Magma conditions recorded in eruption products of paleo- to modern Mount Pinatubo, Philippines

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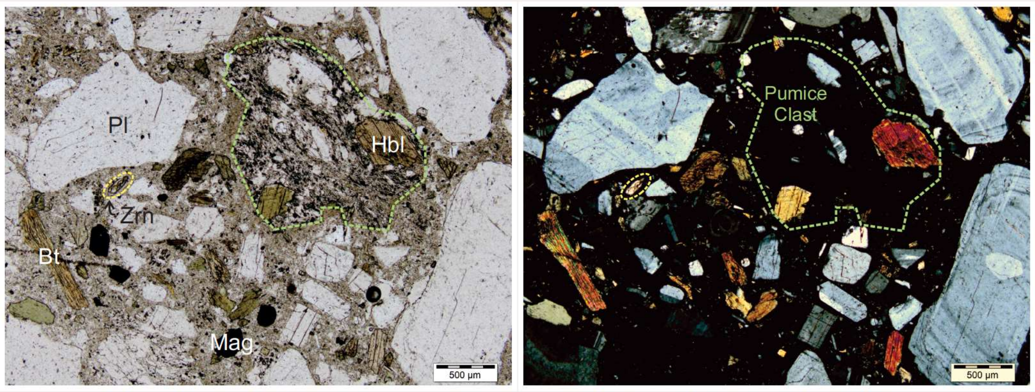
Introduction

The 1991 Plinian eruption products of Mount Pinatubo have been studied in great detail; however, much remains unknown about the conditions of the magma reservoirs prior to 1991. Therefore, in this study, older eruption products of Mount Pinatubo were examined together with those of 1991 to evaluate change in the magma reservoirs over a million-year-scale timespan.

Samples: Samples comprise chiefly vesiculated dacites from modern Pinatubo (1991 AD, 500 BP, 3400 BP, 5100 BP and 35000 BP), the Pleistocene ancestral volcano (~1.1 Ma) and paleo-Pinatubo. The paleo-Pinatubo eruption products, from Dizon Mine, are late Tertiary to early Pliocene in age (>2.5-2.7 Ma). Samples were collected from pyroclastic flow deposits along the Sacobia, Abacan, Pasig Potrero, O'Donnell and Marella Rivers, whereas the paleo-Pinatubo volcanics were collected from outcrops and talus debris at Dizon Mine.

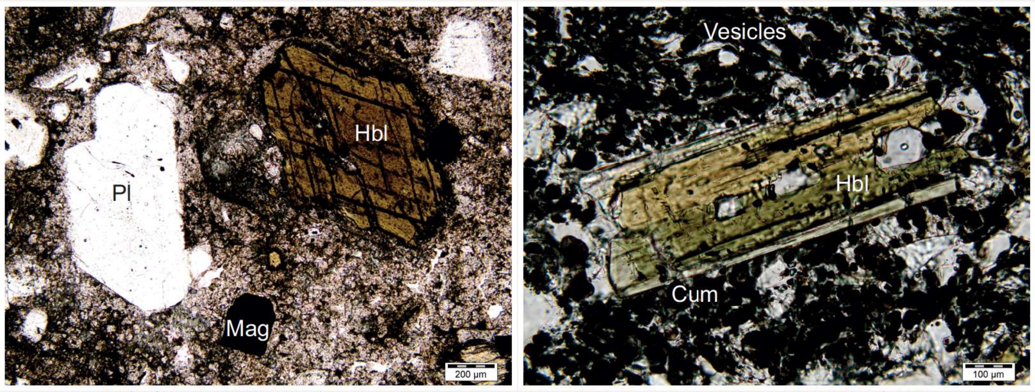
Methods: Samples were prepared into standard polished thin sections for polarized microscopy, SEM-BSE imaging (JEOL 6610LV) and EPMA analysis (JEOL 8230). Whole-rock major element data were collected by XRF spectroscopy, while trace element (including REE) data were obtained by sodium peroxide fusion followed by ICP-OES and ICP/MS analyses.

Mineralogy



Above: Sample 161205-06B (pumiceous Bt-dacite lapilli-tuff, ~35000 BP), PPL (left) and XPL (right)

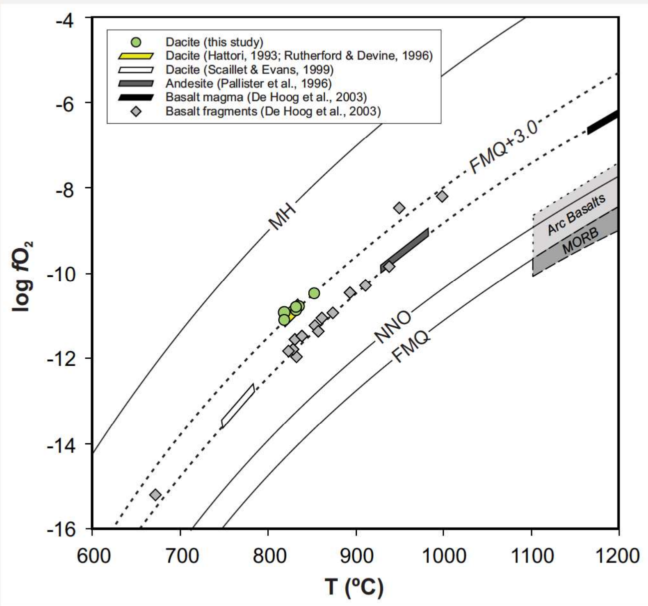
The primary mineralogy in older Mount Pinatubo volcanics remains the same as in 1991 products. This includes an equilibrium phenocryst assemblage of Qz +Pl +Hbl +Cum +Mag +Ilm ±Bt, as well as trace amounts of Zrn and Ap. Rarely, xenocrysts of Cpx, Opx and Ol are found. The groundmass consists primarily of Pl microlites, Hbl microphenocrysts and devitrified glass, and vesicles account for up to ~45% of total rock volume.



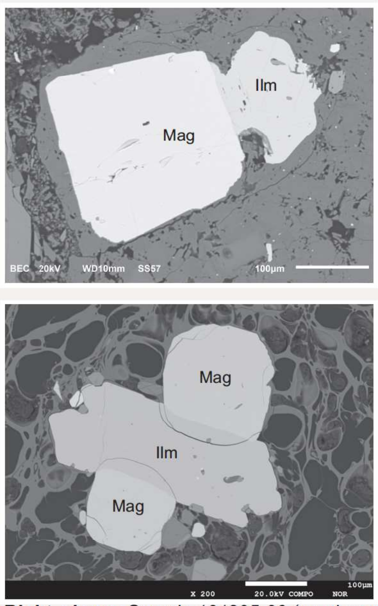
Left: Sample 161207-02 (unmineralized and least-altered Dizon dacite porphyry, >2.5-2.7 Ma), PPL
Right: Sample 161206-15 (pumiceous dacite tuff, ~5100 BP), PPL

In unmineralized and least-altered samples from paleo-Pinatubo (Dizon Mine), primary mineralogy is preserved and large phenocrysts show minimal signs of post-volcanic change. More importantly, the equilibrium mineral assemblage is also the same as the 1991 eruption products. These equilibrium minerals and presence of Cum rims on Hbl phenocrysts attest the constancy of magma reservoir conditions at temperatures ~800°C and high water content (up to ~6.5 wt%; Scaillet and Evans, 1999) over a million-year-scale timespan.

Fe-Ti-Oxide Thermobarometry



Left: Calculated T and fO_2 from co-existing Fe-Ti-oxide pairs (green circles), compared to 1991 values from other studies (see symbol key) and common mid-oceanic ridge (e.g. Bézos & Humler, 2005) and arc basalt fields; modified from De Hoog et al. (2003).



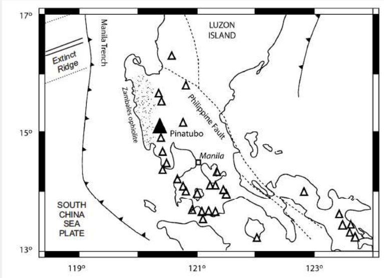
Right, above: *Sample 161205-06 (pumiceous Bt-dacite lapilli-tuff, ~35000 BP), BSE image*
Right, below: *Sample 161206-15 (pumiceous dacite tuff, ~5100 BP), BSE image*

Co-existing pairs of unexsolved magnetite-ülvospinel$_{(ss)}$ and ilmenite-hematite$_{(ss)}$ grains yield corrected magmatic temperatures ranging 790-830°C and fO_2 of FMQ +3.0 to +3.1. There is no systematic change in T or fO_2 values with eruptive age. This is consistent with the presence of Cum rims on Hbl phenocrysts in dacite, and similar to the values calculated by Hattori (1993) and Rutherford & Devine (1996). This suggests highly oxidized magma conditions in paleo- to modern Mount Pinatubo.

Summary

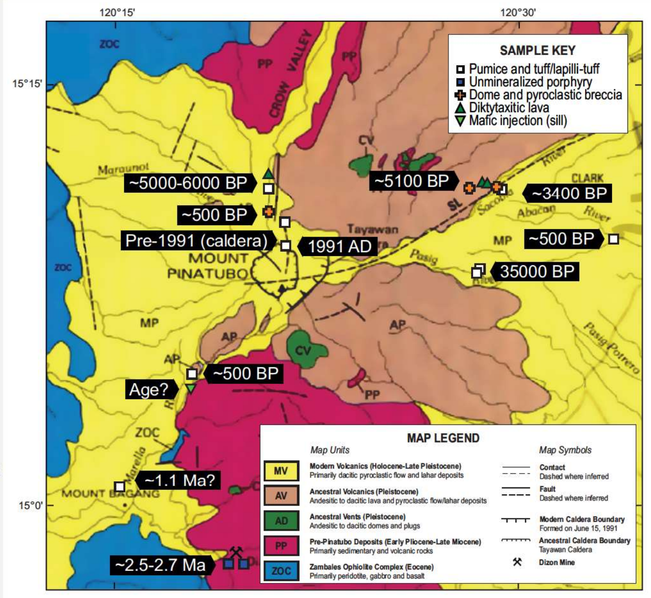
- Mineralogy, whole-rock geochemistry and Fe-Ti-oxide thermobarometry show that the magma conditions for the past eruption products are identical to those for the shallow (~5 km) magma reservoir of the 1991 eruption products.
- Similar magmatic conditions since the Pliocene require a steady-state supply of oxidized melt to magma reservoirs, since the examined timespan is far longer than what is required for the solidification of water-rich magma reservoirs (Shinohara & Hedenquist, 1997).
- A steady-state supply of melt in a spatially-focused manner may in part be explained by an overall compressional regime created by the subduction of the extinct South China Sea ridge system.

Geologic Background



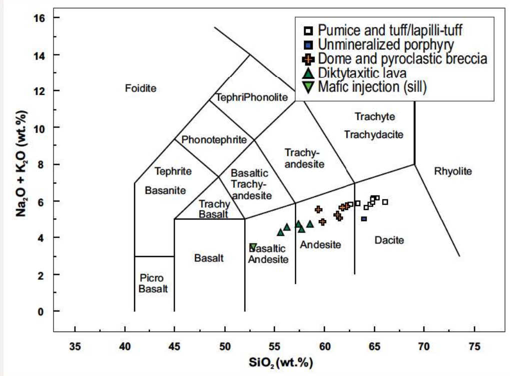
Above: *Regional setting of Mount Pinatubo*

Arc volcanism at Mount Pinatubo is related to eastward subduction of the South China Sea oceanic lithosphere along the Manila Trench in the Taiwan-Luzon Arc. Modern Pinatubo is an andesite-dacite dome complex and strato-volcano surrounded by pyroclastic flow and lahar deposits of dacite. Older eruption products (up to ~35000 BP) are found surrounding the 1991 volcano, whose volcanic centre is similar to that of the Pleistocene (~1.1 Ma) ancestral volcano. The late Tertiary to early Pliocene (>2.5-2.7 Ma) paleo-Pinatubo volcanics are found at Dizon Mine, located ~20 km south of the 1991 crater.



Right: *Geology of the Mount Pinatubo area (modified from Newhall et al., 1996)*

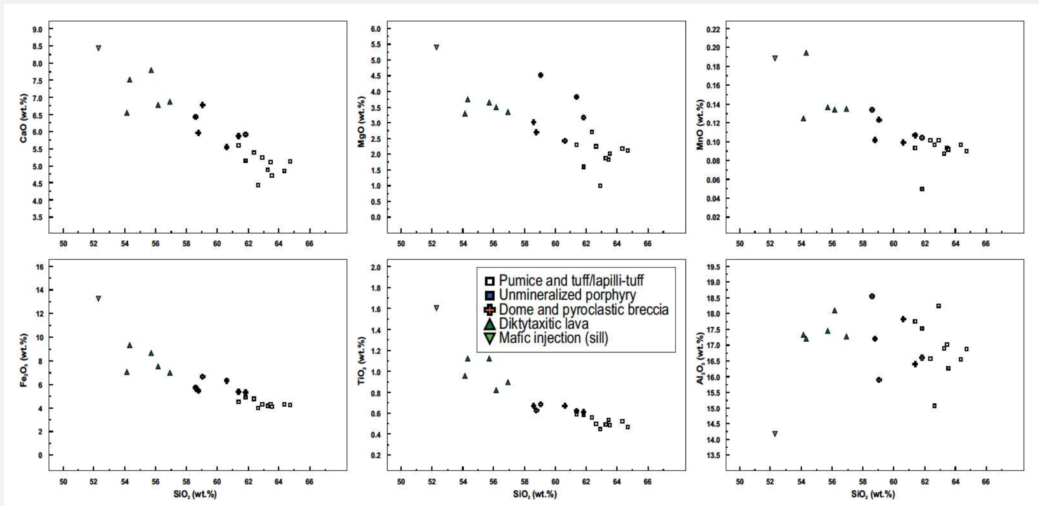
Whole Rock Geochemistry



Whole-rock composition data (including basalt fragments) show a typical calc-alkaline trend: decreasing FeO_{total} (9.30-3.97 wt%) and relatively constant Al_2O_3 (avg. 16.8 wt%) with increasing SiO_2 (54.3-64.8 wt%). A diorite-gabbro sill (sample 161207-05, along Marella River) of unknown age that intrudes into dense basaltic trachyandesite shows a SiO_2 value of 52.3 wt%. Although there is no systematic relationship between SiO_2 values and eruptive age, SiO_2 content in older dacites is slightly lower than in 1991 (63.1 vs. 64.5 avg. wt%). Overall, data show a good fractional crystallization trend, highlighting increasing incompatible elements (e.g. K_2O = 0.68-1.61 wt%) with increasing SiO_2.

Left: *Total alkalis vs. SiO_2 diagram of paleo-Pinatubo (>2.5-2.7 Ma) to modern (up to ~500 BP) eruption products and diorite-gabbro sill (age unknown).*

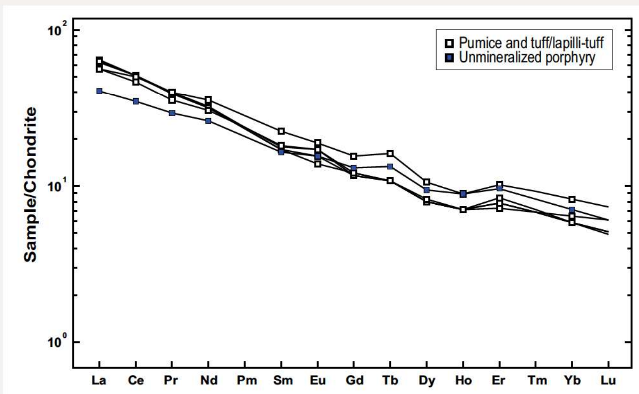
Below: *Harker diagrams of six major oxides by weight % (CaO, MgO, MnO, Fe_2O_3, TiO_2, Al_2O_3) vs. SiO_2 content.*

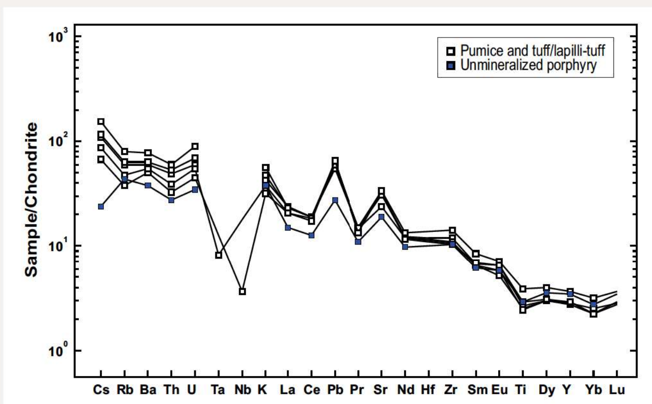


Chondrite-normalized REE profiles of dacitic eruption products (including paleo-Pinatubo samples from Dizon Mine) show a weakly negatively-sloped pattern ($(La/Yb)_N$ =~6.6) and a small positive Eu/Eu* (~1.07).

Right: *Chondrite-normalized rare-earth element profiles of dacitic eruption products from paleo- to modern Mount Pinatubo.*

Below: *Chondrite-normalized trace element diagram of dacitic eruption products from paleo- to modern Mount Pinatubo.*





Trace element data are similar among all eruption products of varying ages, and show strong depletion in Nb, Ta and Ti and elevated U, Pb, Cs and Sr. All rocks show enrichment of fluid-mobile elements, reflected by high Ba/La ratios (avg. 27.4).

Sr/Y ratios (18.2-53.6) and moderate Y contents (avg. 15.9), in conjunction with the above data, indicate a typical island arc signature in the Mount Pinatubo volcanics.

Acknowledgements

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References

Bézos, A. & Humler, E. (2005). Geochimica et Cosmochimica Acta **69(3)**, 711-725.
De Hoog, J.C.M. et al. (2003). Contributions to Mineralogy and Petrology **146**, 750-761.
Hattori, K. (1993). Geology **21(12)**, 1083-1086.
Newhall, C.G. et al. (1996). In: Fire and Mud: Eruptions and Lahars of Mount Pinatubo, Philippines, pp.807-824.
Rutherford, M.J. & Devine, J.D. (1996). In: Fire and Mud: Eruptions and Lahars of Mount Pinatubo, Philippines, pp.751-766.
Scaillet, B. & Evans, B.W. (1999). Journal of Petrology **40(3)**, 381-411.
Shinohara, H. & Hedenquist, J.W. (1997). Journal of Petrology **38(12)**, 1741-1752.