# DROWNED ANCIENT ISLANDS OF THE PACIFIC BASIN *

by

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Abstract

Some one hundred and sixty curious flat-topped peaks have been discovered in the Pacific Basin between Hawaii and the Marianas. They appear to be truncated volcanic islands rising about nine to twelve thousand feet from the ocean floor. The flat level summits generally range from three to six thousand feet below sea level. Some less-developed ones are deeper. The flat upper surface is commonly bordered by a gently-sloping shelf a mile or two wide. The summit surfaces are apparently not all of the same age since adjacent peaks may have flat tops which differ in elevation by as much as a thousand feet, though in some cases groups of peaks do have the same elevation. The relationships to atolls of the Marshall Islands group indicate that the surfaces are older than the atoll formation. An hypothesis is tentatively advanced suggesting that the summit surfaces are very old and possibly represent marine planation surfaces in a pre-Cambrian ocean in which reef-building organisms did not exist. It is suggested that the present depths of the surfaces may be accounted for by the relative rise of the ocean surface as a result of accumulation of sediments on the floor. Thus the deeper the surfaces are, the greater their age.

## Part I.

## DESCRIPTION

A large number of curious flat-topped peaks have been discovered scattered over millions of square miles in the Pacific Basin. These peaks are roughly oval in plan and their slopes suggest volcanic cones. The remarkable feature about them is that they are truncated by a level surface which now stands approximately 750 fathoms (4500 feet) below sea level. For convenience in discussing these submerged flat-topped peaks which rise from the normal ocean floor, the writer will henceforth call them "guyots" after the 19th century geographer, Arnold Guyot.

Betz and Hess (1942) discussed the major features of the floor of the North Pacific. This was in the nature of a broad areal reconnaissance of the largest features of this extensive region. Since 1942, Hess has spent two years at sea in the Western Pacific and has thus had the opportunity to fill in some details which bring to light many new relationships and necessitate some modification of ideas originally set forth. The data presented in this paper were obtained on random traverses incidental to war-time cruising on board the U.S.S. *Cape Johnson*. What passed beneath the ship was recorded, but it was not feasible to investigate further such interesting features as were encountered. Nevertheless it is evident that much information can be obtained on the geological history of an oceanic area by judicious use of available techniques. It is a vast and intriguing field of research under more auspicious peace-time conditions.

## SCOPE OF PRESENT INVESTIGATION

From random sounding traverses across or merely grazing guyots an attempt will be made to construct a picture of their physical features. The data collected of the cruises of the *Cape Johnson* have been supplemented by soundings obtained from the files of the Hydro-

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graphic Office, U.S. Navy. The origin and age of the flat upper surfaces of guyots represent the main problem of this paper. Secondarily the relation of guyots to atolls of the northern Marshall Islands will be discussed.

## AREAL DISTRIBUTION OF GUYOTS

The distribution of known and suspected guyots is shown in fig. 1. Roughly they are known to occur north of the Carolines and east of the Marianas and Volcano Islands between latitudes 8°30' North and 27° North and longitudes 165° West to 146° East. None has been found west and south of the above boundaries though this area has been at least as well explored as the former. North and east of the region outlined above it appears from scattered soundings that the area containing guyots does extend to 45° North and 165° West. Some of the seamounts in the Gulf of Alaska described by Murray (1941) almost certainly are guyots whereas others appear to be of a different character. Twenty bona fide guyots were encountered at sea by the writer and some 140 more are indicated by soundings on Hydrographic Office charts and documents. Considering sparseness of deep-sea soundings in parts of the area mentioned above, it is likely that a large number of undiscovered ones are present.

## PHYSICAL FEATURES OF GUYOTS

One of the best profiles obtained across a guyot was one encountered south of Eniwetok on October 6, 1944, in latitude 8°50' North, longitude 163°10' East. This guyot is about

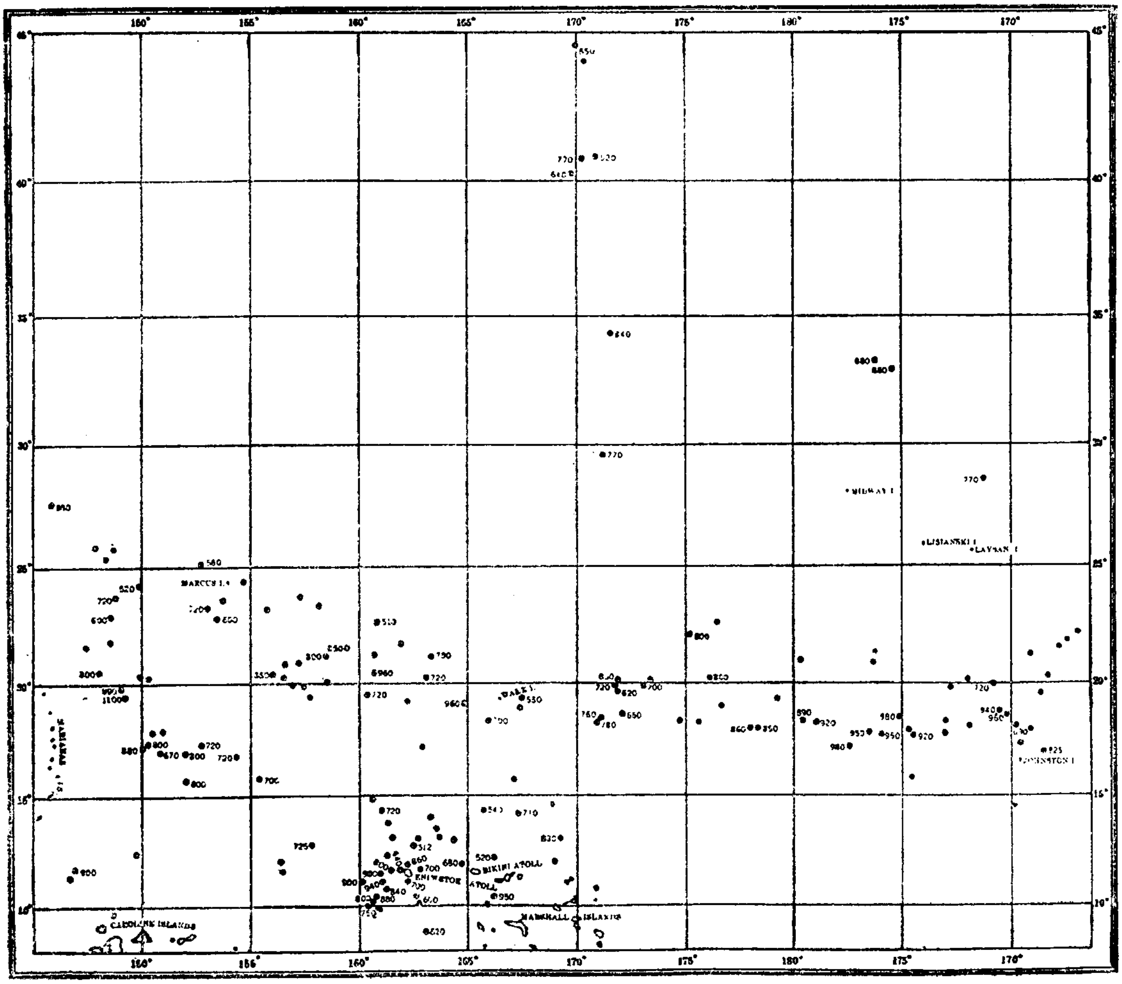


**Fig. 1**

Areal distribution of guyots in the western and Central Pacific.
The numerals next to some of the guyots indicate the depth in fathoms to the flat upper surface.

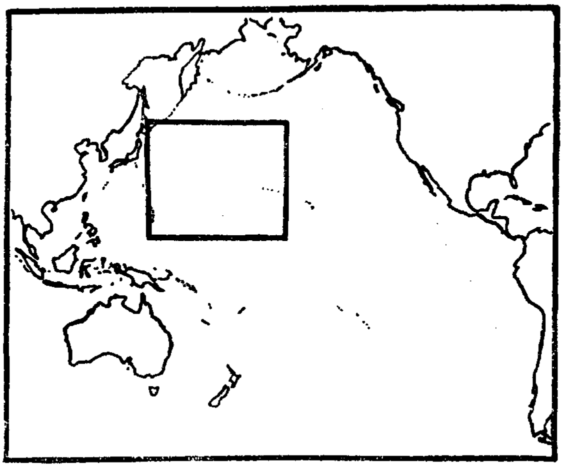

**Fig. 1 a**
Index Map showing area included in fig. 1.

35 miles in diameter at the base, and the truncated upper surface is about 9 miles in diameter. The top is remarkably flat at a depth of 620 fathoms(1). The outer rim of the top is bevelled by a gently-sloping shelf one or two miles wide (slope 2° to 3°). The outer margin of the gentle slope is about 70 fathoms deeper than the inner margin. This gentle slope breaks abruptly to 22° at its outer margin. The profile from the edge of the shelf to the normal ocean floor at 2600 fathoms is, as might be expected, concave upwards. From an average of 22° at the top it gradually decreases in steepness until it forms a smooth tangent with the ocean floor at the bottom. Figure 2 (A and B) below is a reproduction of the sounding traverse across the guyot.

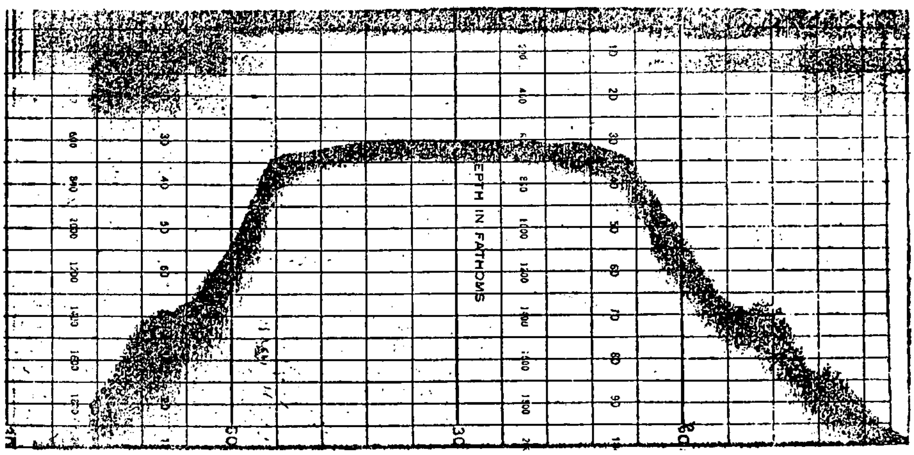


**Fig. 2 a**
Fathometer recorder trace of a typical guyot. Note irregularities on lower slopes with considerable thickening (lengthening) of the echo trace. These indicate steep slopes to the side (parallel to ship's course) and necessitate an adjustment to obtain the approximate depth immediately beneath the ship. The adjustment has been made in fig. 2 b below.

Guyots vary widely in size. One a few miles northeast of Eniwetok has a flat summit only a couple of miles across (latitude 11°45' North, longitude 162°55' East); whereas one some distance farther northeast apparently has a flat upper surface 35 miles wide and has a diameter of 60 miles at its base (latitude 14° North longitude 167°30' East). In general they appear to be circular or oval in plan. No correlation has been noted between the depths of

(1) Note: All soundings mentioned in this paper are uncorrected for salinity, temperature and pressure and were taken with fathometers set to a speed of sound in the seawater of 4800 feet per second. The corrections would be too small to be of significance in this discussion.

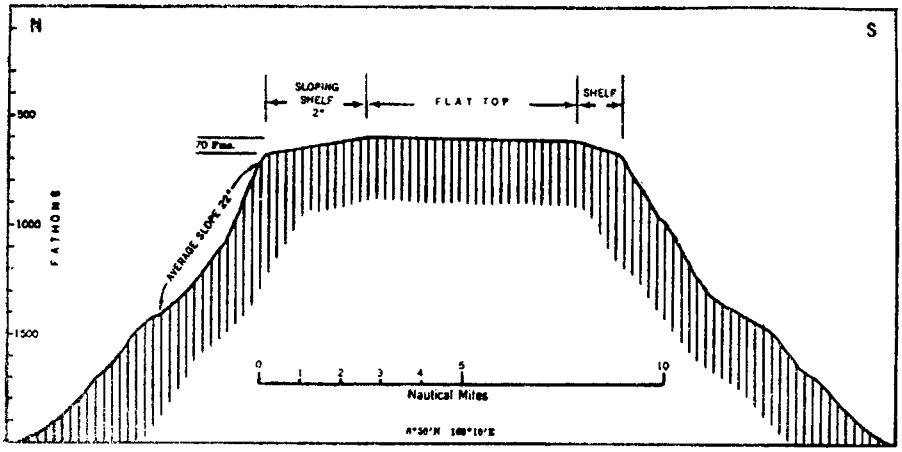


Fig. 2 b

This diagram was traced directly from fig. 2 a and adjustments, for steep slopes to the side, made. The vertical and horizontal scales and numerical values of the slopes in degrees are given.

the flat upper surfaces and the depths of the surrounding ocean floor which normally ranges from 2600 fathoms (15,600 feet) to 3100 fathoms (18,600 feet). The observed depths of the flat upper surfaces of typical guyots range from 520 fathoms (3120 feet) to near 960 fathoms (5760 feet), with most values concentrated near the centre of this group (800 fathoms). Thus the guyots rise from 10,000 to 15,000 feet above the ocean floor. The flat tops of guyots in general do not exhibit accordance of summit levels. It is quite common to find groups of guyots in a relatively small area with flat tops varying several hundred fathoms from one to another among the group. Less commonly two or three guyots in a group will have approximately the same depth.

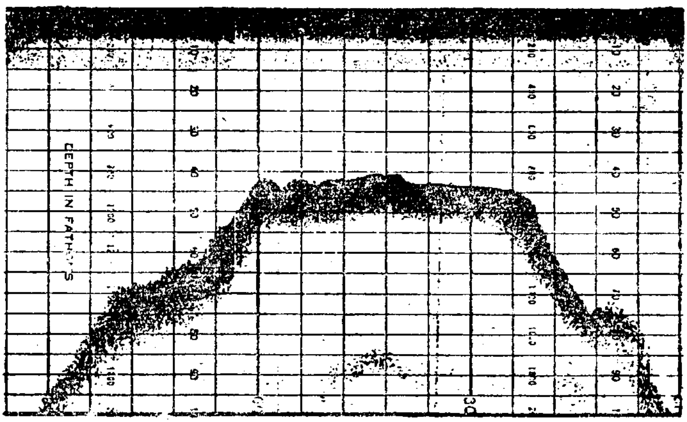


Fig. 3 a
Guyot showing hummocky type of upper surface.

A few guyots were found to have flat upper surfaces which were gently undulating rather than flat. These undulating or hummocky surfaces have a maximum relief of about 40 fathoms. In most cases the flat surface can be seen here and there in the profiles and it passes *beneath* the hummockly material (figure 3). Judging from the evidence most guyots have been swept clean of the fine sediments which must be continually settling upon them. In the case of the rare, hummocky ones it would appear that the fine precipitates had for some reason not been completely swept off. It is rather surprising that the normal guyots are swept clean since water currents at such depths as these are thought to be slight. One must look to occasional bottom stir-up by tsunami (Bucher 1940) though possibly currents related to tides might be strong enough. Once the sediment on these isolated, flat-topped peaks is stirred up, very little of it would be expected to fall back on top of the guyot. It would be dispersed over the surrounding area.

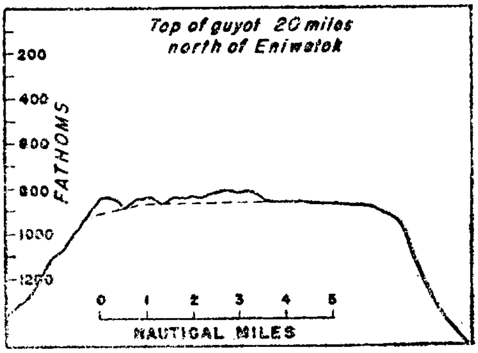


Fig. 3 b

Tracing of fathometer record shown in fig. 3 a adjusted and with scales indicated.

Though few guyots show any suggestion of terraces on their outer slopes, one large guyot near latitude 20° North, longitude 148° East has a well-developed flat upper surface at 800 fathoms and projecting from under its southeastern margin there appears to be a terrace or older guyot with a flat upper surface at 1100 fathoms. In the area between Wake Island and Johnston Island there are a number of normal guyots rising from hilly areas which have numerous flat or nearly flat surfaces between 1100 and 1900 fathoms. These hilly areas with flat or nearly flat surfaces have as yet been insufficiently explored to understand the relationships they exhibit. They may represent areas of older, deeper guyots partly buried by sediments, but until a more detailed examination of them can be made, their nature will have to remain rather obscure. Such areas do not appear to be common elsewhere. Some of Murray's Gulf of Alaska seamounts possibly also fit into this category. The great majority of guyots rise from the normal ocean floor.

## RELATION OF GUYOTS TO ATOLLS IN THE MARSHALL ISLANDS

Many guyots are present in close association with atolls in the northern Marshall Islands. The present discussion is centred about Eniwetok Atoll of that group. This atoll apparently rests in part upon two guyots so that the flat upper surfaces of the guyots project out beneath its southern and northwestern slopes resulting in a well-developed bench on those sides at a depth of 700 fathoms. The eastern side of Eniwetok shows a normal atoll slope with no suggestion of a bench, and the central portion of the western side shows similar features.

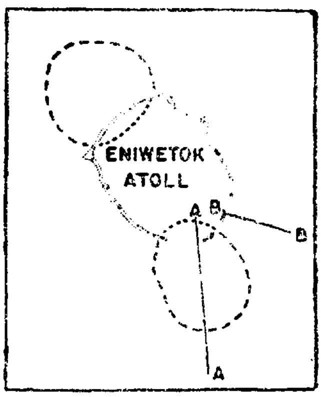


Fig. 4

Relation of Eniwetok Atoll
to two nearby guyots which are outlined on the diagram by dashed lines.

Figure 4 shows the relationship between Eniwetok Atoll and the nearby guyots, and figures 5 and 6 show two profiles, one approaching the passage between Japtan and Parry Islands from the east and the other approaching Wide Passage at the south end of the atoll from the south, which shows the guyot apparently disappearing beneath the atoll slope.

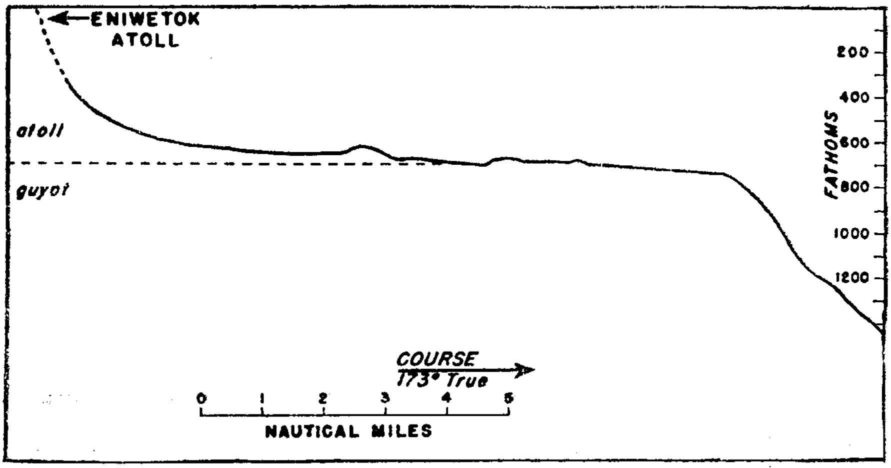


Fig. 5

Tracing from fathometer recorder of traverse extending southward from Eniwetok showing the atoll presumably superimposed upon a guyot (A-A of fig. 4).

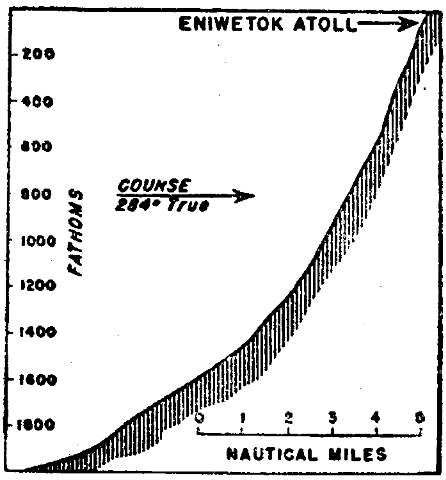


Fig. 6

Profile B-B of fig. 4, showing normal atoll slope approaching Eniwetok from the East.

The absence of a 700 fathom bench locally around part of Eniwetok Atoll strongly suggests that the atoll and its volcanic core are younger than the benches which project from its southern and northwestern sides. The whole structure of the atoll, in other words, seems to have been superimposed upon the older and already existing surface of the guyots. Since it can, without too much license, be assumed that the other nearby atolls of the Marshall group developed simultaneously with Eniwetok, their slopes might be examined for 700 ± fathom benches for further substantiation of the age relations postulated above. Only two of these have been adequately charted, Majuro and Kwajalein, and neither of them shows 700 fathom benches. When it is considered that a relatively small atoll such as Majuro shows no bench at 700 fathoms while not very far away a guyot has a truncated upper surface 35 miles across, it is evident that Majuro could never have been subjected to the conditions which planed off the 35-mile-wide surface of the guyot.

## Part II.

## THEORY

The writer has given a great deal of thought to the problem of origin of guyots since first encountering them in 1944. In Part I of this paper the physical features of guyots so far as they are known, are described. It now remains to account for them. During the past two years, many hypotheses were tried and discarded. Finally the writer arrived at the hypothesis here presented. Though it explains the facts at present available, it is highly speculative and might easily be wrong. Nevertheless, it seems worth presenting as a working hypothesis, particularly since it has many interesting ramifications some of which would be worthy of investigation even if the parent hypothesis were found to be invalid.

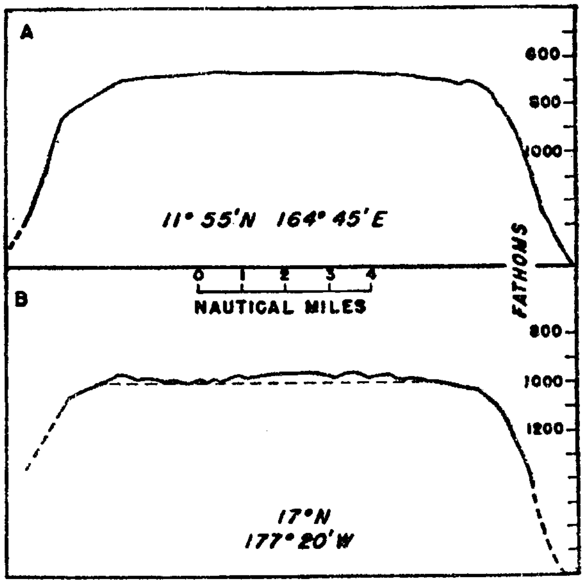


Fig. 7

Profiles accross two guyots; A is normal except that the gently sloping shelf is lacking on the right hand side, B is an example of the hummocky type of upper surface.

## EXPLANATION OF DEVELOPMENT OF UPPER SURFACE OF GUYOTS

When the writer first discovered guyots, he supposed that they were drowned atolls. However, this hypothesis proved untenable upon further study. A profile of an atoll should show a rise along the outer margin representing the area of active reef growth and should be dished in the middle, the lagoon, unless it were filled in with younger sediments. On an atoll, the profile breaks abruptly outside of the living reef and descends in slopes averaging about 25°. There is no feature comparable to the gently-sloping shelf found around the

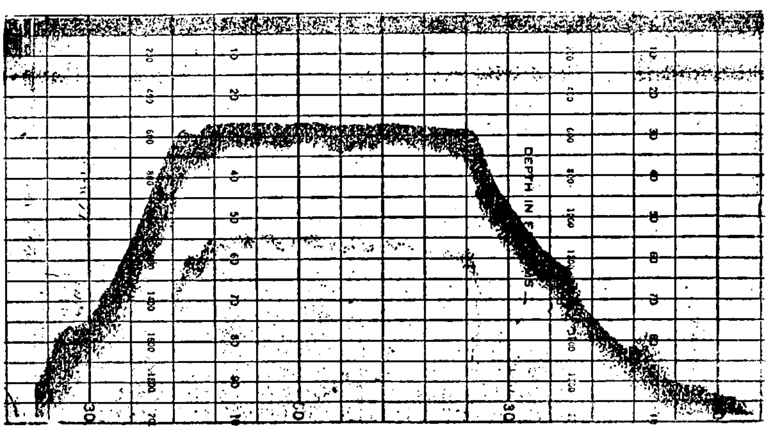

Fig. 8

Fathometer recorder trace of guyot in latitude 14°20' N., longitude 165°55, W. Ship's speed, 13,7 knots; course 059° true.

flat tops of nearly all guyots. In fact there seems to be no way of accounting for these shelves unless the guyots had developed in a sea which did not support reef-building organisms.

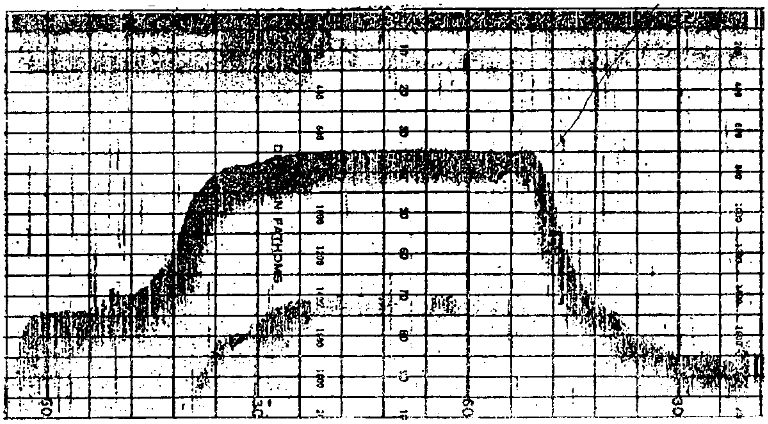

**Fig. 8 b**

Fathometer recorder trace of guyot near latitude 21° N., longitude 173° E. Ship's speed, 13,5 knots; course 059° true.

It may reasonably be assumed that guyots were originally volcanic peaks. After a long period of time they became stabilized and were eroded down to low relief. At this time they developed gently-sloping shelves around them as might be expected in the case of a maturely dissected island. This was followed by a long period of marine planation, unhampered by reef growth, ultimately forming the flat upper surfaces. If marine planation cut the island down to about 30 fathoms below sea level then the outer margin of the gently-sloping shelves, normally some 70 fathoms deeper, would have originally represented approximately a 100-fathom-curve around the island.

Possibilities of accounting for the reef-free surface of the guyots by some connection with a glacial epoch were considered and rejected. If reef-growth had been inhibited by a glacial epoch, the guyots would have had to have suffered marine planation followed by sudden subsidence to below the level at which reef growth would recommence at the end of the glacial epoch—a coincidence which makes the hypothesis very unlikely. The glacial epoch would have had to be a very long one to permit complete planation of the larger guyots. It cannot possibly be referred to the Pleistocene epoch since the Marshall Islands atolls are younger than the guyots and there could obviously not have been time for marine planation, subsidence and upbuilding of the atolls all in this short epoch aside from the inconsistency that the cold water was called upon to keep the guyot surface reef-free but later on permitted the upbuilding of the atolls.

## GENERAL RELATIONS WITHIN PACIFIC BASIN

Since it is difficult to discuss any theory of origin of guyots against the background of misconception and ill-founded theories which at present confound geologic literature on ocean basins and the Pacific Basin in particular, the writer proposes to wipe the slate clean and start on a new basis.

The Pacific Basin is here considered to comprise the central portion of the ocean and is bounded by an almost continuous belt of strong late Cretaceous-Tertiary mountain building. On the northern and western borders this belt is characterized by elongated deeps which lie over downbuckles of the Earth's Crust (2). Related island arcs show intense volcanic and seismic activity (3). On the eastern margin are found the cordilleras of the North and South American west coasts and on the south little-known Antarctica. The volcanic rocks of the islands of the Pacific Basin are dominantly basaltic whereas those related to the island arcs

(2) See the works of Vening Meinesz and others on gravity at sea.

(3) There is general agreement as to the position of the "andesite line" along the western margin of the Pacific Basin except for the area of the Carolina Islands. Some place these inside and some outside of the "andesite line". The writer tentatively includes most of the Carolines in the Pacific Basin and traces the "andesite line" down their western margin including Ulithi, Yap, Ngulu and the Palaus behind — on the west side of — the "andesite line". This is essentially the same as the line drawn by Hobbs (1944).

and their uplifted cordillera equivalents are dominantly andesitic. The area of arcs and cordilleras bordering the Basin is tectonically the most active and unstable area of the Earth's Crust to-day. The Pacific Basin itself seems to be tectonically a most stable area and possibly has been throughout geologic time (4). One encounters no evidence of folding anywhere over its broad expanse. Though fault scarps can be found their rarity bespeaks great stability. Seismic activity in the Pacific Basin is almost nil.

The writer favors Buddington's (1943) concept of the nature of the Earth's Crust and considers that the suboceanic crust probably consists of horizontally layered rocks including such types as norite, gabbro, anorthosite, pyroxenite, peridotite, dunite and probably some eclogitic facies. These are relatively strong rocks. Stronger than the granitic to quartz dioritic rocks which presumably make up the "granitic" layer of continents. The writer believes the oceanic crust is very strong though this opinion is at variance with existing text-books and much of the current literature. However, Jeffreys (1929), Daly (1940), and Longwell (1945) all favor a strong oceanic crust. The only bases for judging its strength are its behaviour and the strength of the rocks of which it is thought to be composed. Both of these indicate strength. The reason it has been generally considered to be weak, appears to be related to calling it the exposed sima or the basaltic substratum and consciously or unconsciously bringing in Daly's theory of a weak glassy basaltic substratum. But Daly postulated a strong crust and weak substratum at considerable depth. Those favoring the hypothesis of continental drift assumed a very weak basaltic crust below the oceans without, so far as the writer is aware, presenting evidence other than the hypothesis of drift to substantiate the assumption.

Many authors have correlated the observation that island arcs (and hence mountain building) develop in the ocean basins along the margins of continents with the concept that the continental massifs are strong and the oceanic crust weak, thereby accounting for the localization. However, if mountain building forces are related to convection currents within the Earth (Griggs 1939), the most satisfactory of the present theories, then the localization can more reasonably be explained on the basis of heat relations within the crust. Being warmer under continents and cooler under oceans the downward flow part of the convection cell would be more likely to be localized under the ocean and would be supplemented in some cases by the outward flow of warm material from beneath the continental area.

Having concluded that the Pacific Basin was in general strong and stable, it is now appropriate to turn to exceptions in detail to these generalities. All volcanic islands of the ocean basin proper (excluding from this discussion the highly unstable island arc areas) are subject to frequent vertical movements as long as vulcanism is active. In this sense they are unstable. The expansion during magma generation, injection of magma into the crust below the volcano, crystallization of magma and contraction, extrusion of magma from a central vent and isostatic adjustments to the load, out-flow of weak oceanic clays from beneath the volcanic load, etc., all tend to result in vertical movements of the volcanic island. Such islands may have terraces extending to hundreds of feet above sea level and at the same time have drowned shore lines and exhibit a series of submerged terraces as well. Of the hundreds of atolls and banks with their volcanic pedestals beneath them, one can find very few in the Pacific Basin which have their coral reefs uplifted by as much as 150 feet (5).

Aside from vulcanism and its effect of producing local points of instability, convection currents of lesser intensity than those producing island arcs may result in vertical movements of the suboceanic crust at times.

## HYPOTHETICAL DEVELOPMENT OF THE HISTORY OF THE PACIFIC BASIN AND THE ORIGIN OF GUYOTS

Most discussions of Pacific historical geology jam all the known history into the late Tertiary, Pleistocene and Recent ages. To be sure the rocks visible on the surface of volcanic

(4) Having obtained considerable first-hand information in the Pacific during the past few years, the writer must now revise the views expressed in Betz and Hess (1942). The tentative trend lines shown on the chart should be considerably reduced in number by eliminating practically all of north-easterly trends. Further development of the bottom topography shows that they do not exist. The hypothesis that certain linear groups of islands and shoals, particularly the Hawaiian group, lie along a major Earth fracture which may be a strikeslip fault is retained. The relationship on a small scale of the volcanic activity to fractures has been demonstrated by Stearns and MacDonald in Samoa and Hawaii. The trends of these fractures are approximately parallel to the elongation of Samoa and the elongation of the Hawaiian chain.

(5) Vening Meinesz (1941) re-examines gravity data for oceanic islands. Though large, local, positive, isostatic anomalies are found on such islands, the regional anomalies show that such small islands are regionally and not locally compensated and thus closely approach isostatic equilibrium. This indicates a geologically rapid adjustment to the disturbance of equilibrium brought about by vulcanism.

islands are mostly very young, predominantly Recent plus some Pleistocene and very rarely rocks that can be demonstrated to be as old as Tertiary. Many writers seem inclined to place Pacific atoll formation in the Pleistocene though others extend it back into the Tertiary (Stearns 1946). On the other hand the Pacific Basin is generally considered to be very old, probably dating from early pre-Cambrian time (Kuenen 1937). It seems reasonable to suppose that volcanic activity in the Pacific Basin and hence island formation has gone on sporadically since early pre-Cambrian. Where then are the pre-Cambrian, Paleozoic and Mesozoic islands ? In order to answer this it is necessary to digress along several other channels.

Any island formed in the Basin can be assumed to have begun as a volcano or group of volcanoes. After vulcanism ceased and the island had become stabilized, the following sequence of events would necessarily take place. The island would be eroded to low relief, and after a long period of time (providing growth of reef-forming organisms did not interfere) the island would completely disappear as a result of marine planation. Such must have been the fate of all pre-Cambrian islands before reef-forming organisms existed.

Kuenen (1937 and 1941) has concluded that there has been little change of sea level since early pre-Cambrian time. He estimated that the rate of sedimentation in the deep sea is approximately 1 cm. in 10,000 years for red clay, since the end of the pre-Cambrian, and 1 cm. in 5,000 years for globigerina ooze. Since most of the material deposited on the ocean floor has ultimately come from the continents, isostatic adjustment of the load on the sea floor and the loss of weight on the continents has resulted in the sinking of the former and rise of the latter so that relative sea level with respect to the continents has not changed very much. One obviously cannot put a layer of several thousand feet of sediments into the oceans without causing the water to rise by an equivalent amount (less the water included in pore space in the sediments). Thus, quite apart from the discussion of isostatic adjustment mentioned above, every centimetre of sediment put into the ocean causes sea level to rise with respect to an oceanic island by just a little less than a centimetre (less by the amount of water in pore space of the sediment). Even though the figure cited for the rate of sedimentation may be inaccurate it nevertheless follows that oceanic islands are and have always been slowly sinking relative to sea level.

It stands to reason that once lime-secreting organisms appeared in the oceans, presumably in Cambrian time, they would grow upon any available shallow, wave-cut platform and both tend to protect it from further wave action and build it up to sea level. These reef-forming organisms need not have been very efficient reef builders to keep pace with a settling rate of 1 cm. in perhaps 5,000 years. So that beginning in Cambrian time every island in warm seas which at that time had not been submerged below the level at which these organisms could live, would be built up to sea level or nearly to sea level and could henceforth maintain its growth. In other words all Paleozoic, Mesozoic and Tertiary islands which were eroded to low relief and submerged in warm seas must inevitably become banks or atolls and be maintained as such throughout the remainder of geologic time except for the interference of some rare diastrophic accident. Epochs of glaciation might inhibit growth of reef-forming organisms temporarily. But these epochs are too short to permit the islands to sink to such a level that growth would not recommence with the return of warmer water.

We may now turn to the ultimate objective of this long series of digressions, the guyots. It is proposed that they represent the relics of pre-Cambrian islands formed by the processes suggested above. The group of guyots with which we have been mainly concerned range from 520 to 960 fathoms (3120 to 5700 feet) below sea level. Accepting Kuenen's figures for accumulation of sediments, at least 2000 feet of sediments (solid) would have been deposited in the deep sea since pre-Cambrian time. The great bulk of sediments, however, are deposited along continental margins, on the shelves, slopes and shallow epeiric seas. It is almost impossible to estimate the amount of water displaced by these inasmuch as a thickness of tens of thousands of feet may displace only a relatively small amount of water since the bottom of such basins of sediments tend to sink isostatically under the load. These thick prisms of sediments may at a later time be deformed and welded to the continents, thereby enlarging the continents at the expense of the oceans. Certainly these processes have decreased the areal extent of the oceans a considerable if unpredictable amount since the end of the pre-Cambrian. If sediments deposited in shallow waters around the continents displaced only half as much water as deep-sea sediments, an estimate which seems to the writer to be on the conservative side, then one could account for a rise of sea level relative to an oceanic island of 3000 feet (500 fathoms) since the end of the pre-Cambrian which is comparable to the present depth of the shallowest guyots. Thus we might attribute most guyots to a Proterozoic episode of vulcanism. The occasional, less well-preserved surfaces mentioned in the text, having depths between 1100 and 1900 fathoms might be older and well back in the pre-Cambrian in age.

## RECOMMENDATION FOR FUTURE RESEARCH

With above hypotheses in mind it would be exceedingly interesting to dig a hole 5000 feet deep in the centre of a Pacific Basin atoll. It is necessary to avoid the outer margin of the atoll since it may well have built outward over its own debris. From another point of view, a hole drilled on the southern rim of Eniwetok would almost certainly penetrate into the underlying guyot at a depth of approximately 4200 feet. It would be extremely interesting also to make magnetic surveys of a number of atolls to estimate the depth to the volcanic core and perhaps couple such an investigation with seismic and gravimetric work. Bottom samples with the piggot sampler taken from the flat tops and gentle marginal slopes of guyots might bring up some of the rock of which they are formed, provided these surfaces had been swept completely clean of sediments. Pleistocene to Recent banks in high latitudes where cold water would inhibit growth of reef-forming organisms should be investigated to compare their profiles with those of the guyots. A further investigation of Murray's seamounts in the Gulf of Alaska might furnish some of the missing clues to the origin of guyots, and might, if the hypothesis here presented is correct, show features exactly comparable to guyots but at depths shallower than 500 fathoms. At the latitude of the Gulf of Alaska the water may have been too cold for reefs to grow on the platforms.

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