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SHRIMP U-Pb Zircon Geochronology of High-Pressure Granulites in the Sanggan Area, North China Craton: Timing of Palaeoproterozoic Continental Collision

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The North China Craton (NCC) has recently been subdivided into Eastern and Western Blocks separated by a Central Zone which was considered to be a collisional orogenic belt between these blocks (Zhao et al., 1998, 1999, 2000). This model is supported by lithological, structural, geochronological and, in particular metamorphic data. In the Central Zone, high-pressure (HP) granulites and retrograde eclogites occur as sheet-like and lenticular enclaves in highly deformed tonalitic gneisses and granulites. They have clockwise P-T paths with moderate temperatures of 750-850 °C and high pressures of 1.1-1.5 GPa, which demonstrate that these HP rocks are products of the continental collision (Zhao et al., 2001; Guo et al., 2002). However, the time of the collision is still in debate. Late Archaean ~2.5 Ga and Palaeoproterozoic ~1.8 Ga have been favored to be the collision time by different authors (Li et al., 2000; Zhai et al., 2000; Zhao, 2001; Wilde et al., 2002; Zhao et al., 2002). In this contribution we present SHRIMP U-Pb zircon ages of the HP granulites, which provide a robust constraint on the time of this continental collision.

Geological Setting and Sample Description

In the North China Craton, HP mafic granulites are widely distributed in central to north part of the Central Zone (Fig.1). In this study, HP granulites in the Huaian gneiss terrain of the Sanggan area are chosen for SHRIMP U-Pb zircon dating since they have been investigated structurally and petrologically in detail. The Huaian gneiss terrain in the Sanggan area is located in the northern part of the Central Zone. It is mainly composed of gneisses and granulites with a TTG composition, which enclose or include mafic two-pyroxene granulites of gabbroic to dioritic composition and felsic biotite-rich enderbitic to charnokitic rocks (Dirks et al., 1997). The terrain is an oval gneiss dome (Zhang, et al., 1994; Dirks, et al., 1997; Li et al., 1998). HP granulites are distributed around the outer part of the gneiss dome (Guo et al., 1993; Dirks, et al., 1997; Li et al., 1998).

HP mafic granulite samples MJ35 and MJ36 are from the Manjinggou outcrop. They occur as small sheet like bodies or lenticular enclaves within two-pyroxene granulites of intercalated tonalitic and gabbroic to dioritic compositions (Guo et al., 1993). Sample XW22 and XW23 are from the Xiwangshan outcrop. They occur as parallel, long and

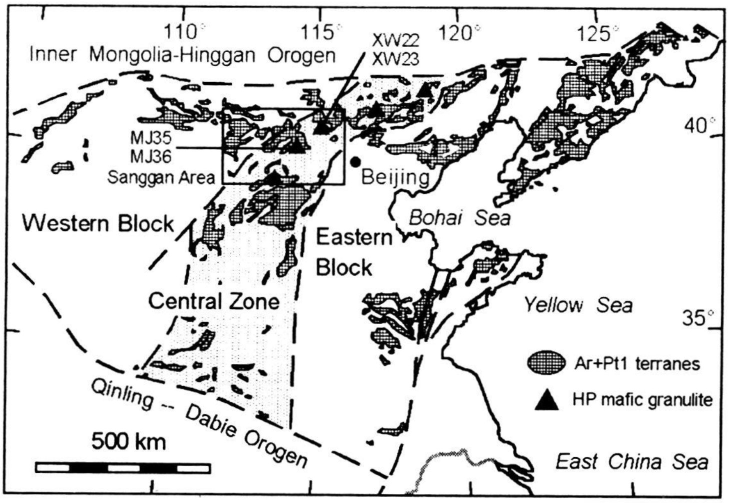

Figure 1. The three-fold division of the North China Craton (after Zhao, et al., 1999) with distribution of Archaean and Palaeoproterozoic exposures and HP mafic granulites.

narrow (1×10 m) lenses within garnet-bearing tonalitic granulites, indicating that they were likely to be originally mafic dykes. Among the 4 HP mafic granulite samples, MJ36 and XW23 contain more plagioclase and less garnet than samples MJ35 and XW22.

Analytical Techniques

U-Pb zircon analyses were performed on SHRIMP II mass spectrometer at the Institute of Geology, Chinese Academy of Geosciences in Beijing, following the standard operating techniques. Temora zircon (417 Ma) and SL-13 were taken as standards. Before SHRIMP analyses, cathodoluminescence (CL) images were performed for each grain on a JEOL scanning electron microscope. Circular to oval areas of 20-30 μm were analyzed from morphologically distinct domains chosen by CL images. Data collection was performed for five scans in dynamic mode. Correction for the common Pb contribution was made using the measured ^{204}Pb amount and model common Pb composition (Stacey and Kramers, 1975). Isotope ratio and apparent age uncertainties are given at 1σ confidence level.

Dating Results

All zircons from the four HP mafic granulite samples are clear, spherical to oval, multifaceted crystals. In the CL images, most zircons are low to high luminescent with fir-tree sector zoning or unzoned structure showing metamorphic/recrystallized characteristics (Vavra, 1990; Vavra et al., 1996; Sanchez-Rodriguez and Gebauer, 2000, Hoskin and Black, 2000). There are also some very low-luminescent structureless zircon and very high-luminescent structureless zircons. They are also considered as metamorphic zircons. Planar banded domains have been observed occasionally. In the U-Pb concordia diagrams and our age calculations, the very high-luminescent structureless (VHL) zircons are rejected since they have very low U contents and cause large errors in isotope ratios and ages.

Samples MJ35: When three VHL zircon analyses were excluded, all the other investigated grains are moderate to high luminescent zircons with unzoned structure and/or fir-tree sector zoning. Their U contents range from 18 ppm to 74 ppm, and Th/U ratios are between 0.2 and 0.6. The analysis spots cluster around the concordia curve (Fig. 2a), yielding a weighted average $^{207}Pb/^{206}Pb$ age of 1817 ± 12 Ma. It is obviously interpreted to represent the metamorphic age of the HP mafic granulite.

Samples MJ36: Most analyzed grains are low, moderate to high luminescent zircons with unzoned structure and/or fir-tree sector zoning. Their U contents are from 15 ppm to 85 ppm, and Th/U ratios are between 0.2 and 0.7. There are also 5 very low-luminescent structureless zircons containing much high U contents of 242-961 ppm. But the range of their Th/U ratios and apparent $^{207}Pb/^{206}Pb$ ages are similar with others. All these data are plotted around the concordia of 1800-2000 Ma, showing a large variation of the $^{207}Pb/^{206}Pb$ ages (Fig. 2b). Then, $^{207}Pb/^{206}Pb$ age distribution pattern with multiple peaks has been shown in a cumulative diagram (inset of Fig. 2b). The major peak is the youngest one which yields a weighted average $^{207}Pb/^{206}Pb$ age of 1817 ± 12 Ma, the same with the age we got on sample MJ35. This age is favored to represent the major metamorphic age of the HP mafic granulite.

Sample XW22: Five analyses on VHL zircons are not included in calculations and plot because of their very much low U contents. Most other analyzed grains are low to moderate luminescent zircons with unzoned structure. Planar-banded domains have been observed adjacent to unzoned domains in certain grains. Their U contents are from 34 to 475 ppm, and Th/U ratios are between 0.03 and 0.35. All their U-Pb analyses populated around the concordia of 1800 - 1900 Ma (Fig. 2c). However, their apparent $^{207}Pb/^{206}Pb$ ages show bi-model distribution pattern in the cumulative diagram (inset of Fig. 2c), giving weighted average $^{207}Pb/^{206}Pb$ ages of 1803 ± 9 Ma (n = 8) and 1872 ± 16 Ma (n = 5) respectively.

In addition, a single old zircon core has been recognized. It has high Th/U ratio of 1.56 showing magmatic characteristics. So, it seems to be a recrystallized magmatic xenocryst. It plotted on the mid-way of a conceived discordia line from ~2.5 Ga to ~1.8 Ga (Fig. 2c). In view of the major Pb loss at ~1.8 Ga, it must have been a recrystallized inherited magmatic xenocryst formed at Archaean originally during the formation of the protolith of the HP mafic granulite.

Sample XW23: All the analyzed grains are low, moderate to high luminescent zircons with unzoned complicated structure or without clear structure. Their U contents are from 27 ppm to 182 ppm, and Th/U ratios are between 0.1 and 1.0 with a single exception of 1.5. Despite the large variation range of 1755-2007 Ma (Fig. 2d), the apparent $^{207}Pb/^{206}Pb$ ages show a mono-peak distribution pattern in the cumulative diagram (inset of Fig. 2d), yielding an average $^{207}Pb/^{206}Pb$ age of 1819±16 Ma. This age can be accepted as an estimate of metamorphic age of the HP granulite.

Each of the four samples has some U-Pb zircon analyses spots plotted above the concordia causing reverse discordance. In general, reverse discordance can be induced by more than one factor. For the present case, we observed approximate correlation between the reverse discordance and the measured $^{206}Pb/^{204}Pb$ ratios from the measured data. That is to say, the spot with lower $^{206}Pb/^{204}Pb$ ratio seems to show more reverse discordance. So, we intend to consider that the high common Pb contents incurred the reverse discordance. No matter how it was caused, the limited reverse discordance shown in our data will affect the $^{207}Pb/^{206}Pb$ ratio very little, and the $^{207}Pb/^{206}Pb$ ages presented here are still reliable.

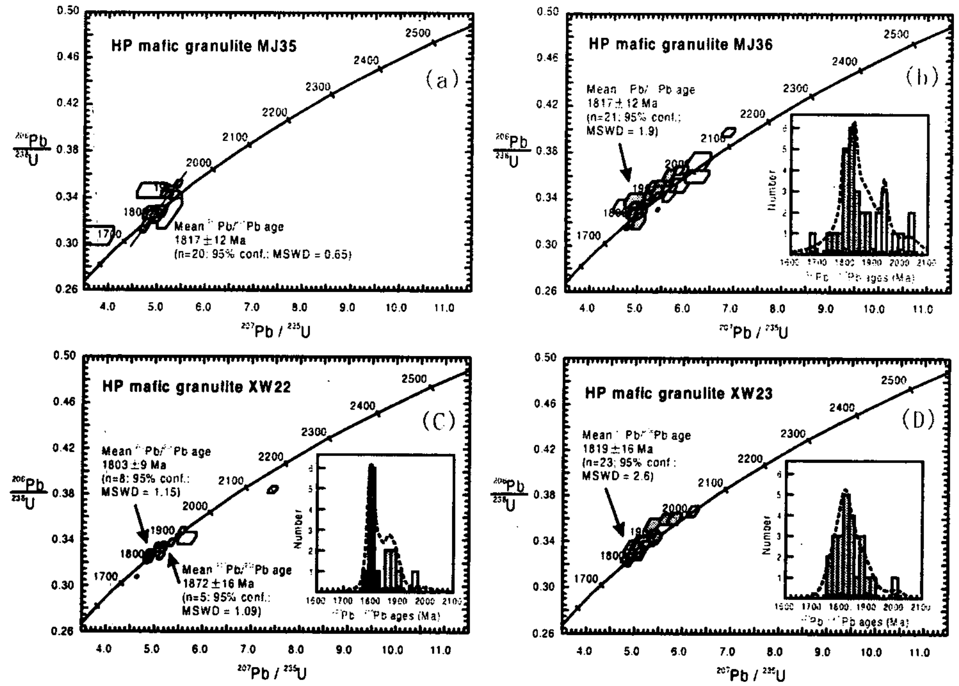

Figure 2. U-Pb concordia diagrams summarizing the SHRIMP zircon data of the HP mafic granulite samples. Inset figures are $^{207}Pb/^{206}Pb$ age cumulative diagram.

Discussion and Conclusions

Metamorphic age of the HP mafic granulites

For the HP mafic granulite samples MJ35, MJ36 and XW23, major fractions of zircons give identical U-Pb age of ~1.82 Ga. Zircons of sample MJ35 and MJ36 have Th/U ratios of 0.2-0.7, and zircons of sample XW23 contain Th/U ratios of 0.1-1.0. Such ranges of Th/U ratios show metamorphic and recrystallized zircon characteristics (Hoskin and Black, 2000), identical with the zircon morphology and internal structure observations by CL images. Therefore, the age of 1.82 Ga is interpreted to date the metamorphism of these HP mafic granulites.

Apart from the major $^{207}Pb/^{206}Pb$ age peak at ~1.82 Ga, some zircon analyses from samples MJ36 and XW23 have older apparent $^{207}Pb/^{206}Pb$ ages which can not be included in the major age peak (insets of Fig. 2b, 2d). The two samples have more plagioclase and less garnet. Their protoliths, therefore, were likely to have magmatic zircons during formation. Relict magmatic zircons could cause U-Pb analyses obviously older than the major metamorphism. But no unambiguous magmatic zircon relict has been recognized yet in the CL images. Alternative possibility to produce mentioned older U-Pb zircon ages is a metamorphism just prior to the major ~1.82 Ga event. Fortunately, it has also been implied by U-Pb analyses of sample XW22, which yielded two distinct $^{207}Pb/^{206}Pb$ age peaks in the cumulative diagram (inset of Fig. 2c). Their

Th/U ratios of 0.03-0.35 are in typical range of metamorphic zircons (Hoskin and Black, 2000). The younger age of 1803 ± 9 Ma is identical with those obtained from the above three samples within error and can be interpreted as the metamorphic age of the HP granulite. But the older age of 1872±16 Ma is inferred to provide the age of another metamorphism prior to the major ~1.82 Ga metamorphism. The ~1.87 Ga metamorphic age has also been dated by SHRIMP U-Pb zircon age on TTG gneisses in the Hengshan complex and the Fuping gneiss terrane south to the Sanggan area in the Central Zone (Zhao et al., 2002, and ref. therein).

The whole-rock Sm-Nd isochron age demonstrated that the protoliths of these HP granulites formed in late Archaean ~2.5 Ga (Guo et al., 1993). It was also implied by the SHRIMP U-Pb analyses of the inherited magmatic xenocryst from sample XW22. In previous publications, SHRIMP U-Pb zircon data and multiple grain isotope dilution U-Pb zircon age clearly show that the dominant TTG gneiss in the Huaian gneiss terrain formed at ~2.5 Ga and subjected to an intensive thermal event at about 1.85 Ga (Liu et al., 1997). These ages are identical within errors, indicating that both the protoliths of the HP mafic granulites and their country gneisses formed in late Archaean.

Geotectonic Implications

HP granulites are proved to be direct products of continental collision (Zhao et al., 2001; Guo et al., 2002; O'Brien et al., 2003). SHRIMP U-Pb zircon ages present here demonstrate that the high pressure granulite-facies metamorphism occurred at ~1.82 Ga ago. That is consequently interpreted to date the time of the continental collision developed along the Central Zone (Fig. 1). Some published isotope ages for main lithologies in adjacent areas in the Central Zone show similar age results on both the HP granulites and on TTG gneiss. It is concluded that most parts of the Central Zone, especially the northern to central parts, have been involved in the continental collision at ~1.82 Ga ago, and subjected to high-grade metamorphism. The Central Zone was a Palaeoproterozoic continental collisional orogen. No evidence of Archaean collision has been confirmed.

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