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Concave slab out board of the Tonga subduction zone caused by opposite toroidal flows under the North Fiji Basin

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ABSTRACT

An alternative scenario is proposed for the origin of a concave NE-facing slab under the North Fiji Basin between the Tonga subduction slab and Vanuatu Arc. During rollback of the Australian Plate, Vanuatu Arc rotated clockwise, whereas Fiji Platform rotated counterclockwise from 12/10 Ma until 1.5 Ma ago. Thereafter, only Vanuatu Arc rotated until the present. During the period of opposite rotations, toroidal flows entered the mantle around the northwest slab edge of Vanuatu Arc and from the northeast slab edge of Fiji Platform. The latter lies close to the northern end of the Tonga slab where arc-parallel flows are shown by volcanic geochemistry and mantle anisotropy. Opposite toroidal flows with upwelling and downwelling components generate the concave form of the combined Vanuatu/Fiji Platform slab, match its extent to mapped deep seismicity, explain its position overlying the Tonga slab, provide a mechanism for high heat flow in the North Fiji Basin as well as enriched MORB and OIB basalts in the northern NFB, and obviate slab collisions invoked to produce slab curvature.

1. Introduction

The seismically-defined slab between the Vanuatu and Tonga slabs (Fig. 1) was considered part of the Vitiaz subduction zone (Chen and Brudzinski, 2001; Hamburger and Isacks, 1987), as detached from the Tonga slab (Bonnardot et al., 2009; Brudzinski and Chen, 2003), part Vitiaz and part Tonga (Okal and Kirby, 1998) or as detached from the Vanuatu slab (Chatelain et al., 1993; Richards et al., 2011).

Here I propose, following Richards et al. (2011), that the concave slab forms part of the Australian Plate. Whereas Richards et al. (2011) consider rollback only of the Vanuatu slab, the North Fiji Basin (NFB) developed via opposite rotations (Fig. 2) of the Vanuatu Arc and the Fiji Plateau from 12/10 Ma until 1.5 Ma (Martin, 2013).

Secondly, during rollback, toroidal flows around slab edges lead to a curved slab (Faccenna et al., 2010; Funiciello et al., 2006; Schellart, 2008). Such a model (Fig. 3) provides a mechanism for the shape of the concave slab underlying the NFB.

Thirdly, the evolution of this indented slab is described in terms of double saloon door tectonics in the NFB (Fig. 4). This generates the concave geometry of the slab, matches its extent to mapped deep seismicity, explains its existence under Fiji Platform but overlying the Tonga slab, provides a mechanism for high heat flow in the NFB and E-MORB and OIB basalts in the northern NFB, and obviates the slab collision invoked by Richards et al. (2011) to explain slab curvature.

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2. Revised model of North Fiji Basin development

The NFB developed with northeast-directed subduction of the Australian Plate 12/10 Ma ago. Single saloon door clockwise rotation of the Vanuatu Arc (Richards et al., 2011; Schellart et al., 2002) agrees with GPS data (Calmant et al., 2003). However, palaeomagnetic data (Taylor et al., 2000) show that Fiji Platform rotated counterclockwise while Vanuatu Arc rotated clockwise (Fig. 2) for most of the development of the NFB (Martin, 2013). The NFB developed via double saloon door tectonics from 12/10 Ma to 1.5 Ma, and then via single saloon door rotation of Vanuatu Arc. Lau Basin developed from 6 Ma, separating Lau and Tonga Ridges (Zellmer and Taylor, 2001). Reconstructions of the related subduction slabs (Fig. 4) are based on this scheme.

3. Development of a concave slab via toroidal flows into the mantle under North Fiji Basin

In the orthodox backarc model, gravitational pull of a sinking slab drives subduction rollback. Related deviatoric tensile stresses in the overlying plate and induced convection in the underlying mantle drive backarc extension and seafloor spreading (Schellart and Moresi, 2013; Shemenda, 1993). Opposite toroidal flows (Faccenna et al., 2010; Schellart, 2008) concentrate flow in a central location within the mantle wedge, generating opposite rotational torques (Fig. 3). The influence of slab curvature engenders the radiating flow geometry (Kneller and Van Keken, 2008). If slab pull is orthogonal to a curved slab, the force is no longer planar. Slab pull at one edge of a curved slab deviates from slab

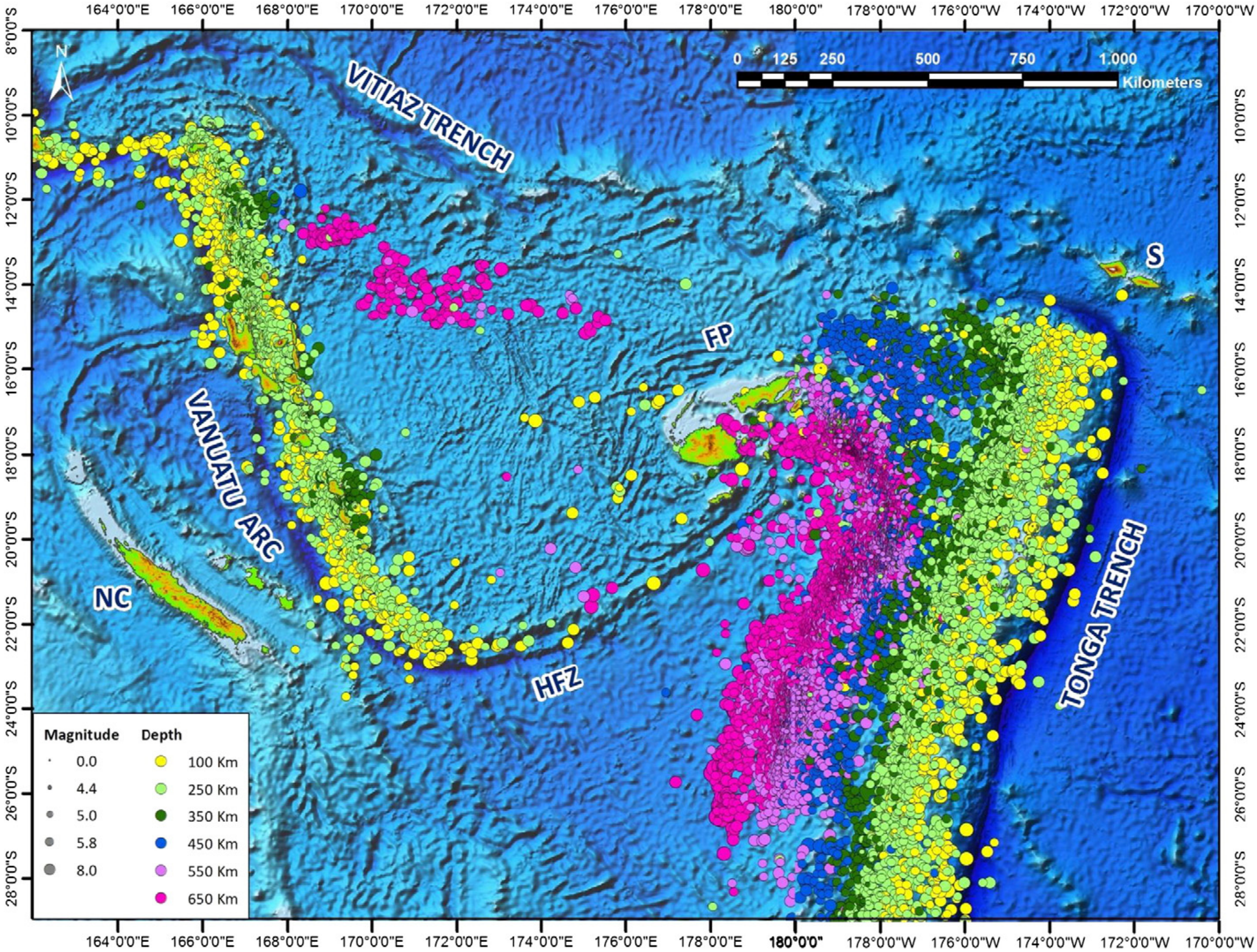

Fig. 1. Earthquake hypocentres from the USGS catalogue (earthquakes from 0 to 70 km depth excluded for clarity), overlain on shaded relief bathymetry showing tectonic elements of the Vanuatu/Tonga area. FP = Fiji Platform. HFZ = Hunter Fracture Zone. NC = New Caledonia. S = Samoa.

pull at the other slab edge, thereby augmenting the opposite rotational torques.

Geochemical markers in volcanic rocks (Gill and Whelan, 1989; Pearce and Stern, 2006; Turner and Hawkesworth, 1998) and anisotropy (Hall et al., 2000; Smith et al., 2001; Wiens et al., 2008) demonstrate flow around the north end of the Tonga Arc into the NFB and Lau Basin.

At its northwestern end, Vanuatu slab meets the EW-oriented Solomon slab. Richards et al. (2011) map these slabs to only 200 km, and 100 km respectively (cf Fig. 1). Tomographic depth slices (Hall and Spakman, 2002; Schellart and Spakman, 2012) suggest a gap at 200–500 km between the Vanuatu and Solomon slabs. Toroidal flows likely enter the mantle wedge above the Vanuatu slab from the northwest (Fig. 4).

4. Alternative geodynamic scenarios for the evolution of a concave slab under the NFB

4.1. Slab created during single-saloon-door opening of the NFB

In the Richards et al. (2011) scheme, part of the Vanuatu slab detaches, slides eastward and collides with the Tonga slab. Subsidence of the eastern end of the detached slab is slowed by the Tonga slab, whereas the central part continues subsiding, producing the concave-upward shape.

This model is flawed on several grounds. Firstly, no mechanism is given to explain the eastern motion and collision of the Vanuatu slab with the Tonga WBZ. Although motion of the Australian Plate and Vanuatu slab is towards the northeast (Calmant et al., 2003), the Tonga slab is retreating to the east even faster (Bevis et al., 1995). Secondly, in order to collide, Vanuatu slab has to subside faster than Tonga slab. The exact reverse is likely because Tonga slab comprises 100–120 Ma old cold lithosphere of the Pacific Plate (Van der Hilst, 1995), whereas 42–55 Ma old, less dense lithosphere subducts at Vanuatu (Schellart et al., 2002). Thirdly, Richards et al. (2011) envisage the collision at 500–600 km, whereas a slab west of Tonga slab may extend to only ~200 km. Although not resolved in tomographic cross-sections, depth slices (200, 320, 500 and 628 km — Hall and Spakman (2002); and 200, 400, 500, and 600 km Schellart and Spakman (2012)) show a possible slab under and southeast of Fiji, as do Vp/Vs tomographic images (Conder and Wiens, 2006). Chen and Brudzinski (2001) consider hypocentres as shallow as 350 km to be outboard of the Tonga WBZ (but see Fig. 4e). A shallow slab at only 200 km depth requires almost horizontal movement for the Vanuatu slab to collide with the Tonga slab, rendering slab collision implausible.