High Pressure, Al Rich Megacrystic Pyroxenes from The Basalts of Magpie Table of Northeastern OR: Evidence of Deep Crystal Mush?

Arron Steiner and Joe Boro: School of the Enviroment, Washington State University; arron@wsu.edu, joseph.boro@wsu.edu

Introduction

The Basalts of Magpie Table (BMT) of northeastern Oregon, USA, are an assembly of small volume lavas (<5 km3), which are surrounded by the Columbia River Basalt Group (CRBG), and are stratigraphically above the basaltic andesite and rhyolite lavas of the Strawberry Volcanics (SV) (Fig. 1). Field relations constrain the BMT to younger ages than the most proximal dated SV lavas of 15.6 Ma, which suggests that these lavas were co-eruptive with the waning phase of the CRBG. The lavas that form the BMT are ~5 m thick and limited to 3-5 different flows with no evidence of time gap (e.g. paleosol or erosional features between flows). This eruption likely occurred as a single event. Figure 1 shows a linear dike feature, which has been interpreted as the vent source for the fissure eruption of the BMT. These lavas contain large (>4 cm) megacrysts of clinopyroxene (cpx), plagioclase and olivine with spinel and Cr spinel inclusions within the cpx and olivines (Fig. 2).

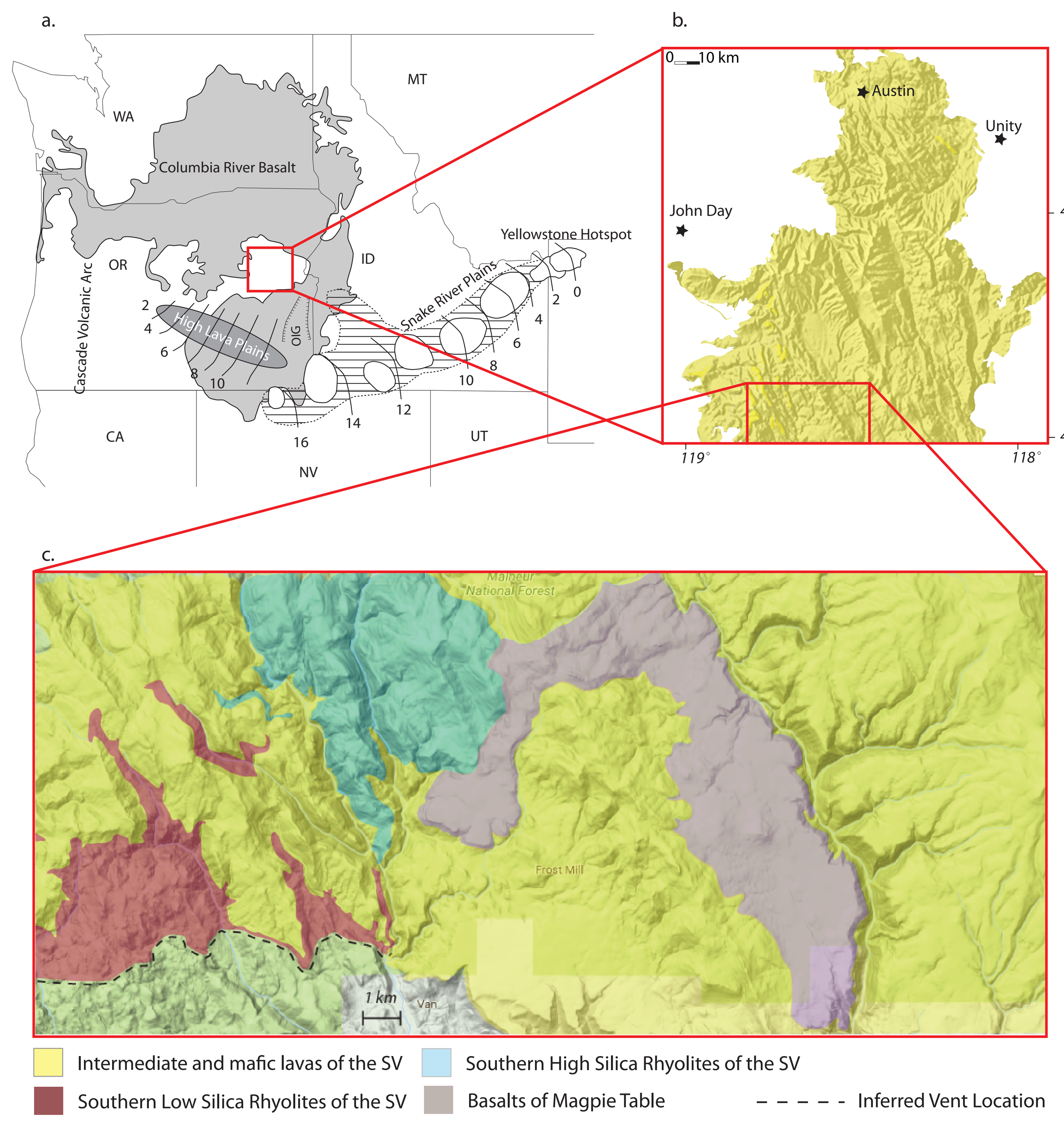


Figure 1: Field location of the BMT and other Middle Miocene lavas within the area. a) Volcanism associated with the onset of the Snake River Plains - Yellowstone Hot-Spot, including the CRBG and younger lavas of the High Lava Plains, Snake River Plains and present-day Yellowstone Hot-Spot location. b) Shows the location of the SV from the inset location in Fig. 1a. c) Geologic map of the BMT and surrounding units of the SV.

Whole Rock Geochemistry

- The BMT lavas are primitive, high-alumium olivine tholeiites with ~8.0 to 8.8 wt% MgO and ~47.0 to 48.5 wt% SiO2 Fig. 3a and b).
- They can be distinguished from the SV by clear differences in major elements (higher MgO and lower TiO2 and P2O5 wt.% at comparable wt.% MgO) and incompatible trace elements; BMT have elevated HFSE (Nb, Ta, Th, and U) and lower Pb relative to the SV (Fig. 3c and d).
- The BMT have similar trace elements patterns on normalized multi-variable diagrams as the CRBG and SV, with the exception of Pb and elevated Nb and Ta (Fig. 3c and d).

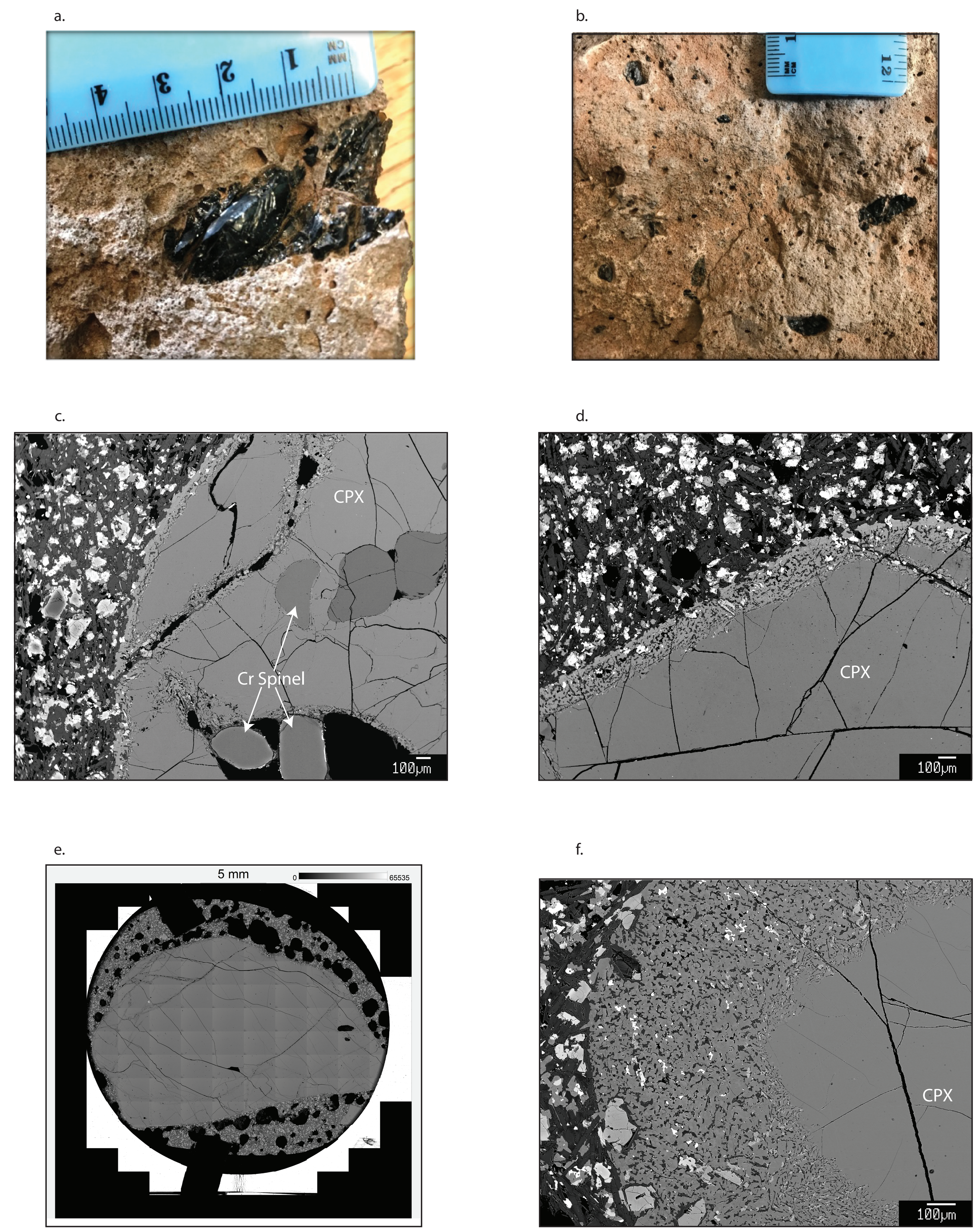


Figure 2: Photographs and back scatter electron (BSE) images of megacrystic cpx within the host rock of the BMT. a) Photograph of large ~4 cm long cpx crystal within the lavas of the BMT. b) Photograph of hand sample from the vent location of the BMT (Fig. 1), showing the abundance of the megacrystic cpx. c) BSE image of cpx megacryst with Cr-Spinel inclusions. d) BSE of cpx megacryst with ~100 µm rim. e) BSE map of mounted puck of an entire cpx crystal showing the homogeneity throughout the crystal. f) BSE of cpx megacrysts with ~600 µm rim.

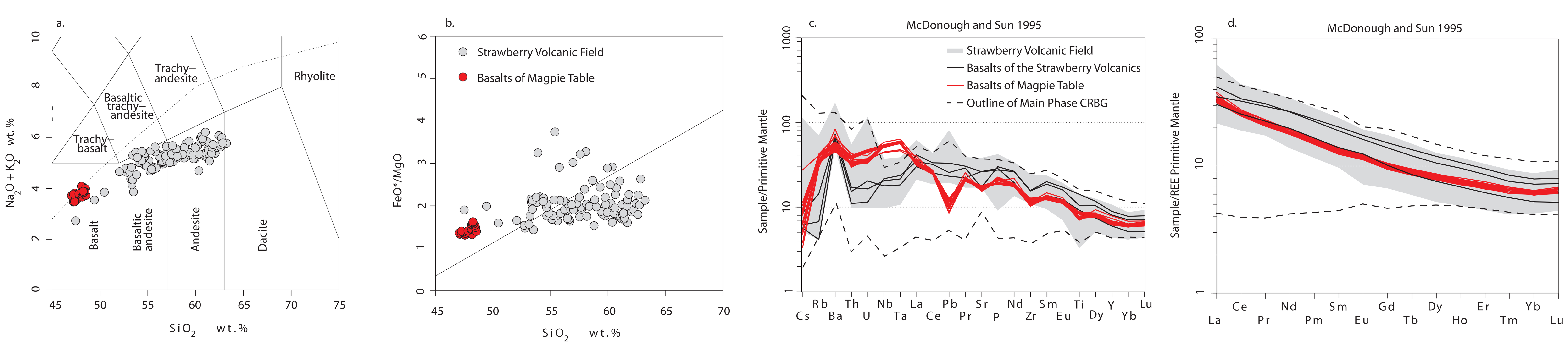
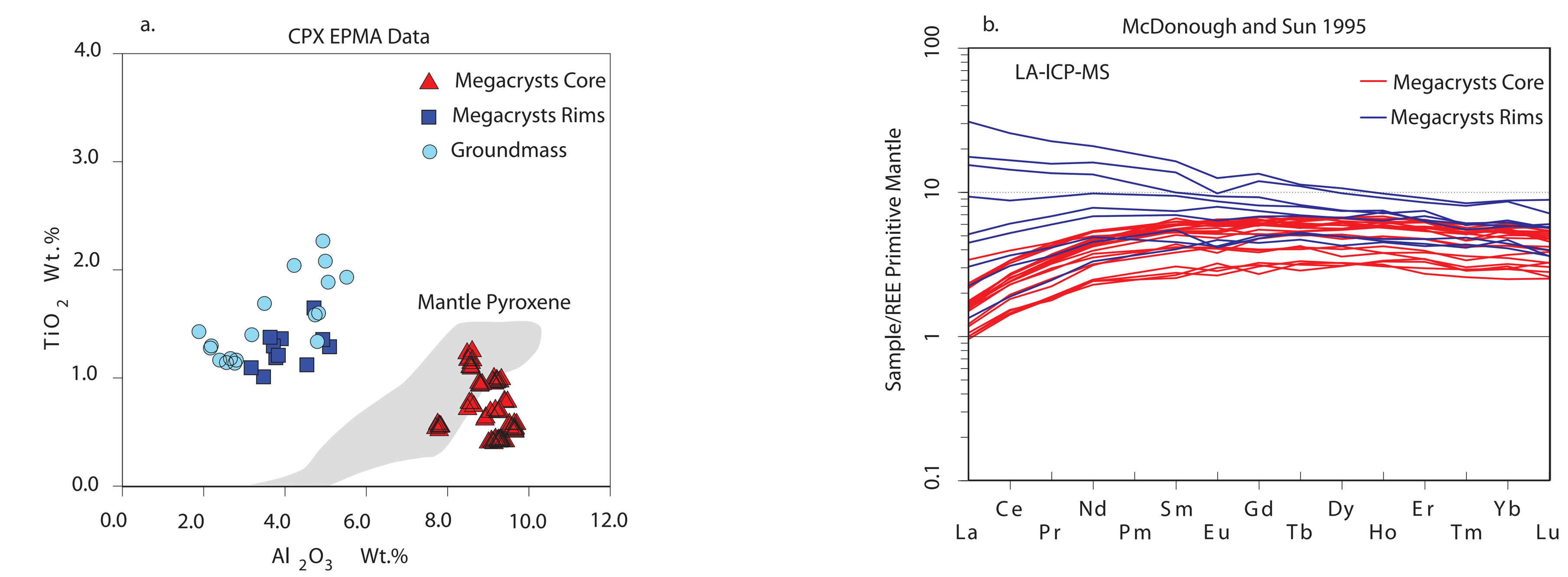


Figure 3: Whole rock geochemistry of the BMT with a comparison of the SV and the main phase of the CRBG. a) TSA diagram highlighting the slightly more alkaline and narrow composition range of the BMT to the SV lavas. Dashed line divides the alkaline vs sub-alkaline. b) Tholeiitic vs calc-alkaline Miyashiro (1974) discrimination diagram of the BMT with comparison to the SV lavas. c) Normalized primitive mantle from McDonough and Sun (1995) multi-variable trace element diagram highlighting commonality and differences between the SV field, the SV basalts, and the main phase CRBG. d) Normalized primitive mantle from McDonough and Sun (1995) multi-variable Rare Earth element diagram highlighting commonality and differences between the SV field, the SV basalts, and the main phase CRBG. Data for the SV from (Steiner and Streck, 2018) and CRBG data from (Wolff et al., 2008).



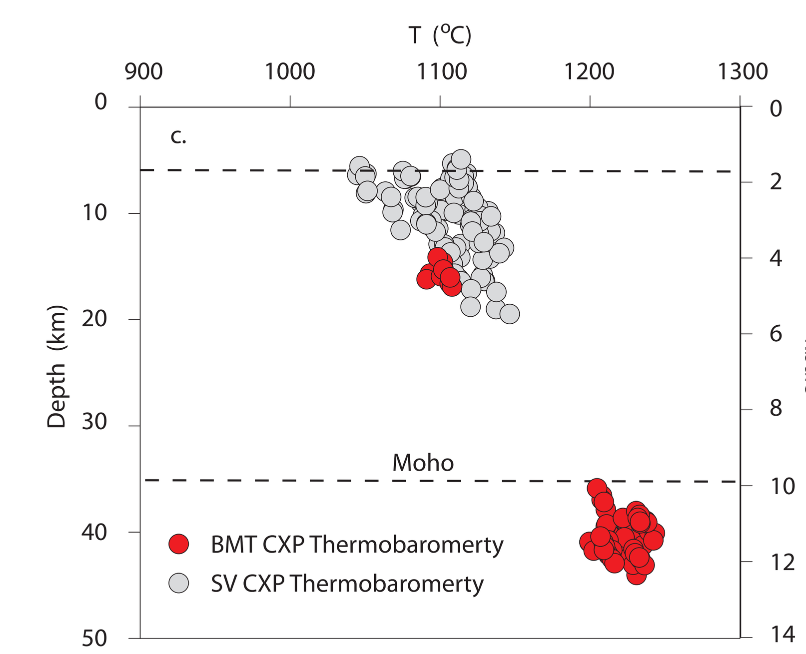


Figure 4: Mineral chemistry data from cpx cores, rims and groundmass. a) Electron probe microanalysis (EPMA) of cores, rims and groundmass cpx comparing TiO2 vs Al2O3. b) Normalized primitive mantle from McDonough and Sun (1995) multi-variable Rare Earth element diagram from laser ablation ICP-MS analysis of cpx cores and rims. The cores have lower LREE than the rims consistent with the variations seen in the EPMA analysis. c) Thermobarometry of cpx cores and rims using methods by Neave and Putirka (2017).

Mineral Chemistry

- All analyzed megacrystic cpx cores have ~8–10 wt% Al2O3 with <1 wt% TiO2 and Mg#'s of 79–83 (Fig. 4a and b).
- Rims of the cpx are chemically akin to groundmass cpx with moderate Al2O3 (~3–5 wt%) and Mg# of 74 (Fig. 4a and b).
- Laser ablation ICP-MS analyses of the megacrystic cpx indicate that there is minor variability in trace elements between core of cpx but are enriched in LREE at the rims.
- The most Al-rich cpx cores are less enriched in trace elements and REEs than the lower Al-rich cpx rims (~3–5 wt%).
- Both cores and rims of the cpx are in equilibrium with the liquid (KD(Fe-Mg)cpx-liq = 0.27 ± 0.03) within uncertainty and pass for equilibrium from Neave and Putirka (2017).
- Cpx thermobarometry indicates that the cores were originally grown in a magma between 10-13.5 kbars (~35-45 km depth) at ~1210-1240°C, then moved to a second storage location between 3-5 kbars (11-20 km depth) at ~1110-1140°C before erupting to the surface.

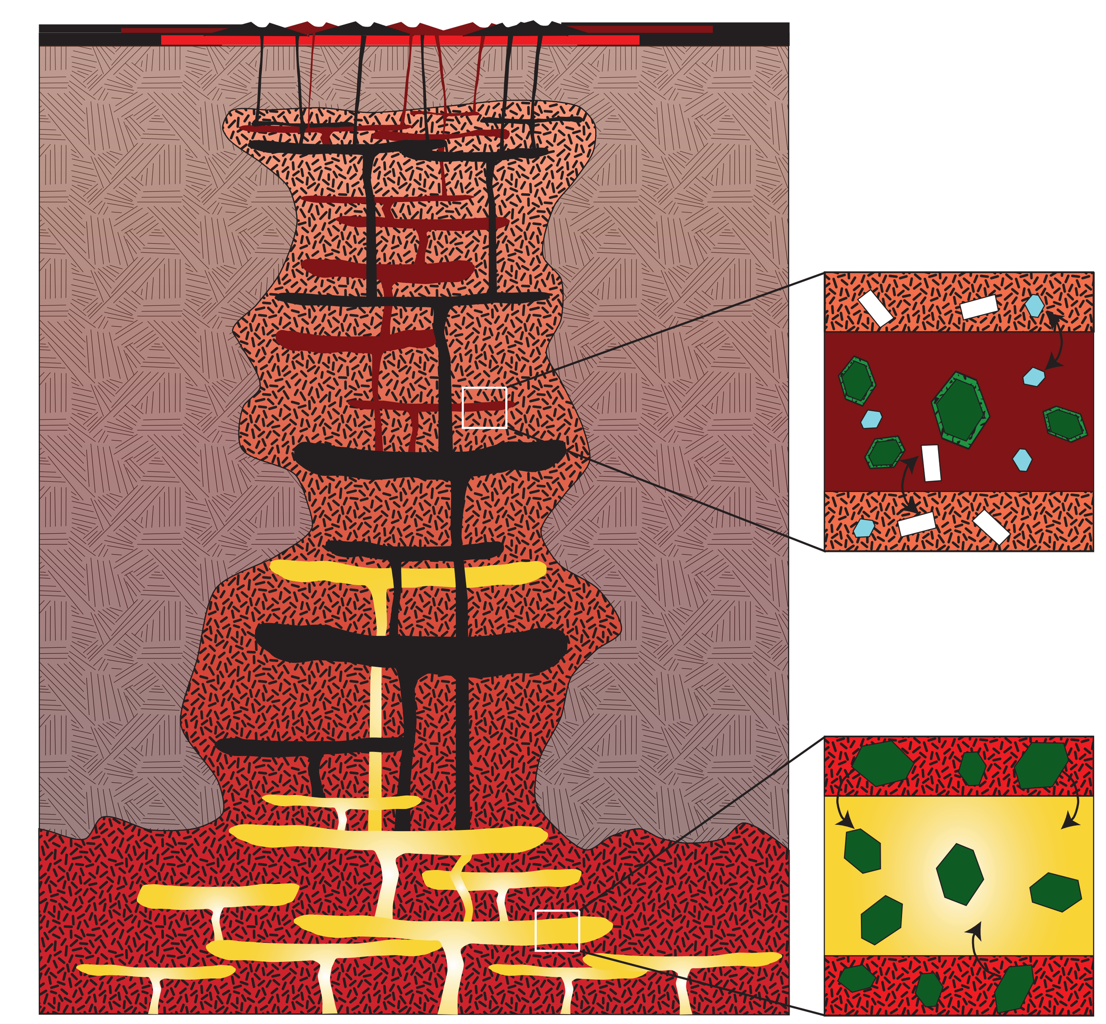


Figure 5: Cartoon illustration of a thermally mature crust with a crystal mush zone through the entire crust. This region supplied the crustal reservoirs for the CRBG and the BMT. The cpx thermobarometry indicates these crystals grew in a liquid at 35-45 km in depth. These crystals were likely part of the liquid/crystal mush at the base of the Moho and ascended to an upper chamber at ~15 km before erupting to the surface.

Conclusions

- Whole rock geochemistry indicates that the BMT and the SV are chemically distinguishable from each other and have different parental magmas but share common geochemical affinities with the SV and the CRBG.
- Megacrysts of cpx with Cr-spinel inclusions are most abundant at the vent location of the BMT but also persist throughout the eruptive sequence.
- Mineral geochemistry of cpx megacrysts indicate that these pyroxenes are Al2O3 rich ~>10 wt.% with rims of ~4 wt.%.
- Cpx thermobarometry indicates a complicated path from the mantle through the crust to the surface with >8 wt% Al2O3 cpx derived within a liquid in the mantle at the base of the Moho at ~35 km deep.
- These cpx megacrysts rose to a second magmatic storage chamber at ~ 15 km deep indicated by cpx rims before rising to the surface.
- This study highlights the current model for the generation of large igneous provinces and hotspot-related volcanism, which shows that the crustal reservoirs produce crystal mush zones which extend throughout the entire crust.
- This explains the variable geochemical differentiation and isotopic variability within lavas from the CRBG derived within outline of the crustal reservoirs

Acknowledgments

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