Article 89

GRAVITY SURVEY OF THE ISLAND OF HAWAII

By W. T. KINOSHITA,[1] H. L. KRIVOY,[2] D. R. MABEY,[1] and R. R. MacDONALD,[2]

[1] Menlo Park, Calif., [2] Hawaiian Volcano Observatory, Hawaii

Abstract.—Large gravity highs are centered over 4 of the 5 major volcanoes on the island of Hawaii. A lower amplitude gravity high occurs near the fifth volcano, Hualalai. These highs are attributed to intrusive rocks and denser parts of flows that are near the surface beneath the volcanoes and are convergent at depth.

Local gravity surveys in the vicinity of Kilauea volcano and its two major associated rift zones (Krivoy and Eaton, 1961) have been supplemented by a regional survey of the island of Hawaii (fig. 89.1). Measurements along the main roads and trails provided generally good coverage at elevations below 6,000 feet, but at higher elevations large areas are inaccessible and the gravity map is necessarily generalized. An average density of 2.3 g per cc was used for all above-sea-level material in the gravity reductions and terrain corrections. The reductions were made to sea level and the terrain corrections were made for above-sea-level terrain to a distance of about 100 miles from the station. Terrain corrections were made at about half the stations and interpolated at the remainder because the topography is such that a near-linear relation exists between station altitude and amount of correction in many parts of the island. A few corrections for submarine topography were made, and it was found that their effect on a map with a 10-mgal contour interval was negligible.

Because the total relief on Hawaii is more than 13,000 feet, the selection of a density to compute the Bouguer corrections determines to a large extent the character of the Bouguer anomaly map. The density of 63 dry samples, collected by R. R. Doell from the denser parts of numerous flows for remanent-magnetization studies, ranged from 1.8 g per cc to 3.0 g per cc but averaged 2.3 g per cc. Although the probable average density of the intrusive and nonvesicular flow rocks as shown by a few measurements is about 2.8 g per cc, these rocks constitute only a small part of the exposed rock on the island. Woollard (1951) found by a gravity-profile method that a density of 2.3 g per cc was the most applicable for his gravity study on Oahu.

The Bouguer gravity-anomaly map (fig. 89.1) shows pronounced gravity highs over Kohala Mountain, Mauna Kea, Mauna Loa, and Kilauea, 4 of the 5 major volcanoes which make up the island of Hawaii. Hualalai, the fifth volcano, lies at the north end of an elongate high of much lower amplitude than those over the other four. Other features of the gravity map include an east-trending gravity nose on the northeast slope of Mauna Kea, southwest-trending and east-trending gravity noses from the summit of Kilauea, a south-trending gravity nose from the summit of Mauna Loa, and low-gravity fields at Hilo and at the northwestern part of the island between Hualalai and Kohala Mountain.

The general correlation between the gravity highs and the topographic highs suggests that the density assumed in making the Bouguer corrections is too low, and that some discussion of these reductions is needed. There is little question that 2.3 g per cc is a reasonable approximation of the dry density of the exposed flows, and there is no reason to expect significant compaction of these flows between the surface* and sea level.* When this density is used in making the Bouguer correction, the anomalies obtained reflect the presence of masses with densities different from this value. In making the Bouguer reductions, no effort has been made to remove the part of the anomaly caused by density contrasts above sea level. An examination of the gravity map reveals several areas where substantial gravity differences do not correlate with surface topography. The most striking example is the +251-mgal value on the 8,000-foot summit of Hualalai, which is about the same as the gravity values at sea level along the southeast and east shores of the island.

ART. 89 *IN* U.S. GEOL. SURVEY PROF. PAPER 475–C, PAGES C114–C116. 1963.

* except for elevations > 1000 m

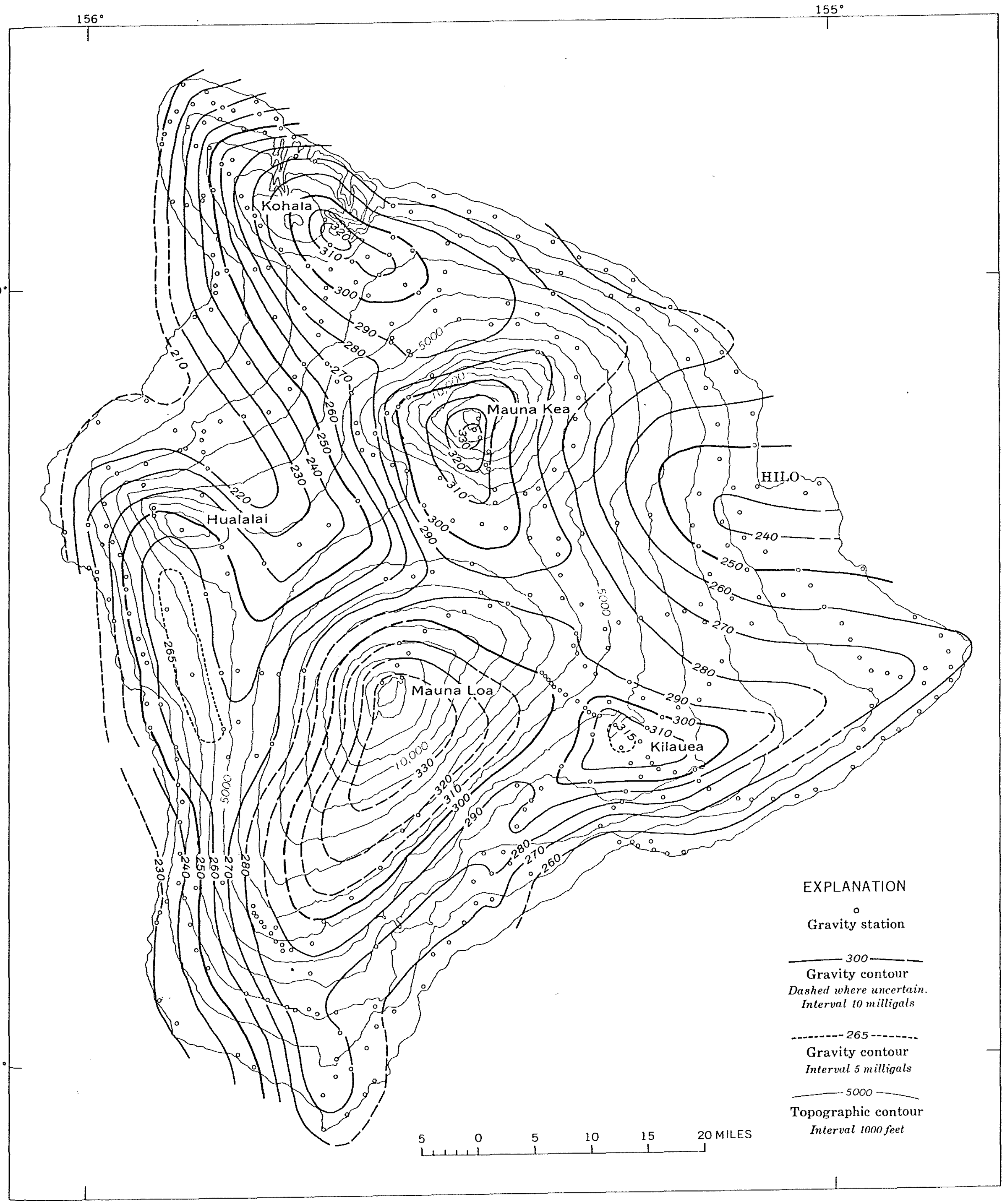

FIGURE 89.1.—Bouguer gravity-anomaly map of the island of Hawaii.

The four gravity highs over the individual volcanoes are part of a more extensive high that covers the central part of the island, so that although the total gravity relief is about 120 mgals, the gravity decreases only about 50 mgals between volcanoes. In this respect the island of Hawaii is quite different from Oahu, where Woollard (1951) found maximums of about 110 mgals over the volcanoes and no connecting high between volcanoes. Horizontal distances between the adjacent volcanoes on both islands are about the same.

Quantitative analyses of the gravity highs are incomplete, but some qualitative conclusions on the cause of the anomalies can be reached. The amplitude of the highs and steepness of the gradients indicate that the highs are probably produced by mass anomalies above the sea floor and maybe even above sea level. The central high on Hawaii indicates the presence of relatively dense rocks at depth between the 4 volcanoes and suggests the presence of one or more of the following rock configurations: (1) a continuous intrusive mass, extending from Kohala Mountain to Mauna Loa and Kilauea, with cupolas beneath the 4 volcanoes having gravity maximums, (2) flow rocks between volcanoes, with a bulk density approaching that of intrusive rocks, or (3) interfingering of intrusive rocks with flows from the 4 volcanic centers, the whole mass of which has a bulk density approaching that of intrusive rocks. East-west asymmetry of the gravity anomalies requires the denser rocks to have a greater lateral extent to the east than to the west in all three possibilities. The third possibility is favored by the writers because there is no evidence of interconnection between volcanoes above the sea floor. Furthermore, although some massive parts of flows have measured densities of 3.0 g per cc, there is no surface evidence that such flows accumulate only in certain areas.

The absence of a pronounced closed high over Hualalai is surprising because Hualalai is the third highest volcano on the island, and it is similar in most respects to the other volcanoes on Hawaii. Hualalai's summit lies at the northern end of an elongate gravity high that reaches a maximum value at least 8 miles to the south. This high has very small closure and its maximum value is about 85 mgals less than the maximums over Mauna Kea or Mauna Loa, but the local relief of about 55 mgals is about the same as the relief between the other volcanoes on the island. An interesting possibility is that Hualalai lies on the north rift zone of an older volcano buried by Mauna Loa lavas. The elongate, rather than bull's-eye, gravity-contour pattern could be produced by diametrically opposed north- and south-trending rift zones of the buried older volcano. The gravity effect of the southern rift zone could be masked by its proximity to the larger Mauna Loa anomaly. A recorded offshore eruption near the south end of this high in 1877 (Dana, 1891) occurred at about the same time as a Mauna Loa summit eruption, and possibly the two were related.

Relatively narrow, low-amplitude gravity noses occur over or near the more conspicuous rift zones of Mauna Loa and Kilauea. The east-trending high on the northeast slope of Mauna Kea lies between a rift zone pointed out by Stearns and MacDonald (1946) and an east-trending submarine ridge off the northeast coast of the island. These highs are probably produced by the greater abundance of intrusive rocks in the rift zones, although it is possible that ponded flows in parts of the rifts are responsible for at least a part of the gravity maximums.

The gravity lows at Hilo and at the western part of the island in an area bounded by Kohala Mountain, Mauna Kea, and Hualalai are over areas probably covered with thick accumulations of low-density flow rocks.

REFERENCES

Dana, J. D., 1891, Characteristics of volcanoes: New York, Dodd, Mead and Co., 399 p. [1890].

Krivoy, H. L., and Eaton, J. P., 1961, Preliminary gravity survey of Kilauea Volcano, Hawaii: Art. 360 *in* U.S. Geol. Survey Prof. Paper 424–D, p. D205–D208.

Stearns, H. T., and MacDonald, G. A., 1946, Geology and groundwater resources of the island of Hawaii: Hawaii Div. Hydrography Bull. 9, p. 168.

Woollard, G. P., 1951, A gravity reconnaissance of the island of Oahu: Am. Geophys. Union Trans., v. 32, no. 3, p. 358–368.