Geophysical Research Abstracts
Vol. 18, EGU2016-4866-1, 2016
EGU General Assembly 2016

Implications of a reducing and warm (not hot) Archaean ambient mantle for ancient element cycles

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There is considerable uncertainty regarding the oxygen partial pressure (fO_2) and potential temperature (TP) of the ambient convecting mantle throughout Earth's history. Rare Archaean eclogite suites have elemental and isotopic compositions indicative of formation of crustal protoliths in oceanic spreading ridges, hence unaffected by continental sources. These include some eclogite xenoliths derived from cratonic mantle lithosphere and orogenic eclogites marking the exhumation of oceanic crust at Pacific-type margins. Their compositions may retain a memory of the thermal and redox state of the Archaean convecting mantle sources that gave rise to their low-pressure protoliths.

Archaean eclogites have TiO_2-REE relationships consistent with fractional crystallisation of olivine$\pm$plagioclase and cpx during formation of picritic protoliths from a melt that separated from a garnet-free peridotite source, implying intersection of the solidus at $\leq$2.5 to 3.0 GPa [1]. Low melt fractions (<0.25) inferred from samples with the least fractionated (lowest TiO_2) protoliths further argue against deep intersection of the mantle solidus. This suggests a moderately elevated TP $\sim$ 1420-1470 degrees C (lower than some estimates for the ambient convecting mantle at that time [2]), which would support an early onset of plate tectonics [3] and emergence of continents [4], heralding a transition to modern chemical cycles. Moderate TP further indicates that deep recycling of carbon and water, though reduced compared to today, may have been possible in the Archaean [5,6].

Carefully screened eclogites have V/Sc (reflecting the redox state of the ambient mantle during protolith formation [7]) corresponding to ΔFMQ corrected to 1 GPa as low as -1.7 at 3 Ga [1]. Such low oxygen fugacities have consequences for the location of the peridotite solidus and for the types of melts generated during redox melting [5,8]. They also modulate the redox state of volatiles liberated at oceanic spreading ridges [7] in the Archaean, with implications for the composition and oxygenation of the palaeo-atmosphere. Subsequent subduction of such reducing oceanic crust must have also affected the cycling of volatile elements (soluble instead of molecular species [9]) and of redox-sensitive ore-forming metals [10] during metamorphic dehydration and melting reactions.

[1] Aulbach&Viljoen (2015) Earth Planet Sci Lett 431; [2] Herzberg et al. (2010) Earth Planet Sci Lett 292; [3] Sizova et al. (2010) Lithos 116; [4] Rey&Coltice (2008) Geology 36; [5] Dasgupta (2013) RIMG 75; [6] Magni et al. (2014) G3 15; [7] Li&Lee (2004) EPSL 228; [8] Stagno et al. (2013) Nature 493; [9] Sverjensky et al. (2014) Nat Geosci 7; [10] Evans & Tomkins (2011) Earth Planet Sci Lett 308.