Magma storage, recharge and the caldera cycle at Rabaul, Papua New Guinea

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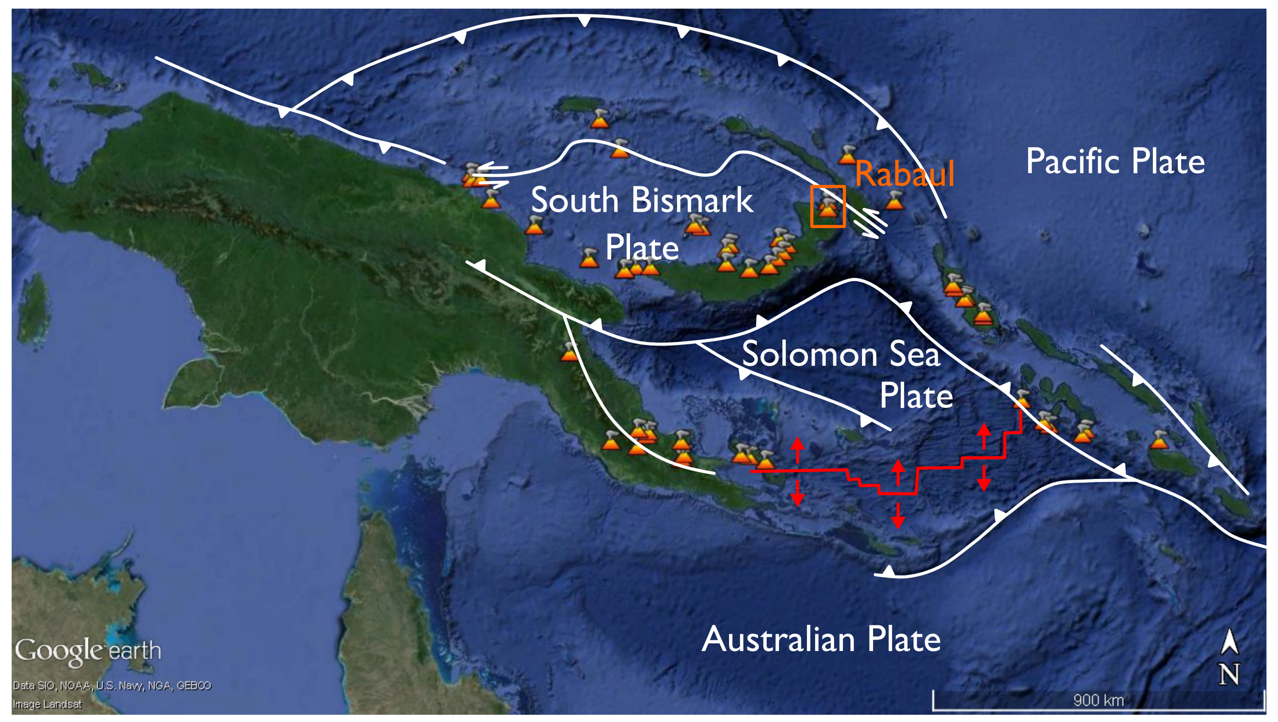
1. Introduction

While forecasts of the start of an eruption are improving, a central question still remaining is whether we can predict the size of the next eruption. Although many caldera volcanoes have a repeated history of large, caldera-forming eruptions, their eruptive records are dominated by relatively minor activity. Understanding what controls whether such volcanoes will erupt gently or catastrophically would help in interpreting monitoring data from quiescent or restless calderas, and could potentially alert us to a future major eruption. It is with this in mind that we have focused on Rabaul, a caldera in Papua New Guinea.

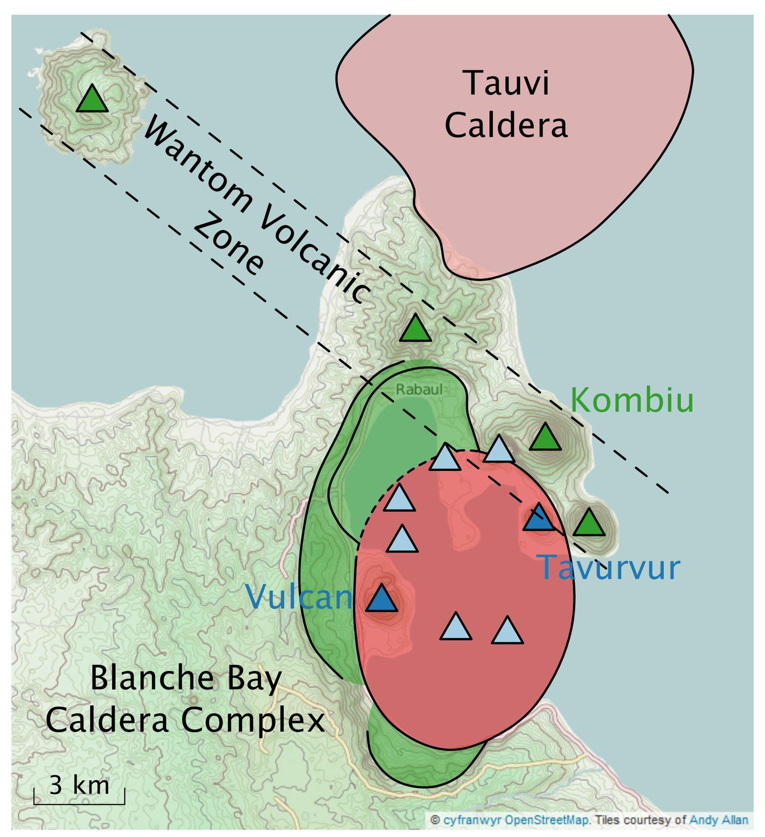
2. Geological Setting



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

3. The volcanic history of Rabaul

Rabaul has shown repeated caldera cycles, with at least 11 ignimbrite eruptions preserved in the surrounding area that were erupted over the last ∼500 ky (Nairn et al., 1995). These are interspersed with the deposits from many more minor eruptions, dating back to at least 1.2 Ma (Johnson et al., 2010). We have focused on the most recent activity, from the last caldera-forming eruption (the "1400 BP") to the present day.



1994–2014 CE

Current phase of activity. Started with simultaneous sub-Plinian eruptions from Vulcan and Tavurvur, two vents on opposite sides of the caldera. Mostly strombolian and vulcanian activity. Last eruption was August 2014.

∼1200–1943 CE

Post-caldera volcanism, effusive and minor explosive eruptions (up to VEI 4), from both Vulcan and Tavurvur, and from other vents across the caldera.

667–699 CE

"1400 BP" Ignimbrite, which erupted $>11\,km^3$ and lead to the collapse of the most recent caldera in Blanche Bay (McKee et al., 2015).

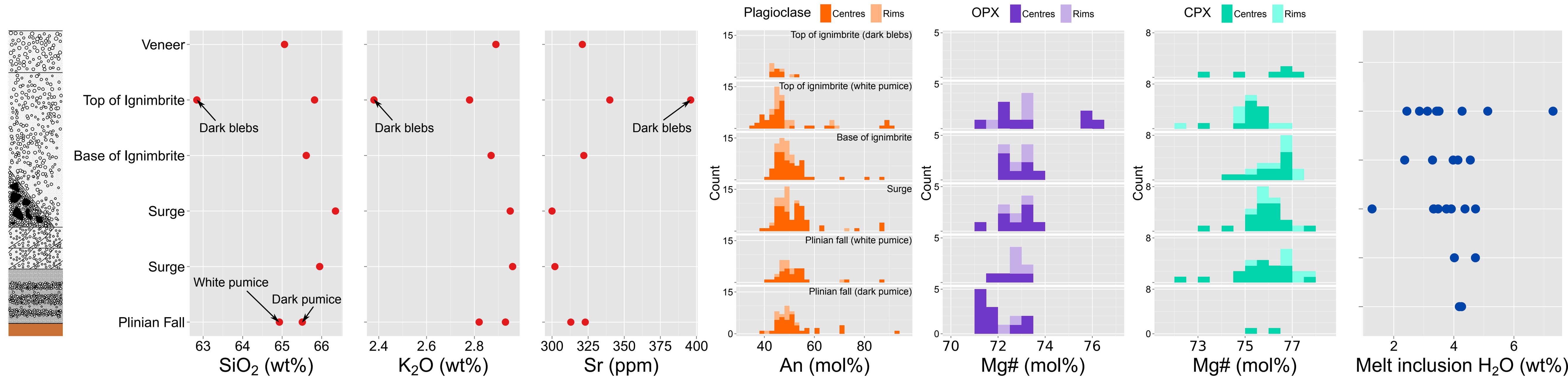
∼7,000 years BP

Raluan Ignimbrite, probably erupted from the offshore Tavui Caldera.

1,200–7 ka

All pre-Raluan activity, including multiple large ignimbrite eruptions and the formation of several large stratovolcanoes along the north of the Blanche Bay Caldera Complex.

4. The detailed stratigraphy of the 1400 BP ignimbrite



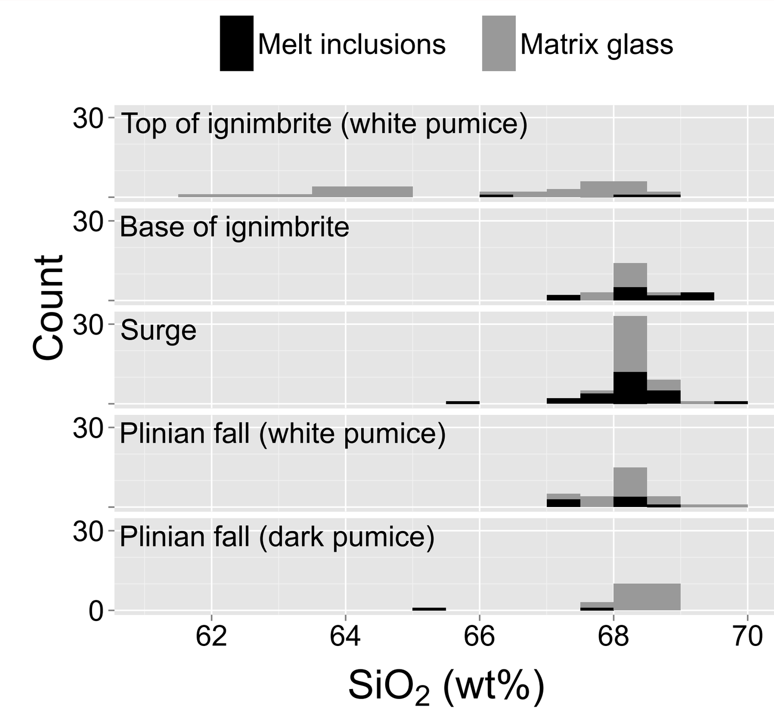
The dacitic (65–66 wt% SiO_2) magma reservoir that fed the 1400 BP was well-mixed, as demonstrated by the lack of systematic changes in either whole-rock or mineral chemistry with stratigraphic height. A single phenocryst population is observed, of An_{44-52} plagioclase, $En_{69-71}Fs_{25-28}Wo_3$ (Mg# = 72–74) orthopyroxene and $En_{43-46}Fs_{13-15}Wo_{40-41}$ (Mg# = 74–77) clinopyroxene, with smaller amounts of magnetite and apatite.

The H_2O content of the melt inclusions trapped in plagioclase was measured by SIMS for the top of the ignimbrite and by reflected FTIR for the other samples, and does not show a significant trend with stratigraphy. This suggests either the 1400 BP magma was not water saturated, or the storage region was not vertically extensive (e.g. it was stored in a sill).

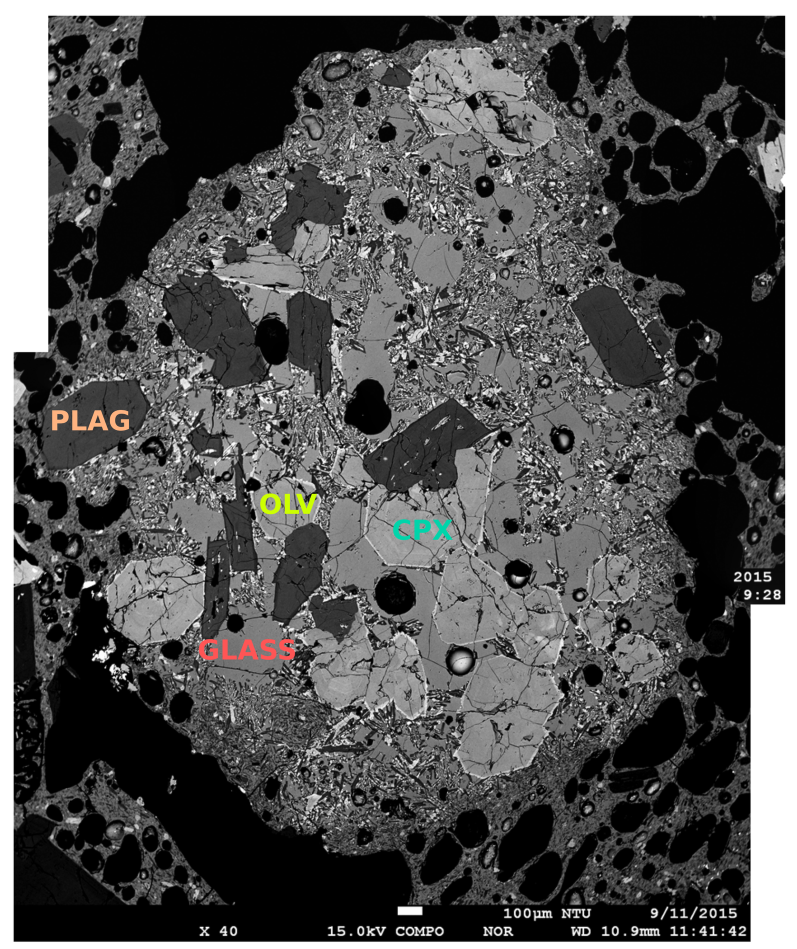
5. Evidence for mixing and mingling before the 1400 BP eruption

Dark, andesite blebs (63 wt% SiO_2; pictured left) are found only towards the top of the ignimbrite, and probably represent a late-stage injection of fresh magma at the base of the reservoir. However, there is no mafic crystal population found in either the andesite blebs or the dacite, suggesting that this recharge was aphyric. The crystals in the mafic blebs are identical in composition to those found in the dacite, which have dacitic melt inclusions with a similar composition to the matrix glass (right).

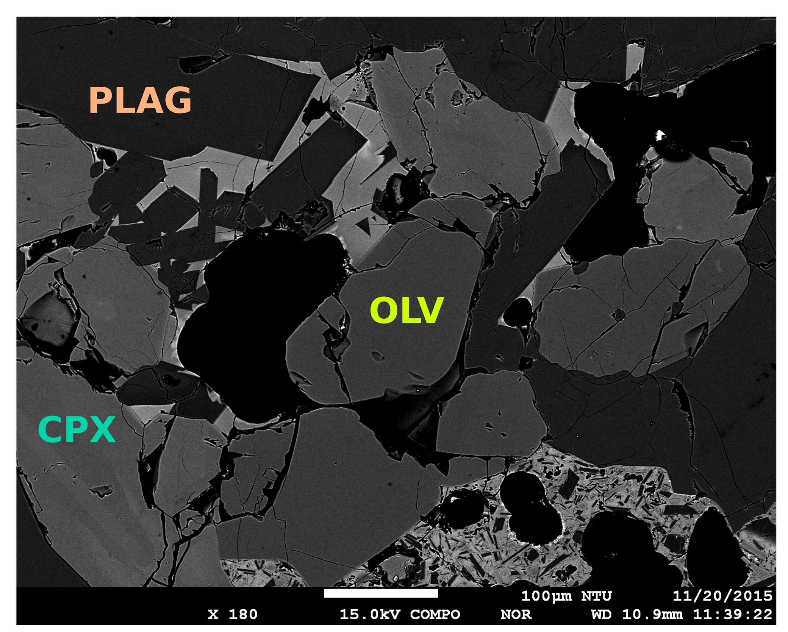
The matrix glass also shows evidence for a late-stage recharge event (right). The majority of the 1400 BP matrix glass has a very narrow compositional range (67–69 wt% SiO_2), again demonstrating that the dacitic reservoir was well-mixed. However, at the top of the ignimbrite, a large range of matrix glass compositions is found (down to 60 wt% SiO_2). The injected mafic magma had begun to mix and hybridise with the resident dacite prior to eruption.

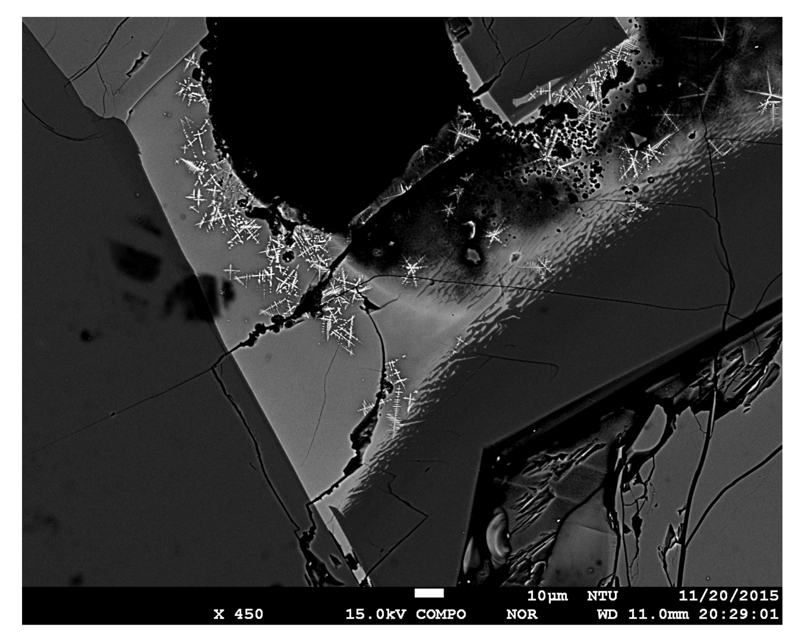


6. Magmatic recharge before minor eruptions



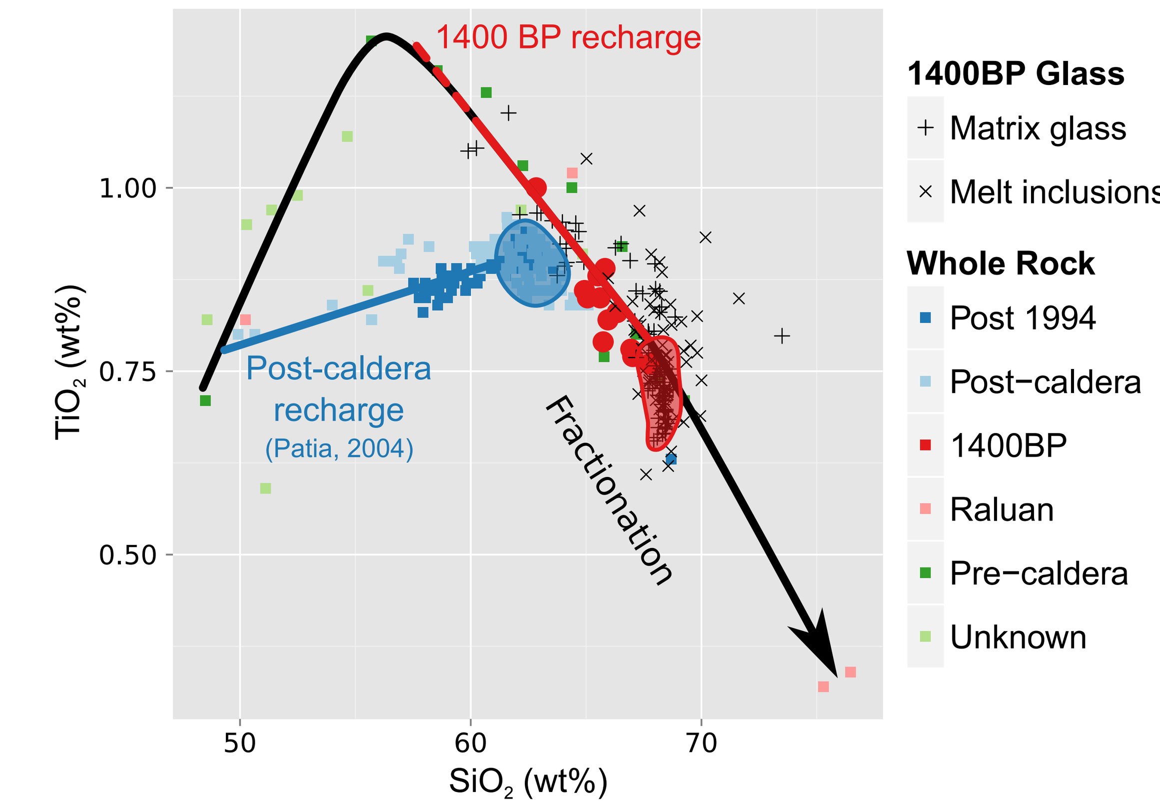
Mafic recharge is often preserved in the deposits from the minor eruptions of Rabaul as clusters of plagioclase, olivine and clinopyroxene (Bouvet de Maisonneuve et al., 2015). Examples of these from the August 2014 eruption of Tavurvur (left) and a strombolian eruption of Kombiu (below) are shown. The groundmass surrounding these clusters is often very crystalline, and these microlites are often skeletal or dendritic, and occasionally form symplectites. This is indicative of rapid growth, and suggest that the recharge magma was quenched as it was injected into cooler magma already resident in the reservoir.





7. Comparing magma mixing and mingling across the caldera cycle

The post-caldera magma reservoir is replenished by injections of basalt. This is shown by the quenched mafic enclaves, and is clearly seen on a plot of TiO_2 against SiO_2 (below). The post-caldera magmas form a linear array that lies below the curved fractionation trend. The high TiO_2 of the matrix glass in the 1400 BP, however, means that the intruding magma had to have $\gtrsim$56 wt% SiO_2.



Whole rock data: 1400 BP: This study; other data: Heming & Carmichael (1973), Wood et al. (1995), Patia (2004)

There are two possible interpretations for the different recharge compositions:

1. More evolved recharge causes a more evolved reservoir to form
2. The presence of a more evolved reservoir prevents basaltic recharge from entering the shallow system

The lack of post-caldera samples that fall along fractionation trends suggests that fractionation may not be a significant process at present, and that the silicic component in the current activity may be left over from the 1400 BP. However, the silicic component from the past-caldera activity is less evolved than the silicic component of the 1400 BP, suggesting that the 1400 BP emptied the most evolved, crystal-poor portion of the reservoir, perhaps leaving a crystal mush behind.

8. Conclusions and future work

- The crystal-poor, dacitic portion of the 1400 BP magma reservoir that was erupted was well mixed, and was possibly sill-shaped.
- Shortly before eruption, an andesite with between ∼56 and ∼60 wt% SiO_2 was injected into the base of the chamber.
- Mafic recharge is common during inter-caldera, constructive phases of activity at Rabaul. However this recharge is basaltic rather than andesitic.
- The different composition of the recharge before the 1400 BP eruption suggests that the plumbing system under Rabaul is not the same before caldera-forming as it is during periods of minor eruptive activity.

- In order to test this hypothesis, other caldera-forming eruptions of Rabaul will be investigated.
- CO_2, H_2O, S, F and Cl contents in melt inclusions will be measured by SIMS to get a better understanding of the 1400 BP reservoir.

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