oxide, with a core of serpentine (?) in some cases.

Sample 663 is a single slab of deeply weathered fine-grained basalt. In thin-section, small phenocrysts of augite and olivine occur in a groundmass of plagioclase laths, minute crystals of augite and magnetite, and devitrified glass. The devitrified glass constitutes about 60% of the rock. A spherulitic zeolite, probably phillipsite, fills fractures and small vesicles.

A pebble selected at random from sample 664 was thin-sectioned. It is extremely finegrained and dense, consisting of a microcrystalline aggregate of feldspar, augite, and magnetite, with a few larger embayed grains of iron-rich biotite.

One of the larger fragments from the breccia obtained from Erben Guyot (sample 667) was thin-sectioned. It is a vesicular olivine basalt porphyry, with lath-shaped phenocrysts of plagioclase up to about 8 mm. in length, phenocrysts of augite up to about 3 mm., and occasional smaller phenocrysts of altered olivine. The ophitic groundmass consists of plagioclase laths with interstitial magnetite, augite granules, and a little devitrified glass.

A group of angular to subrounded pebbles and cobbles is shown in plate 3, figure 1. These constitute a part of sample 662 from Fieberling Guyot. One hundred pebbles were quartered out of this sample; half of these were in the 16-32 mm. size class and half were in the 32-64 mm. class. All are basalt; about half are vesicular. Roundness of these pebbles was measured by a visual comparison method devised by Krumbein (1941) and sphericity was measured by a method devised by Pye and Pye (1943). Results of these measurements are represented graphically in figures 4 and 5. Roundness and sphericity of each pebble were plotted against each other in a scatter diagram (figure 6). In general there seems to be little correlation between roundness and sphericity. Roundness is about the same in both size classes, averaging 0.48 in the 16-32 mm. class and 0.30 in the 32-64 mm. class. Sphericity is nearly the same in both classes, averaging 0.75 and 0.73, respectively.

A copy of these results was sent to W. C. Krumbein to determine how they compared with other data on sphericity and roundness of pebbles from various environments. In his reply, Krumbein states that the roundness and sphericity dis-

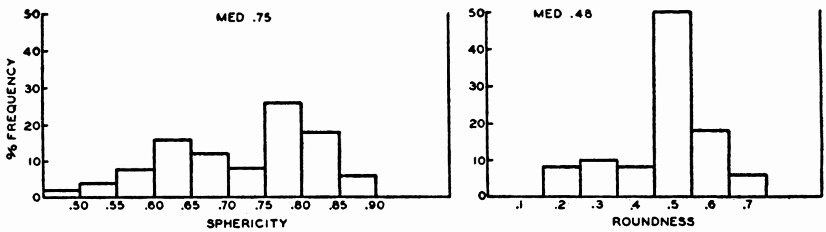

Fig. 4. Histograms of sphericity and roundness showing variation of 50 pebbles in size grade 16-32 mm. selected at random from Sample 662 (Fieberling Guyot).

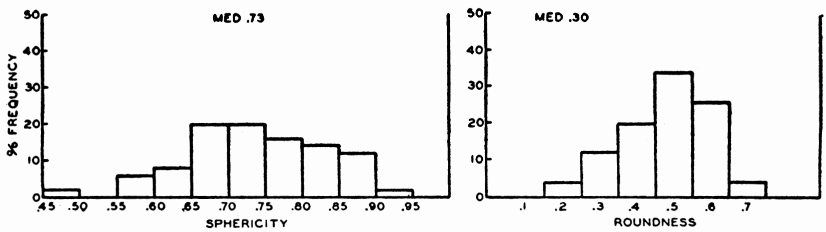

Fig. 5. Histograms of sphericity and roundness showing variation of 50 pebbles in size grade 32-64 mm. selected at random from Sample 662 (Fieberling Guyot).

TABLE 2 Description of Guyot Samples

NEL Sample Number	*Rocks*	*Authigenic Minerals*	*Organisms*
662 Fieberling	Angular to subrounded pebbles and sand composed of basalt ranging in diameter from 10 mm. to 175 mm. Includes a conglomerate of cemented basalt pebbles and one piece of foraminiferal marl.	MnO_2, possibly wad, as cement and as a veneer on the upper surface of some pebbles.	Foraminifera in crevices and holes in rocks, and in bank sand. Also ostracode tests, ophiuroids, abundant sponge spicules, and a few echinoid spines. Encrusting forms include Foraminifera, Bryozoa, serpulid worm tubes, alcyonarians, and a few solitary corals.
663 Fieberling	Large slab of weathered basaltic ledge rock.	MnO_2 as veneer on top surface.	Encrusting serpulids, solitary corals, and brittle stars, especially on the upper surface.
664 Fieberling	Angular to subrounded basalt granules, pebbles, and cobbles from 2 mm. to 175 mm. in diameter cemented together to form a breccia boulder.	MnO_2 and collophane coating sand grains and rocks, and as cement.	Foraminifera, mostly *Rupertia stabilis;* sponge spicules; fish teeth and shark teeth; a few echinoid spines; fragments of pelecypod shells; and a few euphausiids; all in a foram sand. Worm tubes, brittle stars, and Bryozoa on rock surfaces.
665 Erben		MnO_2 in slabs about $2—1^2/_2$ to 5 cm. thick.	A few Foraminifera and sponge spicules in the MnO_2 slabs.
666 Erben		Several pieces of encrusting MnO_2	Similar to Sample 665. A few Foraminifera and sponge spicules in the bottom layer of MnO_2; also a broken gastropod shell and a sea pen.
667 Erben	A large MnO_2 coated nodule. Rock within the nodule is a $CaCO_3$ and collophane coated breccia made up of grains and pebbles of basalt 2 mm. to 125 mm. in diameter.	MnO_2 coating 5 cm. thick on the top of the nodule, 1 cm. thick on the bottom. Some collophane as cement. A few phillipsite crystals in cavities.	Foraminifera along the oldest layer of MnO_2, together with sponge spicules. Poorly preserved foraminifera and molluscan fragments in pockets within the nodule; also a few teeth of fish and sharks. Exterior of the nodule is encrusted with brittle stars, worm tubes, sponges, and Bryozoa.
668 Erben		Small fragment of MnO_2.	A few pelagic Foraminifera.
669 Erben	Basalt grains between 1/16 and 4 mm. in diameter.		Broken and complete foraminiferal tests and sponge spicules comprising over 90% of the sample.
670 Erben		Grains of MnO_2.	A few broken tests of pelagic Foraminifera, and sponge material consisting of spicules and spongin.

tributions and average values compare well with observed data for both beach and stream pebbles. The high concentration of roundness in the central class suggests beach conditions, but the sphericity distribution of the 16-32 mm. size class suggests some stream deposits Krumbein has seen. He states further that the pebbles may be part of a beach deposit, but the evidence in support of this origin is not conclusive. Krumbein also suggests the possibility that the relatively high degree of roundness of the basalt pebbles may be inherited from lapilli or volcanic bombs or from unaltered cores left by spheroidal weathering. There is no evidence from the pebbles themselves to support either of these last two possibilities. Thus it is believed that the rounding displayed by these pebbles and

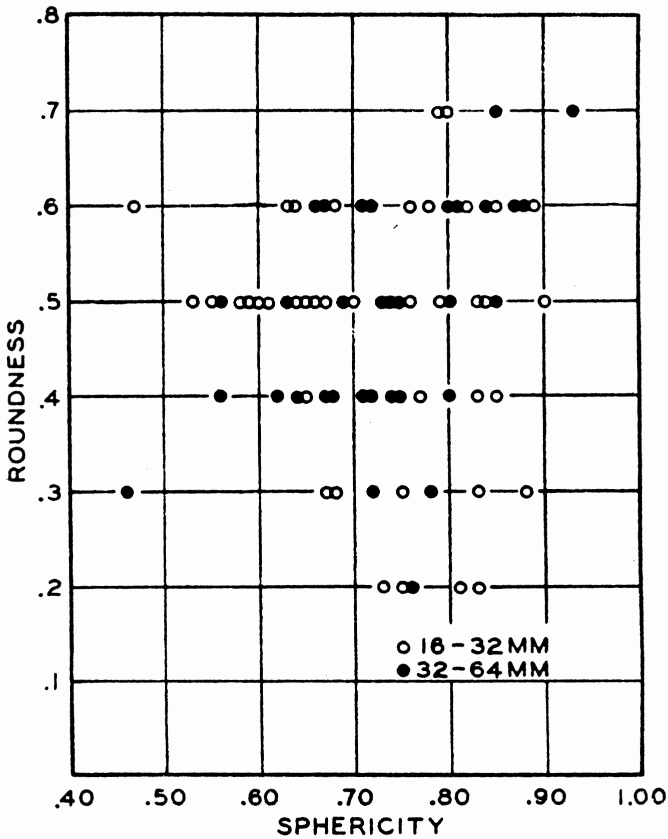

Fig. 6. Relation of roundness and sphericity for 50 pebbles in size grade 16-32 mm., shown in white circles, and 50 pebbles in size grade 32-64 mm., shown in black dots; all from Sample 662 from Fieberling Guyot.

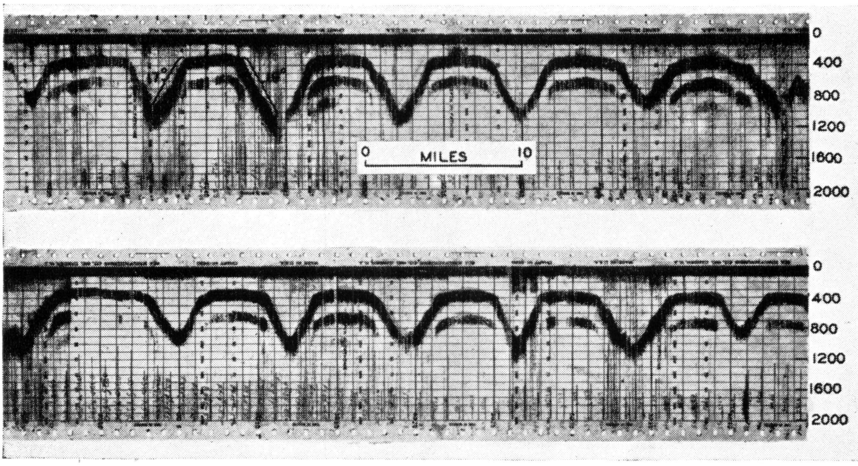

Fig. 1. Portion of fathogram showing successive crossings of Fieberling Guyot. Vertical scale exaggerated 4.8 times.

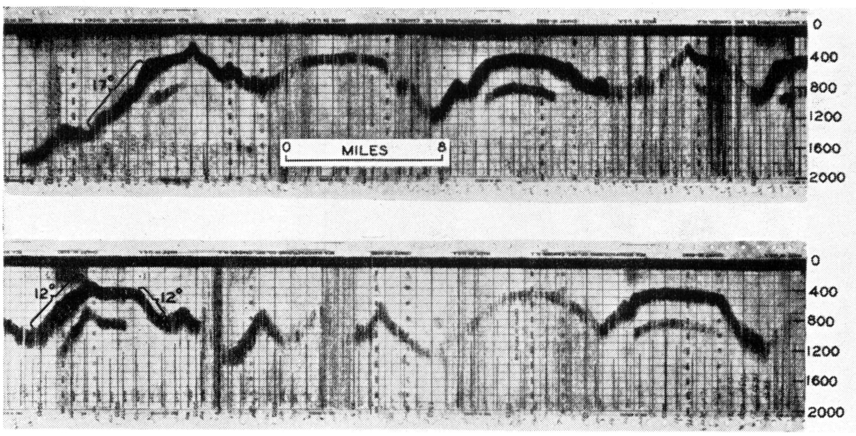

Fig. 2. Portion of fathogram showing successive crossings of Erben Guyot. Vertical scale exaggerated 3.7 times.

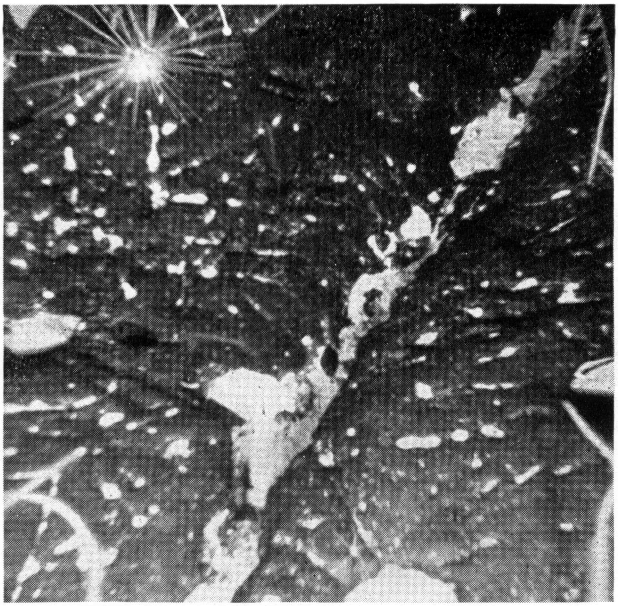

Fig. 1. Bottom photograph taken in 275 fathoms showing the basaltic surface of Fieberling Guyot. Note the echinoid in the upper left and the joint in the center of the picture which has been partially filled with globigerina ooze. The deposition of the globigerina ooze only in pockets demonstrates the existence of bottom currents competent to move the sediment. Area shown is approximately 12 square feet.

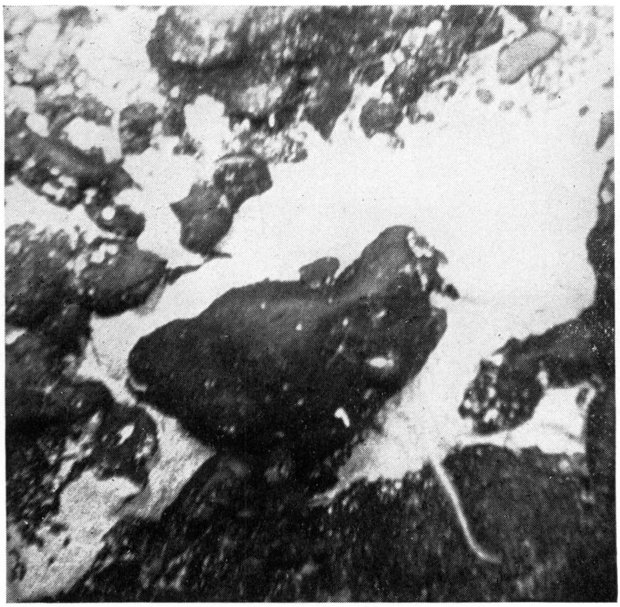

Fig. 2. Bottom photograph taken in 275 fathoms at Fieberling Guyot. Note the rocky surface covered only by large cobbles, boulders and organic detritus composed mostly of calcareous and siliceous material. The long white filament in the lower right is a "sea pen." Area is about 12 square feet.

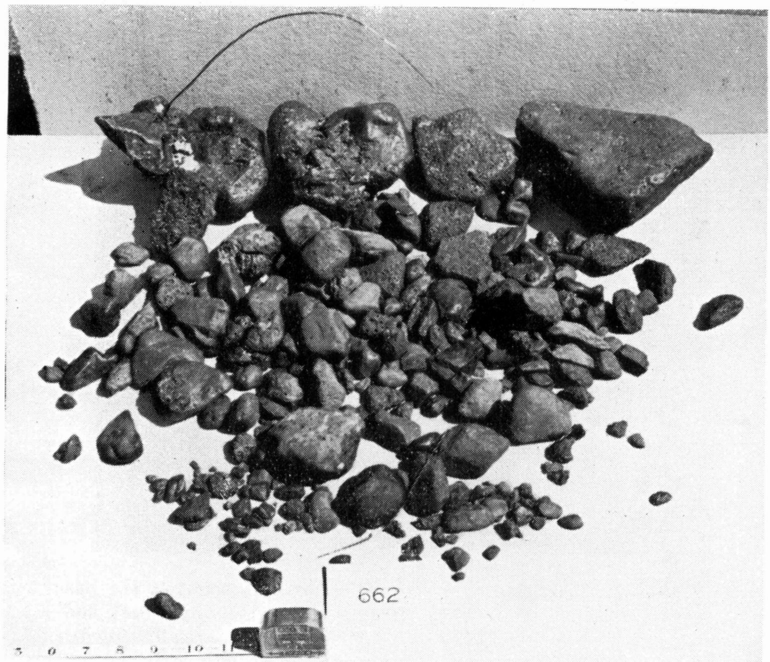

Fig. 1. Photograph of portion of dredge sample 662 taken at Fieberling Guyot. Note subrounded nature of cobbles and pebbles. The slender object in the left background is an alcyonarian ("sea pen").

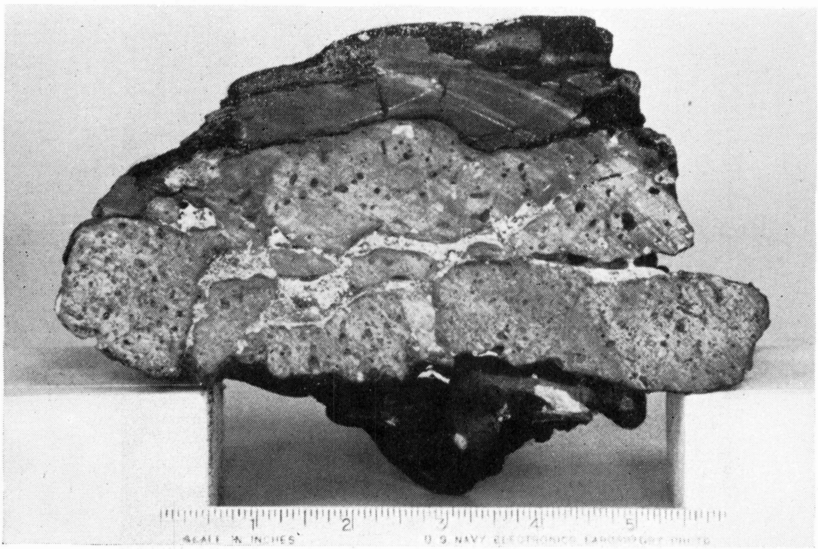

Fig. 2. Photograph of cross section of nodule dredged at Erben Guyot. The dark uppermost and lowermost layer is manganese oxide, which encrusts a breccia composed of pebbles. The fossil foraminiferal assemblage described in the report was taken from the interstitial calcareous material.

cobbles was not accomplished in their present environment. It is more reasonable to propose that they were rounded when they constituted part of a cobble beach formed during a relatively lower stand of sea level when waves truncated the seamounts.

Authigenic minerals.—The authigenic minerals identified are collophane, phillipsite and manganese oxide minerals. A small amount of collophane is present as a thin, brown polish on some mineral and rock grains and, in one place, as a cementing substance. It has also partially replaced some sharks' teeth. Small prisms of a zeolite mineral identified as phillipsite were found in cavities and vesicles in Sample 667 from Erben Guyot. Hydrated manganese dioxide was found in great abundance, especially at Erben Guyot, where it is the dominant constituent of all samples. At both guyots, manganese dioxide is present as a surface coating on most rocks, but at Erben Guyot it occurs as a thick encrustation up to two inches thick. Plate 3, figure 2 shows a large nodular mass from Erben Guyot consisting of an encrustation of manganese dioxide covering a cemented deposit of basaltic fragments and foraminifera. This manganese dioxide resembles wad, and is of the same type that is commonly found in deep sea deposits.

Organisms.—The patches of sand that occur on top of the banks are largely composed of organic remains. The bulk of the sediment is made up of foraminiferal tests. In some samples pelagic types are most abundant, but in others the benthonic form *Rupertia stabilis*, which lives attached to rocks, occurs as the flood constituent in the sediment. Other organic remains include sharks' teeth, echinoid spines, ostracode tests, and a profusion of sponge spicules. Forms which were found encrusting or attached to the rock include bryozoans, brittle stars, serpulids, alcyonarians, and *Rupertia stabilis*. However, the benthos is not abundant as on the neritic banks of similar depth near the southern California coast. This is presumably related to the relative poverty of nutrients in the surface water of this oceanic environment.

Table 3 is a faunal list of the foraminifera from Samples 664 and 669 identified by M. L. Natland of the Richfield Oil Corporation.

According to Natland (personal communication), the assemblage is unique and unlike any living or fossil fauna found along the Pacific Coast. It is likely that the fauna is largely

TABLE 3

List of Recent Foraminifera from Guyot Samples

Species	*Fieberling Guyot (Sample 664)*	*Erben Guyot (Sample 669)*
Angulogerina carinata Cushman	C	
Bolivina spissa Cushman		R
Cassidulina cushmani Stewart & Stewart		R
Cassidulina cf. *subglobosa* H. B. Brady		R
Cassidulina sp.	R	
Ehrenbergina bradyi Cushman	F	C
Epistomina cf. *elegans* (d'Orbigny)	C	
Eponides cf. *subtenera* (Galloway & Wissler)		R
Eponides sp.	C	R
Globigerina bulloides d'Orbigny		C
Globigerina inflata d'Orbigny	C	R
Globigerinoides rubra (d'Orbigny)	C	
Globorotalia menardii (d'Orbigny)	C	
Globorotalia truncatulinoides (d'Orbigny)	C	
Lagena sp.	C	
Laticarinina pauperata (Parker & Jones)	R	
Orbulina universa d'Orbigny	VA	
Rupertia stabilis Wallich	F	C
Robulus sp.	R	
Uvigerina senticosa Cushman	A	C
Vaginulina sp.	R	

Key to Abbreviations

F — Flood A — Abundant
VA — Very Abundant C — Common
R — Rare

endemic and is characteristic of an environment of a type which would not normally be represented in the marine sedimentary rocks exposed on the continents. No extinct species were identified in either of the samples. Natland states further that the benthonic foraminifera are, in general, those normally found living elsewhere at depths similar to those at which the samples were collected, but that some of the species from Fieberling Guyot are typical of greater depths.

The manganese-coated breccia (Sample 667) from Erben Guyot contained many fossil foraminifera in the limy detritus cementing the fragments of basalt (plate 3, fig. 2). Fred B. Phleger, Jr., and Miss Frances Parker, of the Scripps Institution of Oceanography, and O. L. Bandy, of the University of Southern California, have kindly examined the fossil foraminifera and expressed their opinions regarding the age of the assemblage. Phleger and Parker stated (personal communication) that the fauna is tropical in aspect, but that it cannot be compared to any Recent or fossil assemblage known to them, so it may be endemic. They classified the fauna as definitely post-Cretàceous and pre-Pleistocene and most likely about mid-Tertiary. Bandy (personal communication) assigned a Miocene age to the assemblage, which is listed in table 4.

TABLE 4

List of Fossil Foraminifera in Nodule from Erben Guyot

O. L. BANDY

1. *Robulus* (Spinose and loosely coiled form, undescribed).
2. *Cassidulina cuneata* Finlay—Miocene of New Zealand.
3. *Ceratobulimina pacifica* of LeRoy (may not be the same as that of Cushman and Harris)—Miocene of the East Indies.
4. *Valvulineria inequalis* of Cushman (not d'Orbigny)—Recent.
5. *Valvulineria inequalis* var. *lobata* Cushman and Renz—Miocene of Venezuela.
6. *Hoglundina elegans* of LeRoy—Miocene of the East Indies.
7. *Uvigerina auberiana* var. *attenuata* Cushman and Renz—Miocene of Venezuela and Trinidad.
8. *Uvigerina carapitana* Hedberg—Oligocene to Miocene of Trinidad and Venezuela.
9. Globigerinidae of no age significance.

Sharks' teeth from the same nodule were sent to J. Wyatt Durham and R. H. Reinhart of the University of California. Reinhart (personal communication) identified them as from *Isurus*, which has a geologic range from Upper Cretaceous to Recent in North America. They appear to be closely related to forms from the Middle Miocene of Shark Tooth Hill, Kern County, California. However, Durham emphasizes that Tertiary sharks' teeth are not well known, so that specific criteria have not as yet been well enough established to warrant their use as index fossils.

DISCUSSION AND CONCLUSIONS

General.—Any attempt to outline the history of the guyots on the basis of the few data available is necessarily speculative. In contrast to subaerial landforms, which are subjected to vigorous erosional processes, deeply submerged submarine features are subjected to, at most, extremely slow weathering and erosion, so that one may think of them as physiographic "museum pieces." The rocky nature of the upper surface of the guyots shows that sedimentation has not masked these features. This indicates the presence of currents competent to sweep off most of the sediment that settles from the overlying waters.

Volcanic origin.—Both the petrologic and the geomorphic evidence indicate that the seamounts originated by local submarine vent eruptions of olivine basalt which produced large volcanic cones. From the geomorphic point of view, the oval plan of the guyots and the uniformly steep flanks with a slope of about 15 degrees strongly suggest that the seamounts are extinct volcanoes. Indeed, it is difficult to conceive of any reasonable alternate explanation. The recovery of olivine basalt from the tops of the guyots furnishes additional evidence, although the presence of volcanic rock on a physiographic feature is, of course, no final proof that it is a primarily volcanic landform.[2]

Erben and Fieberling Guyots appear to be isolated volcanoes. No topographic connection between them is apparent, nor are they part of any major lineation of seamounts so far as can be determined from existing bathymetric data. Thus there is no reason to suppose that the eruptions were simultaneous or penecontemporaneous.

The olivine basalt composition is typical of the insular rocks of the Pacific Basin proper as defined by the "andesite line." This line is usually drawn along the foredeeps of the western Pacific but is often not defined in relation to the eastern Pacific, partly because of the lack of islands, to furnish petrologic data on which it can be established. The olivine basaltic composition of Erben and Fieberling Guyots is in contrast to the more acidic rocks of the islands of the continental terrace off southern California. Thus, an andesite line might be drawn between these two group of features—most logically along the base of the continental slope.

Truncation of the guyots.—The present form of Erben and Fieberling Guyots is not the initial form of a volcanic

[2] The writers' interest in examining these guyots was aroused by a sediment sample obtained from the *USS Fieberling's* buoy anchor which was planted on Fieberling Guyot. This anchor was reported to have been a new one which had never been previously used. The sediment sample had a mineral suite which could only have come from an acidic igneous and metamorphic terrane. This was difficult to reconcile with the presumed volcanic nature of the seamounts. The subsequent survey of these guyots clearly proved the spurious nature of the supposed guyot sample, re-emphasizing the probable volcanic nature of Pacific seamounts.

landform of any type. Subsequent to formation of the guyots the summits must have been eroded so that each has the form of a truncated cone. These flat summits are almost certainly planes of marine abrasion formed close to sea level.

This belief is supported by the discovery of subrounded cobbles on the top of Fieberling Guyot, which are probably explainable as beach cobbles. The lack of coral on the tops of the guyots eliminates the possibility that the flat tops are due to a drowned coral reef capping.

The writers believe with Dietz and Menard (1951) that waves erode effectively only in the surf zone, and not, as is sometimes stated, down to wave base. If this is correct, then the plane of marine abrasion must have been cut within 5 fathoms of sea level, because this is about the maximum depth at which surf forms. No known marine process except wave action near sea level is capable of vigorous enough erosion to remove such a basaltic mass with a basal area of about 20 square miles at each bank.

Inasmuch as any marine fossils found on top of the truncated basalt surfaces most likely postdate the time of truncation, the 400-fathom truncated surface of Erben Guyot, on which the fossils of probable Miocene age were found, is probably Miocene or older. No similar information is available for the 280-fathom summit plane of Fieberling Guyot, but the depth, which is 720 feet shoaler, suggests that it might be a younger abrasional surface than that of Erben Guyot. If the ideas presented below concerning subsidence of guyots are correct, it follows that, for guyots of similar mass, the depth of the truncated summit may be roughly a function of the age of the seamount.

With regard to the time of truncation, it is noteworthy that the flat tops of Erben and Fieberling Guyots are considerably shoaler than any of the large number of similar features described by Hess (1946) from the coral reef region of the west central Pacific. Hess states (pp. 777-778) that the flat upper surfaces of these guyots range from 520 to 960 fathoms. He suggests that they were formed and truncated in the Precambrian before the advent, in the Cambrian, of reef-forming organisms, and that the more recently formed volcanic islands in the coral reef seas have been preserved as atolls rather than as guyots. For reasons too lengthy to consider here, the writers do not consider Hess's reasoning regarding the extremely great age of the guyots to be compelling; and, in fact, the recent recovery of mid-Cretaceous shallow water fossils from three of the west central Pacific guyots strongly suggests that these were truncated in the Cretaceous (Hamilton, 1952). From the standpoint of depth, Erben and Fieberling Guyots more closely resemble the guyots of the Gulf of Alaska (Menard and Dietz, 1951). These writers concluded that at least one of the guyots described in this paper predates the formation of the Aleutian Trench and may be pre-early Tertiary in age.

Subsidence and recent history of the guyots.—The submergence of these two guyots might have been caused in a number of ways. First, sea level might have risen absolutely because of an increase in the amount of water on the earth, or because of a decrease in the size of the ocean basins related to tectonics or to sedimentation. However, it is unlikely that a large sea level change could be accomplished in the Cenozoic by any of these mechanisms (Kuenen, 1950, pp. 532-551).

Second, large oscillations of sea level related to the locking up of water on land as glacier ice during the Pleistocene might have permitted truncation of the tops of the seamounts during some glacial maximum (sea level minimum). However, Pleistocene glaciation is considered to have been accompanied by a maximum sea level lowering of about 400 feet, which is insufficient to account for the wave cut surfaces. Also, the recovery of Miocene fossiliferous materials from Erben Guyot is evidence that the top of this guyot was not disturbed by Pleistocene oscillations of sea level.

Third, subsidence of the guyots might be caused by regional tectonic movements of the sea quite unrelated to the guyots. For example, Menard and Dietz (1951) have identified a guyot in the axis of the Aleutian Trench which they believe was submerged in part by the down-buckling of the Trench. However, much evidence has been presented to show that the central Pacific is a strong and stable mass (e.g., Hess, 1946, pp. 786-788) where epeirogenic and orogenic movements are rare. Isostatic depression of the Pacific floor caused by the loading of sediments must be a real process, but this effect would be small since the Miocene (Kuenen, 1950, pp. 545-547). To the present writers, it seems that although regional subsidence cannot be ruled out as a possibility, it is probably not the dominant cause of drowning of these guyots.

Fourth, the guyots may have subsided because they are large superposed "rootless' masses on the earth's crust, with a strong tendency to sink. The writers believe that this is probably the dominant mechanism accounting for the submergence of the guyots. The process might be envisioned as follows: As the volcano is built up, the unconsolidated, plastic sediment underlying the volcanic pile is squeezed out. For the next few tens of thousands of years, subsidence continued at a slower but still fairly rapid rate until "isobaric" equilibrium is attained (Gunn, 1949). In isobaric equilibrium the superposed load is supported, in part hydrostatically, by the displacement of the dense and plastic asthenosphere underlying the elastic lithosphere and in part by vertical strees in the crust—thus "like a boy standing on thin ice." It may be during this initial period of subsidence that the seamount is truncated. The summits of the guyots are not so level as to preclude some subsidence contemporaneous with their cutting. Finally, even after isobaric equilibrium is attained, it seems likely that slow subsidence might continue because of slow crustal yielding related to processes like the recrystallization and slippage along crystal glide planes. These processes would result in the relief of the stresses in the earth's crust and gradual transfer of support of the superposed load to the underlying asthenosphere. The depth of the guyot platform would then be a function of the time during which these processes have acted and the mass of the superposed load.

The absence of a fossil coral cap on Erben and Fieberling Guyots is worthy of brief discussion. At the present time, the February minimum sea surface temperature in the vicinity of the banks is 15° C. Coral reefs cannot form at a temperature colder than 18° C. (Vaughan, 1916) which places the northern limit of the coral reef region about 300 miles south of these banks. In recent papers, however, Durham (1949, 1950) presents evidence that considerably warmer temperatures prevailed in this region in the past. He states (1949): "The data available indicate that in the Upper Cretaceous the February 20°C. marine isotherm along the Pacific Coast must have been some place between 50° and 55° N. Lat. and that it gradually migrated southward, possibly with minor fluctuations, during the Tertiary until the Pleistocene. During the Pleistocene it obviously fluctuated both northward and southward, but the correlations available during that interval do not permit of a synthesis of the data. During the Paleocene and Eocene the 20°C. isotherm was north of 49° N. Lat.; during the middle Oligocene it was near 48° N. Lat.; in the middle Miocene it was about 35° N. Lat.; during the middle Pliocene it was around 28° N. Lat.; possibly during the upper Pliocene it was near 30° N. Lat. At present the 20°C. isotherm is near 24° N. Lat. in February." Thus, if Durham is correct, it appears that at least the temperature conditions were favorable for reef growth when these ancient islands were truncated. However, reef-producing corals and algae are highly specialized forms so that some other ecological factors may have been unfavorable for their development.

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