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Partial melting control of water contents in the Cenozoic lithospheric mantle of the Cathaysia block of South China

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ABSTRACT

Major and trace element and the H_2O contents of minerals in peridotite xenoliths hosted by the Cenozoic basalts of Jiande in the Cathaysia block were evaluated using electron microprobe, laser-ablation ICP-MS and Fourier transform infrared spectroscopy, respectively. The correlations among the major elements of the minerals define a melting trend, and modeling of the Y and Yb contents in the clinopyroxenes indicates that the degree of partial melting ranges from 1% to 15%. Most samples (22 out of 29) show depleted chondrite-normalized rare earth element patterns and a degree of partial melting <4%. The H_2O contents (weight in ppm) of the clinopyroxenes, orthopyroxenes and olivines are 390–590 ppm, 160–330 ppm and ~0 ppm, respectively. Although potential H-loss during xenolith ascent cannot be excluded for olivines, pyroxenes largely preserve the H_2O content they have in the mantle prior to sampling by the host basalts, as inferred from (1) the homogenous H_2O content within single pyroxene grains, and (2) the equilibrium H_2O partitioning between the clinopyroxene and orthopyroxene. Based on the mineral modes and assuming a partition coefficient of 10 for H_2O between the clinopyroxene and olivine, the calculated whole-rock H_2O contents range from 90 to 220 ppm, similar to that of the MORB source. When combined with previously reported data for peridotites hosted by Cenozoic basalts at other localities of the Cathaysia block, the correlation of H_2O content with melting index (such as Yb content in cpx, Cr# in spinel) suggests that extent of partial melting is the main factor controlling H_2O abundance in these rocks. Nevertheless, the variations in whole-rock H_2O contents cannot be perfectly modeled as a simple modal melting process using available experimental partition coefficients of H_2O between peridotite and melt. The lack of coherent variations between the H_2O contents of the whole rocks and the metasomatic index (La/Yb ratio in clinopyroxene) indicates that mantle metasomatism did not modify the initial H_2O contents after the melting event(s). Based on the similarities in major and trace elements, and of H_2O contents in the Cathaysia block peridotites and those inferred for the MORB source, we propose that the Cenozoic lithospheric mantle of the Cathaysia block is accreted from the upwelled and cooled asthenospheric mantle. In addition, the H_2O contents of the Cenozoic lithospheric mantle of the Cathaysia block are much higher than those of the North China Craton of similar fertility (100 ppm vs. 20 ppm for whole rock H_2O contents), where lithospheric thinning occurred during the Mesozoic. This implies that either the Cathaysia block did not undergo similar lithospheric thinning or that the mechanism of the lithospheric thinning was different.

1. Introduction

The presence of water in nominally anhydrous mantle minerals (olivine (ol), orthopyroxene (opx), clinopyroxene (cpx), garnet) greatly affects the physical (e.g., rheology, electrical conductivity, seismic velocity) and chemical (e.g., elemental diffusion, partial melting) properties of mantle domains (Hirth and Kohlstedt, 1996; Karato and Jung, 1998; Hier-Majumder et al., 2005; Hirschmann et al., 2005). Peridotite xenoliths hosted by alkali magmas and kimberlites are samples from the lithospheric mantle, and they can be used to infer the amount and distribution of H_2O in the lithospheric mantle (Bell and Rossman, 1992a,b; Ingrin and Skogby, 2000; Peslier et al., 2002; Peslier and Luhr, 2006; Grant et al., 2007; Li et al., 2008; Bonadiman et al., 2009; Xia et al., 2010; Yu et al., 2011; Hao et al., 2012; Peslier et al., 2012; Xia et al., 2013).

Eastern China consists of three tectonic blocks, the Xing-Meng Block, the North China Craton (NCC) and the South China block (SCB). The SCB includes the Cathaysia block (CAB) and the Yangtze Craton (Fig. 1). Cenozoic basalts are widespread throughout these blocks, and many carry mantle xenoliths, providing a good opportunity to study the characteristics of the lithospheric mantle in this wide region. Yu et al. (2011) analyzed the major elements and the H_2O contents of

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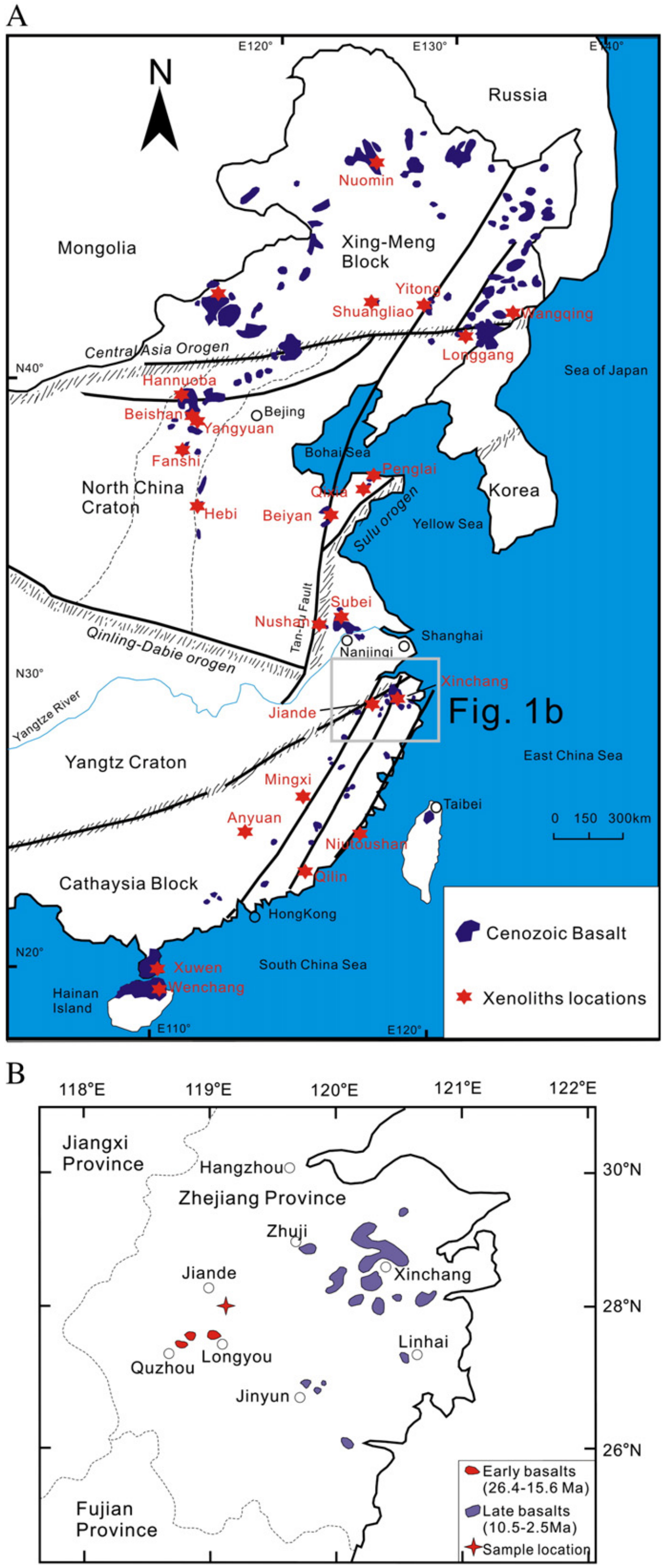

Fig. 1. Xenoliths hosted by the Cenozoic basalts in eastern China (A), the distribution of Cenozoic basalts in Zhejiang Province and sample location (B).

peridotite xenoliths from four sites in the Cathaysia block (CAB). The water contents (expressed as H_2O wt.%) of cpx, opx and ol ranged from 58 to 488 ppm, 38 to 213 ppm and 0 to 41 ppm, respectively. The whole-rock H_2O contents calculated from the mineral modes ranged from 12 to 94 ppm (average 60 ± 20 ppm) and were much higher than those of the peridotite xenoliths from the North China Craton (NCC, Xia et al., 2010, 2013). The authors explained this higher H_2O content as resulting from the refertilization of old lithospheric mantle induced by metasomatic event(s), but they did not provide trace element data to evaluate the proposed metasomatic effect(s).

In this paper, major and trace elements and H_2O contents of minerals in the peridotite xenoliths hosted by the Cenozoic basalts of Jiande in the Cathaysia block are reported with the aims of: i) investigating water distribution in the lithospheric mantle of the Cathaysia block; ii) exploring the factors controlling water contents of peridotite xenoliths; iii) comparing water distribution and geochemical characteristics of the two main blocks in Eastern China (NCC and CAB), and providing new constraints for the evolution of the lithospheric mantle beneath Eastern China.

2. Geological setting and samples

As noted above, Eastern China is composed of three blocks, the Xing-Meng Block, the NCC and the South China Block from north to south. These blocks are separated by the Central Asian orogen and the Qinlin–Dabei–Sulu orogen, respectively. The South China block can be divided into the Yangtze Craton in the northwest and the CAB in the southeast by the Jiangshan–Shaoxing and Pingxiang–Yushan fault zone (Zhao and Cawood, 1999). Based on Ar–Ar data, Ho et al. (2003) suggested that the Cenozoic basaltic eruptions were concentrated within two stages corresponding to 26.4–15.6 Ma and 10.5–2.5 Ma, with a few volcanoes displaying activity outside these ranges. The basalts hosting peridotite xenoliths are mostly from the CAB (Fig. 1A).

For this research, 29 peridotite xenoliths were collected from Jiande (Fig. 1B), northwest Zhejiang province, where the K–Ar age of the host basalts is ~30 Ma (Chen LH, personal communications). The Jiande peridotite xenoliths are fresh and 5–15 cm in diameter. Mineral modal contents were estimated by point-counting of about 1600 points for each section. Most of them are spinel lherzolites (>5 vol.% cpx) with two spinel harzburgites (<5 vol.% cpx). Textures vary from protogranular to porphyroclastic (Mercier and Nicolas, 1975) (Table 1). The ol and opx are 3–5 mm in size, while the cpx and spinel are smaller (1–3 mm). A few porphyroblastic peridotites (e.g., JD07, JD11 and JD18) have opx grains greater than 10 mm in size. The sample JD13 has a fine-grained texture with ol, opx and cpx grains smaller than 2 mm in size. In most samples, cpx and spinel occur in direct contact with the larger opx and ol grains and generally exhibit a triple junction texture, but the spinel also commonly forms vermicular crystals inside the opx or between opx and cpx grains. Modal mineral assemblages of Jiande peridotites vary substantially, with ol (50–80 vol.%), opx (16–30 vol.%), cpx (4–20 vol.%) and approximately 1 vol.% spinel. No hydrous phases were found.

3. Methods

3.1. Electron microprobe analysis (EMPA)

The mineral compositions were determined using a Shimadzu Electron Probe Micro-analyzer (EMPA 1600) at the CAS Key Laboratory of Crust–Mantle Materials and Environments at the University of Science and Technology of China. The following operating conditions were applied: 15 kV accelerating voltage, 20 nA beam current and 1 μm beam diameter. The standards are natural minerals and synthetic oxides, and a program based on the ZAF procedure (Armstrong, 1989) was used for data correction. The measurements were made from the core to the rim of each mineral grain; and in general, three to four grains of each mineral were analyzed in each sample. The uncertainty for all elements was below 5%, except for Na, for which the uncertainty may be as high as 10%.