Variation of the magmatic plumbing systems in the Rabaul area (Papua New Guinea) across space and time

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1. Introduction

Caldera volcanoes commonly show cycles, with repeated ignimbrite eruptions interspersed with long periods of minor activity. The caldera-forming magma bodies must develop during these periods of minor activity. Calderas can also have multiple vents, which may tap different melt bodies. To understand the behaviour of silicic calderas, we must ensure our sampling is representative both in time and in space. Rabaul is an ideal location to study these variations, as it has had at least five caldera-forming eruptions in the last 20 ky and has multiple vent locations.

2. Geological Setting

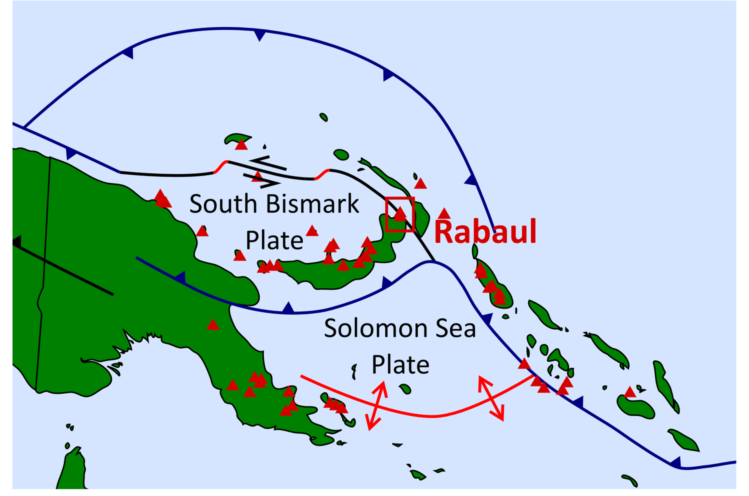

Figure 1: Rabaul is part of the New Britain Arc, where the Solomon Sea Plate is subducted beneath the South Bismark Plate.

3. Volcanic history of Rabaul

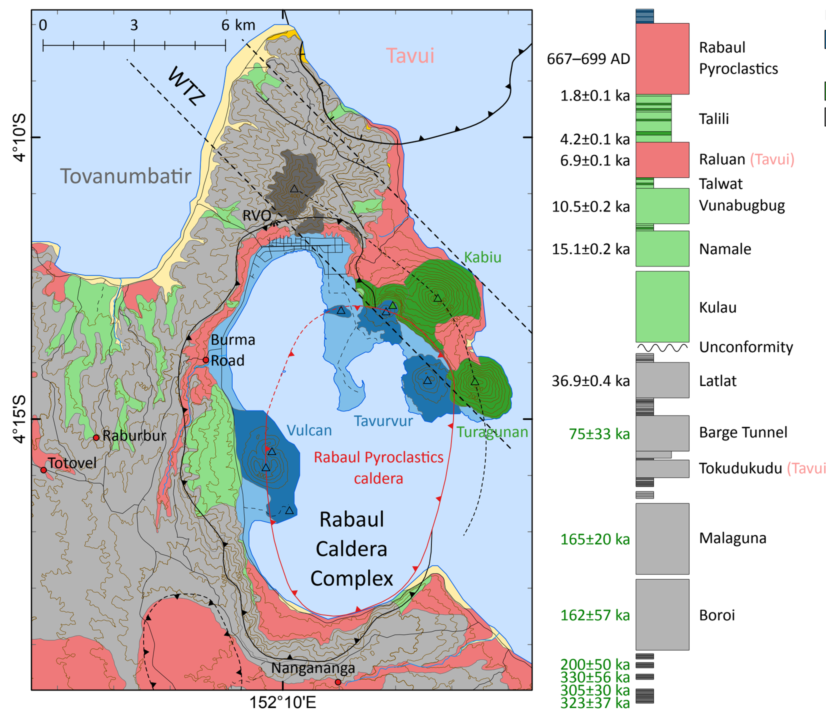

Figure 2: Geological map of Rabaul, modified from Nairn et al. (1989). Dates from Nairn et al. (1995) and McKee & Duncan (2016).

- Several overlapping calderas make up the *Rabaul Caldera Complex* (RCC). Eruptions from within the RCC are mostly dacitic.
- To the north and east lies a zone of five dominantly mafic stratocones, the *Watom–Turagunan Zone* (WTZ).
- Directly north of the RCC lies the submarine *Tavui Caldera*. Products from Tavui range from basaltic andesite to rhyolite.
- Historical activity has taken place at several locations within the most recent caldera. The most recent period of activity started in 1994 with simultaneous eruptions from *Vulcan* and *Tavurvur*, on opposite sides of the caldera.

We have focused on activity during the Late Pleistocene–Holocene, a period that includes the most recent complete caldera cycle, from the 10.5-ka *Vunabugbug Ignimbrite* until the 1.4-ka *Rabaul Pyroclastics*. Between these two caldera collapses lie the *Talwat* and *Talili* subgroups, a sequence of at least 11 explosive eruptions. These include both basaltic scoria fall deposits and dacitic fall, flow and surge deposits.

Figure 3: View of the volcanoes of the Rabaul Caldera Complex and the Watom–Turagunan Zone, taken from the Rabaul Volcano Observatory (RVO, see Figure 2 for colour scheme and location), looking south. Vulcan, Tavurvur, Sulphur Creek and Rabalanakaia (hidden behind Palangiangia in this photo) have all been active in the last ∼250 years. Kabiu, Palangiangia and Turagunan have all been active in the last 4.2 ky, but with the possible exception of a lava flow from Turagunan, have not erupted since the Rabaul Pyroclastics eruption about 1.4 ka.

4. The stratigraphy of the Rabaul Pyroclastics

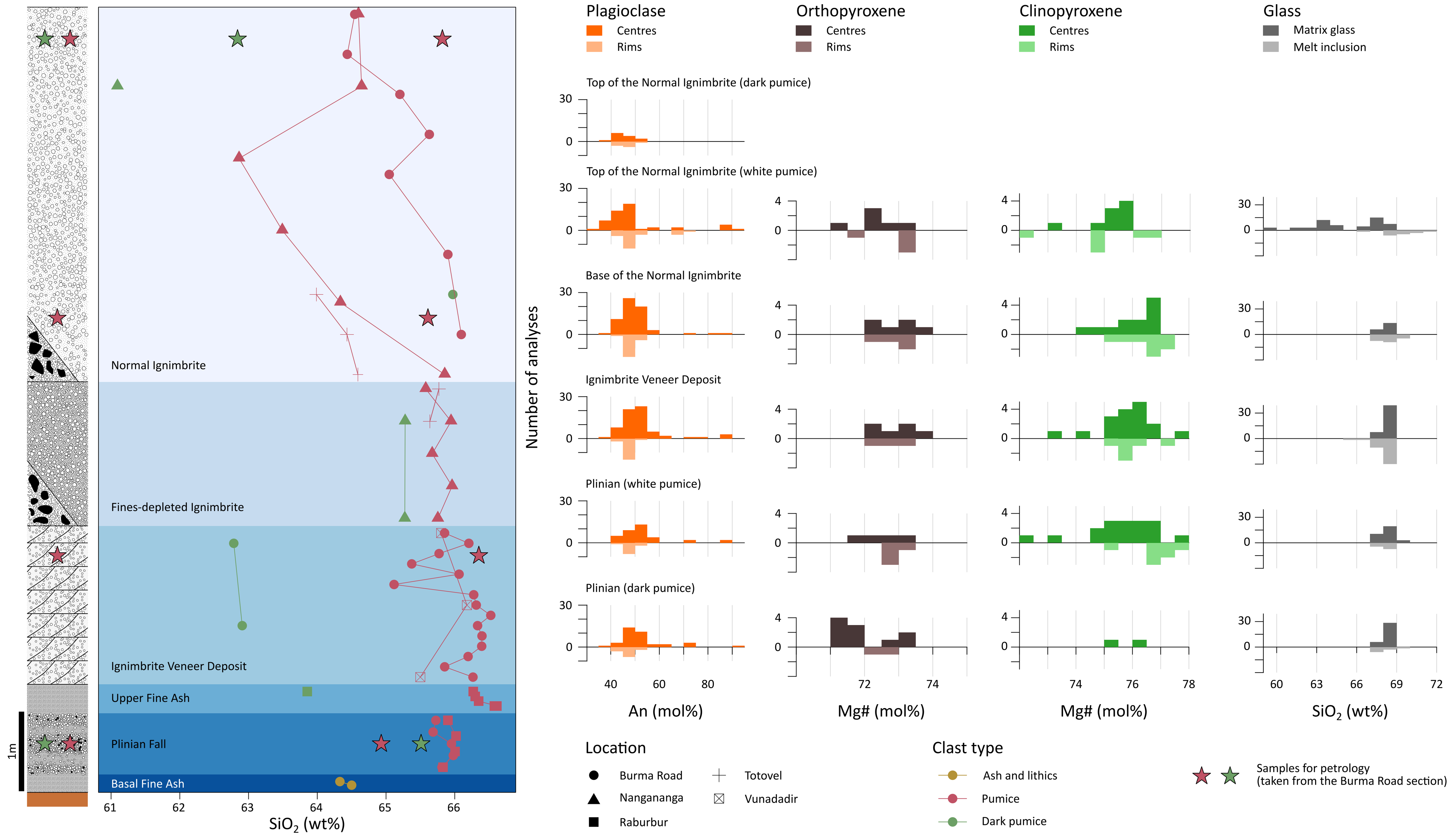

Figure 4: Stratigraphic variations in the chemistry and petrology of the Rabaul Pyroclastics. Locations are shown in Figure 2.

- There are two juvenile components in the Rabaul Pyroclastics: dark (<5%) and white pumice (>95%).
- The white pumice is dacitic, wile the dark pumice tends to be more andesitic.
- Towards the top of the normal ignimbrite the two magma types become more mingled: the dark pumice is found as thin streaks in the white pumice, and the composition of the glass in the white pumice at the top of the ignimbrite shows a larger range than any of the other samples.
- There is only one dominant phenocryst population, as shown by mineral and melt inclusion compositions.
- The dark pumice represents an almost aphyric, andesitic recharge magma injected shortly before eruption.

5. Pre-eruptive magma storage conditions

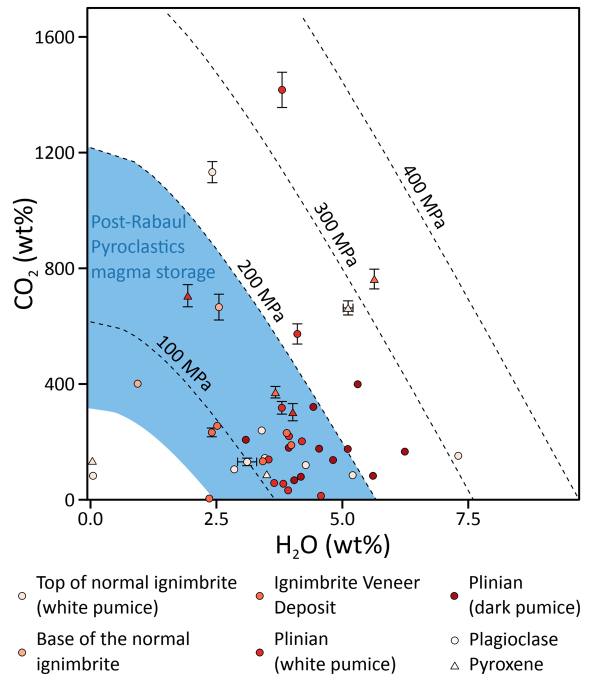

Figure 5: Volatile contents of melt inclusions from the Rabaul Pyroclastics. Isobars calculated for a rhyolite at 930°C using VOLATILECALC (Newman & Lowenstern, 2002). The blue shaded region is the range of storage pressures estimated for the recent, post-Rabaul Pyroclastics eruptions by Bouvet de Maisonneuve et al. (2015).

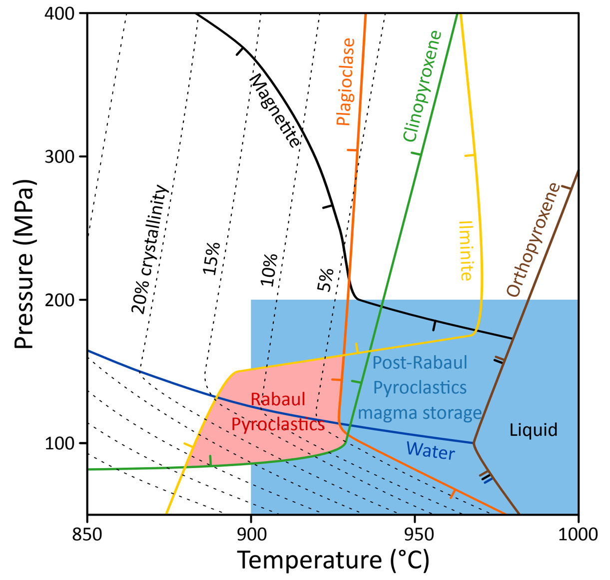

Figure 6: Equilibrium phase assemblages calculated for the Rabaul Pyroclastics dacite using Rhyolite-MELTS (Gualda et al., 2012; Gualda & Ghiorso, 2015). The blue shaded region is the range of storage pressures estimated for the recent, post-Rabaul Pyroclastics eruptions by Bouvet de Maisonneuve et al. (2015).

- Rabaul Pyroclastics dacite was stored at ∼100–200 MPa (3.8–7.6 km) and ∼900–930°C, as shown by both MELTS modelling and melt inclusion volatile contents.
- The present-day magma reservoir is at a similar depth, as shown by: deformation (top of the reservoir 1.9–3 km; Ronchin et al., 2013), gravity (top of the reservoir >1.8 km; McKee et al., 1989), seismic tomography (3–5 km; Finlayson et al., 2003, and melt inclusion volatile content (1.9–7.6 km; 50–200 MPa; Bouvet de Maisonneuve et al., 2015).
- Deformation data and the simultaneous eruption of the same magma from both Vulcan and Tavurvur shows that the present-day magma reservoir extends laterally across much of the Rabaul Pyroclastics caldera.

6. Variations in the magmatic plumbing systems

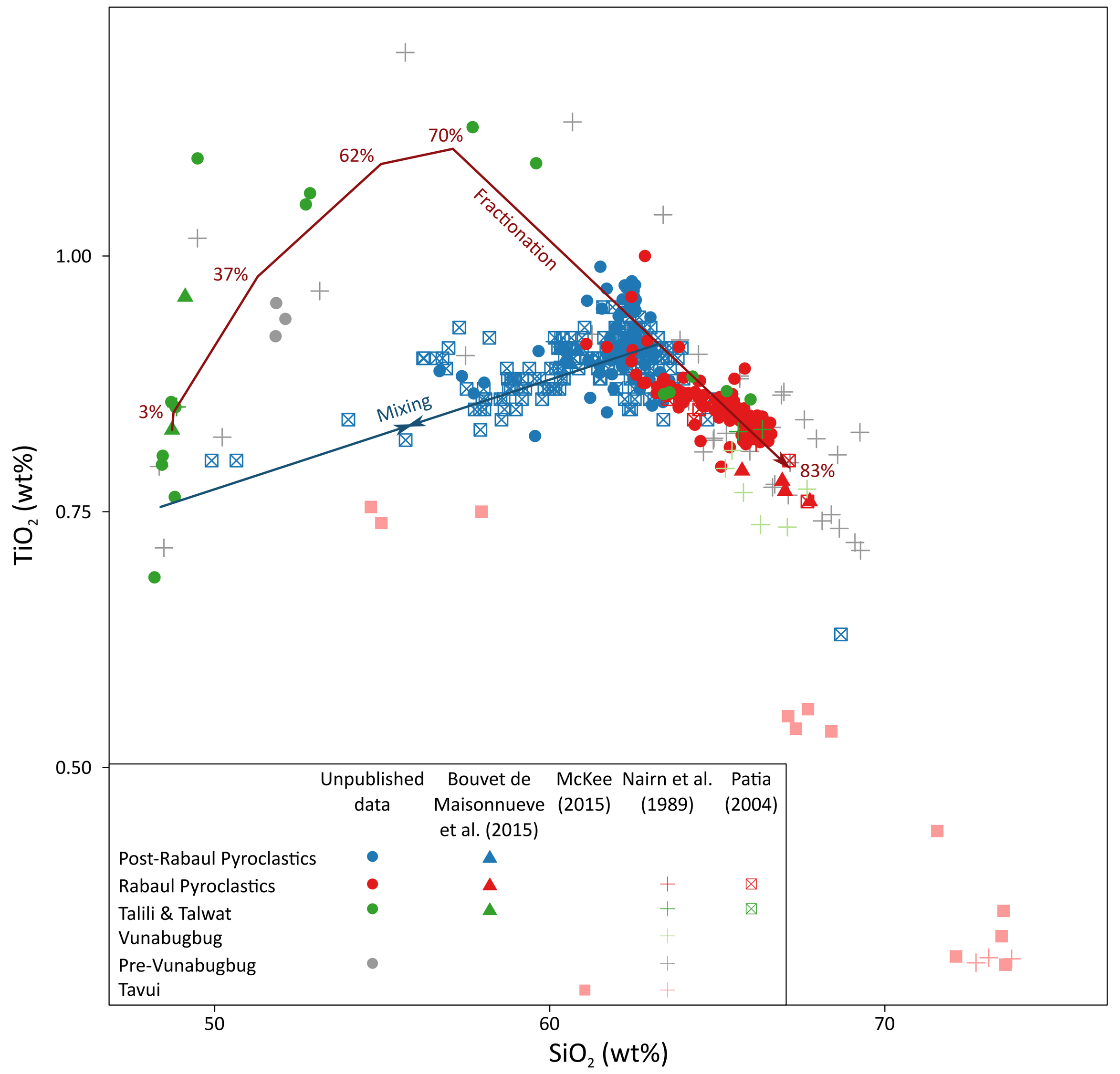

Figure 7: Composition of Rabaul magmas. Fractional crystallisation path modelled using mass balance for major elements, and partition coefficients from the GERM Partition Coefficient Database (https://earthref.org/KDD/) for trace elements.

Variations in space

- Tavui magmas fall on a different fractional crystallisation trend, due to the presence of amphibole (no amphibole is found in RCC and WTZ magmas), suggesting that they do not share a magma reservoir. Tavui magmas also have lower K_2O and incompatible trace element concentrations. WTZ and RCC magmas fall on the same fractional crystallisation trend, but dacite is restricted to the RCC.

Variations in time

- The post-Rabaul Pyroclastics magmas fall on a linear trend that cuts across the fractional crystallisation trend (Figure 7). Basaltic enclaves are also common. This demonstrates that basaltic recharge is an important process in the present-day magma reservoir under the RCC.
- The dark pumice in the Rabaul Pyroclastics shows that mafic recharge also occurred prior to that eruption. However, both the dark and light pumice fall on the fractional crystallisation trend—the recharge must be andesitic ($SiO_2 \gtrsim 57\%$).
- The presence of a more developed reservoir prior to the Rabaul Pyroclastics prevented basaltic recharge from entering the shallow system. After eruption, basalt can now enter the shallow system again.
- The Talili eruptions also fall on the fractional crystallisation trend, suggesting that a large silicic reservoir existed under the RCC since at least 4.2 ka.

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