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Late Archean to Early Proterozoic lithospheric mantle beneath the western North China craton: Sr–Nd–Os isotopes of peridotite xenoliths from Yangyuan and Fansi

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Abstract

Sr–Nd–Os isotopic analyses are presented for peridotite xenoliths from Tertiary alkali basalts in Yangyuan and Fansi with the aim of identifying and characterizing the relics of ancient lithospheric mantle that survived lithospheric removal in the western North China Craton (NCC). The analyzed samples are residual lherzolites and harzburgites, ranging from fertile to highly depleted (0.36–4.0 wt% Al_2O_3) composition. Some LREE-enriched samples are characterized by moderate $^{87}Sr/^{86}Sr$ (0.7044 to 0.7047) and low ε_{Nd} (−6.9 to −10.6), pointing to an EMI-type signature. This is distinct from the predominant depleted isotopic composition in mantle xenoliths from eastern China. Os isotopic ratios range from 0.1106 to 0.1325. The lower limit is the most unradiogenic value measured so far for Cenozoic basalt-borne xenoliths from eastern China. Two samples show radiogenic Os ratios higher than that of the primitive upper mantle, one sample has an anomalously high Os concentration (>9 ppb). These samples also show high La/Yb, consistent with the addition of radiogenic components during the infiltration of asthenosphere-derived and/or subduction-related melts in the lithospheric mantle. The remaining samples define positive correlations between $^{187}Os/^{188}Os$ and indices of melt extraction, which yield a model age of ∼2.6 Ga. This age of melt extraction overlaps with the Nd model age of the overlying crust, indicating a coupled crust–mantle system in the western NCC. This contrasts with the decoupled nature in the eastern NCC, suggesting distinct mantle domains underneath the NCC. Such a heterogeneous age structure of the upper mantle is compatible with the view that the lithospheric removal was largely limited to the eastern NCC.

Keywords: Sr–Nd–Os isotopes; Peridotite xenolith; Lithospheric mantle; Age; Yangyuan and Fansi; Western North China Craton

1. Introduction

The North China Craton (NCC) experienced widespread lithospheric extension during the Late Mesozoic and Cenozoic, which resulted in the removal of a large portion (>100 km) of mantle lithosphere (Menzies et al.,

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1993; Griffin et al., 1998; Xu, 2001; Gao et al., 2002). This lithospheric thinning was accompanied by a change in mantle composition, probably due to the replacement of the thick, old, cold and refractory lithospheric keel by thin, young, hot and fertile mantle. In recent years, the timing, mechanisms and tectonic driving forces responsible for lithospheric removal have been intensely debated. For instance, two end-member models have been proposed as mechanisms of lithospheric thinning, i.e., delamination *versus* thermo-mechanical erosion. Different physical mechanisms involved in lithospheric thinning have distinct implications for the vertical extent of lithospheric removal (Reisberg et al., 2005). Delamination would probably result in the removal of the entire mantle lithosphere and part of the lower crust (Wu et al., 2003; Gao et al., 2004). Geophysical data indicate that the current lithospheric thickness beneath eastern China is 60–100 km; thus, the lithosphere may have been re-thickened by conductive cooling subsequent to the removal processes (Menzies and Xu, 1998; Xu, 2001). In this sense, the mantle lithosphere is young. In contrast, thermal erosion may remove only part of the mantle lithosphere, leading to the co-existence of old and young mantle lithosphere. If thermal erosion of the lithosphere induced by the upwelling of asthenosphere took place gradually from the base of the lithosphere, a stratified architecture is envisaged with the old lithospheric relict overlying the newly accreted one (Griffin et al., 1998; Menzies and Xu, 1998; Xu, 2001). If mantle upwelling preferentially focused along weak zones in the Archean lithospheric root (Yuan, 1996), dispersal of the ancient lithosphere in newly formed mantle will result.

The lateral extent of lithospheric thinning in the NCC is equally poorly constrained. The contrast in crustal and lithospheric thickness, topographic height and gravity anomaly across the Daxinganling-Taihangshan gravity lineament (DTGL, Fig. 1) suggests that lithospheric removal may be largely limited to the region east of the DTGL (Griffin et al., 1998; Menzies and Xu, 1998). Temporal and spatial evolution of Cenozoic volcanism further reveals that lithospheric thinning was probably diachronous with that in the western NCC being later than in the eastern NCC (Xu et al., 2004b). If thermo-mechanical erosion is the main mechanism of lithospheric thinning (Griffin et al., 1998; Xu, 2001; Xu et al., 2004a), and assuming that the lithospheric protolith under the NCC was entirely ancient prior to the Mesozoic, one can speculate that the present lithosphere mantle under the western NCC consists mostly of the relics of ancient mantle, in contrast to the co-existence of ancient mantle and newly accreted mantle in the eastern NCC. Clearly, the age of mantle samples from throughout the NCC will be needed to ultimately understand the nature of the thinning event.

The Re–Os isotopic system has proven useful in constraining the age of lithospheric mantle formation (Walker et al., 1989; Carlson and Irving, 1994; Pearson et al., 1995; Pearson, 1999; Reisberg and Lorand, 1995; Peslier et al., 2000a,b; Handler et al., 2003; Gao et al., 2002; Wu et al., 2003, 2006; Reisberg et al., 2005). This is because Os has a highly compatible nature and Re is incompatible during mantle melting. Therefore, depleted peridotites have high Os contents and low Re/Os ratios. Melting residue, if isolated in the lithosphere, will develop low time-integrated $^{187}Os/^{188}Os$ relative to the convective mantle. The Re–Os isotopic system was originally considered to be immune from disturbance due to metasomatic alteration because common mantle metasomatic agents (e.g., silicate and carbonatitic melt) are low in Os (Handler et al., 1997). Recent studies, however, have revealed a more complex response of the Re–Os system to metasomatic processes (Alard et al., 2002; Widom et al., 2003; Chesley et al., 2004; Griffin et al., 2004). A careful evaluation of the effect of metasomatism on the Re–Os system in peridotites is therefore necessary. When the effect of metasomatic sulfide addition is minimal, Re–Os isotope systematics remains a powerful tool to date the lithospheric mantle (Pearson et al., 2004).

In this study, analyses of major and trace element abundances and Sr–Nd–Os isotopic compositions have been carried out on a suite of peridotite xenoliths collected from Tertiary alkali basalts in Yangyuan (Hebei Province) and Fansi (Shanxi Province), western NCC. These data will be used to explore the effect of metasomatism on the composition of highly siderophile elements and to determine the age of the lithospheric mantle in the western NCC. Coupled with available data, the implications for the extent and nature of lithospheric removal in the NCC will be discussed.

2. Geologic background and petrographic characteristics

The NCC can be separated into two different tectonic domains by the N–S trend Daxinganling-Taihangshan gravity lineament (DTGL) (Ma, 1989; Menzies and Xu, 1998). The region located west to the DTGL is characterized by thick crust (>40 km), large negative Bouguer gravity anomalies, low heat