Gravity Relations in American Samoa and the Society Islands[1]

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BECAUSE OCEANIC ISLANDS in general have an underlying volcanic platform which can be expected to include a primary feeder pipe containing recrystallized magma, the gravity field observed will reflect both the topographic mass effect of the platform rising from the sea floor and a contribution from the feeder pipe presumably having a filling of denser material. Certainly the early study of Oahu by Woollard (1951) shows that the pipe contribution can amount to more than +100 mgal. To satisfy such a high anomaly requires a density contrast of about 0.5 gm/cc. As there is a geologic restriction on the density of both the platform material and that filling the pipe, one is forced to postulate mantle-like material with a density of about 3.3 gm/cc near sea level in the pipes where such high local anomalies occur. The Bouguer anomaly in such pipe areas often exceeds +300 mgal. If there were no difference between the density of the pipe filling and that of the platform, the anomaly would be only about +200 mgal.

The absolute value of the Bouguer anomaly and the local gravity gradient, therefore, have considerable geologic value, and presumably could be diagnostic in the study of the distribution of tholeiitic basalts, such as are found in Hawaii, and the more alkalic basalts, such as are found in the Society Islands, because there is a significant difference in their respective density values. This is especially important since recent work, such as that of Engel and Engel (1964*a*, 1964*b*), has led to the proposal that the major part of all oceanic island platforms is composed of tholeiitic basalt with only a veneer of alkalic basalt on the islands.

To test this hypothesis the writer carried out a series of gravity studies in American Samoa and the Society Islands, where the predominant lavas at the surface appear to be alkalic basalts, for comparison with the data from the Hawaiian Islands. The table of principal facts is reported elsewhere (Hawaii Inst. Geoph., 1965, Table 10).

MEASUREMENTS IN AMERICAN SAMOA

The Samoan Islands form a chain trending east to west between 169° and 171° W, at about 14°30′ S. They are situated north and slightly east of the Kermadec-Tonga Trench and lie on the oceanic side of the Andesite Line as defined by Macdonald (1949).

From west to east the islands are Tutuila, Ofu, Olosega, and Tau. During July and August 1964, 130 gravity stations were established on these islands, through the use of a Worden gravimeter No. 366. All data are based on the absolute gravity value, at the Hawaii Institute of Geophysics, of 978.9562 gal, as determined by Woollard (unpublished).

Tutuila

Tutuila is the largest island of the Samoan group and covers an area of 54 sq miles. The water increases uniformly to normal oceanic depths north and south of the island, while underwater ridges extend to the east and west. The island is surrounded by fringing coral reefs. Surface geologic investigations show alkalic and tholeiitic basalts, with minor amounts of quartz trachyte and andesite. The highest elevation, atop one of the quartz trachyte plugs, is 2141 ft. A major caldera is situated in the center of the island and extends 6 miles east to west and 3 miles north to south, as determined by Stearns (1944). Well-developed rift zones extend northeast and southwest from the caldera area. The age of the volcanics is estimated to be late Pliocene or early Pleistocene. A brief summary of the geologic history of Tutuila I. as given by Stearns (1944) follows:

[1] Hawaii Institute of Geophysics Contribution No. 97.

1. Outpourings of tholeiitic basalts along a major rift zone.
2. Volcanic activity subsides.
3. Explosive volcanic activity increases with outpourings of andesitic basalts.
4. Collapse and burial of the crater.
5. Period of submergence followed by emergence.
6. Renewed volcanic activity with small outpourings of alkalic basalts to recent times.

The Bouguer gravity anomaly map (Fig. 1) in general corroborates Stearns' conclusions. As the Bouguer anomaly values vary from +233 on the southeast to +293 near the center of the main caldera area, they are very similar to those found in Hawaii. Stearns advocated a single large caldera in the vicinity of Pago Pago, whereas the present gravity survey suggests there may be two separate areas of eruption within the area of this single large caldera. However, because of the ruggedness of the jungle terrain and lack of time, it was not possible to make a firm case for this hypothesis. The secondary caldera proposed by Stearns near the eastern end of the island is not substantiated by the gravity data. However, it is possible that another caldera may occur offshore from the western end of the island. Well-developed rift zones trending N 60°E and S 60°W are readily apparent from the contoured Bouguer anomaly map. The gravity gradient averages 10 mgal per mile, southwest from the primary caldera, and increases to 20 mgal per mile near the coastline. A low anomalous area is indicated slightly south and east off the east end of the island, and another offshore low is suggested south of the west end of the island. However, their geological significance is not known.

Ofu and Olosega

Together these islands have an area of 3.5 sq miles. They have a bar-bell shape and are separated by a narrow channel that can be waded during periods of low tide. The bathymetry falls off to the north and south, with shallow areas extending east and west of the islands. The highest point on Ofu is 1590 ft, and on Olosega, 2095 ft.

According to McCoy (1965), the predominant exposed rock types are alkalic basalts, and no trachytes are observed. Small exposures of more basic basalts, thought to be more recent in age, also outcrop. It is possible that tholeiitic basalts are present but, if so, they are effectively masked by more recent alkalic volcanics.

Here, as on Tutuila, the gravity data substan-

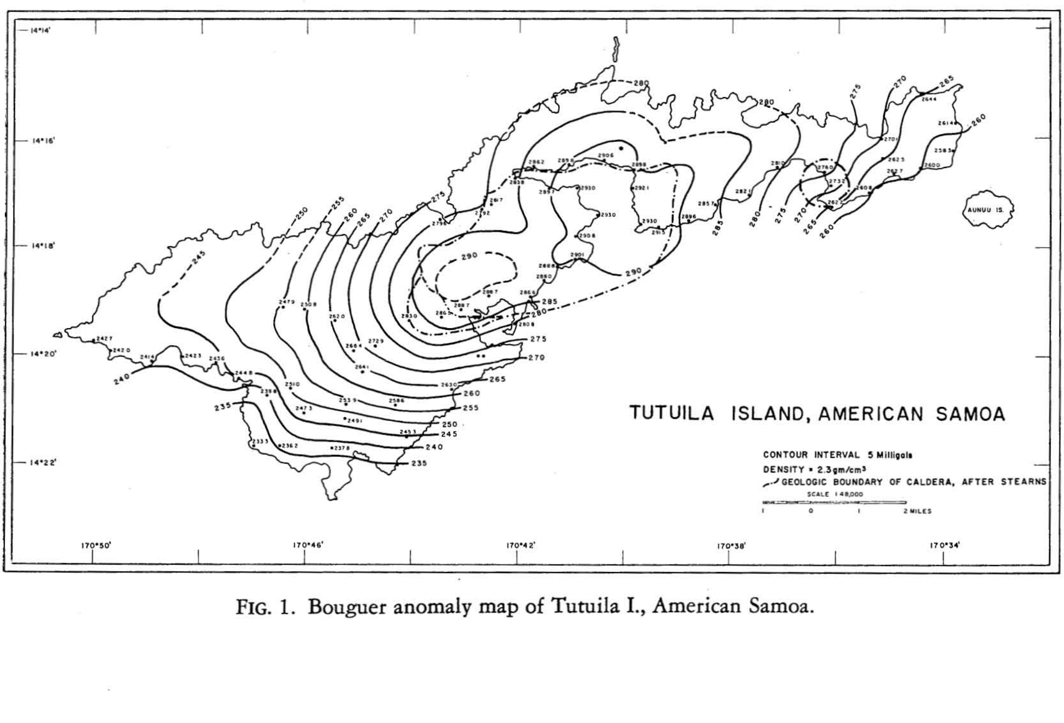

FIG. 1. Bouguer anomaly map of Tutuila I., American Samoa.

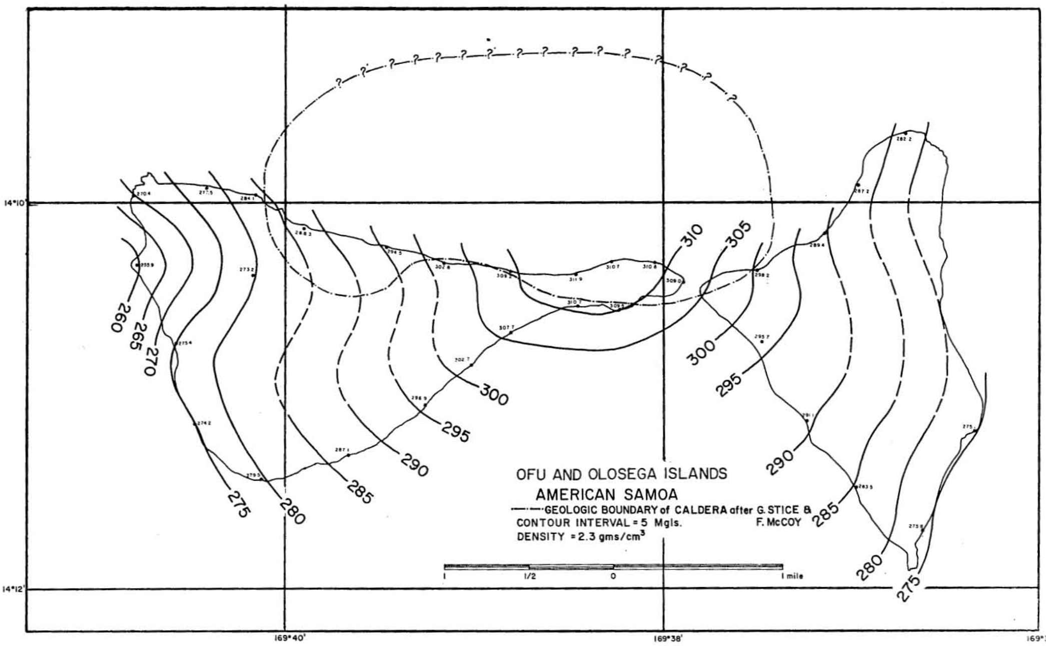

FIG. 2. Bouguer anomaly map of Ofu and Olosega Is., American Samoa.

tiate the geologic information. The gravimetric center of the caldera lying between the two islands (Fig. 2) is slightly east of the geologic center. The major portion of the structure lies offshore to the north of the islands. The Bouguer anomaly contours directly parallel the major rift zones which trend in southwest and southeast directions. The Bouguer anomaly values range from +260 on the east to +312 mgal in the center of the caldera area. A low anomalous area is suggested off the west end of Ofu Island. The maximum observed gradient is 20 mgal per mile. Thus, there is evidence that the island platform mass is tholeiitic basalt and that the feeder pipe contains ultrabasic rock.

Tau

Tau has an area of 15 sq miles, and the highest point of 3056 ft is found near the island's center. The water depth increases to the north and south, with a ridge area extending east and west from the land mass. Fringing reefs surround the island. The topography, as on Tutuila, and on Ofu and Olosega, is rugged with precipitous cliffs occurring on the north sides whereas the southern slopes are usually more gentle. Dense jungle vegetation covers most of the interior, making overland traverses extremely difficult. The geology according to Gary Stice and Floyd McCoy (personal communication) is similar to that observed on Ofu and Olosega. As seen from the northwest, Tau presents a perfect outline of a shield-type volcano.

The Bouguer gravity anomaly map (Fig. 3) depicts a single closure located in the south central portion of the island. The anomaly values vary from +250 to +290 mgal. The anomaly pattern is roughly circular in shape and its center coincides with the caldera which has rift zones extending to the northeast and the northwest from its center. The maximum anomaly gradient of 23 mgal per mile occurs to the north. The gravimetric center of the caldera was not reached, but the maximum anomaly value would appear to be near +300 mgal. Although the geologic indications are that the center of the caldera occurs offshore a short way south of the center of the island, the gravity data suggest that the intrusive center lies directly northward toward the land mass. As on the other islands studied in the Samoan group, the gravity data indicated that the island platform is

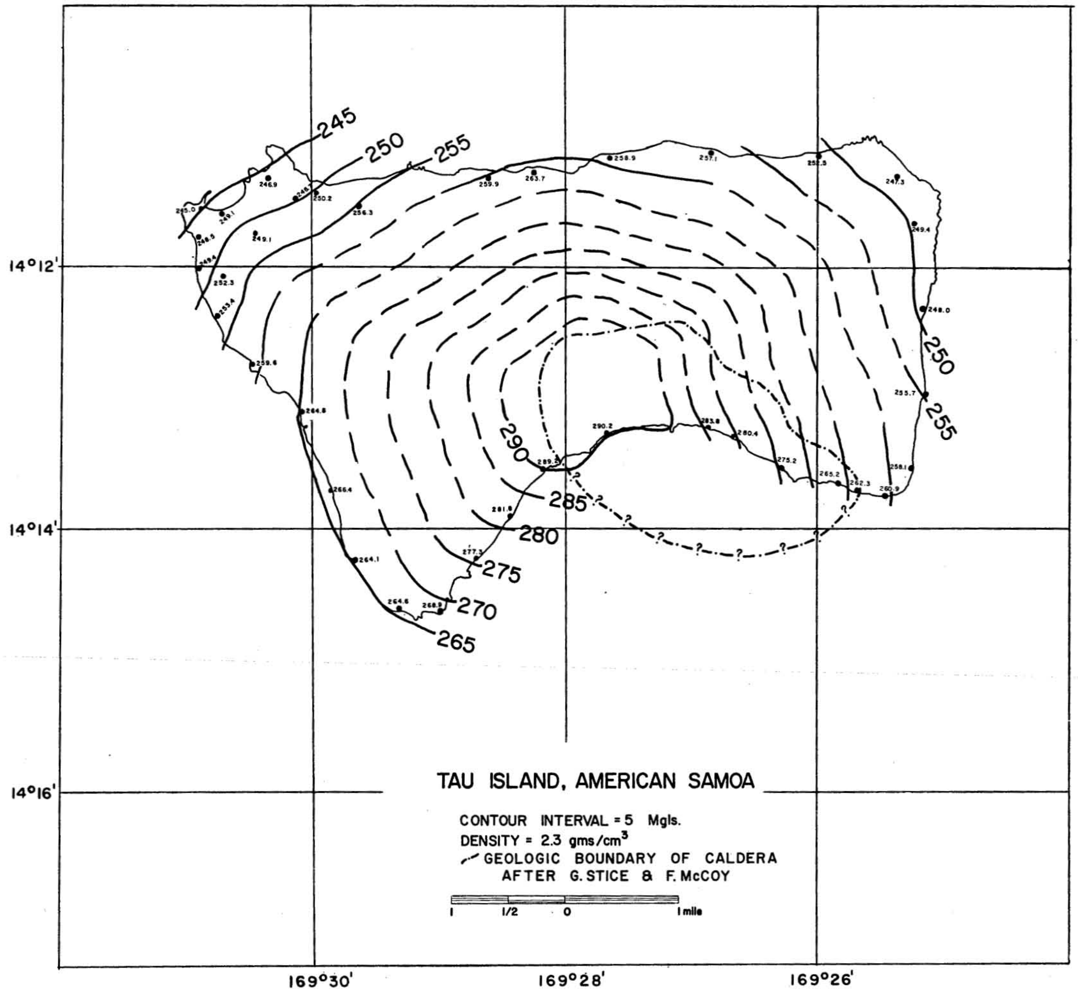

FIG. 3. Bouguer anomaly map of Tau I., American Samoa.

tholeiitic and that the feeder pipe contains ultrabasic rock.

THE SOCIETY ISLANDS

The Society Islands trend in a N 60° W direction and are located between 148° and 152° W and 16° and 18° S. During August 1964, the writer, using a Worden gravimeter No. 366, made 137 gravimeter observations on the islands of Tahiti and Moorea. All gravity data are referred to the absolute value of 978.9562 gal established for the Hawaii Institute of Geophysics gravity base in Honolulu, Hawaii (Woollard, unpublished).

Tahiti

Tahiti can be geomorphologically compared with the island of Maui: each is a large, high land mass, connected with a small, lower one by a narrow isthmus. Tahiti-Nui is roughly elliptical in shape, measuring 23 by 18 miles, and is connected by the isthmus of Taravao to the Taiarapu Peninsula which is positioned to the southeast of Tahiti-Nui and measures 14 by 9 miles. The highest point on Tahiti is 7339 ft and is located near the geometric center of the island. The highest point on the Taiarapu Peninsula is 4341 ft, and it is located near the geometric center of the peninsula. The mountainous and precipitous interior of Tahiti and the complete lack of roads precluded any overland traverses, hence the present survey was confined to the coastal regions accessible by automobile. Viewed from the northwest, Tahiti presents a perfect shield-shaped structure, similar to the island of Tau, American Samoa.

The island of Tahiti is composed chiefly of alkaline basalts (Williams, 1933). The exposed caldera plug is composed of nepheline monzonites, theralites, and of subordinate nepheline syenites. The geological evidence indicates that a volcanic pipe is located near the geometrical center of Tahiti-Nui. The Taiarapu Peninsula volcanic pipe is geologically defined as being near the center of the peninsula just north of the highest topographic peak. The rock types that form the plug are generally more basic than those observed on Tahiti-Nui, consisting primarily of essexites and theralites. The original volcanic activity on the Society Islands chain is believed to have originated in the west and migrated eastward. Tahiti is extensively ringed by barrier and fringing reefs.

Although the gravity picture on Tahiti-Nui and the Taiarapu Peninsula is incomplete, due to the absence of data from the interior, the magnitude of the anomalies and gradients observed are diagnostic. The Bouguer gravity anomaly contours on Tahiti-Nui (Fig. 4) outline a circular form with the steepest coastal gravity gradients of 10 mgal per mile occurring in the north half of the island. The size and position of the gravity gradients suggest that the gravimetric center of the caldera will be found slightly north of the geologic position. The observed Bouguer anomaly values range from +180 on the northeast coast to +230

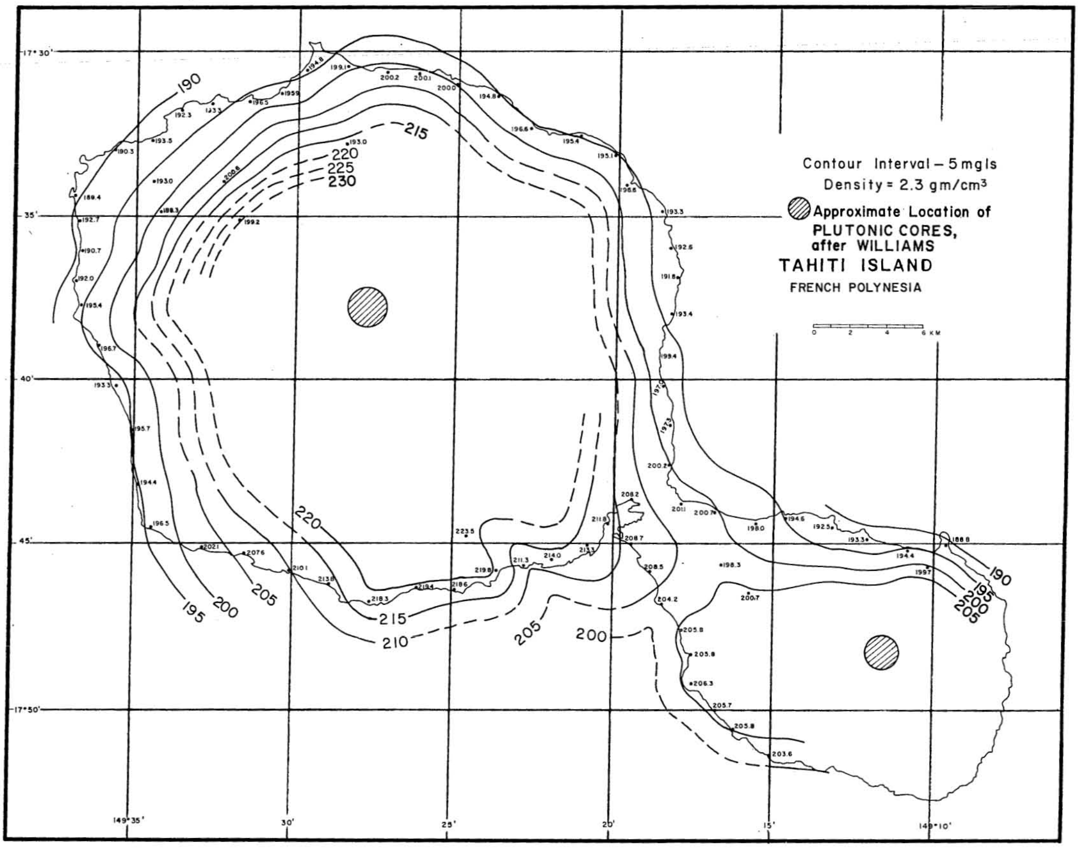

FIG. 4. Bouguer anomaly map of Tahiti I., French Polynesia.

mgal going southeast into the interior. Projecting from the coast the observed maximum gravity gradient of 20 mgal per mile would result in a +300-mgal maximum at the center. Only one high is apparent from the data. Numerous rift zones are discernible trending in the northeast, north, west, and southeast directions.

The Bouguer anomaly map of the Taiarapu Peninsula (Fig. 4) shows contours elongated in an east-west direction separated from the Tahiti-Nui anomaly by the +205-mgal contour line. The lowest observed value was +189 and the highest was +205 mgal. The maximum gradient was 10 mgal per mile, occurring on the northeastern end of the peninsula. Projecting this to the southwest would give a maximum value of +230 mgal at the center of the caldera, with the gravimetric center closely coinciding with the given geologic position. Although the gravimetric data support the geologic locations of the caldera, they do not substantiate the observed changes in lithology. According to the gravity data Tahiti-Nui is more basic than is Taiarapu Peninsula.

Moorea

Topographically Moorea is the complete opposite of Tahiti, appearing in profile as a series of jagged peaks separated by moderately sloping valleys. The island is triangular in shape, measuring 10 miles on each side; and the highest point, located south of the island center, is

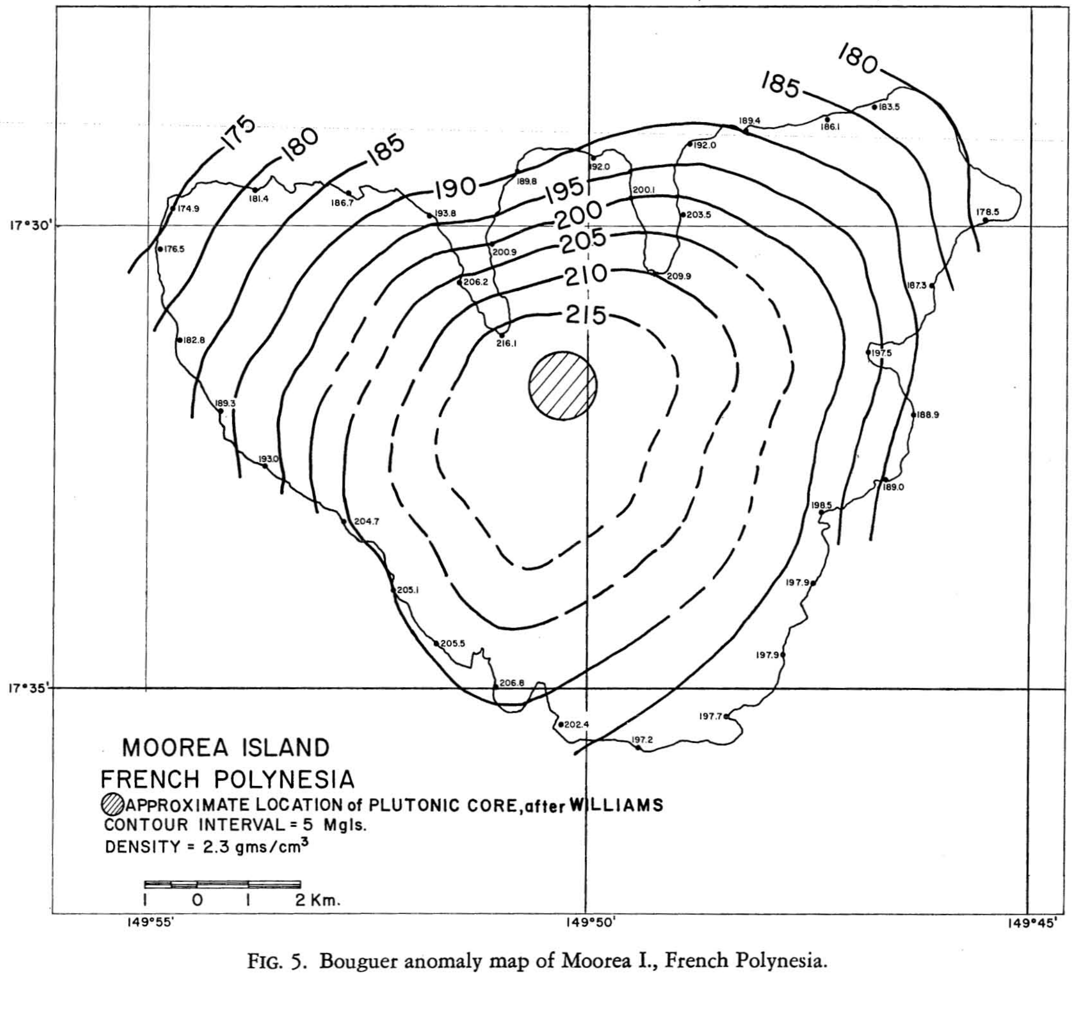

FIG. 5. Bouguer anomaly map of Moorea I., French Polynesia.

3975 ft. Fringing and barrier reefs surround the island. Geologically, Moorea differs from Tahiti in that there is an absence of visible intrusive rocks. The primary outcropping rock is a basaltic lava with subordinate amounts of nepheline-bearing trachytes and some andesites. The geologic position of the caldera has been fixed northeast of the center of the island. The entire area of the caldera is effectively covered by a mantle of laterite; consequently, the exact nature of the volcanic plug cannot be ascertained by surface examination.

The gravity contours (Fig. 5) form a roughly triangular shape corresponding to the shape of the island. The lowest value of +195 mgal was found in the northwest while the highest value of +216 was found near the assumed center of the caldera. The maximum gradients of 11 mgal per mile, outlining probable rift zones, occur trending north, northwest, and northeast from the gravity high with the minimum gradient trending southwards. Because of the absence of roads, an extensive series of observations into the center of the caldera area was impossible. Projecting the gravity gradient southward, however, would produce a +225-mgal Bouguer anomaly maximum over the caldera. The gravimetric center would then be in approximately the same position as the geologic center described by Williams (1933). Inasmuch as the absolute Bouguer gravity anomaly values are all similar to those observed in Hawaii, it is probable that the island platform is composed of tholeiitic basalt, but that the pipe material is basic rather than ultrabasic in character.

To summarize, the gravity field observed on Tahiti and Moorea conforms closely with the topography and geology of the islands. A steeper gravity anomaly gradient as the main caldera on Tahiti-Nui is approached suggests a value not unlike those observed in Hawaii (+300 mgal). Direct observations were precluded by the mountain jungle interior. On Moorea observations near the caldera area were possible. The gradient, however, was only +11 mgal per mile, and the maximum Bouguer anomaly probably does not exceed +225 mgal. This value is only slightly higher than the mass effect to be expected for the island platform. The pipe effect, therefore, is quite small as compared with that observed in the Hawaiian Islands and as projected on Tahiti.

ACKNOWLEDGMENTS

The work reported was carried out under NSF Grant No. GP 2256, and operations were greatly implemented in Samoa by Mr. Floyd McCoy, who was carrying out his geologic studies at the same time under NSF Grant No. GP 2196.

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