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# Upolu (Samoa): Perspective on Island Subsidence from Volcano Loading

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From the present subsea elevation of the ferry berth Lapita archaeological site off Mulifanua at the western tip of Upolu in Samoa, Dickinson and Green (1998) inferred that the site has subsided ~4 m at a mean rate of ~1.4 mm/yr since occupation of the site at ~2750 yr BP during the waning phases of the mid-Holocene hydro-isostatic highstand in tropical Pacific sea level. Subsidence of westernmost Upolu was attributed to the influence on the underlying lithosphere of the growing volcano load produced by continuing eruptive activity on nearby Savaii, about 20 km from Mulifanua across a narrow strait. Goodwin and Grossman (2003) subsequently showed that a paleoshoreline at Maninoa on the south coast of Upolu has subsided no more than ~2.5 m since the peak of the mid-Holocene highstand at ~4000 yr BP, and argued that the implied subsidence rate of less than ~0.6 mm/yr calls into question the higher subsidence rate inferred for Mulifanua. However, the geometry of flexural subsidence of lithosphere under a volcano load actually requires differential subsidence at different distances from the volcano load, and Maninoa lies ~30 km farther away from Savaii than Mulifanua. I argue here that the contrasting subsidence rates at Mulifanua and Maninoa are mutually compatible within the framework of flexural loading theory, which requires close attention to the spatial dimensions of the cone of subsidence surrounding a volcano load.

When a volcanic edifice loads a flexible oceanic plate of lithospheric mantle and crust overlying viscous asthenospheric mantle capable of flowage, a dimple-like cone of depression develops in the flexurally deformed lithosphere with its center beneath the centroid of the volcano load (McNutt and Menard 1978). Beyond the cone of depression is a compensatory uplift in the form of an annular arch. The radius of the cone of depression is a function of the flexural wavelength, $l$, which depends upon the inherent flexural rigidity of the lithosphere and the density of the material, dominantly water in the oceanic case, lying within the moat formed between the volcanic edifice and the uplifted

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annular arch surrounding the cone of depression. The outer limit of the cone of depression lies at $4l$, an inflection point where neither uplift nor subsidence affects the elevation of the top of the lithosphere. The amount of subsidence within the cone of depression increases from the distance $4l$ back toward the centroid of the volcano load.

To assess the compatibility of subsidence rates at Mulifanua and Maninoa with a flexural model, it is necessary to cast the observational data for Mulifanua into the same context as the data for Maninoa, and to update the age of the Mulifanua site using more recent information than was available previously. The dated paleoshoreline feature at Maninoa is paleobeachrock that formed as a cemented spit within the intertidal zone during an interval defined by radiocarbon ages of 4390 ± 150 yr BP and 4485 ± 128 yr BP from the bottom and the top, respectively, of the paleobeachrock layer. The best estimates of the two ages are thus out of sequence, but the age uncertainties overlap to define a calibrated age of approximately 4500–4600 cal yr BP (Hughen et al. 2004), which predated the end of the mid-Holocene highstand in regional sea level at ~4 kyr. As the paleobeachrock is now exposed within the modern intertidal zone, the indicated net subsidence since its formation is the total post-4 kyr drawdown in sea level from the mid-Holocene highstand, which is estimated as 2.1 ± 0.5 m above modern sea level for Samoa (Mitrovica and Peltier 1991:Fig. 8j). The indicated mean late Holocene subsidence rate for Maninoa is thus 0.52 ± 0.12 mm/yr.

At Mulifanua, the artifact-bearing Lapita horizon has yielded calibrated radiocarbon ages of 2880–2750 cal yr BP (Petchey 2001), and is capped by a paleobeachrock layer, comparable in intertidal origin to the paleobeachrock at Maninoa, with its base ~2.25 m below modern mean sea level. The age of the paleobeachrock, which incorporates Lapita potsherds into its base, can be taken from the age range of the Lapita horizon below it as ~2750 cal yr BP, at which time declining hydro-isostatic sea level in Samoa is estimated to have stood 1.2 ± 0.4 m above modern sea level (Mitrovica and Peltier 1991:Fig. 8j). The indicated mean late Holocene subsidence rate for the paleobeachrock at Mulifanua is 1.25 ± 0.15 mm/yr, slightly less than inferred previously, but overlapping the previous value and still more than twice the subsidence rate at Maninoa.

Figure 1 tests the compatibility of the inferred subsidence rates at Mulifanua and Maninoa with a flexural model for subsidence from volcano loading by comparing them with the pattern of flexural subsidence well known from Hawaii (Moore et al. 1996). Absolute rates of subsidence are less for Samoa than for Hawaii because the eruption rate on Savaii is much less than the eruption rate at Mauna Loa, and the growth rates of the volcano loads at the two controlling volcanic edifices are accordingly different. Relative spatial rates of subsidence at varying flexural wavelength, $l$, are closely similar, however, for Samoa and Hawaii, as shown by the parallelism of the two subsidence curves drawn between control points. The flexural wavelength, $l$, is ~40 km for Samoa but ~68 km for Hawaii (Dickinson 2001:211–213).

The plot indicates that subsidence from volcano loading remains a viable hypothesis for the subsidence of Upolu, despite contrasting subsidence rates at different places on the Upolu coastline. Given the length of Upolu (70 km or $1.75l$), Figure 1 implies that local subsidence rates decline to <0.1 mm/yr at its eastern end. Comparably large

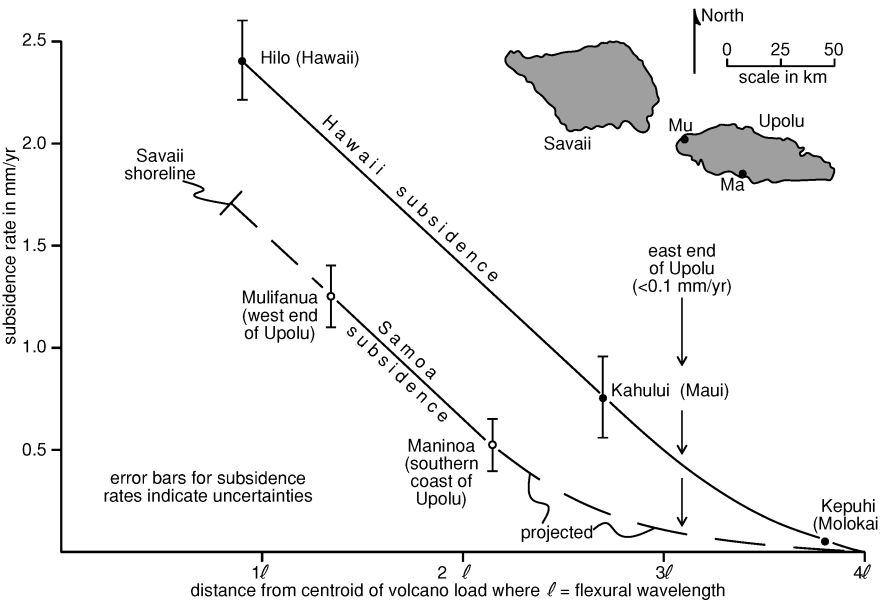


***Figure 1.*** *Correlation of flexural cones of subsidence for Samoa and Hawaii. For spatial comparison, distances between sites are normalized to multiples of the flexural wavelength from centroids of volcano loads at Mauna Loa in Hawaii and Savaii in Samoa. Positions of Mulifanua (Mu) and Maninoa (Ma) relative to Savaii indicated on key map (upper right). Jim Abbott of SciGraphics drafted the figure.*

islands lying within flexural cones of subsidence surrounding volcano loads can be expected to display similarly variable subsidence rates at different locales along their coasts.

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