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COMPARISON OF THE GEOLOGY OF THE SOCIETY AND THE HAWAIIAN ISLANDS

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FIGURE 1.—Huge blocks of rock in Tainuu Marae on Raiatea Island. The gray blocks are reef limestone quarried from the fringing reef. The brown blocks are natural partly weathered slabs of trachyte. Photo by H. T. Stearns.

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*Volume XXIV of the Occasional Papers is published in honor of Edwin H. Bryan, Jr., whose service to Bishop Museum began in 1919. He was for many years Curator of Collections, and at present is Manager of the Museum's Pacific Scientific Information Center. A Symposium, at which several of the papers in this volume were read, was held at the Museum on April 13, 1968, honoring Mr. Bryan on the occasion of his 70th birthday.

THE SOCIETY ISLANDS are located in the southern Pacific Ocean, 2,730 miles south of Hawaii (Fig. 2). They comprise nine volcanic islands and five coral atolls stretching for 400 miles along two fissures in the earth's crust between latitudes 15° and 18°S., and longitudes 148° and 155°W. The fissures have nearly the same directional trend as the 1,600 mile long fissures on which the Hawaiian Islands lie. The principal islands are Tahiti and Moorea, the windward islands, and Raiatea, Tahaa, Tetiaroa, Huahine, Borabora, and Maupiti, the leeward islands (Fig. 3). The remaining islands shown in Figure 3 are atolls. All are in the belt of the trade winds which blow from the southeast. Although usually rain falls nearly every day, a severe drought occurred between October, 1972, and March, 1973. Fires had burned on many of the ridges to elevations of 2,000 feet above sea level on the major islands leaving them brown and devoid of vegetation. The ridges to that elevation chiefly support staghorn fern which is highly inflammable when dry. A drought also occurred at the same time in Hawaii. Table 1 gives the principal geographic data regarding the islands.

The writer visited the islands in January, 1973, and was fortunate to have the company of John Mink and Michael Becker. The former is a consultant on water supplies on Borabora and the latter was the resident geologist with the Bureau of Public Works in Tahiti. Mink kindly criticized the manuscript. Deneufbourg (1960-1965) mapped the geology of six of the islands.

TABLE 1

GEOGRAPHIC DATA FOR THE SOCIETY ISLANDS*

ISLAND	AREA (sq. miles)	ALTITUDE (ft.)	ALTITUDE (m.)	POPULATION**	PRINCIPAL TOWN
Tahiti	402	7,337	2,237	100,000	Papeete
Moorea	51	3,960	1,207	5,000	Papetoai
Huahine	183	2,233	680	2,900	Fare
Raiatea	111	3,380	1,033	6,500	Uturoa
Tahaa	32	1,934	590	3,500	Vaitoare
Borabora	15	2,379	725	2,200	Vaitape
Maupiti	9.6	698	379	658	Vaiea
Maiao	5	525	160	2.8	—
Mehetia	0.8	1,494	455	0	—

*Data supplied by Edwin H. Bryan, Jr., the Tahiti Tourist Board, and Chevalier (1974).

**The 1971 census gives a total of 120,000 people in the islands.

VOLCANIC DEVELOPMENT

The Society Islands are highly dissected, deeply submerged and weathered, basaltic volcanoes. All the main volcanoes are nearly equal in age, probably having been built above sea level in the late Pliocene or early Pleistocene. Potassium-argon (K/Ar) ages indicate that Tahiti-nui is about 650,000 years old,[1] Tahiti-iti about 480,000, and Moorea about 1,650,000 (Dymond, 1975). Intrusive rocks from the center of the volcano of Tahiti-nui reach ages of 11 million years ± and 30 m.y. (Krummenacher and others, 1972). The oldest rocks in the main Hawaiian Islands are 5.6 m.y. old (Stearns, 1966, p. 75). The most conspicuous difference between Hawaii and the Society Islands is the lack of active volcanoes in the latter. The next most obvious difference is the greater stream dissection and the greater submergence of the Society Islands. All the bays there are deeply drowned river valleys, but some are influenced by faults and calderas. The ocean crosses Huahine Island completely over the pass that formerly separated two valleys from which streams drained into the sea on opposite sides of the island.

Most of the lava flows are typical thin-bedded pahoehoe and aa basalts, usually 20 feet or less in thickness. Many carry olivine phenocrysts, as they do in Hawaii, but all are alkalic basalts. If tholeiites exist they must be deeply buried in the volcanoes. Alkalic basalts occur only in the caps of extinct Hawaiian volcanoes. The lava beds dip 5° to 10° seaward from the eruptive centers and many islands have deeply eroded calderas. The islands closely resemble West Maui in Hawaii. The cause of the relatively steep dips in the lava flows is puzzling unless the flows veneer steep ash cones formed by explosions before the original cones reached sea level. The flows were too liquid to pile up at such steep angles.

All the volcanic islands have gone through the eight stages shown in Figure 4 to reach their present form, as have the Hawaiian Islands. All five atolls are in the eighth stage. Pillow lavas, indicative of lavas flowing over wet ground or erupting under water, have not been found. Stark and Howland (1941) reported pillow lavas on Borabora, but the writer visited their locality and found the outcrops to be typical bulbous subaerial pahoehoe (Fig. 5). The absence of pillow lavas indicates that the islands were formed subaerially, in sharp

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[1] This age is too young based on the date of about 440,000 years for the posterosional lava flow in Papenoo Valley (Becker and others 1974). Krummenacher and Noetzlin (1966) give 1.4 m.y. as the age of Tahiti-nui.

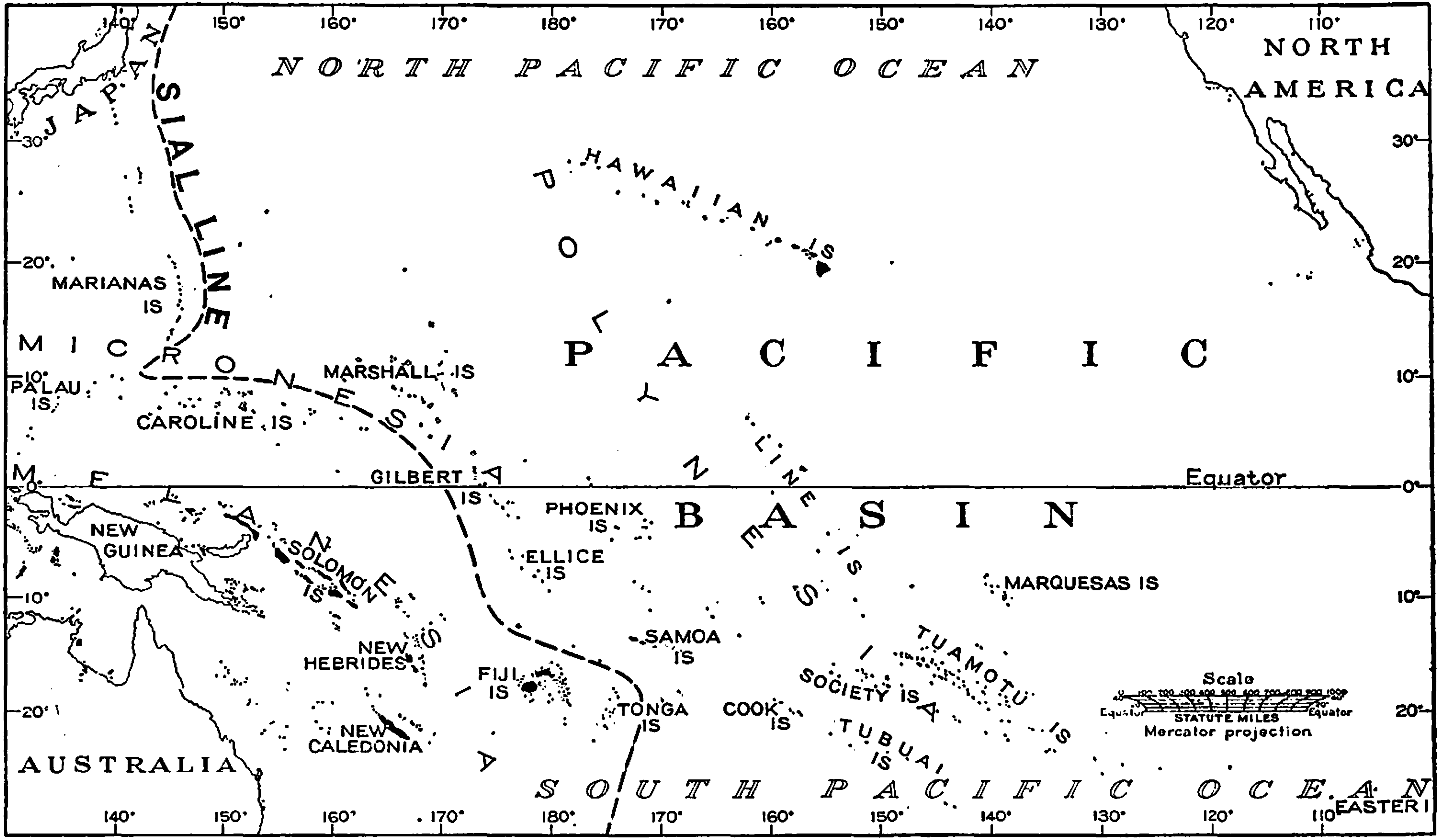
NORTH PACIFIC OCEAN
NORTH AMERICA
JAPAN
SIAL LINE
MARIANAS IS
MICRONESIA
PALAU IS
CAROLINE IS
MARSHALL IS
GILBERT IS
HAWAIIAN IS
POLYNESIA
PACIFIC BASIN
LINE IS
PHOENIX IS
ELLICE IS
MARQUESAS IS
Equator
NEW GUINEA
MELANESIA
SOLOMON IS
NEW HEBRIDES
NEW CALEDONIA
FIJI IS
SAMOA IS
TONGA IS
COOK IS
SOCIETY IS
TUAMOTU IS
TUBUAI IS
AUSTRALIA
SOUTH PACIFIC OCEAN
EASTER I
Scale
STATUTE MILES
Mercator projection
140° 150° 160° 170° 180° 170° 160° 150° 140° 130° 120° 110°
30° 20° 10° 0° 10° 20°

FIGURE 2.—Map of the Pacific showing the Society Islands. The islands west of the Sial line are Sialic (continental) islands and those to the east are Simatic (oceanic) islands. "Sial" is a word coined from silica and alumina, and "Simatic" from silica and magnesia.

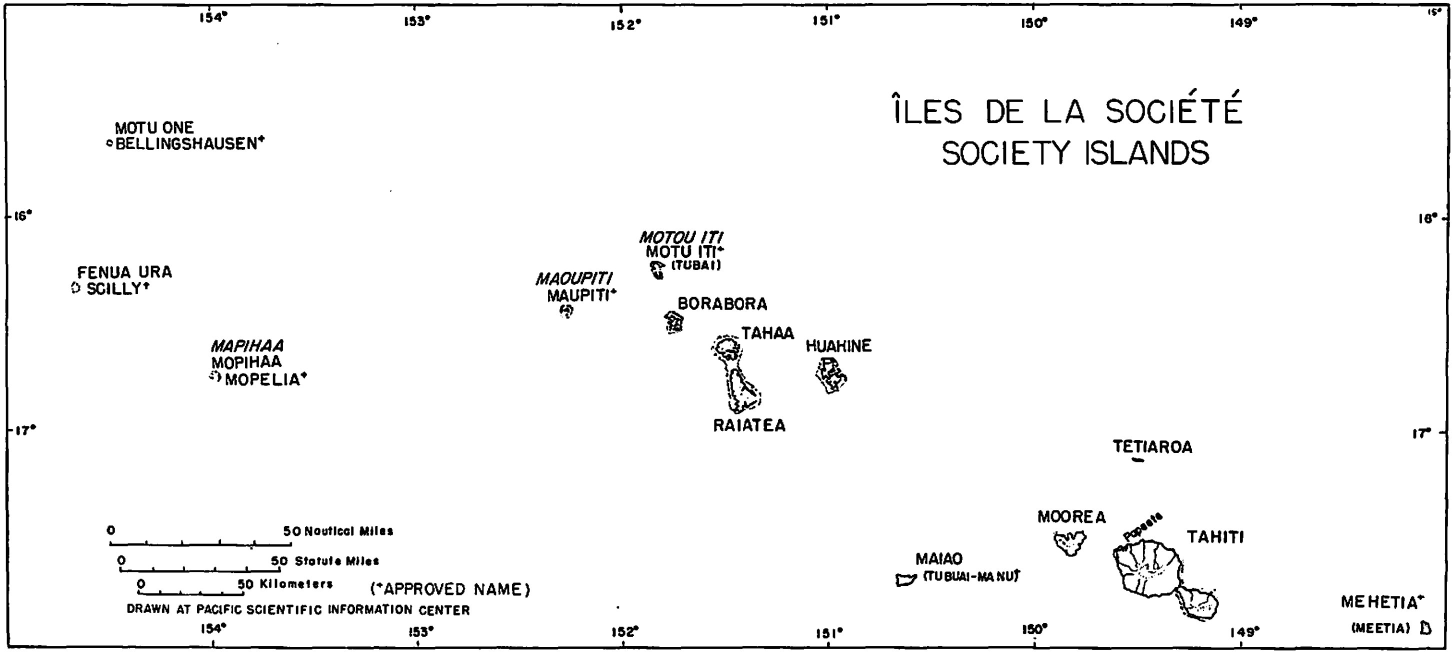

FIGURE 3.—Map of the Society Islands by Edwin H. Bryan, Jr.

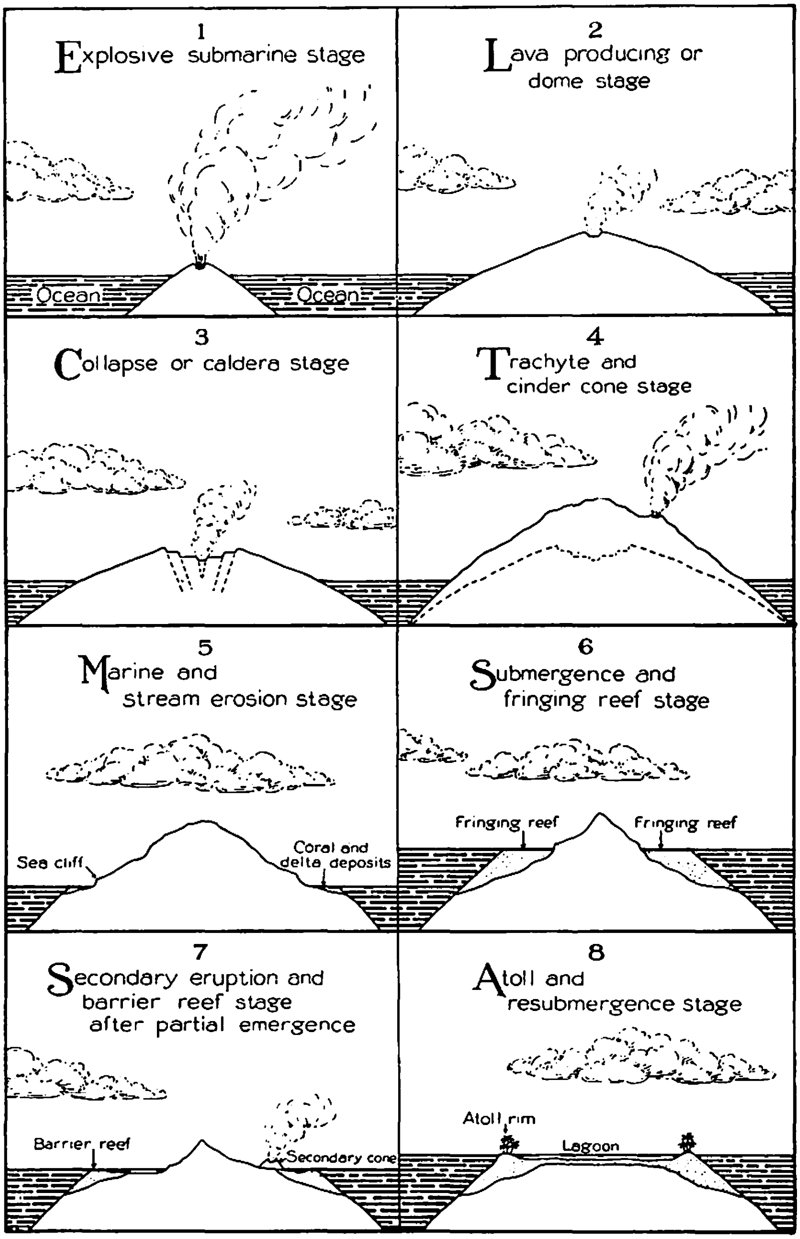

FIGURE 4.—Eight stages in the geologic history of a typical volcanic island in the central Pacific.

contrast to Sialic islands in the Pacific which were mostly formed under the sea and later uplifted.

The lavas of Tahiti-iti overlap Tahiti-nui; hence they are later. This was shown by a hole drilled on the isthmus connecting them which penetrated coral sand 264 feet below sea level beneath Tahiti-iti lava (data supplied by M. Becker).

Calderas, even though deeply eroded, are easily recognized, as in Hawaii, by the presence of secondary minerals in the vesicles of the lavas and by radiating dike zones and rocks which cooled in subjacent plugs. The basaltic dikes average about 2 feet across as in Hawaii (Fig. 6) but the andesite and trachyte dikes are wider. One diabase dike 100 feet across was described by Stark and Howland (1941) on an islet off the coast of Borabora. Large intrusive bodies in the caldera of Tahiti-nui yield diverse rocks, some of which are not found elsewhere in the central Pacific. The most unusual are nearly white nepheline syenite and nepheline gabbro with pegmatitic veins an inch or so across. The petrology of the islands has been studied extensively (Lacroix, 1927; Williams, 1933; McBirney and Aoki, 1968). Cobbles of porphyritic ankaramites with augite crystal ½-inch across are common in Papenoo Stream, which drains the caldera. Except on Tahiti, streams carrying basaltic boulders and cobbles to the coast are scarce, in contrast to Hawaii, where such streams are numerous on the high islands.

It is believed that the fourth stage in Figure 4 was shorter-lived in the Society Islands than in the Hawaiian Islands, indicating that cones and stubby flows of the andesite and trachyte phase were of insufficient volume to bury the calderas. Differentiated lavas may not have erupted on some islands. The most prominent trachyte flows are on Raiatea where they are exposed as light gray ridges. They also occur on Tahiti, Moorea, and Huahine. The Hawaiian and Society Islands lack interbedded soils and ash beds in the lavas that built the domes.

Two late Pleistocene cones exist on Tahiti-nui and three on Tahiti-iti. The Taharaa Hotel is built on the most prominent cone on Tahiti-nui where sections of the cone have been left exposed in the corridors. On the bottom floor, a very vesicular basaltic dike 2 feet wide, cutting through layers of red cinders and beds of lithic vitric tuff, may be seen. Exposed along the black sand beach below the hotel is a massive fine-grained crater fill of basalt. A similar but smaller exposure of a late cone is adjacent to the Bel Air Hotel at Tataa Point. Coral fragments in the tuff are common. The corals are

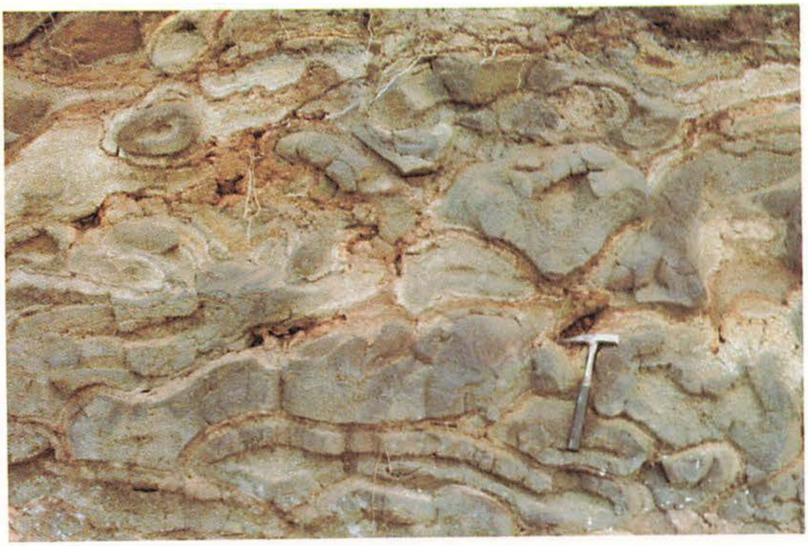

FIGURE 5.—Typical subaerial bulbous pahoehoe basalt, Raiatea Island. Photo by H. T. Stearns.

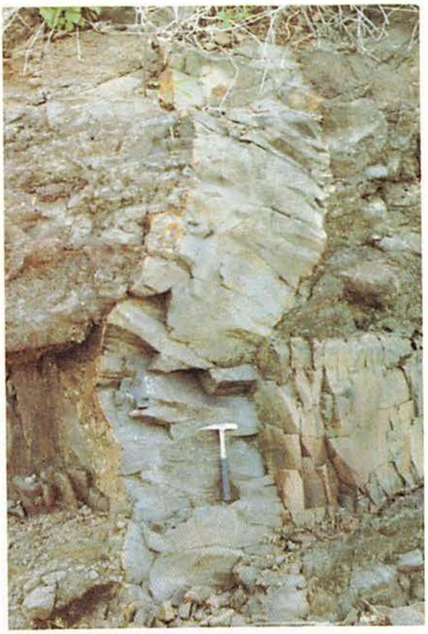

FIGURE 6.—Basaltic dike crossing a sill in Borabora. Photo by H. T. Stearns.

not living today (Williams, 1930, p. 48). The striking difference between the hydromagmatic cones in Tahiti and those on Oahu is that the former are smaller and they have an abundance of thick beds of cinders and thin beds of lithic vitric tuff. The magma started exploding as it reached the surface but insufficient water rushed into the vents to keep the magma explosions continuous. Thus, cinders and flows were produced with only intermittent explosions producing lithic tuffs. The youngest lava flows, reported to be only a few thousand years old, are on Meetia.

Williams (1933, p. 47) says the parasitic or secondary cones are along the coast because the magma was "no longer capable of rising into the tops of the central conduits a mile or more above" the shore. This explanation is not valid; magma has no trouble reaching the top of Mauna Loa volcano in Hawaii at an elevation of 13,679 feet. Also secondary eruptions occurred in the center of Tahiti-nui, as shown by the thick agglomerates in the major valleys. Secondary explosions are caused by the entrance of seawater into vents thereby building tuff cones.

Tahiti passed through Stage 7 (Fig. 4), but it is not known how many of the other islands had secondary eruptions. It is believed that the nephelinitic lava flows belong to posterosional eruptions, as in Hawaii.

AGGLOMERATE

The most unusual volcanic rocks in Tahiti are the agglomerates in the major valleys draining the caldera. They are described briefly by Williams (1930) as lahars or mudflows, but they are very unusual volcanic features in Simatic islands. One huge mudflow is known on Maui (Stearns and Macdonald, 1942) and others on Kauai (Macdonald and others, 1960) but none of these in Hawaii appears to relate to volcanic eruptions except one on Oahu (Stearns and Vaksvik, 1935, p. 124) and another extensive one on West Maui discovered during test drilling by the writer in 1975. A microscopic examination by G. A. Macdonald of a core furnished by Becker from a bore hole in Papenoo Valley in Tahiti shows that the agglomerate has a tuffaceous matrix filled with mixed volcanic ejecta, mainly caldera rocks and some waterworn pebbles. Agglomerates are not cut by dikes.

Agglomerate is well exposed in Punaruu Valley. It is a hard rock and forms boulders 4 feet in diameter in the alluvium on the valley floor. It outcrops as wedges veneering the valley walls, and as a thick high valley fill about 1½ miles upstream from the mouth. It is obvious that the valley had been cut to its present shape before the agglomerate was emplaced. About ½ mile upstream on the north side of the valley wall it has a thickness of 150 feet and has prominent bedding dipping about 30° toward the valley floor. The lowest bed contains numerous waterworn boulders 1 to 2 feet in diameter. Toward the top of the outcrop the blocks decrease in size, but occasional large blocks occur.

The agglomerate indicates that gigantic and voluminous hydromagmatic explosions in the ancient caldera in the head of Papenoo Valley occurred in the late Pleistocene. A deep blanket of ejecta must have once covered most of the interior of the island. Subsequently it was washed from the sharp interstream divides into the valleys draining the interior. The agglomerate is at least 350 feet thick in Punaruu and Papenoo Valleys. A valley 500 feet deep was cut into the agglomerate and later filled with a dense nephelinite-melilite basalt flow as shown by drilling at the damsite in Papenoo Valley (Fig. 7). The basalt has a K/Ar age of about 440,000 years (Becker and others, 1974) and is analogous in age and chemical composition to the valley-filling basalts of the Honolulu volcanic series on Oahu. The water necessary to cause the explosions must have been stored between the dikes in the caldera area or in a crater lake. The water supply probably was similar to that which caused the great explosions in Kilauea Volcano in 1924 (Stearns, 1946, p. 44).

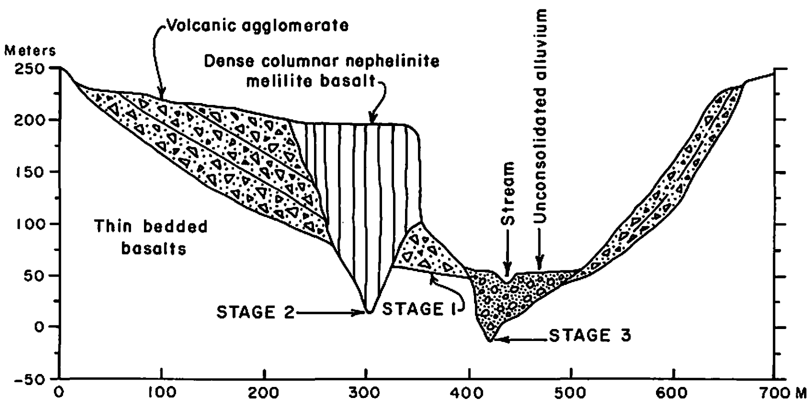

FIGURE 7.—Geologic section of Papenoo Valley at the damsite (after Becker and others, 1974).

The agglomerate in Punaruu Valley contains fragments of very diverse rocks but notably caldera rocks with the vesicles filled with white secondary minerals. Dike fragments, cinders, clinker, flow basalt, and pebbles are abundant. No clay, soils, or stratified ash beds were observed in the agglomerate. Sorting of the debris is virtually absent but bedding planes 3 to 10 feet apart are present in Punaruu Valley.

GEOMORPHOLOGY

Amphitheater-headed valleys, so characteristic of the Hawaiian Islands, also characterize the major valleys in the Society Group. One of the scenic tourist stops is the short Valle de Faarumai, a typical amphitheater-headed valley with three main waterfalls, about 200 feet high, and several smaller ones. The water probably comes from a zone of saturation confined by dikes. The dissection is more advanced in the Society Islands than in some of the Hawaiian Islands, perhaps because of higher rainfall. The valleys are more closely spaced, causing the interstream flow slope remnants to be narrower and shorter. They are called "planezes" in Tahiti. Weathering to a depth of 50 feet is common but the soil is thinner than in Hawaii because of erosion. The weathered rock is called "mamu" in Tahiti.

Older alluvium, so common in the large valleys in Hawaii, is present in much smaller quantities in the Society Islands. It is later than the agglomerate in Punaruu Valley. A prolonged drought during the writer's visit caused exceptionally low flow in the streams, which are all spring-fed. Agriculture is practiced on very steep slopes where the soil would be washed away in a few years in Hawaii. This indicates that the storms in these islands are less torrential than those in the Hawaiian Islands.

MARINE HISTORY

The most striking features, seen from the air, are the large bays occupying deeply drowned valleys and the barrier reefs enclosing deep blue lagoons. The upward growth of coral reefs barely kept up with subsidence, even in the Pleistocene. The extensive littoral plains, usually covered by coconut trees and consisting of black soil mixed with coral fragments, indicate a very late emergence of about 5 feet. This corresponds to the height of the sea when the 6-foot bench described by Williams (1933, p. 23) was cut. A pronounced nick point is present at about 5 feet above sea level at the base of the 25-foot terrace. Coral at 0.8 meter above sea level on Mopelia Atoll is 3,450 years old (Guilcher, 1969). This is correlative with the Kapapa 5-foot stand on Hawaii (Stearns, 1974).

The 25-foot terrace is correlative with the Waimanalo terrace in Hawaii formed during the Sangamon interglacial epoch about 120,000 years ago. Although emerged reefs are common on Oahu at this level, no emerged reefs at any level were found in the Society Islands. The next higher terrace is about 40 to 60 feet above sea level. The slopes above this level are not terraced nor is the soil washed away as would have happened during the pre-Yarmouth interglacials. This suggests that submergence has been in progress throughout most of the Pleistocene, in contrast to Hawaii, which has been stable during the latter part. Marshall (1913, p. 282) reports having been told that there were coral deposits at 300 feet elevation on Moorea but the writer could not find them. White, weathered outcrops of trachyte were seen by the writer, which might have been mistaken at a distance for coral.

Many of the islands are surrounded by narrow barrier reefs, some of which have low islands on them. The barrier reefs take the brunt of the waves and have coral cobbles and beachrock on them. The fringing reefs are more abundant than in Hawaii and are covered with flourishing corals, algae, and mollusks. Limestone blocks 6 feet wide, 10 feet long, and 12 to 18 inches thick were quarried by the Polynesians from the fringing reefs and stood on end to form marae, or temples (Fig. 1). No one knows how these people were able to quarry and move such large blocks from the reef. One of the blocks contains a single huge coral head. The Tainuu Marae on Raiatea contains huge trachyte blocks, but they were not quarried.

The abundance of barrier reefs, in contrast to Hawaii, is puzzling. Possibly subsidence was so rapid, until the late Pleistocene, that the rapidly growing reefs were able to keep up to the ocean surface as the sea rose eustatically, whereas in Hawaii growing conditions for coral were less favorable. Drilling at Ewa, Oahu, showed that an extensive barrier reef existed there seaward of the present shoreline during most of the Pleistocene (Stearns and Chamberlain, 1967). The deep lagoons behind the barriers indicate rapid submergence. At the present time the sediments from waves pounding on the barriers are carried across them and dropped into the lagoons where the water is too deep for the debris to be moved shoreward. Consequently coral sand beaches are scarce on all the islands surrounded by barrier reefs. Many beaches that exist are full of shells and large fragments of

Figure 8.—Coral reef growing on basalt at Mahaena, Tahiti. Photo by H. T. Stearns.

Figure 9.—Horizontal wells yielding water from a dike complex in Fautaua Valley, Tahiti. Photo by Michael Becker.

staghorn coral which are sharp to walk on barefooted. Only at Mahaena on Tahiti, where a wide pass in the barrier reef occurs, did the writer see large blocks of limestone piled up along the shore. Broken coral boulders and coral cobble beaches so typical of typhoon-swept islands are missing, probably because the barrier reefs surrounding the islands take the brunt of the waves of tropical storms. It was surprising to see house sites being developed on the fringing reef by simply building a loose cobble wall 1½ to 2 feet high and then filling the enclosure with dirt trucked from nearby ridges. Such low fills would not survive a single storm in Hawaii.

The high barren sea cliffs cut in basalt, such as characterize Hawaiian coasts, are not found in the Society Islands — further evidence that the islands have been subsiding until such a late time that most cliffs are deeply drowned. However, abandoned sea cliffs 600 to 900 feet high were noted along the southwest coast of Tahiti and on Moorea with fairly fresh basalts exposed in them. The writer believes Davis (1928) was correct in attributing them to wave action when the islands stood higher.

Williams (1930, Fig. 7) showed a photograph of a reef under basalt flows at Mahaena on Tahiti which would mean the lavas there rest on a reef basement. The writer found the outcrop shown in the photograph (Fig. 8) and also found that the coral appears to go under the basalt but really does not. It is alive and forms a veneer only a few inches thick.

A professional diver on Raiatea reports a well-developed notch at minus 60 feet in the fringing reef, a level also observed by Becker on Tahiti. This level is among the youngest of the submerged shorelines on Oahu (Stearns, 1974). Another platform at minus 150 feet is reported also. It is similar in depth to one in Hawaii.

WATER SUPPLIES

Papeete obtains its main supply from dike-confined water. Horizontal wells drilled into the dike complexes at the head of Fautaua Valley and equipped with valves have excellent yields (Fig. 9). Ten wells in this valley yield more than 5,000 gallons per minute. Dug wells are scarce, and the natives still obtain water from streams. Papeete plans to build a $40,000,000 dam in Papenoo Valley for both power and water supply. All the present power comes from diesel generators. Drilling indicates that the reservoir will hold water because it lies entirely within impermeable agglomerate.

Drilled wells up to 130 feet deep have been successful in recovering 10 to 40 gallons per minute from the decomposed zone called "mamu" on Borabora. So many dikes cut across the island that yields are very low in the intervening basalts. This same condition was found in the Waianae Range, Oahu (Stearns, 1940, p. 17).

The islands lack thick sedimentary caprocks along the shore, which are present in Hawaii. The caprock causes a thick Ghyben-Herzberg lens of artesian water on Oahu, and a voluminous water supply (Stearns and Vaksvik, 1935, p. 65).

ROAD METAL

All the roads on the outside Society Islands are made of reef detritus dredged from the fringing reefs. A roadway is built 18 inches above tide for the dragline to move onto the fringing reef, and the coral debris is hauled by trucks and dumped on the roads. The material compacts rapidly under traffic and cements by rainfall. It makes a satisfactory road for light traffic. The road around Tahiti is paved with asphaltic concrete. The only batching plant is in Punaruu Valley where basaltic cobbles are crushed for aggregate.

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