GU Xiaofeng, LIU Yican, 2013. Multiple Metamorphic Events and Petrogensis of High-T/UHP Eclogites in the Dabie Orogen, Central China. *Acta Geologica Sinica* (English Edition), 87(supp.): 459-461.

Multiple Metamorphic Events and Petrogensis of High-T/UHP Eclogites in the Dabie Orogen, Central China

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The Dabie orogen is located in the intermediate segment of the Qinling–Dabie–Sulu orogenic belt formed by the collision of the North China Block and South China Block in the Triassic. It is generally subdivided into five major lithotectonic units from north to south (Xu et al., 2005; Liu et al., 2007a, 2011b): (1) the Beihuaiyang zone; (2) the North Dabie complex zone (NDZ); (3) the Central Dabie UHP metamorphic zone (CDZ); (4) the South Dabie low-T eclogite zone (SDZ); and (5) the Susong complex zone. The NDZ is one of three eclogite-bearing units in the region. Rare eclogites in this zone have been previously documented to be transformed from mafic lower continental crust of the South China Block by petrology and zircon U-Pb dating investigations (Liu et al., 2007a) and underwent ultrahigh-pressure (UHP) and HP eclogite-facies metamorphism, and subsequent HP granulite-facies overprinting and amphibolite-facies retrogression during continental subduction and exhumation (Liu et al., 2005, 2007a, 2011a). However, because multiple decompression and multistage metamorphic overprinting, the precise ages of subduction and exhumation processes of the NDZ are poorly constrained, rendering knowledge on the exhumation mechanism of UHP rocks and tectonic evolution in the Dabie orogen. In order to better constrain the ages of peak UHP metamorphism and subsequent retrogression as well as the petrogensis of the granulitized eclogites, a combined petrological, zircon U-Pb geochronological and whole-rock element and isotope geochemical study has been investigated on the eclogites from the Luotian dome in the NDZ.

The zircon U-Pb age results indicate that the studied eclogites experienced the same metamorphic events and have a identical multiple $^{206}Pb/^{238}U$ concordant age-groups within analytical uncertainly, i.e. Neoproterozoic, 234±3 – 243±15 Ma, 222±2 – 227±2 Ma, 210±3 – 216±5 Ma, 204±2 – 209±7 Ma, 176±2 – 199±2 Ma and 138+1 Ma (Liu et al., 2007a, 2011b; this study). Neoproterozoic ages defined by relic igneous cores represent their protolith time and the other age-groups reflect their metamorphic records by CL images, low Th/U ratios and mineral inclusions.

The weighted mean ages for age-groups of 226±4 – 227±2 Ma and 210±3 – 216±5 Ma are 226±2 Ma (MSWD = 0.33, n = 6) and 214±2 Ma (MSWD = 0.39, n = 7) (Fig. 1), respectively. Trace element compositions of these two kinds of metamorphosed mantle domains in zircon exhibit obviously consistent REE patterns with clearly flat HREE and no significance negative Eu anomaly, which is compatible with absence of feldspar and contemporaneous growth of zircon and garnet, suggesting that both metamorphic domains formed under eclogite-facies conditions (e.g., Hermann et al., 2001; Rubatto, 2002; Rubatto and Hermann, 2003; Sun et al., 2002; Whitehouse and Platt, 2003). However, the mineral inclusion assemblages suggest that the former domains usually comprise the UHP assemblage of garnet, Na-rich omphacite, rutile, aragonite and coesite, and the latter contain garnet, rutile, quartz and Na-poor omphacite inclusions. The Raman spectrum of the coesite inclusion contains the typical peak of 521 cm^{-1} associated with the quartz peak (466 cm^{-1}), suggesting that coesite was evidently transformed to quartz accompanying a fracture through it during decompression. In addition, the garnets within the former mantle domains of zircon are rich in grossular and poor in spessartine with their end members of 16.99–21.91 mol% and 0.93–2.28 mol%, respectively; while the second are relatively rich in spessartine (1.76–5.67 mol%) and poor in grossular (11.94–16.26 mol%). These are quite consistent with the above petrographic observations (Liu et al., 2007a, 2011c). Combined with trace element and mineral inclusion in zircon from the eclogites, 226±2 and 214±2 Ma were best estimated as UHP and HP eclogite-facies metamorphic ages,

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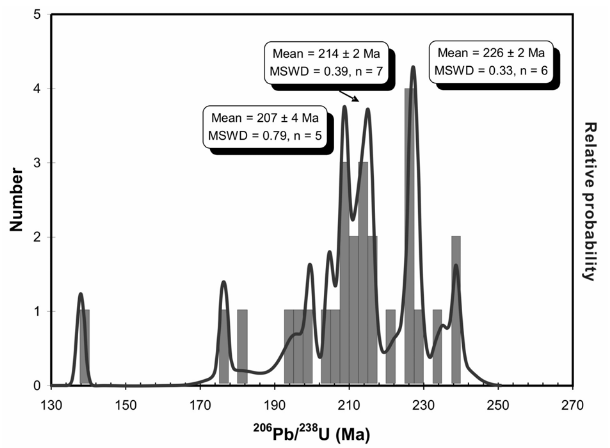

Fig. 1. Multiple metamorphic ages for zircons from the eclogites in the Luotian dome, NDZ

respectively.

Some zircons of the samples display clearly boundary between metamorphic inner and outer domains in a zircon, and the inner domain having U-Pb ages of 214±3–215±4 Ma, containing garnet and rutile inclusions, while the outer domain with the ages of 207± 8–209±4 Ma and no inclusion, suggesting the two metamorphosed domains formed in different metamorphic stages. Furthermore, the domains with the age-groups of 204±2–209±4 Ma (weighted mean age 207±4 Ma, MSWD = 0.79, n = 5; Fig. 1) in zircon show flat HREE patterns and no to negative Eu anomaly, indicating they formed under granulite-facies metamorphic condition. Especially, a zircon grain with U-Pb age of 206±5Ma showing weak igneous crystallized zoning, high Th/U ratio, steep HREE pattern and relative higher LREE contents, indicates that it may crystallize from a LREE-enriched melt formed by decompression melting. The timing of decompression melting or granulite-facies overprinting is for the first time documented to occur at 207±4 Ma. In addition, the ages of 176±2–199±2 Ma and 234±3–243±15 Ma represent amphibolite-facies retrograde age during exhumation and prograde metamorphic timing prior to the UHP metamorphism during subduction, respectively. The young age of 138+1 Ma may record the Yanshannian event.

Due to zircon being relatively stable under high-grade metamorphic conditions, UHP and HP eclogite-facies metamorphic ages as well as granulite-facies overprinting age in the NDZ have been constrained at 226±2, 214±2 and 207±4 Ma by combining with U–Pb age, trace element and mineral inclusion of zircon from the eclogites. However, the other minerals such as garnet and omphacite were easy modified by fluid activity or partial melting during subduction and exhumation, causing their elemental feature to be changed or protolith not to be identified. So, a combined study of whole-rock major and trace elements as well as Sr-Nd-Pb-Hf isotopes on the Luotian eclogites was carried out to constrain the nature and petrogenesis of their protoliths (Gu et al., 2013).

The studied samples plot in sub-alkaline basalt field in the Zr/TiO_2-Nb/Y and SiO_2-Zr/TiO_2 diagrams, they can be divided into two types by both REE and trace element features. The first display enrichment in both LREE and LILE, largely overlapping with the reference values of lower continental crust (Rudnick and Gao, 2003); the second show depletion in both LREE and LILE, but their fluid immobile elements (e.g., HSFE and HREE) also closely match the concentrations of the lower continental crust. The Luotian eclogites have lower radiogenic Pb-isotope compositions with $^{206}Pb/^{204}Pb_i$, $^{207}Pb/^{204}Pbi$ and $^{208}Pb/^{204}Pb_i$ values of 15.217–17.522, 15.077–15.540 and 35.219–38.082 (220 Ma), similar to those of the gneisses and amphibolites from the NDZ (Liu et al., 2002; Zhang et al., 2002; Li et al., 2003a), but different from the CDZ (Zhang et al., 2002; Li et al., 2003a). Thus, the eclogites might be transformed from mafic lower continental crust rocks, consistent with the previous petrological and zircon U-Pb dating investigations (Liu et al., 2007a).

As mentioned above, the protoliths of the Luotian eclogites formed in the Neoproterozoic and were transformed into eclogites during the Triassic subduction (Liu et al., 2007a, 2011b, 2011c), but their protolith nature and origin was still unknown to us. Whole-rock Sr-Nd isotopic results show that the Luotian eclogites exhibit initial $^{87}Sr/^{86}Sr$ ratios of 0.704422 – 0.706927 and $\varepsilon_{Nd}(t)$ values of -12.4–-1.4 when calculated at t = 220 Ma, and can be divided into two subgroups with -12.4–-7.3 and -6.0–-1.4. It is clear that the protoliths of the first subgroup contains more ancient crust components relative to the second one. As a result of multistage metamorphic overprinting, most samples show incorrect $\varepsilon_{Nd}(t)$ values when calculated to the protolith age of 790 Ma, except one sample with positive $\varepsilon_{Nd}(t)$ values of +1.7, which might mean the protolith originated from mantle-derived magma during Neoproterozoic.

As the Hf isotope compositions of original igneous zircons in high-grade metamorphic rocks can be used to trace protolith origin (Zheng et al., 2005), zircon Hf isotope of Luotian eclogites were also investigated. The igneous zircons from the first subgroup display negative ε_{Hf}(790 Ma) values (-9.5–+0.6), indicating a predominance of crustal Hf budget. In contrast, the igneous zircons from the second subgroup having positive $\varepsilon_{Hf}(t)$ values (+2.6–+7.9), suggest that the mixed magma was still dominated by Hf isotope budget of the depleted mantle.

In general, for all studied samples, whole-rock Nd isotopes and zircon Hf isotopes together suggest that the protoliths of the eclogites originated from mantle-derived magmas mixed with variable components of ancient continental crust. The zircon U-Pb ages and Hf isotopic compositions of the eclogites suggest that the mafic lower continental crust overgrew in the South China Block and formed by underplating of Neoproterozoic mantle-derived magmas, and subsequently involved in the Triassic continental subduction. This hypothesis is also important for understanding the extent of delamination and/or recycling of subducted mafic lower continental crust into the underlying mantle in the Dabie orogen (Liu et al., 2007b).

Acknowledgements

This study was financially supported by the National Basic Research Program of China (2009CB825002) and the National Natural Science Foundation of China (40973043, 41221062 and 41273036).

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