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DETACHMENT OF PART OF THE DOWNGOING SLAB AND UPLIFT OF THE NEW HEBRIDES (VANUATU) ISLANDS

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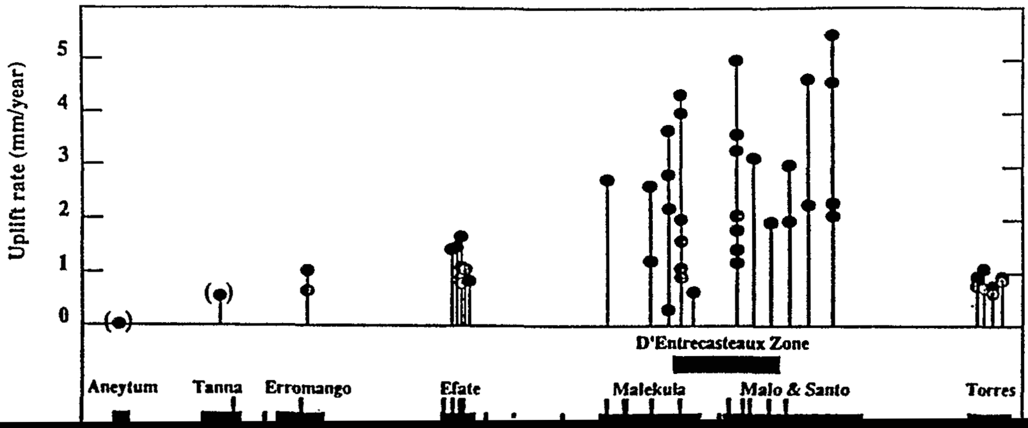
Abstract. Several seismological observations suggest that there is a gap within the downgoing slab of Australian lithosphere plunging beneath the New Hebrides, and ages of elevated coral terraces on the New Hebrides Islands suggest [illegible]

beneath Espiritu Santo, it thins to a width of only about 30-40 km below a depth of only 30-40 km. North of Espiritu Santo, the gap is yet less well defined, but south of Efate it seems to be wider, attaining a width of about 100 km. South [illegible]

[illegible]


Uplift rate (mm/year)
5
4
3
2
1
0
D'Entrecasteaux Zone
Aneytum
Tanna
Erromango
Efate
Malekula
Malo & Santo
Torres

[redacted]

Morgan [1965, p. 6179] showed that the rate of sinking is reduced approximately by a factor of (1 - 3 a/4 D), where D is the depth of the center of the sphere below the surface. Given the uncertainties in the relevant parameters, there is no problem finding a set consistent with rates of sinking of 200-400 mm/a.

The sustained uplift of the islands for hundreds of thousands of years requires that, whatever process causes it, that process was not simply the instantaneous removal of a force pulling the surface down. Studies of Pleistocene rebound demonstrate that isostatic rebound occurs rapidly, in periods of only a few tens of thousands of years or less [e.g. Peltier, 1982; Walcott, 1973]. Thus, the continued uplift for 100 ky or more at rates of 1 mm/a or more requires that a normal stress, changing with time, be applied to the base of the overriding plate of plate.

A sinking body will cause flow of the surrounding viscous fluid, and this flow will, in turn, pull the overlying surface downward. Two competing effects determine the magnitude of the deflection. First, all fluid flow and hence all viscous stresses depend upon the speed at which the body sinks through a fluid otherwise undisturbed; this speed should increase as the body sinks deeper and farther from the surface, where the flow of material around the body is restricted. Second, fluid flow is more rapid, and viscous stresses are greater near the body than far from it; thus, for a given speed of the body, a shallow body deflects the surface more than a deep one.

The simplest analogous, and relevant boundary conditions are for a sphere within a fluid with a flat rigid boundary at the top. Then, an estimate of the normal stress on that surface can be converted into a deflection of surface analogous to that of the Earth by $\sigma = -\Delta\rho\ h\ g$ [e. g. Morgan, 1965], where σ is the normal stress (positive for tension), $\Delta\rho$ is the difference in density between the crust and the fluid through which the material rises (water for the islands), and h is displacement of the surface.

Morgan [1965] obtained an approximate solution for the velocity field and stress field surrounding a sphere sinking into a viscous medium below a rigid surface, which is accurate for small ratios of the radius of the sphere to its depth. Using his equation (11) for the vertical component of velocity of the fluid, his (12) for pressure, and the relationship of them to the normal stress, his (13), the normal stress at the surface is

$$\sigma = (2\,a^3\,\delta\rho\ \ g/3)\,[(3D^3/R^5) + (a^2\,D/R^5) - (5D^3\,a^2/R^7)] \quad (1)$$

where $R = (D^2 + r^2)^{1/2}$, r is the horizontal distance from the center of the sphere, and terms of order $(a/D)^3$ have been

The speed that the surface moves up can be obtained by differentiating (3):

$$dh/dt = (2\,a^3\,\delta\rho\ /3\ \Delta\rho\ )\,[(6/D^3) - (16\,a^2/D^5)](dD/dt) \quad (4)$$

where dD/dt is simply the rate that the sphere sinks and is positive for all time. Again using a = 50 km, and assuming a sinking rate of 400 km/Ma, the calculated rates of surface uplift directly over the sphere at depths of 100, 200, and 300 km are 3.3 mm/a, 1.0 mm/a, and 0.3 mm/a, respectively. These speeds are only useful for a crude comparison, in part because they are based on an approximation, but more importantly because the model of a sphere is obviously a poor geometric representation of the detached slab. Our point here is simply that rates of uplift of the order of millimeters per year are quite reasonable for the surface above a detached slab sinking freely into the asthenosphere.

Inconsistencies with this interpretation

The discussion above is meant to demonstrate that the detachment of a piece of the downgoing slab and its effect on the fluid motion beneath the New Hebrides arc could account for the relatively rapid uplift of the islands. In presenting this argument, however, we have glossed over some details of the uplift that cannot be explained by a freely sinking slab and associated fluid flow, but that instead suggest other mechanical processes.

First, the highest rates of uplift, on Espiritu Santo, do not overlie the widest or most pronounced gap, beneath Malekula and Efate. Moreover, the average uplift rates on Espiritu Santo and Malekula, but not on the Torres Islands, seem to be roughly two times faster during the last few thousand years than during the last 100 kyr. Although one could concoct mechanisms to account for these peculiarities, such as the plausible suggestion of different dates of detachment for the underlying slab, they obviously are not easily explained by one simple detachment.

In addition, the uplift rates (Figure 1) are quite scattered, with different parts of different islands rising at quite different rates, suggesting that the islands are fractured into separate blocks [e.g., Isacks et al., 1981; Taylor et al., 1980, 1987]. The uplift also varies markedly from east to west across the islands with maximum values relatively close to the trench on Espiritu Santo and Malekula, the islands closest to the trench, and decreasing rapidly eastward [e.g. Taylor et al., 1987]. These variations manifest themselves as tilts of the islands, or of parts of them [e.g. Taylor et al., 1980], some of which have detected geodetically [Bevis and Isacks, 1981; Mellors et al., 1991]. Moreover, substantial changes in uplift have been clearly associated with earthquakes [e.g., Edwards et al., the complexities of the deformation of the New Hebrides Islands, it does not provide an obvious explanation for the widespread, relatively rapid uplift of the islands along the arc. This aspect may require a more deep-seated process, and we

[redacted]

Mitronovas, W., and B. L. Isacks, Seismic velocity anomalies in the upper mantle beneath the Tonga-Kermadec island arc, *J. Geophys. Res.*, *76*, 7154-7180, 1971.