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Chondritic osmium isotopic composition of Archean ophiolitic mantle, North China craton

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Abstract

Podiform chromitites are diagnostic but rare features of Phanerozoic ophiolites, and often contain the most pristine textural, chemical and isotopic record of convective upper mantle conditions extant during ophiolite genesis. Ophiolitic podiform chromitites, owing to their high Os concentrations and low Re/Os ratios provide the best evidence for the Os-isotopic evolution of oceanic mantle, but established records of ophiolitic chromites from bona fide Archean ophiolites are still lacking. We report Re–Os isotopic compositions of the world's oldest known ophiolitic podiform chromites from the 2.5 billion year old Dongwanzi–Zunhua ophiolite, North China. This provides the oldest Os isotope composition for the convective upper mantle yet obtained from ophiolitic podiform chromitites, and reveals a chondritic Os isotopic composition of the Archean convective upper mantle.

Keywords: Re–Os; Archean ophiolite; Chromitite; Chondritic; Convective upper mantle

1. Introduction

The Re–Os isotopic system provides critical information on the accretion history of the planet, the distributions of highly siderophile elements (HSEs) in Earth's interior, and the differentiation and evolution of the Earth and its components including the core, mantle and crust (Roy-Barman and Allegre, 1994; Snow and Reisberg, 1995; Schiano et al., 1997; Roy-Barman et al., 1998; Shirey and Walker, 1998; Brandon et al., 2001; Meisel et al., 2001). The Os isotopic composition and evolution of the convecting upper mantle are related to partial melting in the mantle and the recycling of crust via subduction. During mantle melting processes, rhenium is a moderately incompatible element whereas osmium is highly compatible. Therefore, mantle-melting processes such as extraction of oceanic crust affect the mass balance of these elements in the residual mantle, leaving rhenium depleted relative to osmium. If subducted slabs of oceanic lithosphere remain geochemically isolated from the convecting upper mantle, then the $^{187}Os/^{188}Os$ ratio of the mantle should grow more slowly with time relative to undepleted mantle. Determining the $^{187}Os/^{188}Os$ of the convective upper mantle has been previously attempted through analysis of abyssal peridotites, Mid-Ocean Ridge Basalts (MORB) and MORB related glasses and sulfides (Roy-Barman and Allegre, 1994; Snow and Reisberg, 1995; Schiano et al., 1997; Roy-Barman et al., 1998; Shirey and Walker, 1998; Brandon et al., 2001; Meisel et al., 2001).

Ophiolites represent slices of oceanic lithospheric crust and mantle thrust onto continental crust. The $^{187}Os/^{188}Os$ ratios of ophiolitic mantle peridotites may reflect the original characteristics of the Os isotopic composition of the convecting upper mantle at the time the ophiolite formed. Podiform chromites are typically found in ultramafic mantle tectonite portions of ophiolites, and most form through crystallization from a partial melt in dunite lenses within mantle or overlying crustal sequences, or as a result of melt–rock or melt–melt interaction

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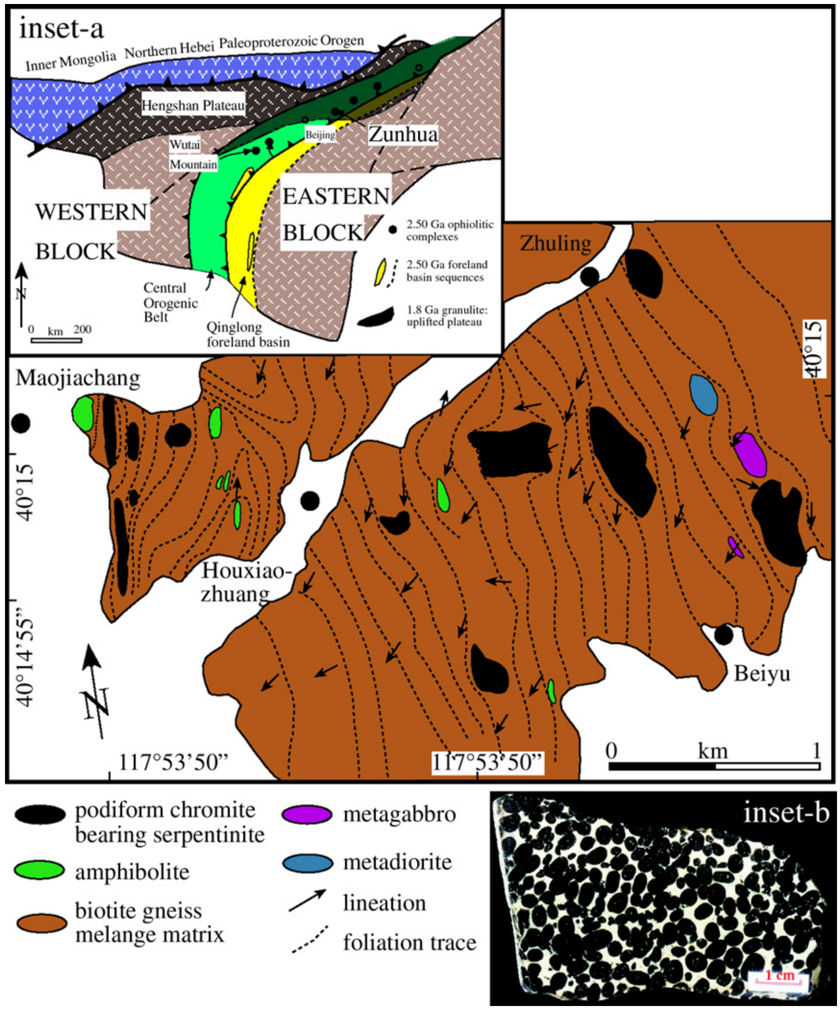

Fig. 1. Geological map of the North Zunhua area showing the distribution of ophiolitic blocks in a biotite- and hornblende-biotite gneiss matrix, based on mapping by authors. Inset-a shows tectonic setting of area in the Archean Central Orogenic belt, an Archean suture between the Eastern and Western blocks of the North China craton. Inset-b is a typical field sample of nodular chromites in serpentinized dunite.

near the crust–mantle boundary (Lago et al., 1982; Nicolas, 1989; Leblanc and Nicolas, 1992; Zhou et al., 1996a,b; Edwards et al., 2000). Because of the high Os concentrations and low Re/Os of podiform chromites, the in situ decay of ^{187}Re into ^{187}Os has minimal impact on ^{187}Os/^{188}Os subsequent to formation. Most mantle tectonite sections of ophiolites are highly serpentinized, from both seafloor alteration and obduction processes. Serpentinization can lead to open-system behavior of the Re–Os system (Snow and Reisberg, 1995). Podiform chromites are extremely resistant to the modification of initial Os isotope compositions through serpentinization or radiogenic fluids or melts derived from subducting slabs.

Ophiolitic chromites of different ages provide the best samples for the study of the long term ^{187}Os/^{188}Os evolution of convecting upper mantle (Walker et al., 2002a,b). Walker et al. (2002a,b) reported Os isotopic compositions of podiform chromites separated from upper mantle and crustal portions of 18 ophiolites from MORB, back arc, and supra subduction zone (SSZ) settings, ranging in age from 50 Ma to 900 Ma. The oldest known ophiolites that Os isotopic compositions have been reported from are the Paleoproterozoic Outokumpu (Walker et al., 1996) and Jourma (Tsuru et al., 2000; Peltonen et al., 2003; Kusky, 2004) ophiolites in eastern and northern Finland and a probable Archean ophiolite from the Ukrainian Shield (Gornostayev et al., 2004). Re–Os system data for chromitites and chromite separates from mafic–ultramafic bodies in the Ukrainian Shield were reported (Gornostayev et al., 2004). But there is no solid and sufficient evidence to conclude that those massifs represent strictly-defined ophiolites of 3.0 Ga. In contrast the formation age of chromitite bearing Lipovenki and Kapitanov massifs within the Golovanevsk suture zone in the Ukrainian shield are constrained by an Os isotope model age based on a chondritic evolution trajectory of Archean convective upper mantle (Gornostayev et al., 2004).

Until recently, these circa 2.0 Ga Paleoproterozoic ophiolites were the oldest recognized on the planet (Kusky et al., 2001; Li et al., 2002; Kusky, 2004); thus, obtaining older oceanic mantle compositions from ophiolitic podiform chromitite was not possible. A complete 2.5 Ga ophiolite has recently been recognized in the Dongwanzi–Zunhua area of the North China craton (Kusky et al., 2001; Li et al., 2002; Kusky, 2004), with dismembered ophiolites distributed in an ophiolitic mélange belt