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Research Advances

Redox Evolution of the Lithospheric Mantle beneath the North China Craton

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Objective

The North China Craton (NCC) is a large Archean craton with a long geological history, yet very few studies have been carried out on the evolution of the redox conditions of its underlying mantle. Oxidation state of the mantle is critical in controlling the formation of metallic mineral deposits because metals can be readily released from the mantle to partial melt under oxidized conditions. In contrast, highly reduced and stable conditions are essential for the crystallization of diamond. The subcontinental lithospheric mantle (SCLM) beneath major cratons in the world has been stable since their formation and highly reduced in its oxidation state, but the SCLM below the NCC is different. It has experienced substantial modifications since early Mesozoic time. The events include the oxidizing metasomatism of the mantle below the margins of the craton by the subduction of oceanic plates, and the removal of the ancient SCLM by upwelling asthenospheric mantle. The redox conditions of the underlying lithospheric mantle provide information related to the tectonic history of the NCC. It is also very useful in targeting the favorable areas for metal exploration. The proposed project is to characterize the SCLM of the NCC and to map different types of SCLM below the NCC.

Methods

This study used mantle xenoliths in Mesozoic high-Mg diorites and basalts along the Talu fault in western Shandong Province, and those in explosive Quaternary volcanic rocks in the central and eastern NCC (Fig. 1a). The oxidation conditions were evaluated using the compositions of olivine, orthopyroxene and spinel determined with an electron microprobe. The fO_2 values are calculated using the reaction equilibrium of three minerals (e.g., Wood, 1990; Ballhaus et al., 1991) and the activity of Fe^{3+} in spinel by Nell and Wood (1991). To mitigate the uncertainties of P and T estimates, fO_2 is expressed relative to FMQ buffer, $\Delta\log fO_2$ (FMQ).

Results

At least, three types of mantle xenoliths are identified (a) *ancient mantle peridotite*, represented by harzburgite xenoliths in Fanshi Cenozoic basalts of Shanxi Province (Fig. 1a; location 1), (b) The *metasomatized ancient mantle peridotite,* which is represented by harzburgite xenoliths in Tietonggou and Jinling Mesozoic high-Mg diorites of western Shangdong Province (Fig. 1a; location 2), and (c) The *young mantle*, represented by mantle xenoliths in the Cenozoic basalts in northeastern margins of the NCC and Xing'An-Mongolian orogenic belt (Fig. 1a; location 3).

The *ancient mantle* peridotite (a) shows moderate equilibration temperatures (910°C–960°C) and relatively reduced oxidation state ($\triangle\log(fO_2)$ FMQ = −2.6–−1.0; Fig.1b), which are comparable with those of the SCLM below ancient cratons, such as Kaapvaal Craton in South Africa, Slave Craton in Canada and Siberian Craton in Russia. The *metasomatized ancient mantle* (b) shows relatively cool temperatures (670°C−810°C) and rather high oxidation state ($\triangle\log(fO_2)$ FMQ = +1.4–+2.4; Fig. 1b). The oxidation state is comparable with that of mantle wedges in modern subduction zones, such as northern Japan and Kamchatka. We consider that the high fO_2 values observed in the metasomatized samples were caused by the north-dipping subduction of the Paleo-Tethyan oceanic plate before the collision of Yangtze Craton with the southern margin of NCC during Mesozoic time. The fluid and/or melt released from subducted Paleo-Tethys oceanic lithosphere and its overlying terrigenous sediments likely caused the oxidizing metasomatism in the mantle below the southern margin of NCC. The third type (c) shows a wide range in temperatures (740°C−1140°C) and rather reduced oxidation state ($\triangle\log(fO_2)$ FMQ =−2.6–+0.4; Fig.1b) comparable with the asthenospheric mantle. The large range in the temperature likely reflects the dynamic environments where cold ancient mantle was replaced by the injection of upwelling hot asthenosphere.

Previous workers suggested that reduced oxidation state

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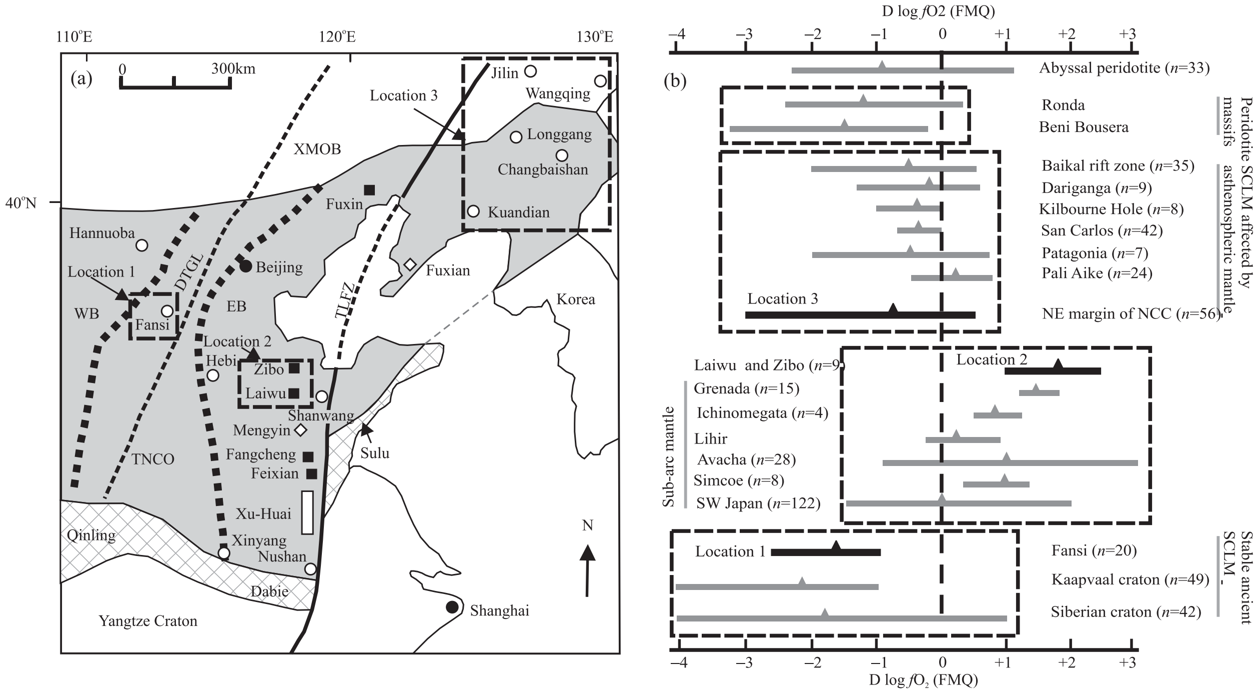

Fig. 1. (a), Schematic geological map showing the sample locations. Late Mesozoic high-Mg basalts and diorites at Fuxin, Zibo, Laiwu, Fangcheng, Feixian, and Xu-Huai are symbolized as solid squares, and all sites with Cenozoic basalts in NCC are symbolized as open circles. Early Paleozoic diamondiferous kimberlites of Mengyin and Fuxian are shown with open diamonds. The NCC is divided by faults (thick dashed lines) into the Eastern Block (EB), Trans-North China Orogen (TNCO), and Western Block (WB). Thin dashed lines are the Daxinganling– Taihangshan Gravity Lineament (DTGL) and Tan-Lu Fault Zone (TLFZ). The map was modified after Wang et al. (2013). (b), Oxygen fugacities (range and median value) for mantle peridotites from the locations 1, 2 and 3 and compared with those from other settings. The data of other areas are from Wang et al. (2013). Overall uncertainties of the estimates are about ±0.5 log units.

of ancient SCLM was caused by high degrees of partial melting, especially in Archean. If this is the case, Cr # in spinel should be inversely correlated with fO_2 values. Our results do not support this interpretation, suggesting that partial melting is not the major factor affecting the oxidation conditions of the mantle.

Conclusions

(1) The present SCLM below the NCC contains at least three types mantle rocks; cold reduced ancient mantle peridotites, oxidized mantle peridotites formed during the subduction of oceanic lithosphere, and young relatively hot mantle peridotites.

(2) There is no evidence supporting a change in fO_2 during partial melting.

(3) Metasomatism is an important factor affecting the oxidation state of mantle peridotites. Fluids/melts released from subducted slabs elevate fO_2 values of the overlying mantle wedge,whereas asthenosphere-derived melt is relatively reduced and does not result in a substantial change in fO_2 during its metasomatism.

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