Geophysical Research Abstracts
Vol. 14, EGU2012-6952, 2012
EGU General Assembly 2012

Extraction of magma from deep in the upper mantle: a model for the formation of Barberton komatiites

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Komatiites are highly magnesian volcanic rocks characteristic of the Archean. Al-depleted komatiites have low Al/Ti, relatively high concentrations of incompatible elements and depleted heavy rare earth elements (HREE); Al-undepleted komatiites have chondritic Al/Ti and flat HREE patterns; and Al-enriched komatiites have high Al/Ti, low concentrations of incompatible elements, enriched HREE and extremely depleted light rare earth elements. The oldest well-preserved examples are found in the Barberton Greenstone Belt in South Africa (3.5-3.3 Ga). All three komatiite types are found in the belt, commonly within the same stratigraphic unit. Based on a comprehensive petrological and geochemical study, we propose a new melting model for their formation. The basis of the model is the observation, from published experimental studies, that at great depths ($\sim$13GPa), the density of komatiitic liquid is similar to that of solid peridotite. At such depths the neutrally buoyant komatiite melt does not escape from residual peridotite. As the source ascends through the mantle, however, the pressure decreases and the density difference increases, eventually making the escape possible. Al-depleted komatiites form first at about 13GPa by equilibrium melting under conditions in which a large proportion of liquid (30-40%) was retained in the source and the residue contained a high proportion of garnet (15%). Al-undepleted and Al-enriched komatiites form by fractional melting at intermediate to shallow depths after the escape of a large proportion of melt and after exhaustion of residual garnet. This model reproduces the chemical characteristics of all komatiite types in the Barberton belt and can probably be applied to komatiites in other parts of the world.