Magma Supply Rate at Kilauea Volcano, 1952–1971

Abstract. *The three longest Kilauea eruptions since 1952 produced lava at an overall constant rate of about 9 × 10⁶ cubic meters per month (vesicle-free). This is considered to represent the rate of magma supply from a deep source, probably the mantle, because little or no summit deformation indicating high-level storage accompanied any of the three eruptions.*

The rate of tholeiitic magma supply from the mantle to oceanic volcanoes is of interest for many reasons, and eruptions at Kilauea and Mauna Loa, Hawaii's most active volcanoes, would seemingly be ideal for such a rate study. However, reliable rates of supply are difficult to calculate because these eruptions are typically so short-lived that rates of extrusion are usually dominated by near-surface processes, such as vent constrictions and cyclic, geyser-like activity. Furthermore, most of the eruptions are accompanied by substantial ground deformation related to the storage of an unknown quantity of magma underground. Thus, it is virtually impossible to determine the ratio of extruded lava to stored lava, a quantity necessary in calculations of magma supply. Since the last eruption of Mauna Loa, in 1950, however, the three Kilauea eruptions lasting 4.5 months or longer each supplied lava nearly continuously to the surface, and the volume of magma stored within the volcanic edifice was small or could be calculated, as shown by increasingly detailed studies of surface displacement and tilt. The extrusion rate for each of these three eruptions is nearly identical, about 9×10^6 m^3/month when recalculated on a nonvesicular basis. This is interpreted to be the rate at which magma is supplied to Kilauea's conduit system from the mantle, at least during the periods of Mauna Loa inactivity.

The 1952 Halemaumau eruption (*1*) produced about 49×10^6 m^3 of basaltic lava in 4.5 months—about 11×10^6 m^3/month. The volume is reliable, because the entire eruption took place in a crater whose dimensions were known. The summit subsided a small amount early in the eruption but then largely recovered by the end of the eruption. The net change was only a few microradians measured at a tilt station 2.5 km from the probable center of subsidence. The small net subsidence may indicate that the calculated eruption rate was slightly larger than the total supply rate.

The 1967–68 Halemaumau eruption (*2*) produced 84×10^6 m^3 of lava in 8.2 months, about 10.2×10^6 m^3/month. Again the entire eruption took place in a crater. The overall summit uplift was less than 10 μrad measured at a tiltmeter 2 km from the deformation center. Activity was continuous during the last 5 months of the eruption, and a constant extrusion rate of about 9.5×10^6 m^3 of lava was maintained. This rate is probably too low to be the true rate of magma supply, for most of the summit uplift took place during this time, which implies that some of the magma was stored underground. Thus, the overall rate of 10.2×10^6 m^3/month is preferred.

The first 7.25 months (24 May to 31 December 1969) of the Mauna Ulu eruption (*3*) produced about 72×10^6 m^3 of lava—about 10×10^6 m^3/month—as determined by estimates of the area and thickness of all new lava flows (*4*). Eruption during this period was episodic. In the intervals between strong eruption, the summit region of Kilauea swelled; during strong eruption phases, the summit contracted. The amounts of swelling and shrinking nearly exactly canceled each other, so that the maximum net summit deformation for the first 7.2 months was only 3 cm of uplift. If this uplift represents storage of magma, the calculated overall eruption rate is slightly less than the supply rate.

The vigor of eruption markedly waned during the first 6 months of 1970, and the summit of Kilauea swelled accordingly, which indicated that magma still being supplied to the volcano was being stored within it. Between 1 January and 30 June, the maximum summit uplift was 45 to 50 cm, based on leveling surveys and extrapolation of tilt and horizontal-strain data. The corresponding volume of uplift was about 25×10^6 m^3, and this volume, together with an estimated 25×10^6 m^3 of extruded lava, indicated a rate of magma addition to Kilauea of about 8.3×10^6 m^3/month. This rate is in excellent agreement with the extrusion rate of 10×10^6 m^3/month during the first 7.2 months, when the uncertainties in the deformation (especially) and extrusion volumes are considered.

Between July 1970 and May 1971, the observed rate of extrusion was remarkably constant, and the summit remained essentially undeformed. Reliable estimates of the area and thickness of new lava flows, the volume of flowing lava in tubes, and the volume of new land produced along the southern seacoast in March and April 1971 (*3*) consistently yielded volumetric rates of 10 to 11×10^6 m^3/month.

Thus, the steady-state (over periods of weeks) eruption rate has been constant for the three longest eruptions since 1952, which together comprise about 16 percent (3 years) of this interval. This constant rate, reduced by 15 percent (*5*) to about 9×10^6 m^3/month to adjust for vesicularity, is interpreted to be the rate of supply of magma to Kilauea's upper conduit system during these three eruptions.

It remains uncertain whether this rate of supply from the mantle was steady or whether it greatly diminished during noneruptive periods since 1952, but several lines of evidence suggest that the rate has been essentially steady. For example, noneruptive periods are typically characterized by swelling of Kilauea's summit area, which indicates storage of an increasingly large volume of magma. Also, Kilauea's eruptions usually end when the summit is reinflating after initial deflation, which shows a continued movement of magma into Kilauea's conduit system. Calculations based on these two relations indicate a magma supply rate consistent with the eruption rate of 9×10^6 m^3/month, although the calculations are crude because of incomplete data. This evidence, together with the difficulty of conceiving of a "stop-start" process acting on a short-term basis in the mantle, suggests a steady rate of magma supply since 1952, and the following discussion is largely based on this assumption.

Estimates of eruption rates for recent eruptions of short duration or for brief periods during the longer eruptions are more variable (*1, 2*), probably because they do not represent steady-state activity. Estimates made for earlier periods of Kilauea's history and adjusted for vesicularity are generally lower, for example, about 2.5×10^6 m^3/month by Stearns and Macdonald (*6*) for the period 1823 to 1945 and 3.6×10^6 m^3/month by Moore (*7*) for the combined historic activity of Kilauea and Mauna Loa. These estimates are minimum values, however, because they do not take into account the volumes of magma intruded and stored underground or erupted unseen on the deep sea floor. Furthermore, the estimate of supply rate to Kilauea made by Stearns and Macdonald (*6*) may be low because several Mauna Loa eruptions took place during the same time interval, if Moore's (*7*) data are reliable. The rate estimates for Kilauea made in this report are for a period of no Mauna Loa eruptive activity, and seismic and geodetic data suggest no substantial deformation of Mauna Loa during this time (*8*).

From an analysis of tide gauge records, Moore (*7*) concluded that the island of Hawaii is subsiding isostatically at a rate of 22.5×10^6 m^3/month because of the addition of magma (mass) to Mauna Loa and Kilauea. This subsidence rate is more than six times the magma supply rate that he used. Moore found from simplified isostatic models that the subsidence rate could be a maximum of only 2.6 times the supply rate, which leaves an apparent discrepancy between the observed subsidence and supply rates of a factor of 2.3. This discrepancy is virtually eliminated by using the magma supply rate calculated in this report. Possibly, therefore, magma has been supplied to the combined reservoir systems of Mauna Loa and Kilauea at a constant rate of about 9×10^6 m^3/month throughout at least historic time, but much of this supply has been intruded into the volcanic pile or extruded on the sea floor where observation is impossible, as suggested by Moore (*7*). Such hidden activity is implied by the numerous subsidence events, with little or no corresponding visible eruption, that have taken place at Kilauea during historic time (*9*) and by the substantial permanent uplift and dilation of the rift zones measured during the past 50 years (*10*).

These considerations suggest that the observed rate of magma supply may be that from the mantle, not simply from some holding reservoir within the volcanic edifice itself. In support of this, the chemical compositions of lava erupted throughout the 1967–68 and Mauna Ulu eruptions show very little variation (*11*), which suggests that an intermediate-depth storage chamber susceptible to magmatic differentiation is not being emptied. Kilauea Volcano could have been built in much less than 4×10^5 years at the magma supply rate presented here, but simultaneous Mauna Loa activity could have extended this period of growth substantially.

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References and Notes

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12. I thank W. A. Duffield and D. W. Peterson for discussion and help in fieldwork and J. G. Moore and T. L. Wright for manuscript review. Publication has been authorized by the director, U.S. Geological Survey.

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Chemical Composition of Sawdust from Lunar Rock 12013 and Comparison of a Java Tektite with the Rock

Abstract. *Abundances of 11 major and minor elements and 11 trace elements have been determined by instrumental neutron activation analysis of two Apollo 12013 rock fragments, a sample of rock 12013,17 sawdust, and a Java tektite (J2). Although the abundances of major elements in tektite J2 are similar to those of rock 12013, comparison of the minor and trace elements shows that no fragment or sawdust of rock 12013 that has been analyzed to date is chemically similar to tektite glass. Rock sawdust is representative of "whole rock" composition only if the amount of contamination from the sawing process is known. After appropriate correction for saw wire contamination, analyses of sawdust yield fairly accurate averaged elemental compositions of complex clastic lunar and other rocks.*

Lunar rock 12013 is undoubtedly the most extensively studied lunar rock to date. It is the oldest metamorphosed or recrystallized heterogeneous rock known [4.0×10^9 years (*1, 2*)]. Since this rock has a very high SiO_2 content (*3*), it is of special interest to the proponents of a lunar origin for tektites. In previous reports (*3, 4*), abundances of 22 major, minor, and trace elements were determined for seven fragments of rock 12013. In addition to aliquants from two previously analyzed 12013 fragments and a 12013 sawdust sample, a fragment of the tektite J2 was also analyzed by instrumental neutron activation. Abundances of 13 major and minor and 4 trace elements in this particular javanite (J2) are very similar to those found in tektites J86 and J87 (*5*). O'Keefe (*6*) observed that the major and some minor elemental abundances are indeed very similar in the J86 and J87 tektites and in the "glassy portion" of rock 12013. From this he concluded that tektites originated from explosive volcanic activity on the moon. There has been no mention of a "glassy portion" thus far in the published petrological descriptions of this complex microbreccia.

Analytical results are listed in Table 1. For the majority of the elements, the results of this work for 12013,10 are in good agreement with the abundances reported (*4*) for analyses of different aliquants of the same fragment powders. However, in case of disagreements, the recent data are considered more reliable. Because longer counting periods and adequate decay measurements were done in this work, the Eu, Th, and U abundances of this work are superior to those of the previous report.

The sawdust sample 12013,17 was collected from the remains of the rock sawing process. The saw wire was fabricated from diamonds impregnated into a copper sheath over an iron core. Comparison of the elemental abundances for sawdust #17 with the average abundances for seven fragments from rock 12013 (Table 1) indicates that abundances in the sawdust are lower by a relatively constant decrement of about 0.3. Assuming 4 percent Mg in the rock (*4*), a dilution decrement of about 0.27 is calculated, which agrees with a