The "1400 BP" caldera-forming magma reservoir (Rabaul, Papua New Guinea) reconstructed from the compositions and volatile contents of melt inclusions

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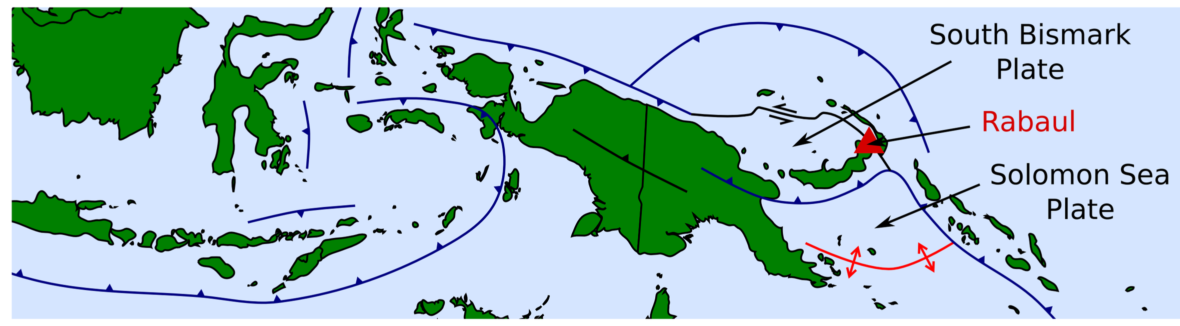
1. Introduction

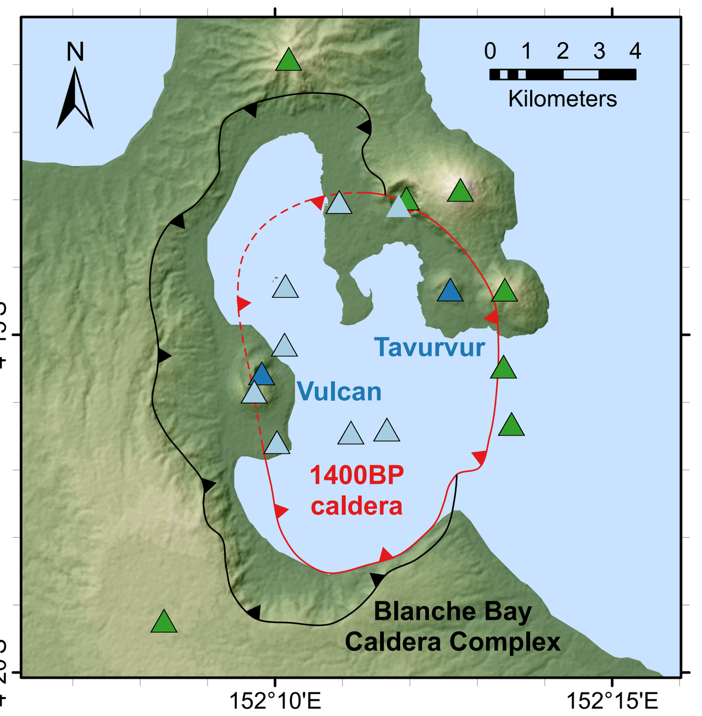
In order to correctly interpret monitoring data at restless calderas, it is important to understand how the plumbing systems of these volcanoes works. Many calderas appear to have repeated cycles of activity, where large, caldera-forming eruptions are interspersed with long periods of minor, mostly effusive activity. How the plumbing system of these volcanoes evolves, and how the caldera-forming magma reservoir is assembled is still an open question. 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. With that in mind, we focus on the "1400 BP" caldera-forming eruption of Rabaul, 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.



- Rabaul has had at least 11 ignimbrite eruptions over the last ∼500 ky (Nairn et al., 1995; Johnson et al., 2010).
- These are interspersed with the deposits from many more minor eruptions.
- 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, followed by 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.

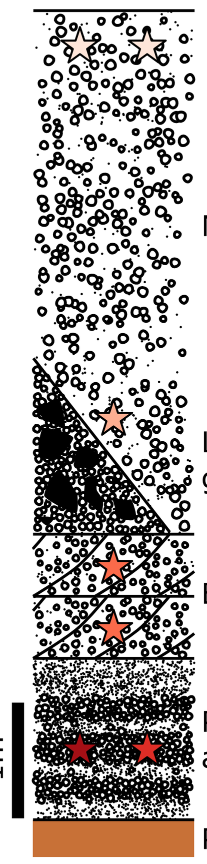
667–699 CE
"1400 BP" Ignimbrite, which erupted >11 km^3 and lead to the collapse of the most recent caldera in Blanche Bay (McKee et al., 2015).

1,200–1.4 ka
All pre-1400 BP activity, including multiple large ignimbrite eruptions such as the Vunabugbug Ignimbrite, and the formation of several large stratovolcanoes along the north of the Blanche Bay Caldera Complex.

3. Methods

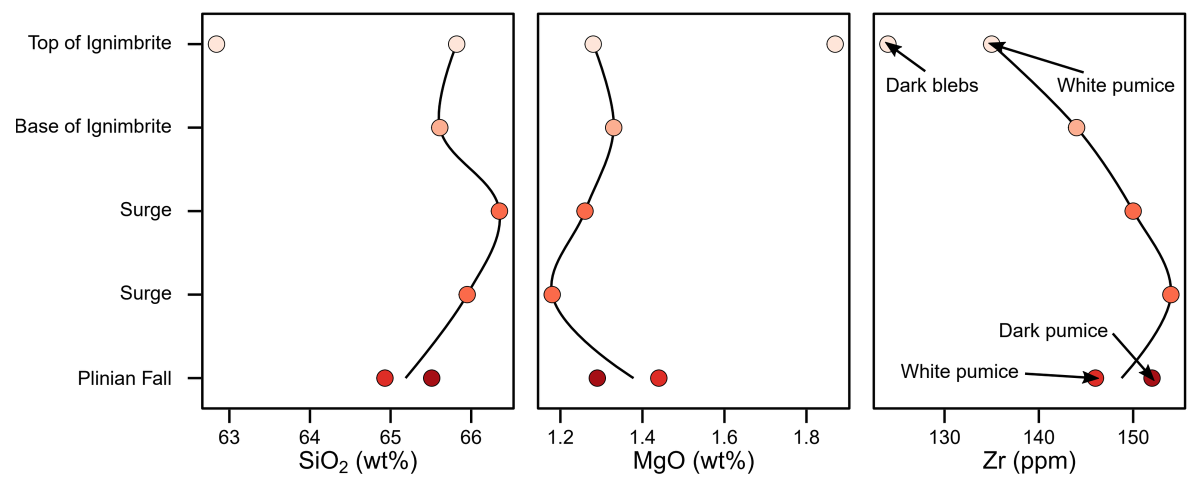
- Whole rock chemistry was acquired by Actalabs (Canada).
- Mineral and glass chemistry was analysed using the Electron Microprobe at Nanyang Technological University, Singapore.
- Melt inclusion volatile contents were acquired by Secondary Ionisation Mass Spectrometry (SIMS) at Woods Hole Oceanographic Laboratory, USA, except for those from the top of the Ignimbrite that are from Bouvet de Maisonneuve et al. (2013).
  - H_2O and CO_2 contents were calibrated using rhyolitic standards, for compatibility with the data of Bouvet de Maisonneuve et al. (2013).
  - F, Cl and S contents were calibrated using basaltic standards.
  - Standards were run multiple times during the session, to correct for analytical drift.

4. The 1400 BP Ignimbrite

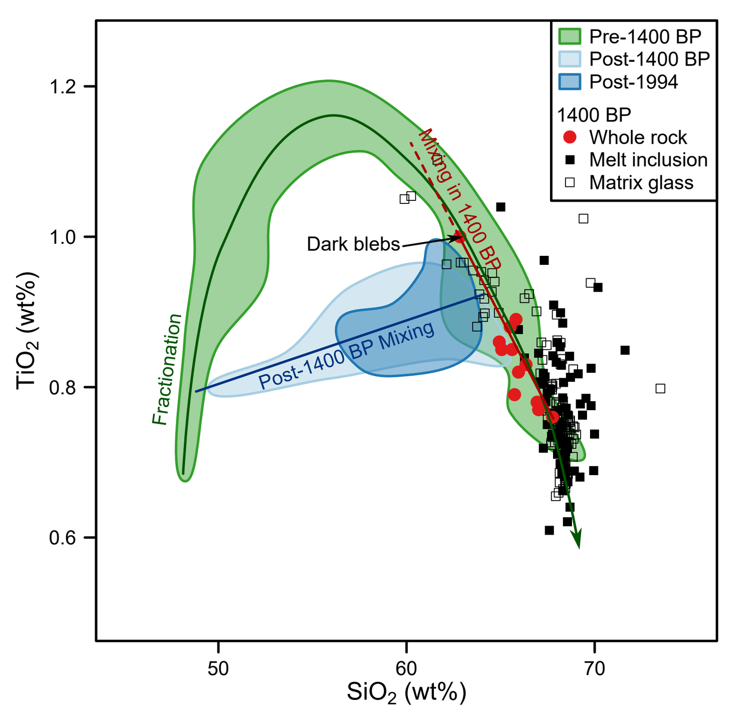


- The deposits of the 1400 BP can be split into two units (left): a Plinian fall unit and an overlying pyroclastic density current (PDC) deposit.
- The fall deposits reach a maximum thickness of 131 cm close to the caldera (Walker et al., 1981). They consist of alternating deposits of coarse pumice and fine ash.
- The PDC deposits vary systematically from 5–10 m in thickness near the caldera to about 0.5 m ∼25 km from the caldera rim (Walker et al., 1981). Within paleo-valleys the PDC deposits can be much thicker—up to 30 m.
- The base of the PDC deposits are sometimes weakly cross-bedded and includes discontinuous, lithic-rich breccia layers.
- Red/pink stars mark the locations of the samples used in this study.

5. Whole-rock chemistry



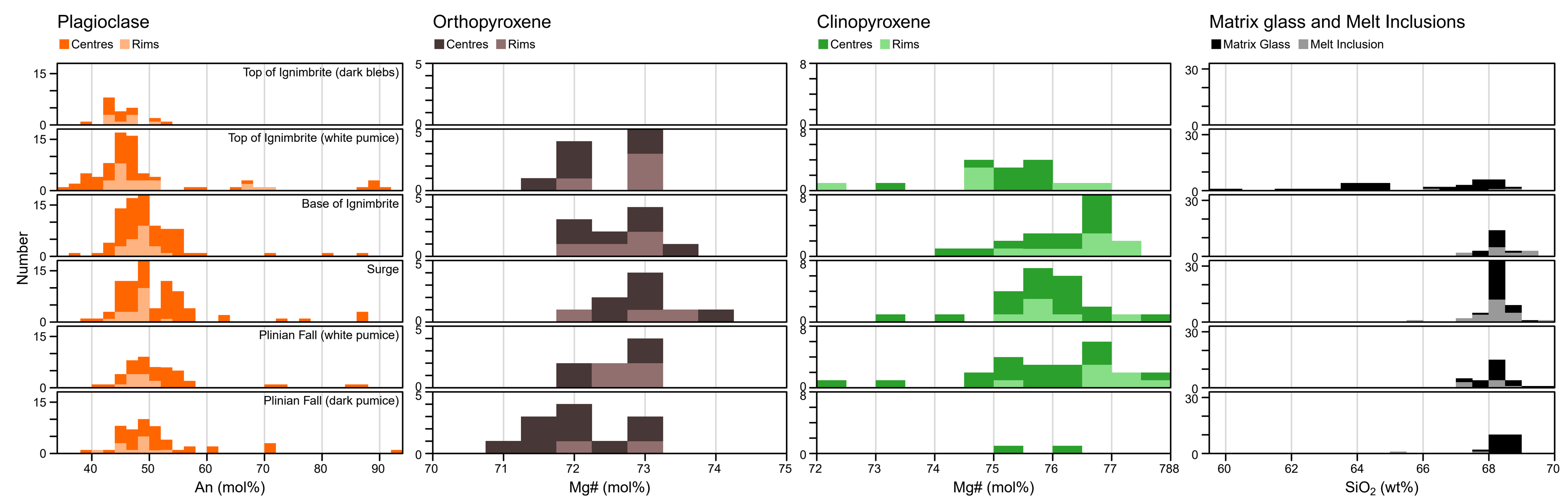
- There is little variation in whole-rock chemistry with height, although there is a slight trend towards less evolved compositions towards the top of the deposits.
- The exception to this is the andesitic blebs that are found towards the top of the ignimbrite. These represent a late-stage recharge injected into the chamber shortly before eruption.



- Pre-caldera rocks show curved traces on graphs of TiO_2 against SiO_2 that are typical of fractional crystallisation.
- Post-caldera rocks lie on a straight line below this curve. This suggests mixing between a dacite (with ∼62–65 wt% SiO_2) and a basalt (∼48–50 wt% SiO_2). Basaltic enclaves are common in post-caldera rocks.
- However, the high TiO_2 of the andesitic blebs in the 1400 BP means that the magma injected into the 1400 BP reservoir must have had $\gtrsim$56 wt% SiO_2.
- 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.

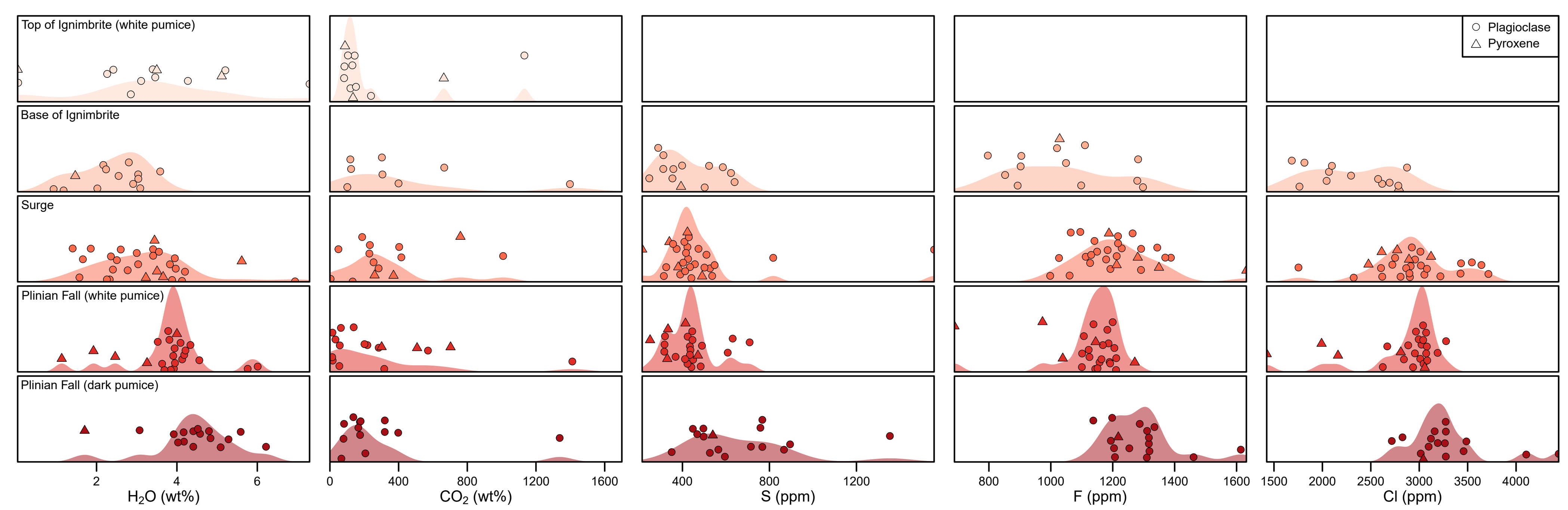
Photo looking south across Blanche Bay, from the roof of the Rabaul Volcano Observatory. Tavurvur is the bare cone on the left, Vulcan is on the right. Note also the three pre-caldera stratocones to the east (left) of Tavurvur.

6. Mineral and melt inclusion chemistry



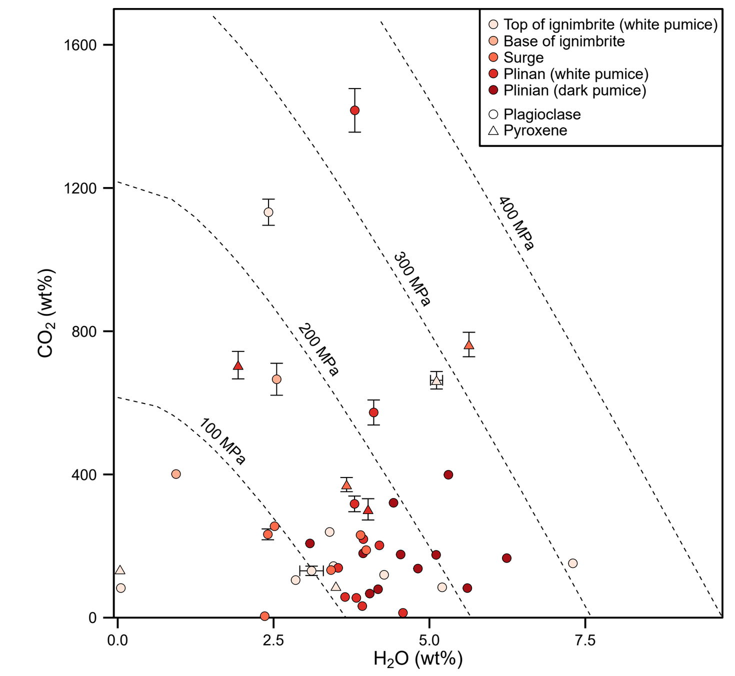
- A single phenocryst population is observed in both the dacite and the andesite: plagioclase (An_{41-55}), orthopyroxene (Mg# = 71–74), and clinopyroxene (Mg# = 74–78), alongside smaller amounts of magnetite and apatite.
- The crystals in the andesitic blebs are the same composition as those in the dacite, suggesting that the recharge was almost aphyric.
- The melt inclusion compositions match the compositions of the matrix glass, suggesting that the crystals grew in the dacite.
- Little variation in both mineral and glass composition suggests that the reservoir was well mixed prior to eruption
- Towards the top of the ignimbrite, the andesitic recharge can also be seen as streaks of more mafic glass

7. Melt inclusion volatile contents

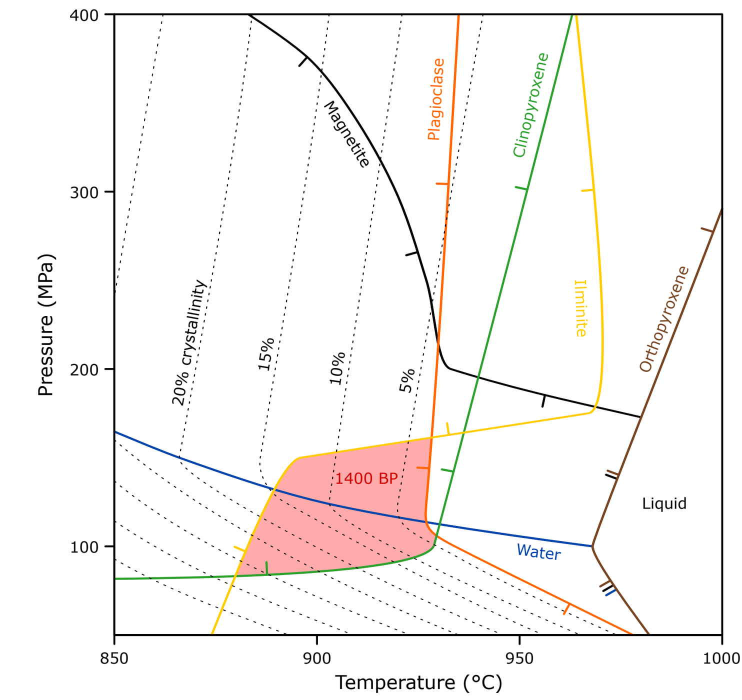


- There is a slight decrease in the volatile content upwards through the stratigraphic sequence.
- This is clearest in the H_2O content, which decreases from ∼3.5–5.5 wt% in the Plinian deposits to ∼1–3.5 wt% at the base of the ignimbrite.
- This trend suggests that the 1400 BP magma reservoir was zoned in volatiles, with a volatile-rich cap.
- The increase in H_2O at the top of the ignimbrite could be related to the intrusion of the andesite, or infiltration of volatiles from a crystal mush below the eruptible reservoir.

8. Pre-eruptive storage



- Melt inclusion H_2O and CO_2 contents suggest that most of the 1400 BP crystallised at between about 100 and 200 MPa (*left*: isobars calculated using the VOLATILECALC rhyolite model; Newman & Lowenstern, 2002)



- This matches the conditions where the 1400 BP mineral assembly would be in equilibrium, according to MELTS (*left*: 890–930 °C, 100–150 MPa; Gualda & Ghiorso, 2015).

9. Conclusions

- The erupted dacitic portion of the 1400 BP magma reservoir was well mixed.
- There may have been a gradient in the volatile content of the reservoir, with a volatile-rich cap becoming progressively more volatile-depleted with depth.
- Shortly before eruption, an andesite (∼56–60 wt% SiO_2) was injected into the base of the chamber.
- This recharge may have injected fresh volatiles into the dacitic reservoir.
- 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-formation as it is during periods of minor eruptive activity.

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