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Generation of Primary Kilauea Magmas: Constraints on Pressure, Temperature and Composition of Melts

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I. PUNA RIDGE PICRITE GLASSES

- Puna Ridge is the submarine extension of Kilauea Volcano.
- The most magnesian glasses reported from Hawaii were found in turbidite sands from the base of Puna Ridge (Clague et al., 1991,1995).
- The glasses contain up to 15 wt% MgO and olivine phenocrysts as magnesian as $Fo_{90.7}$.
- These glasses are an unequivocal evidence for the generation of high-MgO melts below Hawaii.

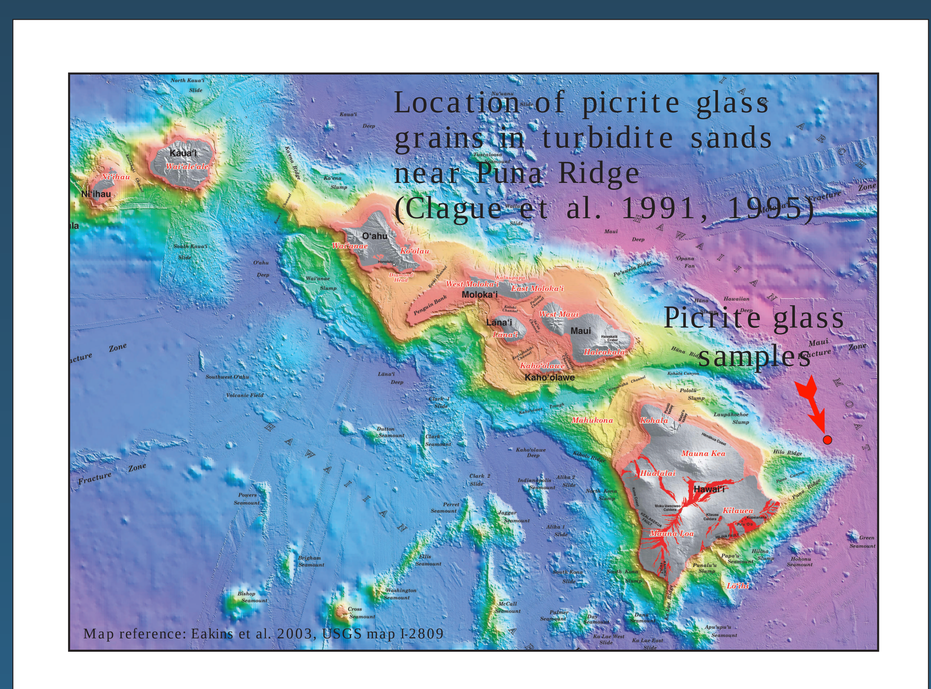

Figure 1.

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II. NORMATIVE TRENDS OF THE PICRITE GLASSES

In Figure 2, we have plotted the normative compositions of the high-MgO Ridge glasses in four different projections. These figures indicate that trend of the high-MgO Hawaiian melts is controlled by olivine fractionation.

The compositions of a large number of MORB glasses and Icelandic tholeiite basalt glasses are also shown in Figure 2.

The trends of the MORB and Icelandic glasses are similar and very different from that of the Puna Ridge picrite glasses. In contrast to Puna Ridge, there is no clear evidence for olivine-dominated fractionation at mid-ocean ridges and in Iceland. This suggests that the physical conditions during generation of primary melts could be different in Hawaii than in Iceland and at mid-ocean ridges.

III. COMPOSITION OF PRIMARY MELTS AND SOURCE - PRESSURE OF MELT GENERATION

Clague et al. (1995) estimated the primary melt compositions for Kilauea on the assumption that they coexisted with olivine with the composition $Fo_{90.7}$. In Figure 2, we include the two extreme and the average reconstructed compositions of Clague et al (1995).

Figure 2 also shows the trace of the isobaric invariant point along which the garnet lherzolite phase assemblage coexists with melt in the $CaO-MgO-Al_2O_3-SiO_2$ (CMAS) system at 3 to 6 GPa pressure. Points at 3, 3.2, 3.4, 5, and 6 GPa are included.

Combined the four projections indicate that the trend of the Puna Ridge picrite glasses is remarkably close to intersecting the solidus of garnet lherzolite in the CMAS system in multicomponent space. Our interpretation of this are the following:

1. The primary picrite melts are derived from a garnet lherzolite source.

2. When the effect of components such as Na_2O and FeO are taken also into account, the high-FeO (also high-MgO with 18.4 wt% MgO) primary Kilauea magma of Clague et al. (1995) is the best estimation of a primary melt composition.

3. The intersection of the CMAS solidus and the picrite glass trend indicates a pressure of melt generation of 5 ± 1 GPa.

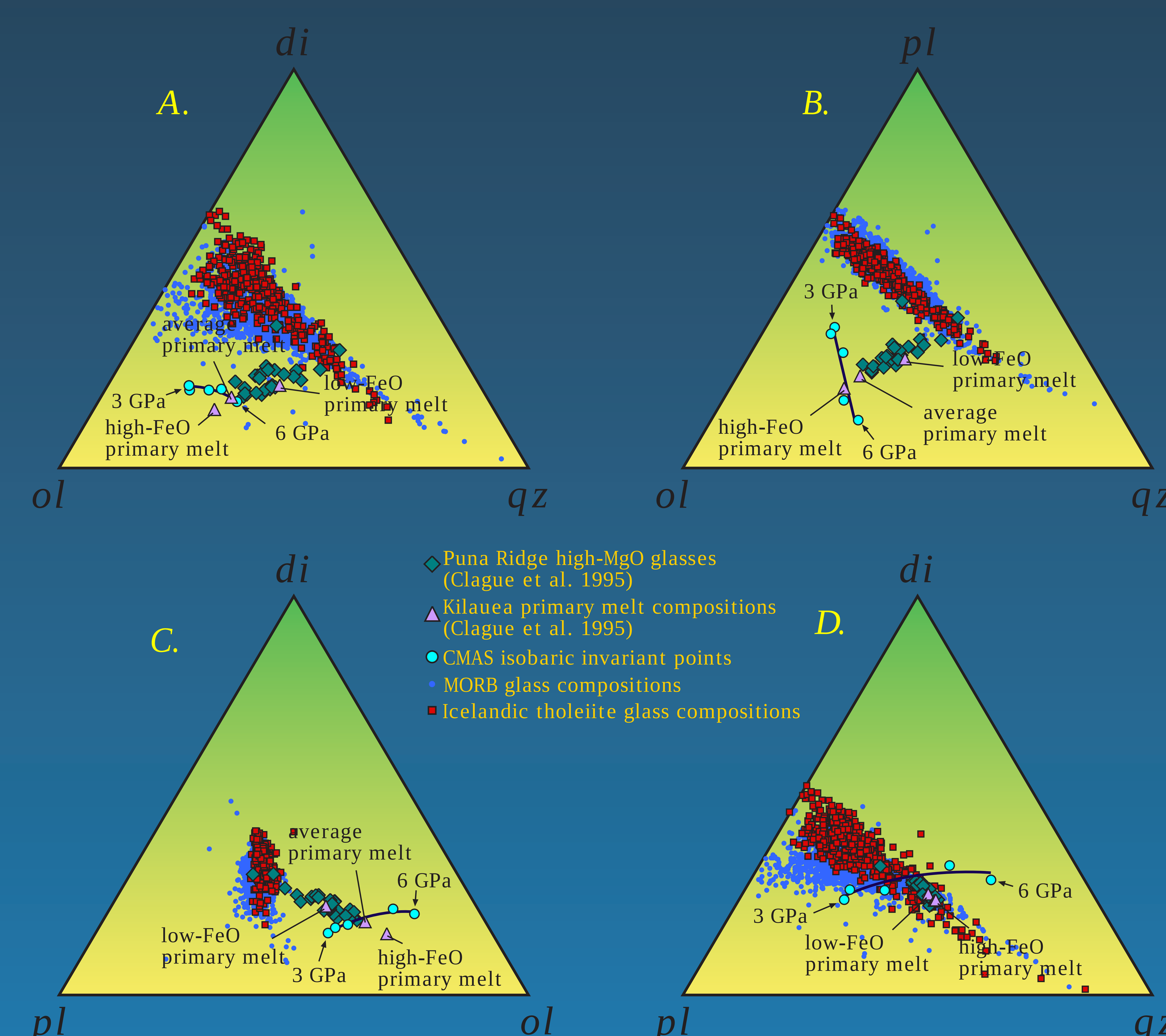

Figure 2

CIPW molecular normative diagrams in projections from A. plagioclase, B. diopside, C. quartz, and D. olivine. The MORB data is from the Smithsonian data base (Melson 1992) and the Icelandic data is mostly from an unpublished data base of the Nordic Volcanological Institute. The thick line indicates the solidus of garnet lherzolite in the CMAS system from 3-6 GPa (Milholland & Presnall 1998, Gudfinnsson & Presnall 1996, Weng 1997, and John Dalton, unpubl. data).

IV. THE CMASNF GEOTHERMOMETER

To calculate temperature at the source of the Puna Ridge picrites, we use the CMASNF geothermometer (Gudfinnsson & Presnall 2001). This geothemometer is pressure-independent and can be used for primitive olivine-bearing basalt and picrite magmas that are multiply saturated (Figure 3)

On the assumption that the most magnesian picrite glass from Puna Ridge represents near-primary melt, the CMASNF geothermometer gives source temperature of 1480 °C. The most magnesian reconstructed primary Kilauea magma of Clague et al. (1995) gives 1596 °C melting temperature

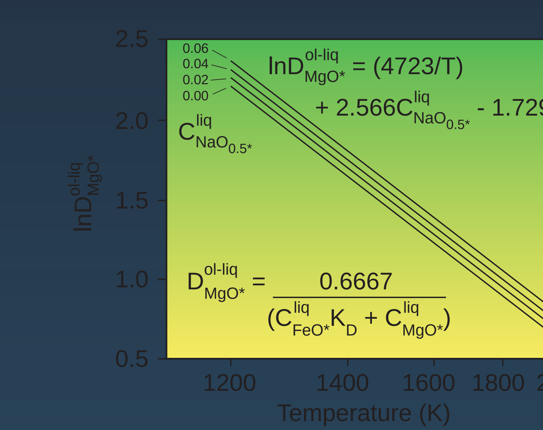

Figure 3

V. THE EFFECT OF VOLATILES

The temperature calculation above does not take into account the effect of the estimated 0.4 wt% H_2O and 0.7 wt% CO_2 present in the primary Kilauea magmas.

We use the equation of Katz et al.(2003) to calculate the solidus-lowering effect of H_2O. This equation gives 22 °C lower temperature relative to the volatile-free solidus.

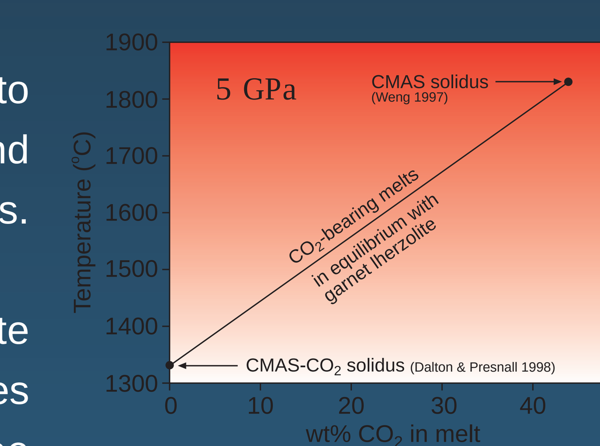

Figure 4

The solidus-lowering effect of CO_2 can be estimated from the difference in solidus temperatures of garnet lherzolite in the CMAS system and carbonate-bearing garnet lherzolite in the CMAS-CO_2 system (Figure 4). This gives only 7 °C lower temperature than the volatile-free solidus.

We estimate that combined the effect of H_2O and CO_2 is to lower the solidus temperature 30 °C. Therefore, the most magnesian picrite glass and reconstructed Kilauea primary magma yield temperatures of about 1450 °C and 1565 °C, respectively, at the source.

VI. T_P OF THE HAWAIIAN MANTLE

Using a solid adiabat of 13 K/GPa, we calculate a minimum potential temperature (T_P) for the mantle below Kilauea of 1385 °C (on the basis of the most magnesian picrite composition) but the best estimate, based on the composition of the reconstructed primary Kilauea magma, is about 1500 °C.

CONCLUSIONS

- primary picrite magmas are generated beneath Kilauea at 5 ±1 GPa (equivalent to about 150 km depth) from a garnet lherzolite source
- the primary melts have MgO content as high as 18.4 wt%
- temperature of generation is as high as about 1565°C
- potential temperature of the Hawaiian mantle is as high as 1500°C