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Petrology, geochemistry and geodynamics of basic granulite from the Altay area, North Xinjiang, China*

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Abstract: The basic granulite of the Altay orogenic belt occurs as tectonic lens in the Devonian medium- to lower-grade metamorphic beds through fault contact. The Altay granulite (AG) is an amphibole plagioclase two-pyroxene granulite and is mainly composed of two pyroxenes, plagioclase, amphibole and biotite. Its melano-minerals are rich in $Mg/(Mg+Fe^{2+})$, and its amphibole and biotite are rich in TiO_2. The AG is rich in $Mg/(Mg+Fe^{2+})$, Al_2O_3 and depletion of U, Th and Rb contents. The AG has moderate ∑REE and LREE-enriched with weak positive Eu anomaly. The AG shows island-arc pattern with negative Nb, P and Ti anomalies, reflecting that formation of the AG may be associated with subduction. Geochemical and mineral composition data reflect that the protolith of the AG is calc-alkaline basalt and formed by granulite facies metamorphism having peak P-T conditions of 750 °C–780 °C and 0.6–0.7 Gpa. The AG formation underwent two stages was suggested. In the early stage of oceanic crustal subduction, calc-alkaline basalt with island-arc environment underwent granulite facies metamorphism to form the AG in deep crust, and in the late stage, the AG was thrust into the upper crust.

Key words: Basic granulite, Petrology and geochemistry, Geodynamics, Altay orogenic belt, North Xinjiang
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INTRODUCTION

Due to granulites representing products of the deeper lower crust-upper mantle and having genetic association with early crustal evolution and formation of large-scale metallogenic-forming and non metallogenic-forming belts, the study of granulites in the world has resulted in much recent attention (Zhai and Liu, 2001; Liu and Zhou, 1994; Yu *et al.*, 1998; 2003; Li *et al.*, 2000; Zhang *et al.*, 2001; Yu *et al.*, 2002; Bingen and Stein, 2003; Blein *et al.*, 2003; Garcia *et al.*, 2003; Owen *et al.*, 2003; Seth *et al.*, 2003; Tsunogae *et al.*, 2003).

The AG was previously regarded as gabbro, non-metamorphosed products which intruded into country rocks with medium- to lower-metamorphic grade. Study of the AG has important significance for further study of formation and tectonics of deeper crust in the Altay area and continental dynamic processes in North Xinjiang and even Central Asia.

This paper addresses petrology, geochemistry and metamorphism, and discusses geodynamics of the AG in Northwest China.

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GEOLOGICAL OUTLINE

The Altay orogenic belt is an important Paleozoic orogenic belt between the Siberia Plate and Kasakhstan Plate and is regarded as a huge Central Asia collisional belt, which formed through post last-stage plate collision in the Early Carboniferous (Fig.1). This belt consists mainly of metamorphic rocks, including crystalline schist, gneiss, migmatite and some meta-sandstone, siltstone tuffaceous sandstone, and intermediate to basic volcanic rocks in the northern town of Fuyun (Han, 1991).

The metamorphic grade increases from the east of Xipodu and becomes amphibolite facies, and intense magmatism and tectonic deformation, including ductile deformation occurred eastward from longitude 89° to Halatongke (Han, 1991). Zhuang (1994) argued that a series of thermal-tectonic-gneissose domes that developed in the Altay orogenic belt, evolved from the sericite-chlorite zone to the sillimanite-cordiorite zone and migmatic granitic gneiss zone from the low-grade metamorphic belt to high-grade metamorphic central dome.

The new found AG body is located in Wuqiagou (an Eastern Funyun town) as a NW-SE trending tectonic lens with fault contact with the early Devonian medium- to lower-grade country rocks (Fig.2). The thickness and outcropped area of the granulite is about 117 m and ca. 35000 m^2 measured from the fracture zone in the northeastern side to granitic gneiss in the southwestern side based on the authors' detailed field geological survey and measured sections.

The AG body has fault contact with granitic gneiss and amphibole plagioclase gneiss on the northeast side and sharp contact with the granitic gneiss on the southwest side. A small-size meta-diabase body or dyke might intrude into the AG. The AG can be divided into coarse-grained granulite and fine-grained granulite with their contact relationship being gradually transitional. The coarse-grained granulite, the main phase in the AG body, is the subject of study in this paper.

PETROLOGY AND GEOCHEMISTRY OF THE AG

The AG is gray to grayish black and has grayish

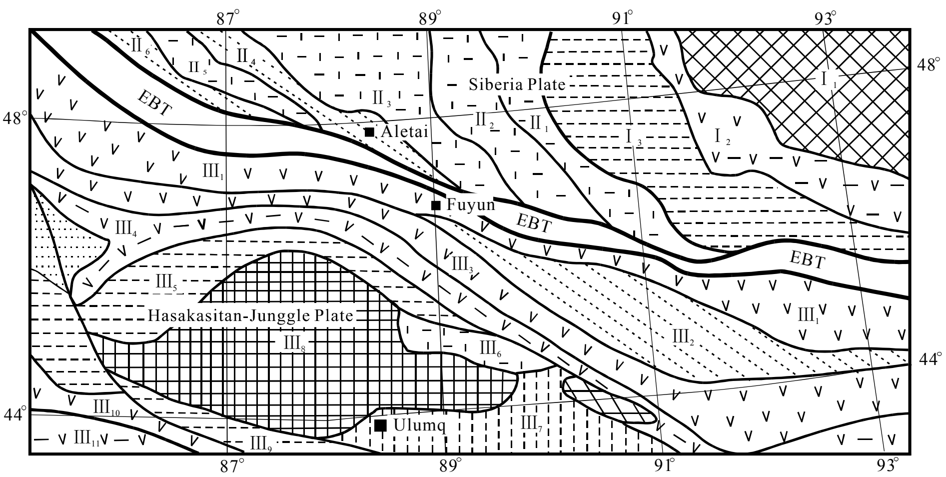

Fig.1 Plate tectonic sketch map of the Central Asia

Notes: I$_1$: Tuwa-Shangjinuo terrain; I$_2$: Bayanwula Sinian-Cambrian island-arc belt; I$_3$: Mengguhuqu Sinian-Cambrian ocean basin; II$_1$: Haerlin Cambrian-Ordovician magmatic arc; II$_2$: Nuo'erte-Wuliegai Devonian-Carboniferous volcano-sedimental basin; II$_3$: Hanasi-Keketuohai Paleozoic magmatic arc belt; II$_4$: Kelan Devonian-Carboniferous back-arc basin; II$_5$: Ka'erba Carboniferous-Permian magmatic arc belt; II$_6$: Xika'erba Carboniferous fore-arc basin; III$_1$: Sawu'er Late Paleozoic magmatic arc; III$_2$: Santanghu Late Paleozoic inter-arc basin; III$_3$: Ta'erbawuhe-A'erwantai early Paleozoic relic ocean basin; III$_4$: Xiemisitai-Kulankazigan Devonian epicontinental volcanic rock belt; III$_5$: Dalabute-Kelamaili Devonian-Carboniferous relic ocean relic ocean basin; III$_6$: Batamayinashan Devonian volcano-sedimental basin; III$_7$: Bogeda Paleozoic rifting; III$_8$: Zhunge'er terrain; III$_9$: Yilanhabi'er Late Paleozoic ocean basin; III$_{10}$: Jueluotage Late Paleozoic rifting; III$_{11}$: Yili Carboniferous-Permian rifting; EBT: E'erqisi-Bu'ergen suture zone

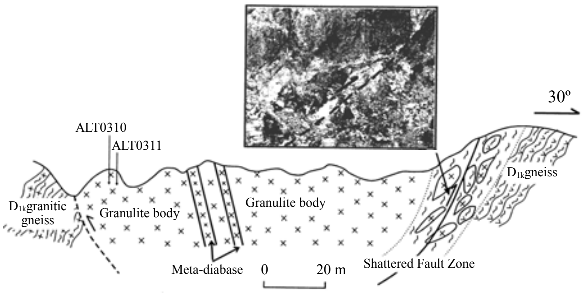

Fig.2 Measured section of the Altay granulite in Fuyun Wuqiagou area

Note: D_{1k}: the early Devonian Kangbutiebo formation

brown orthopyroxene, dark-green clinopyroxene. The mineral assemblage includes hypersthene, augite, plagioclase, amphibole and biotite. Accessory minerals are zircon, apatite, magnetite and titanite. The mineral reaction and texture showed that two pyroxenes retrograded to amphibole and biotite with quartz. This granulite has two water-free pyroxenes, and water-bearing amphibole and biotite. The modal composition amount of the former is higher than that of the latter. The AG has granular texture and massive structure, and is an amphibole-plagioclase two-pyroxene granulite by classification of Sheng (1991).

Based on the mineral composition of the AG (Table 1), orthopyroxene is composed of Mg-rich hypersthene with $En_{61\text{-}64}Fs_{35\text{-}38}Wo_1$ and Mg/(Mg+Fe^{2+}) ratios of 0.64–0.65. Clinopyroxene has $Wo_{46}En_{40\text{-}41}Fs_{13\text{-}14}$, and is Mg-rich augite. Amphiboles have Mg/(Mg+Fe^{2+}) ratios of 0.74–0.88 and are magnesium-hornblendes with higher TiO_2 (1.81%–2.36%). The anorthite contents of plagioclase range from 50 to 55 mol%. The biotite is phlogopite with Mg/(Mg+Fe^{2+}) ratios of 0.57–0.59 and TiO_2 contents of 3.99%–4.11%.

The AG contains SiO_2, 53.18%–53.57%, Al_2O_3, 17.98%–18.32%, (K_2O+Na_2O), 4.07%–4.56%, TiO_2, 0.76%–0.90% and Mg/(Mg+Fe^{2+}), 0.63–0.64 (Table 2). It has high Mg and Al contents, and low Ca content. The AG has high Mg/(Mg+Fe^{2+}) ratios, and its Nb and Zr contents are similar to those of typical island-arc calc-alkaline basalt, but are much lower in contents than that of typical continental basalts. Based on SiO_2-MgO/FeO_t and (Na_2O+K_2O)-MgO-FeO_t (Irvine and Baragar, 1971) discriminative diagrams, the granulite samples fall on the field of calc-alkaline basalt (Fig.3). The AG has low K, Rb, U contents (0.32×10^{-6}–0.36×10^{-6}) and Th contents (1.67×10^{-6}–1.93×10^{-6}), reflecting depletion of thermal-genetic elements and large-radius ion rock-forming elements. The AG is enriched in Ba (115×10^{-6}–158×10^{-6}) and Sr (478×10^{-6}–502×10^{-6}). The AG has total REE amount of 92.38×10^{-6}–96.58×10^{-6}, $(La/Yb)_N$ of 4.31–4.46 and weak positive Eu anomaly of 1.09–1.15 (Fig.4).

Table 1 Representative mineral compositions (%) of granulite

Minerals	Opx	Cpx	Amp	Bt	Pl
Point No.	3	2	1	4	5
SiO_2	51.35	52.81	44.01	37.43	53.42
TiO_2	0.07	0.03	2.32	3.81	0.04
Al_2O_3	0.92	0.72	9.71	14.30	28.73
FeO_t	22.97	8.53	14.87	16.51	0.22
MnO	0.53	0.31	0.10	0.03	0.02
MgO	22.67	13.99	12.40	13.89	0.03
CaO	0.58	22.68	11.76	0.01	11.32
Na_2O	0.09	0.41	1.49	0.09	5.10
K_2O	–	–	0.87	9.08	0.30
P_2O_5	0.11	0.27	0.10	–	0.06
Total	99.29	99.75	97.64	95.15	99.42

Note: Data measured in the State Key Laboratory of Mineral Deposit Research, Nanjiang University; Opx: orthopyroxene; Cpx: clinopyroxene; Amp: amphibole; Bt: biotite; Pl: plagioclase; FeO_t: as total of FeO

Table 2 Major (%), trace elements ($\times10^{-6}$) of granulites

	1	2		1	2		1	2
SiO_2	53.18	53.57	Ba	158	155	La	12.40	13.20
TiO_2	0.90	0.76	Rb	16	17	Ce	27.80	29.30
Al_2O_3	18.32	17.98	Sr	478	502	Nd	14.60	15.30
Fe_2O_3	1.79	1.43	Zr	128	124	Sm	3.80	3.98
FeO	5.25	5.50	Nb	5	4.2	Eu	1.33	1.36
MnO	0.16	0.17	Y	17	17	Gd	3.09	3.46
MgO	6.41	6.63	Th	1.7	1.9	Tb	0.55	0.55
CaO	8.36	8.32	Zn	81	84.5	Dy	3.45	3.46
Na_2O	3.80	3.39	Sc	18.6	20.7	Ho	0.65	0.67
K_2O	0.76	0.68	Cr	149	163	Tm	0.28	0.30
P_2O_5	0.16	0.17	Ta	0.38	0.36	Yb	1.88	2.07
LOI	0.88	1.00	U	0.32	0.36	Lu	0.31	0.35
Total	99.97	99.60						

Note: 1: ALT0310; 2: ALT0311

P-T ESTIMATE OF THE AG

The AG underwent at least two stages of metamorphic processes based on mineral texture.

Peak granulite facies metamorphism

The peak temperature estimated was about 750–780 °C by the two-pyroxene geothermometer of Wood and Banno (1973), and Brey and Kohler (1990), which differed from the high temperature values estimated by the method of Wells (1977). The Altay granulite has the peak pressure condition of ca. 0.6–0.7 Gpa compared with that of granulites in other parts of the world (Zhai and Liu, 2001).

Amphibolite facies metamorphism

The estimated P-T conditions in the amphibolite facies metamorphism were 700–720 °C and 0.23–0.37 Gpa by hornblende-plagioclase thermometer (Zhang and Cong, 1983) and hornblende barometer (Hollister *et al.*, 1987).

GEODYNAMICS OF THE AG

The Ti-Zr-Y (Pearce and Cann, 1973) and Hf-Th-Ta diagrams (Fig.5) as well as lower K_2O and P_2O_5 contents are useful for distinguishing different tectonic settings of basalts. The AG shows affinity with volcanic-arc setting. A tri-doming pattern and strong negative Nb anomaly and medium negative P and Ti anomalies (Fig.6) in the MORB normalized spider diagram of Pearce (1982) reflect that the protolith of the AG is calc-alkaline basalt formed under tectonic setting of island-arc and the formation of the AG has tectonic relation with subduction and/or subduction-related materials.

The field occurrence and spatial distribution of

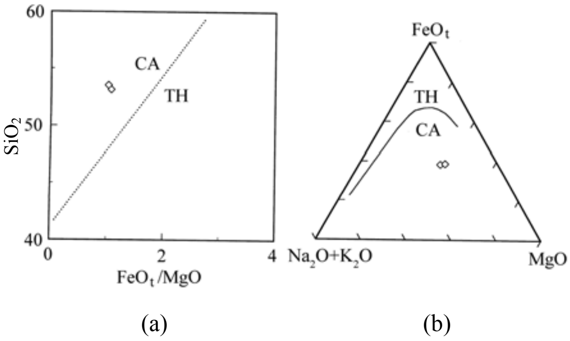

Fig.3 SiO_2-MgO/FeO_t (a) and (Na_2O+K_2O)-MgO-FeO_t (b) diagrams for the AG

Note: TH: tholeiite and CA: calc-alkaline basalt

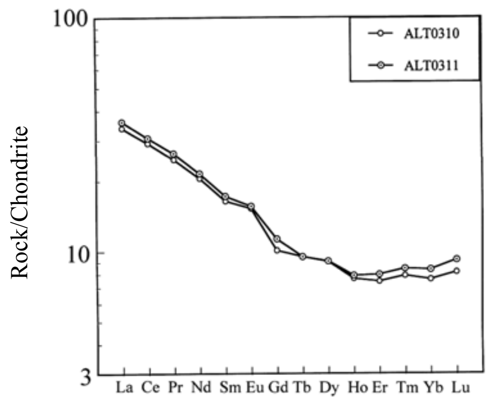

Fig.4 Chondrite normalized REE pattern of the AG

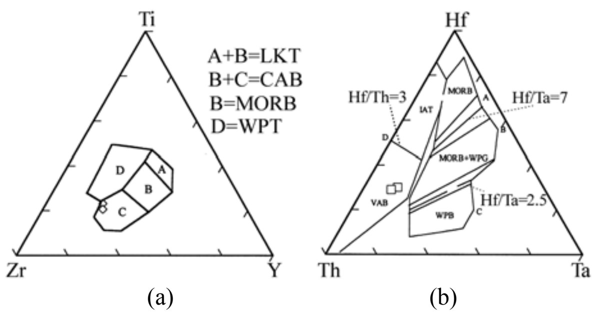

Fig.5 Ti-Zr-Y (a) and Hf-Th-Ta (b) diagrams for the AG

Note: LKT: low-K tholeiite; CAB: calc-alkaline basalt; WPT: within-plate tholeiite; MORB: mid-ocean-ridge basalt; VAB: volcanic-arc basalt; WPB: within-plate basalt and IAT: island-arc tholeiite

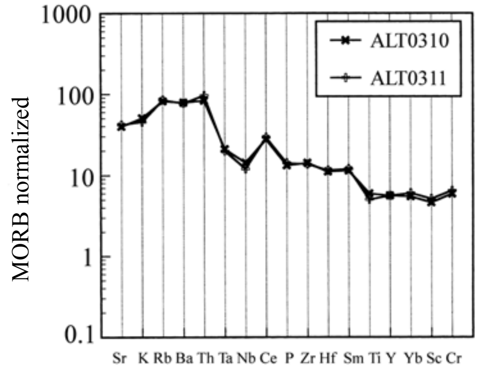

Fig.6 MORB normalized spider diagram of the AG

the AG body shows that it has fault contact with whole rocks of granitic gneiss and amphibole-plagioclase gneiss, and sharp contact with potassium granitic gneiss along a NW-SE direction of field occurrence. Therefore, the authors argue that the present occurrence of the AG is due to thrust fault in the late stage, but cannot be explained by the primary occurrence of the AG. The AG was thrust from deep crust into upper crust and while, undergoing retrograde metamorphism by the thrust process during the continental orogenic process.

Based on the above study, the protolith of the AG is island-arc calc-alkaline basalt and has peak pressure and temperature conditions of ca. 0.6–0.7 Gpa and 750–780 °C, implying lower crustal level, where granulite facies metamorphism occurred. Fang *et al.*(2002) obtained Nd model age of 945±7 Ma and Sm-Nd isochron age of 974±63 Ma from the Wuqiagou mafic rocks in Funyun and argued that it was very possible that the late Proterozoic geological event occurred though the surrounding rocks of this area could be regarded as Devonian material. Therefore, the authors suggest that the AG formation occurred in two stages. In the early stage of oceanic crustal subduction, calc-alkaline basalt with island-arc environment underwent granulite facies metamorphism to form the AG in deep crust, and in the late stage, the AG was thrust into the upper crust and had fault contact with medium- to low-grade metamorphic strata of late Paleozoic, and finally outcropped to the earth surface (Fig.7).

CONCLUSION

1. Petrological and geochemical data showed that the AG is an amphibole plagioclase two-pyroxene granulite and its protolith, calc-alkaline basalt, formed under tectonic setting of island-arc.

2. The P-T condition of metamorphic peak is 750–780 °C and ca. 0.6–0.7 Gpa, and granulite facies metamorphism occurred in middle to lower crust.

3. Formation of the AG can be explained by the calc-alkaline basalt with island-arc environment having undergone granulite facies metamorphism in the deep crust after oceanic crustal subduction, and then the AG is thrust into the upper crust during the late Paleozoic.

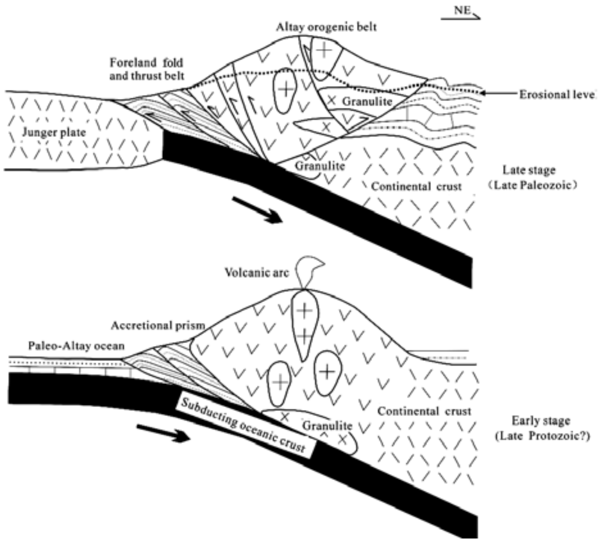

Fig.7 Tectonic model for the formation of the Altay granulite

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