Differing magmatic process before caldera-forming and small eruptions at Rabaul, Papua New Guinea

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1. Introduction

Forecasts of the onset of an eruption are improving, but forecasting the size of that eruption remains difficult. This is especially a problem at calderas such as Rabaul, as the potential size of the next eruption ranges over several orders of magnitude. Improving estimates of eruption size requires a better understanding of the processes that occur beneath a volcano in the build-up to caldera-forming eruptions, and how they differ from those that occur prior to minor eruptions. By studying a complete caldera cycle, from one caldera-forming eruption to the next, we can investigate the changes that occur in the plumbing system in the build-up to a large eruption.

2. Geological Setting

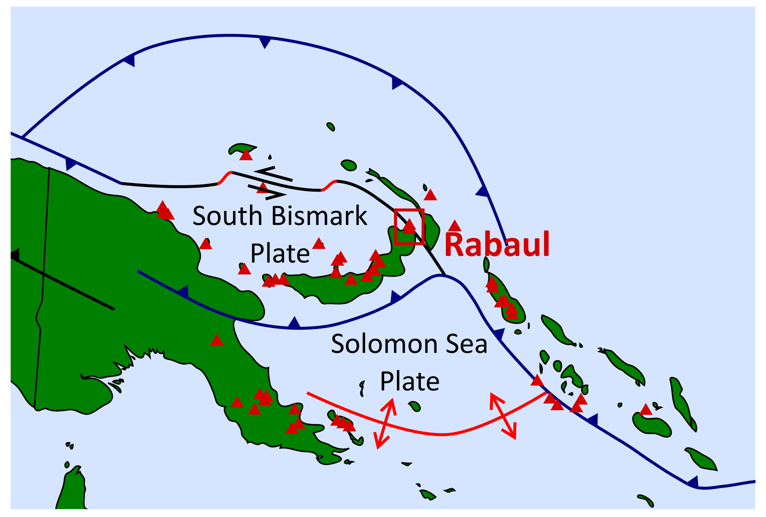

Figure 1: Rabaul is part of the New Britain Arc, where the Solomon Sea Plate is subducted beneath the South Bismark Plate.

3. Volcanic history of Rabaul

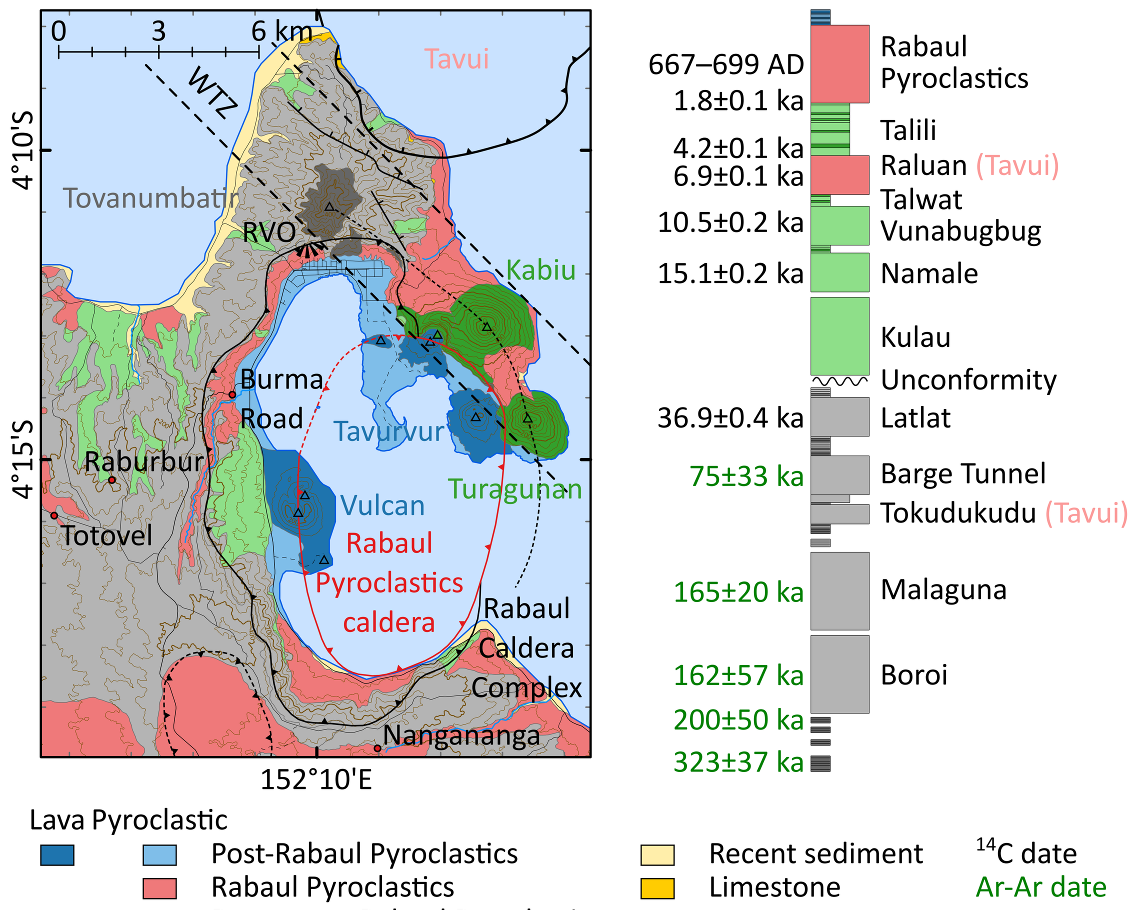

Figure 2: Geological map of Rabaul, modified from Nairn et al. (1989). Dates from Nairn et al. (1995) and McKee & Duncan (2016).

- 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).
- 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 Rabaul Caldera Complex and the Watom–Turagunan Zone, from the Rabaul Volcano Observatory (RVO, see Figure 2 for colour scheme and location). Vulcan, Tavurvur, Sulphur Creek and Rabalanakaia (hidden behind Palangiangia) 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.

4. The stratigraphy of the Rabaul Pyroclastics

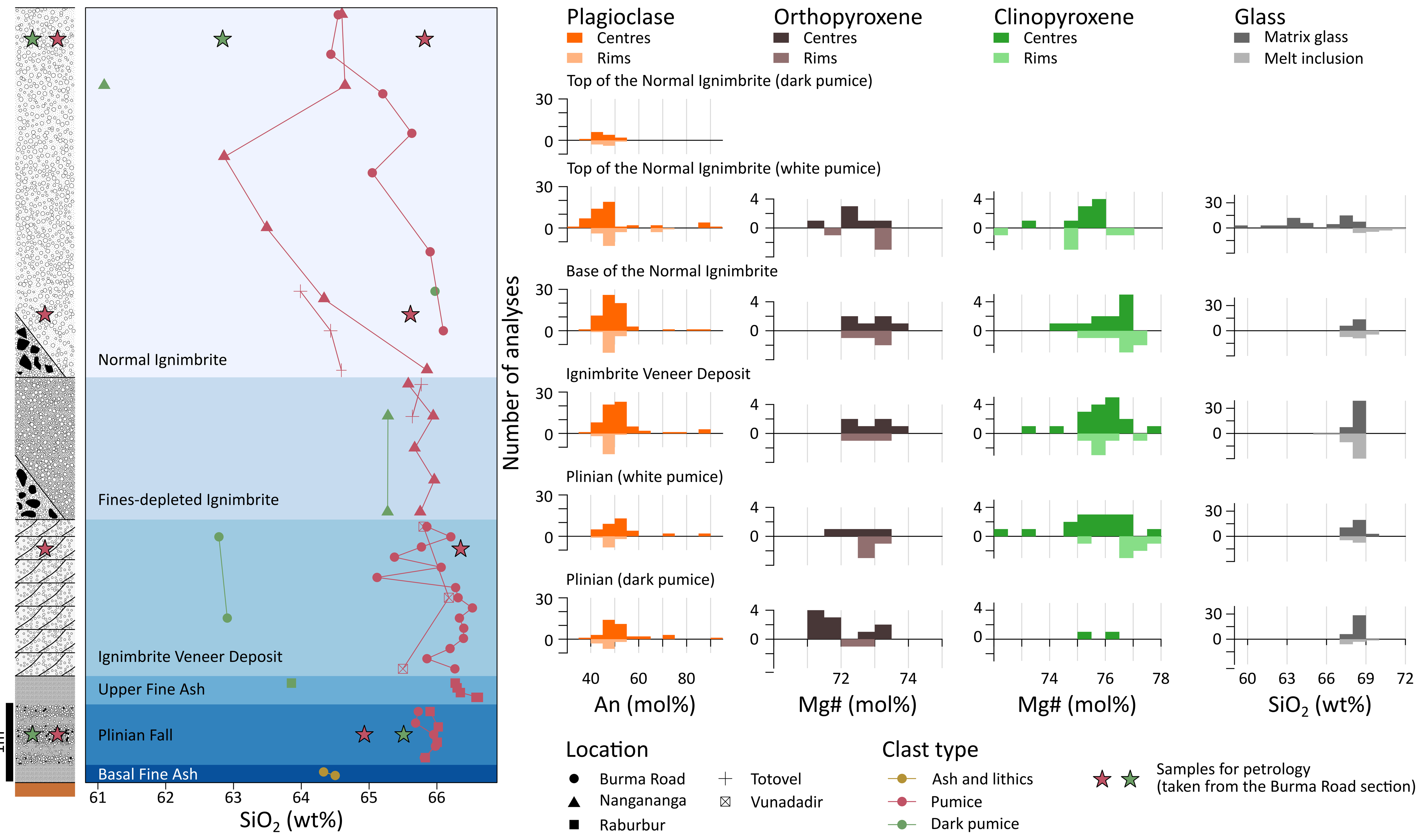

Figure 4: Stratigraphic variations in the chemistry and petrology of the Rabaul Pyroclastics. Locations are shown in Figure 2.

- 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

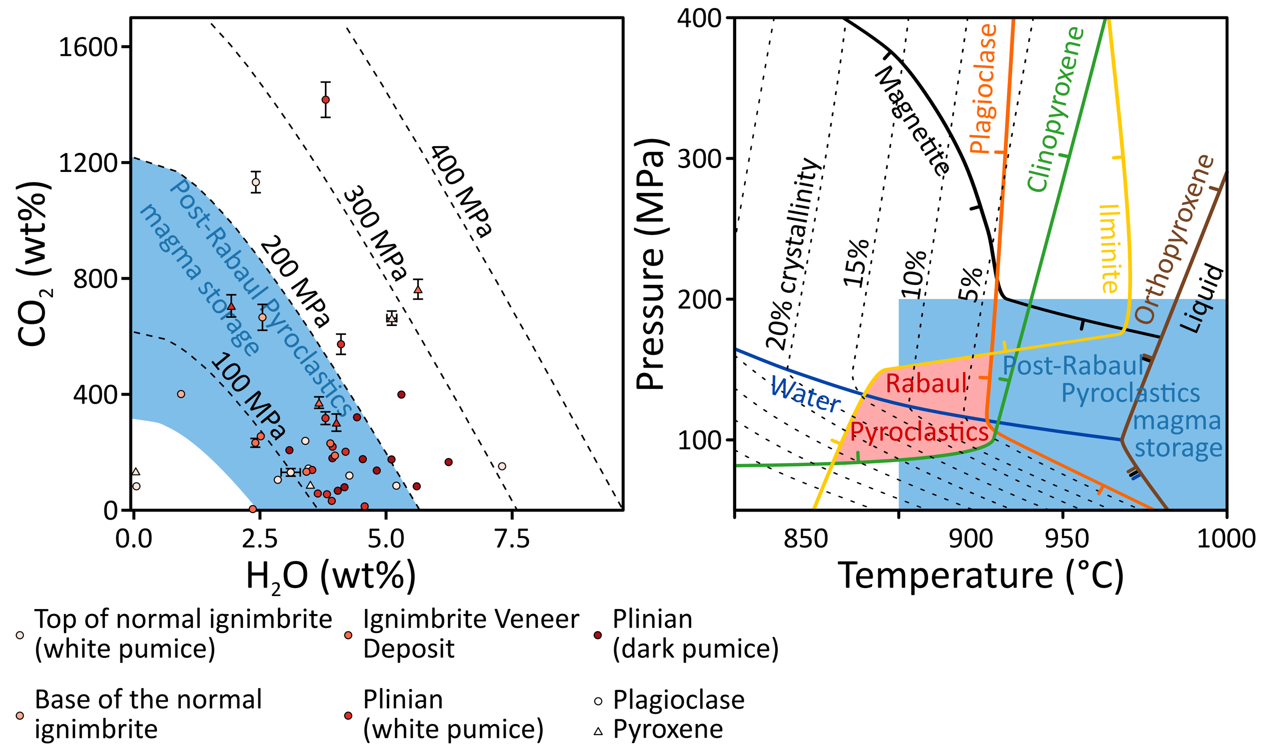

Figure 5: Left: volatile contents of melt inclusions from the Rabaul Pyroclastics. Isobars calculated for a rhyolite at 930°C using VOLATILECALC (Newman & Lowenstern, 2002). Right: Equilibrium phase assemblages calculated for the Rabaul Pyroclastics dacite using Rhyolite-MELTS (Gualda & Ghiorso, 2015). The blue shaded region is the range of storage pressures and temperatures 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.
- 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. Changes in magmatic processes

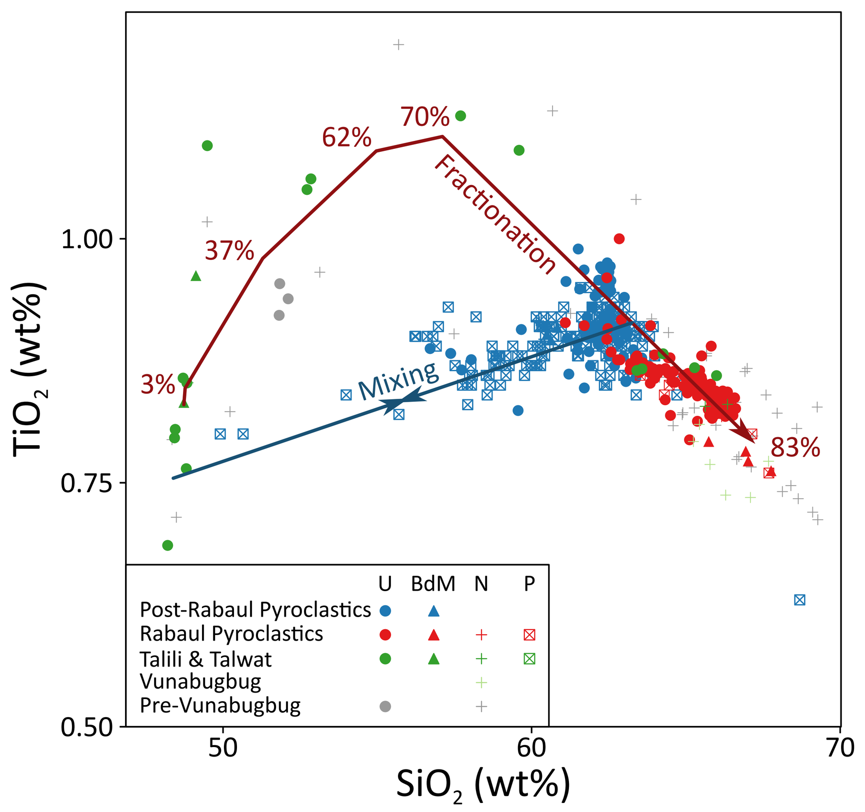

Figure 6: Composition of Rabaul magmas. Fractional crystallisation path modelled using mass balance for major elements, and partition coefficients from the GERM Partition Coefficient Database (https://earthref.org) for trace elements. Data: U: Unpublished, BdM: Bouvet de Maisonneuve et al. (2015), N: Nairn et al. (1989), P: Patia (2004).

- The post-Rabaul Pyroclastics magmas cut across the fractional crystallisation trend (Figure 6). Basaltic enclaves are also common. This demonstrates that basaltic recharge is an important process in the present-day magma reservoir.
- 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 since at least 4.2 ka.

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