Geophysical Research Abstracts, Vol. 7, 06115, 2005
SRef-ID: 1607-7962/gra/EGU05-A-06115

Dynamics of Kilauea Volcano, Hawaii, from gravity observations: Pit crater formation and volcano spreading

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Analysis of gravity and leveling data from regional surveys conducted at Kilauea Volcano, Hawaii between 1975 and 2003 has identified a shallow source that has produced a +250 microgal anomaly (after a correction for height change). Detailed surveys done in 1998, 1999, and 2003 show that this anomaly is continuing to grow at a rate of about +15 microgals/year. Inversion of the gravity change data indicate a source located at a depth of 630$\pm$240 meters immediately to the east of Halemaumau crater, the principle collapse crater within Kilauea's summit caldera. While surface displacements determined from leveling, GPS, and InSAR measurements indicate a trend of continual subsidence of the entire Kilauea summit and proximal portions of the east and southwest rift zone system, a specific significant deformation anomaly is not detected in the area of the anomalous gravity increase. The implication of these observations is that within the shallow source region, low density material is being replaced by higher density material with no net change in volume of the source. Two processes that could operate in this manner are considered here – both involve a magma body close to the surface: 1) crystallization of olivine crystals which accumulate within a shallow magma body and 2) progressive assimilation or stoping of roof rock by an upward advancing magma chamber. Certainly, petrologic modeling indicates that substantial amounts of olivine are crystallized from Kilauea's magmas. Most of these crystals are thought to settle to fill the deep magmatic structures within Kilauea's dense core. It seems unlikely that olivine crystals, which are heavy relative to their host magma, could be permanently stored at the shallowest portion of the magmatic system. Assimilation or stoping is of an upward advancing magma body seems a better explanation. Here, the low density lavas, comprised largely of sub aerially erupted pahoehoe flows,

are melted and replaced by upward advancing higher density magmas. From an energy standpoint, the enthalpy of olivine crystallization may contribute to the heating and melting of wall rock. Furthermore, from a structural standpoint, advancement by assimilation – eventually to the surface - of a shallow magma body is a viable mechanism to explain the eventual formation of crater with a lava lake in the summit of Kilauea.

The regional pattern of gravity change in summit and upper rift zones indicates a steady rate of density increase throughout Kilauea's magmatic system. Essentially, this is a process of active development of Kilauea's already sizable Bouguer anomaly. Olivine crystals are believed to settle and accumulate at depth. It is thought by some that the ductile core of accumulated olivine tends to creep outward, helping to push the south flank seaward. Inversion of the observed gravity changes may yield an estimate of the annual mass of accumulated olivine and, therefore, help quantify the role of olivine cumulates in volcanic spreading at Kilauea.