# Zircon chronology and REE geochemistry of granulite xenolith at Hannuoba

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**Abstract** The lower crustal xenolith of mafic two-pyroxene granulite (the majority) and hypersthene granulite in the Cenozoic basalt at Hannuoba have the characteristics of igneous blastic structure and granulite facies metamorphic recrystallization. Study on the zircon chronology and REE geochemistry of granulite xenolith shows that the underplating of basic magma into the lower crust during late Mesozoic led to the formation of mafic accumulate, which further through metamorphism of granulite facies formed the high-density and high-velocity crustal bottom layer at the lower crust. This suggests that the underplating of mantle magma is the important way for the vertical overgrowth of continental crust since the Phanerozoic and provides new evidence for crust-mantle interaction.

**Keywords:** age of zircon, granulite xenolith, Hannuoba.

MANY studies of lower continental crust have been made mainly through the findings of the

Archean or Proterozoic terrane granulite exposed over a large region, with neutral constituent as the majority of their chemical composition and a wide range of change in composition. Granulite xenolith carried to the surface by volcanism is much younger than terrane granulite xenolith characterized by mafic composition[1]. The difference in occurrence, mineral constituent, physico-chemical behavior and age between terrane granulite and granulite xenolith reflects the time-space change of crust during its growth and evolution. As mentioned above, the problem of lower continental crust and crust-mantle interaction remains up to now a mystery to be unveiled by geologists and solid geophysists.

This article concerns the U-Pb isotopic chronology of zircon and REE geochemistry in high temperature granulite xenolith at Hannuoba[2] and provides the evidence of underplating of mantle basic magma in the lower crust during the late Mesozoic.

## 1 Main rock types and petrographic feature of granulite xenolith

The Hannuoba Cenozoic basalt has always been celebrated for its rich contents of various kinds of mantle xenolith of peridotite and pyroxenite. Over the recent years we have taken note of lower crustal granulite xenolith and found its rock types not monotonic though uncomparable with the mantle peridotite in quantity. The granulite xenolith is dominated by mafic or basic pyroxene granulite generally appearing as two-pyroxene granulite, less as clinopyroxene granulite and garnet granulite). A large amount of lower crustal xenolith in southeastern Australia also consists of basic pyroxene granulite and garnet granulite with very little neutral and acidic granulite[3]. Research on xenoliths in various areas over the world also indicates that the basic granulite accounts for 70%[1]. The above-mentioned results reflect the common feature in distribution of lower crustal granulite over the world, probably also indicate the common features of the lower crustal composition.

Compared with the mineral composition of terrane granulite, the mafic granulite xenolith in Hannuoba does not contain amphibole and micas. The two-pyroxene granulite in this study consists mainly of orthopyroxene and clinopyroxene ( $>80\%$ ) with minor plagioclase. It contains MgO and FeO (15% and 10% respectively). Its relict igneous structure and recrystallized structure indicate that the two-pyroxene granulite is an accumulative mafic rock from basaltic magma. The hypersthene granulite consists of hypersthene and felsic minerals with mineral banded distribution. It is quite evident that hypersthene granulite has experienced metamorphic recrystallization of granulite facies and probably its protolith is an evoluted gabbric rock.

## 2 U-Pb isotopic age of zircon in granulite xenolith

Granulite xenolith and terrane granulite show different sources and genetic evolution in occurrence, mineral composition, chemical composition and $P$-$T$ equilibrium condition. Through the determination of igneous crystallization of granulite xenolith and metamorphic age of granulite facies by zircon U-Pb isotopic dilution method, their history of formation and evolution may be understood.

Two two-pyroxene granulites and one hypersthene granulite were selected. A few tens of grains of zircon were separated from each sample by heavy concentrate method. Six groups of zircons from three samples can be classified into two types in terms of their color and shape. ( i ) Zircon in hypersthene granulite is colorless, transparent, capsular or perfectly rounded and 0.2—0.4 mm in grain size. This kind of zircon, crystallized from slightly $SiO_2$ saturated and mid-acidic magma, is a comparatively typical metamorphic genetic zircon of granulite facies (fig. 1(a), (b)). ( ii ) Zircon in two-pyroxene granulite is pink, semi-transparent to transparent, anhedral, clastic, with local flat surfaces and grain size of 0.1—0.2 mm, and is anhedral igneous zircon crystallized interstitially in late stage of basic magma (figure 1(c), (d)).

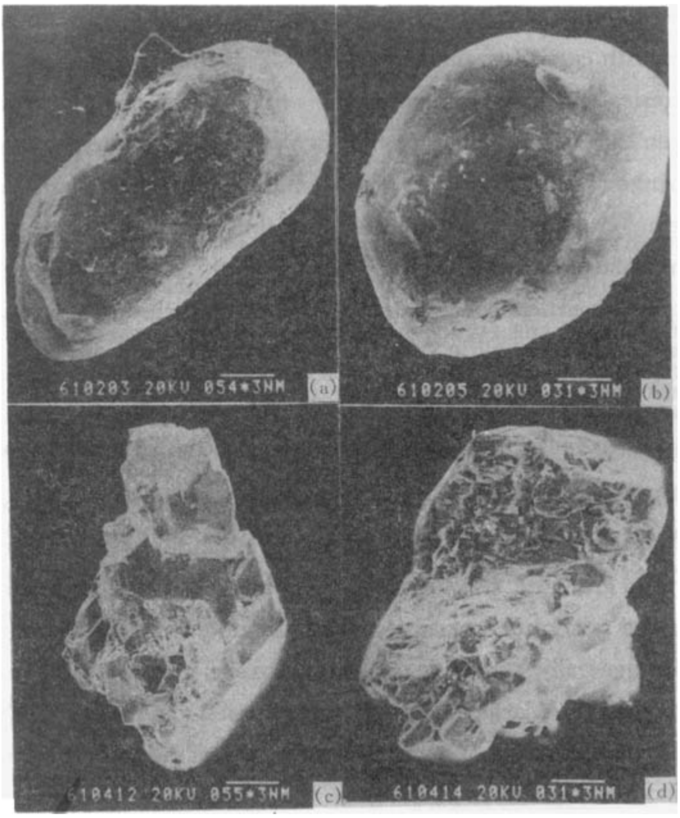

Fig. 1. Scanning electron micrographs for zircons of granulite xenolith in Hannuoba.

The results of U-Pb isotopic dating for six groups of zircon are listed in table 1. The data of the first and the second groups are obtained from single grains of zircon crystals (fig. 1(a), (b)), while those of other four groups are obtained from multiple grains (3—10 grains, because of too small size, young age and small accumulation of radioative genetic lead multiple grains were used) of zircons (fig. 1 (c), (d)). The six groups of zircons from three samples are all Mesozoic zircons and their $^{206}Pb/^{238}U$ surface ages are comparatively reliable. $^{206}Pb/^{238}U$ surface ages of three groups from sample HD-70 are 139.8, 140.6 and 140.1 Ma respectively, very close to each other, while that of one group from sample WD9527 is 124.9 Ma and those of two groups from sample HD-50 are 121.1 and 120.6 Ma respectively. It can be seen from the isochron of U-Pb isotopic

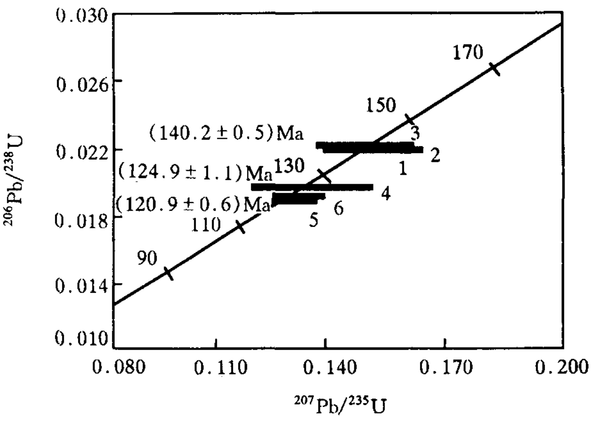

Fig. 2. Zircon U-Pb isochron for granulite xenolith of Hannuoba.

dating that all the data of the six groups fall on the isochron curve with the ages of $(140.2 \pm 0.5)$, $(124.9 \pm 1.1)$ and $(120.9 \pm 0.6)$Ma for hypersthene granulite (HD-70) and two two-pyroxene granulites(WD9527, HD-50) respectively, representing three periods of granulite-facies metamorphism (figure 2).

## 3 REE geochemistry of granulite xenolith

ΣREE of granulite xenolith has relation to its petrology. ΣREE of hypersthene granulite rich in plagioclase and quartz is $64 \times 10^{-6}$. It is rich in LREE ($La_N = 50$) and has REE pattern with slight LREE-HREE fractionation($(La/Yb)_N = 6$) and flat MREE-HREE distribution(fig. 3). Due to the accumulation of plagioclase in hypersthene granulite, the REE pattern shows remarkably positive Eu abnormality, with Ba content 10 times as great as that of the two-pyroxene granulite. ΣREE of two-pyroxene granulite is comparatively low. ΣREE for samples WD9527 and HD-50 are $44 \times 10^{-6}$ and $24 \times 10^{-6}$ respectively, with the former containing more plagioclase (Ba occurring as in plagioclase) and consequently higher ΣREE. REE pattern of two two-pyroxene granulites are slightly richer in LREE ($La_N = 6$—$15$), with slight LREE-HREE fractionation ($(La/Yb)_N = 2$—$4$), without Eu abnormality and showing REE characteristics of pyroxene accumulate (table 2).

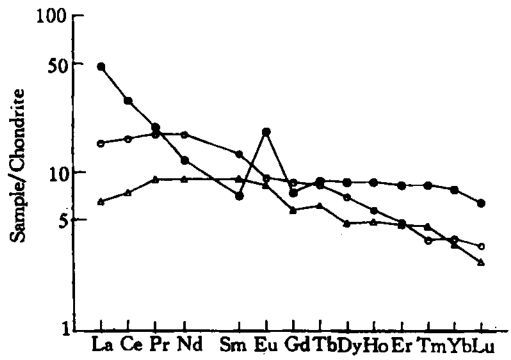


Fig. 3. Chondrite-normalized REE patterns for granulite xenoliths in Hannuoba. Δ, HD-50; ○, WD9527; ●, HD-70.

## 4 Discussion

Fyle[4] first suggested that the underplating of basaltic magma at bottom of the crust is the important form or process for the growth of Archean continent. Furlong *et al*.[5] made an overall description of the continental crust underplating and believed that underplating is the process by which the mantle materials were added to bottom of the crust. Study of granulite xenolith is the important approach for understanding this process.

It can be known from ages of the metamorphic genetic zircons in hypersthene granulite that granulite-facies metamorphism started at the Late Jurassic (~140 MaB.P.). It is inferred that during the Late Jurassic the underplating of mantle magma in North China started with basic magma underplating the lower crust, leading to crust-mantle interaction, granulite-facies metamorphism and the production of hypersthene granulite. The main part of granulite xenolith in Hannuoba is the mafic two-pyroxene granulite. The large-scale underplating evidenced by zircon U-Pb age, petrology and geochemistry mainly took place during the Early Cretaceous (124—120 Ma). Different accumulates were formed by the direct intrusion of basaltic magma into the lower crust, and further through granulite-facies metamorphism, the mafic two-pyroxene granulite was formed. The high-density and high-velosity crustal bottom layer (33—40 km) existing beneath

Table 1 U-Pb isotopic dating for zircon of granulite xenolith in Hannuoba[a)]

| Sample (group)No. | Zircon feature | W /μg | U /μg·g$^{-1}$ | Pb /μg·g$^{-1}$ | Common Pb/ng | U-Pb isotopic atom ratio | | | | | Apparent age/Ma | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | $^{206}Pb/^{204}Pb$ | $^{208}Pb/^{206}Pb$ | $^{206}Pb/^{238}U$ | $^{207}Pb/^{235}U$ | $^{207}Pb/^{206}Pb$ | $^{206}Pb/^{238}U$ | $^{207}Pb/^{235}U$ | $^{207}Pb/^{206}Pb$ |
| HD-50(5) | pink, semi-transparent, anhedral | 30 | 1 668 | 149 | 1.9 | 35.5 | 0.077 86 | 0.018 96 (12) | 0.127 3 (71) | 0.048 7 (26) | 121.1 | 121.6 | 132.4 |
| HD-50(6) | | 20 | 2 364 | 226 | 2.0 | 34.0 | 0.061 70 | 0.018 88 (15) | 0.126 3 (65) | 0.048 5 (24) | 120.6 | 120.8 | 125.6 |
| WD9527(4) | pink, trans-parent, an-hedral | 40 | 423 | 8 | 0.002 1 | 5 057 | 0.048 17 | 0.019 57 (17) | 0.131 0 (177) | 0.048 6 (62) | 124.9 | 125.0 | 126.7 |
| HD-70(1) | colourless, transparent, perfectly rounded | 20 | 539 | 14 | 0.026 | 291 | 0.013 45 | 0.021 93 (14) | 0.154 1 (116) | 0.051 0 (36) | 139.8 | 145.5 | 239.0 |
| HD-70(2) | | 20 | 919 | 25 | 0.068 | 231 | 0.028 80 | 0.022 06 (16) | 0.148 9 (143) | 0.049 0 (44) | 140.6 | 141.0 | 146.7 |
| HD-70(3) | columnar | 30 | 310 | 10 | 0.062 | 137 | 0.064 74 | 0.021 97 (14) | 0.148 5 (113) | 0.049 0 (35) | 140.1 | 140.6 | 146.7 |

a) The values of $^{206}Pb/^{204}Pb$ have been normalized against the diluted agent and blank. The numbers in brackets are $2\sigma$ (absolute error). Analysist: Li Huiming, Tianjin Institute of Geology and Mineral Resources, Ministry of Geology and Mineral Resources.

Table 2 The major elements (%) and REE(μg·g$^{-1}$) of granulite xenoliths in Hannuoba[a)]

| Sample No. | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | FeO | MnO | MgO | CaO | $Na_2O$ | $K_2O$ | $P_2O_5$ | $H_2O^-$ | $H_2O^+$ | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HD-50 | 50.58 | 0.50 | 8.87 | 4.20 | 5.10 | 0.10 | 15.61 | 12.68 | 1.00 | 0.40 | 0.19 | 0.44 | 1.31 | 100.98 |
| WD9527 | 47.80 | 0.51 | 10.19 | 4.05 | 7.02 | 0.11 | 15.74 | 10.59 | 1.40 | 0.45 | 0.27 | 0.45 | 1.85 | 100.43 |
| HD-70 | 60.54 | 0.52 | 13.69 | 2.80 | 3.52 | 0.07 | 6.21 | 5.09 | 2.90 | 1.60 | 0.24 | 0.44 | 2.78 | 100.40 |

| Sample No. | La | Ce | Pr | Nd | Sm | Eu | Gd | Tb | Dy | Ho | Er | Tm | Yb | Lu | Y | Ba |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HD-50 | 2.163 | 6.492 | 1.056 | 5.803 | 1.858 | 0.651 | 1.61 | 0.299 | 1.622 | 0.345 | 1.054 | 0.141 | 0.784 | 0.091 | 8.845 | 80.96 |
| WD9527 | 5.096 | 14.391 | 2.045 | 11.151 | 2.711 | 0.717 | 2.4 | 0.403 | 2.4 | 0.412 | 1.092 | 0.117 | 0.851 | 0.117 | 11.33 | 107.2 |
| HD-70 | 15.850 | 25.235 | 2.256 | 7.642 | 1.465 | 1.416 | 2.06 | 0.428 | 3.002 | 0.617 | 1.908 | 0.258 | 1.746 | 0.218 | 18.19 | 1217 |

a) HD-50, WD9527, Two pyroxene granulite; HD-70, hypersthene granulite. Analysis was made in Institute of Geology, SSB and Institute of Geology, CAS.

the present North China was formed by solidification and metamorphism of basic magma intruding or added to the lower crustal bottom beneath the area. From Nd, Sr, Pb isotopic studies, Chen *et al.*[6] pointed out that granulite xenolith of Hannuoba is the retention of early basaltic magma, different from its host basalt in the deep crust or mantle. The underplating of the Mesozoic dioritic magma bearing deep-seated rock xenolith in Handan-Xingtai of southern Hebei and western Shandong may represent the underplating events of magma in the middle part of North China Platform during the same period[7]. The chronology, REE, isotope geochemistry and petrology of granulite xenolith in Hannuoba are different from those of terrane granulite in North China and its Cenozoic host basalt. This provides the evidence of lower crust underplating in the northern part of North China. The shapes (fig. 1(c), (d)) and ages of zircon in granulite xenolith under study are similar or close to the shapes (fig. 1(c), (d)) and ages ((106.5 ± 0.2) Ma) of zircon in pyroxenite from Quanzhou, along the southeast coast of China[8]. It may be inferred that there might have been underplating from mantle source basic basaltic magma in both North China and along the southeast coast of China during the Early Cretaceous. This might be the important way of vertical growth and horizontal extension of continental crust since the Phanerozoic and may be the key to the understanding of the present lower crust and the geodynamic process of crust-mantle interaction.

**Acknowledgement** This work was supported by the National Natural Science Foundation of China (Grant No. 49572103).

## References

1 Rudnick, R., Xenoliths-samples of the lower continental crust, in *Continental Lower Crust* (eds. Fountain, D. M. *et al.*), Amsterdam: Elsevier, 1992, 269—316.

2 Fan, Q.C., Liu, R.X., High temperature granulite xenolith of basalt in Hannuoba, *Chinese Science Bulletin*, 1996, 41(3): 235.

3 Griffin, W.L., O'Reilly, S.Y., The composition of the lower crust and the nature of the continental Moho-xenolith evidence, *Mantle Xenoliths* (ed. Nixon, P.H.), London: Wiley, 1987.

4 Fyfe, W. S., The granulite facies, partial melting and the Archean crust, *Philos. Trans. R. Soc.* 1973, 273: 457.

5 Furlong, K.P., Fountain, D.M., Continental crustal underplating consideration and seismic-petrologic consequences, *J. Geophys. Res.*, 1986, 91(B8): 8285.

6 Chen, D.G., Zhi, X.C., Li, B.X. *et al.*, The characteristics of geochemistry in non-peridotite xenolith in Hannuoba, in *New Devolopment in Mineralogy, Petrology and Geochemistry Study in China* (ed. Ouyang, Z. Y.) (in Chinese), Lanzhou: Lanzhou University Press, 1994, 146.

7 Xu, W.L., Chi, X.G., Yuan, C., *Mesozoic Dioritic Rocks and Its Deep-seated Rock Inclusions in the Middle Platform of North China* (in Chinese), Beijing: Geological Publishing House, 1993.

8 Li, H.M., Dong, C.W., Xu, X.S. *et al.*, Dating of gabbro by single ziecon——The origion of basic magma, southeast Fujian Province, *Chinese Science Bulletin*, 1995, 40(2): 158.

(*Received February* 10, 1998)