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Short communication

Early differentiation of the bulk silicate Earth as recorded by the oldest mantle reservoir

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ABSTRACT

An emerging challenge for understanding the Earth system is to determine the relative roles of early planetary processes versus progressive differentiation in shaping the Earth's chemical architecture. An enduring tenet of modern chemical geodynamics is that the Earth started as a well-mixed and homogeneous body which evolved progressively over the geologic time to several chemically distinct domains. As a consequence, the observable chemical heterogeneity in mantle-derived rocks has generally been attributed to the Earth's dynamic evolution over the past 4.5 Ga. However, the identification of chemical heterogeneity formed during the period 4.53–4.45 Ga in the ca. 60 Ma Baffin Bay high-magnesium lavas provides strong evidence that chemical effects of early differentiation can persist in mantle reservoirs to the present day. Here, we demonstrate that such an ancient mantle reservoir is likely composed of enriched and depleted dense melts, and propose a model for early global differentiation of the bulk silicate Earth that would produce two types of dense melts with distinctive chemical compositions in the deep Earth. These dense melts ultimately became parts of the thermo-chemical piles near the core-mantle boundary that have been protected from complete entrainment by subsequent mantle convection currents. We argue that although such dense melts likely exhibit some 'primordial' geochemical signatures, they are not representative of the bulk silicate Earth. Our work provides a strong case for the mantle chemical heterogeneity being formed by a major differentiation event shortly after planet accretion rather than through the subsequent geodynamic evolution.

1. Introduction

The Earth's mantle is chemically heterogeneous at all scales (Hofmann, 1997; Zindler and Hart, 1986). Knowledge about the chemical composition and differentiation of the primordial silicate Earth is crucial for understanding how the Earth's mantle works (e.g., Caro, 2011; Hofmann, 1997; Zindler and Hart, 1986). However, chemical signatures related to the Earth's early differentiation are believed to have largely been scrambled or diluted by whole mantle convection, tectonic-plate recycling and continuous exchanges between the mantle and crust over the past 4.5 Ga (e.g., Allègre, 1982; Caro, 2011). As a result, the isotopic and chemical heterogeneities observed in modern mantle-derived rocks are generally believed to reflect later production and recycling of oceanic and continental crust through geological time, and thus bear no direct signature of the primordial silicate Earth (e.g., Allègre, 1982; Hofmann, 1997; Zindler and Hart, 1986). This led to the widely held believe that the Earth started as a well-mixed homogeneous body that evolved progressively over geologic time to several chemically distinct domains (Allègre, 1982; Hofmann, 1997; Zindler and Hart, 1986). However, we demonstrated here that the very-early-formed chemical heterogeneity as recorded by the oldest mantle reservoir can persist in mantle reservoirs to the present day.

The ca. 60 Ma old Baffin Bay picrites between Baffin Island and West Greenland (BIWG) are among the earliest manifestations of the ancestral Iceland mantle plume. The high $^3He/^4He$ end-member of the mantle composition range (up to $50R_A$, where R_A is the atmospheric value of 1.39×10^{-6}) (Starkey et al., 2009) in the picrites may signify an undegassed primitive mantle source or isolated primordial He-rich reservoir that is a residue of ancient mantle depletion (Heber et al., 2007). The recent landmark discovery of a primitive Pb isotopic composition confirmed that the BIWG lavas were derived from a deep-Earth reservoir preserved at the core-mantle boundary (CMB) that has remained isolated since the earliest days of planetary accretion some 4.5 Ga (Jackson et al., 2010). Jackson et al. (2010) proposed that the composition of such an ancient reservoir is representative of the bulk silicate

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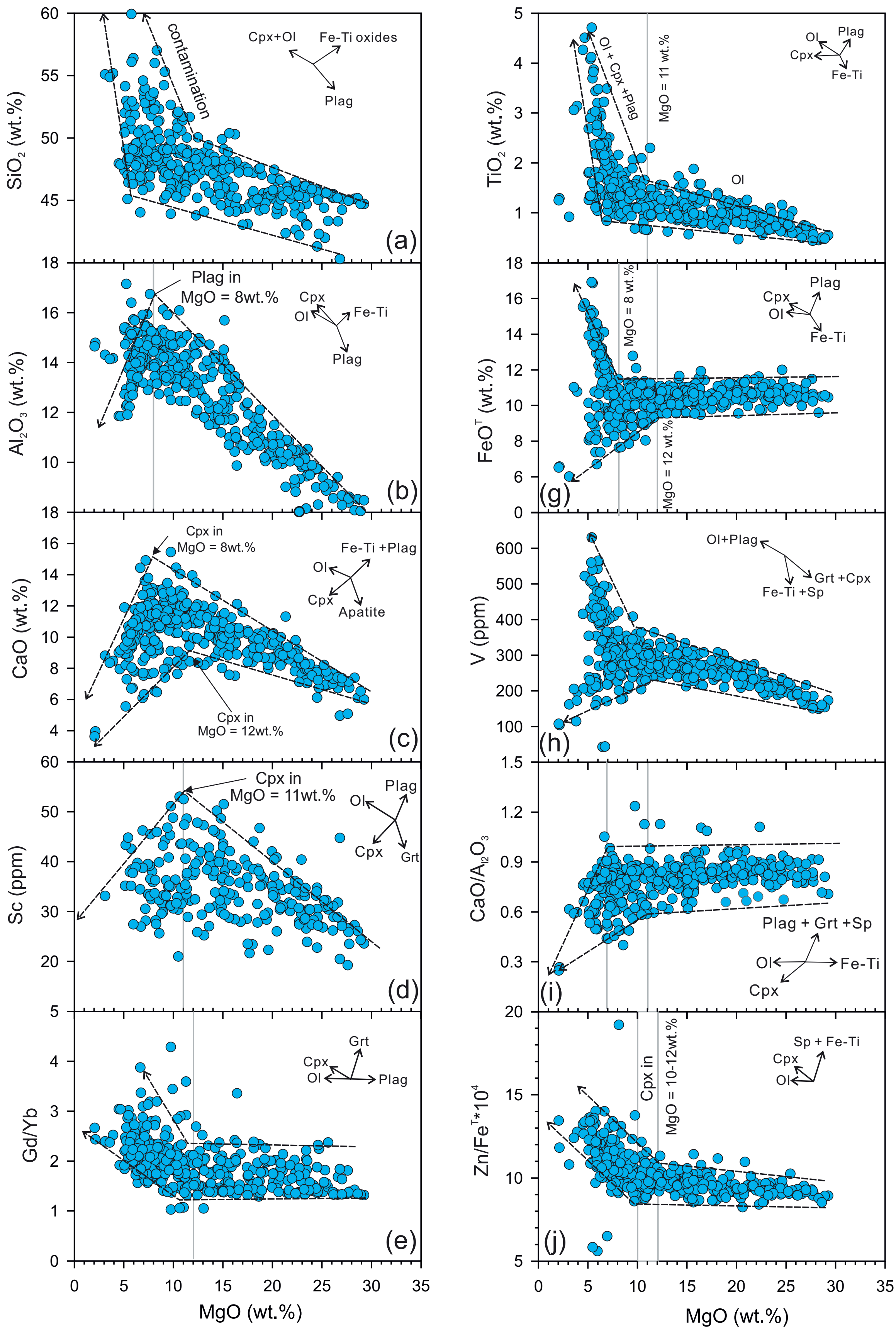

SiO2 (wt.%)
contamination
Cpx+Ol
Fe-Ti oxides
Plag
(a)
Al2O3 (wt.%)
Plag in
MgO = 8wt.%
Cpx
Ol
Fe-Ti
Plag
(b)
CaO (wt.%)
Cpx in
MgO = 8wt.%
Fe-Ti +Plag
Ol
Cpx
Apatite
Cpx in
MgO = 12wt.%
(c)
Sc (ppm)
Cpx in
MgO = 11wt.%
Plag
Ol
Cpx
Grt
(d)
Gd/Yb
Grt
Cpx
Ol
Plag
(e)
MgO (wt.%)
TiO2 (wt.%)
Ol + Cpx +Plag
MgO = 11 wt.%
Ol
Plag
Cpx
Fe-Ti
FeO^T (wt.%)
MgO = 8 wt.%
MgO = 12 wt.%
(g)
V (ppm)
Ol+Plag
Grt +Cpx
Fe-Ti +Sp
(h)
CaO/Al2O3
Plag + Grt +Sp
Fe-Ti
(i)
Zn/Fe^T*10^4
Cpx in
MgO = 10-12wt.%
Sp + Fe-Ti
(j)
MgO (wt.%)