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SHRIMP U-Pb zircon ages for the UHP metamorphosed granitoid gneiss in Altyn Tagh and their geological significance

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Abstract **Cathodoluminescence (CL) and mineral inclusions investigations show that zircons from Yinggelisayi UHP metamorphosed granitoid gneiss in Altyn Tagh exhibit core-mantle-rim internal texture with magmatic residual core, the metamorphic overgrowth mantle and the late stage rim. SHRIMP $^{206}Pb/^{238}U$ ages of 5 spots from the mantles vary from 484±11 to 491±12 Ma with Th/U ratios from 0.01 to 0.03, yielding a weighted average age of 487±10 Ma (2σ) as the age of the UHP metamorphosed granitoid gneiss. The $^{206}Pb/^{238}U$ ages from the oscillatory zoned cores range from 809±19 to 885±21 Ma with Th/U ratios ranging from 0.42 to 0.83, which are interpreted as the crystallization age of the protolith of the granitoid gneiss. The metamorphic age (487±10 Ma) of the UHP metamorphosed granitoid gneiss, well consistent with the peak metamorphic age (about 500 Ma) of the UHP eclogite with crystallization age of the protolith between 809±19 and 885±21 Ma at Jianggelisayi in western Altyn Tagh, indicates the existence of a UHPM belt along the south margin of the Altyn Tagh as a result of deep subduction during Early Paleozoic age of previously existing continental crust.**

Keywords: Altyn Tagh, UHP metamorphosed granitoid gneiss, zircon, SHRIMP dating, metamorphic age.

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Different types of UHP metamorphic rocks have been recently discovered in the Altyn Tagh[1—4], the northern margin of Qadam Basin[5—7], the southwestern Tianshan Mountains[8,9] and the northern Qinling Mountains[10,11] in Central and Western China. And these areas have attracted focus attention of geologists at home and abroad to the studying of UHP metamorphism and continental deep subduction. However, as newly discovered UHP metamorphic terranes, some questions have been arisen about the space and time extent of these UHP metamorphic rocks, peak metamorphic ages, the correlation to the deep subduction of continental crust as well as the tectonic relation between these UHP metamorphic terranes. The recently discovered garnet lherzerlites[1] and their direct country rocks-garnet-bearing granitoid gneisses[2,4] and K-feldspar garnet clinopyroxenites[2,12] from Yingelisayi in the Altyn Tagh have all experienced UHP metamorphism and are the products of deep subduction of crustal rocks. But it is still unclear whether or not these UHP metamorphic rocks construct the same UHP metamorphic belt with UHP eclogites in the western part of the south margin of the Altyn Tagh and the tectonic relationship of these rocks with other UHP rocks discovered in Western China because of the lack of accurate isotopic data of these rocks. Based on the CL images, mineral inclusions and SHRIMP U-Pb dating of zircons, the authors report in this paper the metamorphic age of 487±10 Ma for the UHP metamorphosed granitoid gneisses from Yinggelisayi in the Altyn Tagh. This age is consistent well with that of the UHP eclogites (about 500 Ma) in the western Altyn Tagh, and provides further evidence that different kinds of UHP rocks discovered in this area construct a UHP metamorphic belt along the south margin of Altyn Tagh, and also give a chronological constraint on the relationship of this UHP metamorphic belt with the north margin of the Qiadam Basin and the northern Qinling terrane.

1 Geological setting

The HP-UHP eclogites occur as lenses in the gneisses of the Altyn Group of Proterozoic age[13] along the northern margin of the Apa-Mangya tectonic melange belt in the Altyn Tagh (Fig. 1(a)), and the lenses extend basically parallel to the regional foliations. The eclogites mostly occur in Jianggalesayi-Yushigou area of Qiemo County in the western part of the Altyn Tagh, and the age of peak metamorphisim of these eclogites was dated at 503±5.3 Ma[4—17]. The UHP metamorphosed granitoid gneisses studied in this paper occur in the Yinggelisayi area about 100 km east of Jianggesayi-Yushigou, and are the direct country rock of UHP magnesite-bearing garnet lherzolites. At the outcrops, the granitoid gneisses contain interbeds, bands or lenses of K-feldspar garnet clinopyroxenites and garnet lherzolites[1,2,4] (Fig. 1(b)). As shown by previous studies, the K-feldspar(-bearing) garnet clinopyroxenites chiefly consist of garnet, diopside, perthite, a small quantity of kyanite and retrograde hypersthene+plagioclase or amphibole+plagioclase, and exsolved rod-like clinopyroxene and rutile in coarse-grained garnets indicating the experience of ultra-high pressure metamorphism of the rocks[12]. All of these suggest that all the garnet-bearing metamorphic rocks underwent similar metamorphism. The geological characteristics demonstrate that various types of the UPHM rocks in Yinggelisayi area and the eclogites in the western Jianggesayi-Yushigou area constitute a high-pressure or ultra high-pressure belt in the south margin of the Altyn Tagh.

The granitic gneisses contain coarse-grained porph-

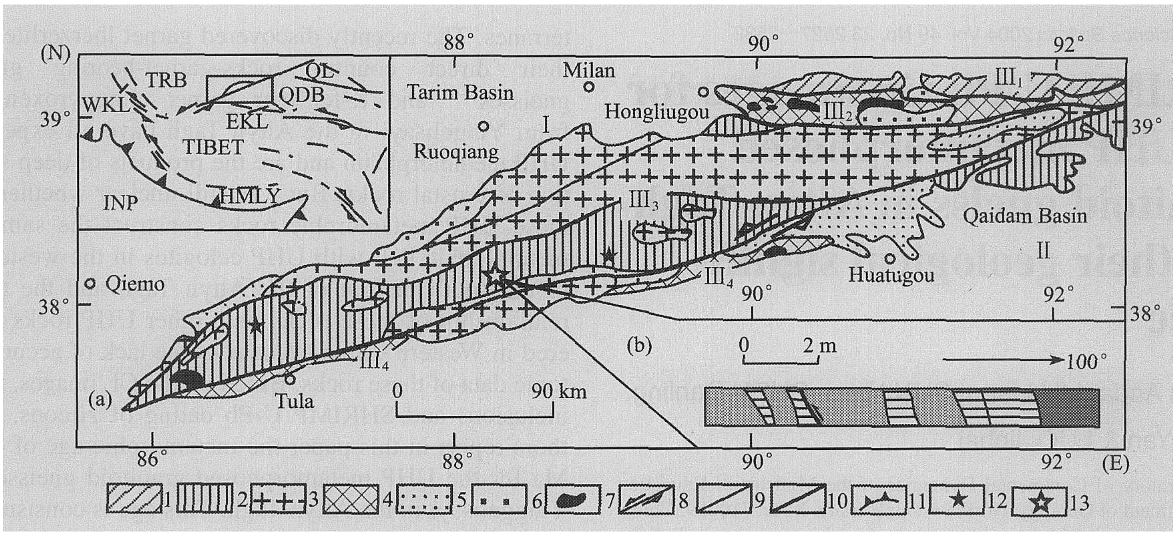

Fig. 1. Geological and structural map of the Altyn orogen (after Liu et al.[1]). 1, Archean; 2, Altyn Group; 3, Middle-Upper Proterozoic; 4, Paleozoic; 5, Mesozoic-Cenozoic; 6, granite; 7, ultra-basic rocks; 8, strike-slip fault; 9, fault; 10, boundary between tectonic units; 11, thrust fault; 12, location of eclogite; 13, location of gneissic K-feldspar(-bearing) garnet clinopyroxenite (Yinggelisayi). TRB, Tarim basin; QL, Qilian Mts.; QDB, Qadam Basin. Ⅰ, Tarim block; Ⅱ, Qadam block; Ⅲ, Altyn orogen; $Ⅲ_1$, North Altyn block; $Ⅲ_2$, Hongliugou-Lapeiquan ophiolitic mélange zone; $Ⅲ_3$, Milanhe-Jinyanshan block; $Ⅲ_4$, Apa-Mangya ophiolitic mélange zone.

yroblastic garnet (5%—20%), perthite (10%—15%), banded quartz (10%—20%) and minor titanite (±3%), amphibole (±3%), clinopyroxene (<3%), kyanite (<2%), biotite (±5%) and zoisite (<1%), as well as accessory zircon, rutile, apatite, ilmenite and allanite. The fine-grained quartz, albite, microcline, biotite and amphibole constitute the matrix of the rocks. The studies[4] have demonstrated that the rocks experienced a complex multiple metamorphic evolution. The peak-stage mineral assemblage consists of Grt+Per (before exsolution)+Ttn (before exsolution)+Ky+Zoi+Qz/Coe±Cpx and accessory rutile and apatite. Rod-like exsolved plagioclase+amphibole can be observed in coarse-grained titanite, and the reconstructed composition of Ttn_1 is of super-Si with Si values of 1.032—1.047 per formula unit, indicating the existence of 6-fold coordinated Si and of the $CaSi_2O_5$ component of 3.1%—4.6% in the precursor titanite. Based on the experimental petrology data and thermobarometry calculation, the metamorphic *P-T* condition is estimated to be 3.7—4.3 GPa and 1000℃. This *P-T* condition, together with high-Al and high-F titanite (Al_2O_3=10.58%—10.77%, F=3.21%—4.00%, X_{Al}=0.39—0.41 and X_F=0.39—0.48) included in the garnet, indicates that the garnet-bearing granitic gneisses had experienced the UHP metamorphism. The geochemical features show that the granitic gneisses have high SiO_2 content (>70%), Al_2O_3=12.58%—14.08%, relatively high K_2O content (>5%) and low Na_2O/K_2O ratio (0.4—0.6), and LREE-enriched patterns with $(La/Yb)_N$=4.3—9.1 and large negative Eu anomaly (δEu = 0.06—0.59). The protolith of the granitic gneiss is therefore probably derived from anatexis of rocks at middle or upper crustal level[4]1).

2 Sample analysis

Colorless and transparent zircons were separated from about 5 kg granitic gneiss sample for SHRIMP U-Pb dating analyses using batches, heavy liquid and electromagnetic methods as well as microscope, and pollution has been avoided during selection process. The zircon mount is made according to the method given by Song Biao et al.[18].

Zircon cathodoluminscence images were performed on electron microprobe analyzer at Institute of Mineral Resource, Chinese Academy of Geological Sciences, and Raman analyses for mineral inclusions in zircon were performed on Laser Raman Spectrophotometer at PetroChina Planning & Engineering Institute. Zircon SHRIMP U-Pb dating was performed with 20—30 μm diameter of spots on SHRIMP II at Open Laboratory on Isotope Geology, Ministry of Land and Resource of China, Beijing. The analysis theories, the analysis programs and parameters were given refs. [18—20]. The criterion zircon TEM (417 Ma) was used for correction of interelement fractionation and SL13 (age=572 Ma, U content = 238 μg/g) was used for calibration of U, Th and Pb contents of the samples. Data were managed with SQUID version 1.0 d program of American Doctor Ludwing and ISOPLT version 2.49 h program. Decay constants of ^{238}U and ^{235}U

1) Wang Yan, Geochemical feature and geological significance of HP-UHP metamorphic complex in western Altyn Tagh (submitted).

were IUGS(1997) recommended values: 1.55125×10^{10} a^{-1} and 9.84850×10^{10} a^{-1} respectively and $^{238}U/^{235}U$ ratio = 137.88. Common lead was corrected according to analysed values of ^{204}Pb and common Pb composition corresponding to 417 Ma under the Stacey-Kramers pattern. The ages commonly were $^{206}Pb/^{238}U$ age data, and the confidence level of weighted average value was 95%.

3 Morphology and internal texture of zircons

Zircons from the granitoid gneiss are generally colorless and transparent, rounded, short or long columnar with grain size from 50 to 200 μm in width (Fig. 2). The columnar grains make up many small crystal faces, showing the morphologic feature of the metamorphic zircons. CL investigation reveals the complex internal texture of the zircons, and obvious core-mantle-rim internal texture develops in most grains. The residual cores, with rounded, lough-like and irregular shapes, are light (Fig. 2, Nos. 5, 6) or light-dark interlayers, and oscillatory zone texture were observed in the cores of Nos. 7, 8 and 9 grains in Fig 2, implying the magmatic origin of the protolith of the UHP metamorphosed granitoid gneiss. The primary texture has been altered partially (No. 4 in Fig. 2) or completely (Nos. 2, 3 in Fig. 2) in some grains, indicating the modification of the magmatic zoning possibly by overprint of metamorphism. The dark metamorphic mantle zone growing around the magmatic core varies in width up to about 80 μm, and the light rim is very narrow (less than 20 μm in width). Based on the CL images, zircons from the UHP metamorphosed granitoid gneiss are zoned and mixture of magmatic core, metamorphic mantle and newly growing rim. The magmatic cores had been altered in different extent during ultrahigh-pressure metamorphism, which produced blurring effect on the oscillatory zone in most grains. The mantles represent the overgrowth during UHP metamorphism, and the intercalation of mantle into the core implies the participation of fluid during UHP metamorphism. The narrow light rim may represent the new growth zone during the retrograde metamorphism or late geological process.

4 Mineral inclusions in zircons

Laser-Raman spectrum analyses show that minerals included in zircons from the UHP metamorphosed granitoid gneiss are mainly clinopyroxene, rutile, apatite, quartz and feldspar. Pyroxene and rutile included only in the mantle, apatite and quartz in both the core and the mantle, feldspar is included only in the core. The Raman spectra of main minerals included in the mantle of zircons are shown in Fig. 3.

According to the literatures, jadeite generally shows the diagnostic peaks at 680—705, 525—528, 370—380 and 1040—1044 cm^{-1}[21], but sometimes, displays the characteristic peak at 660—667 cm^{-1} and has subordinate peaks at 390, 200 and 220cm^{-1} 1). Omphacite has main diagnostic peak at 670—690 cm^{-1}[21,22]1), and sometimes has subordinate peaks at 390 cm^{-1} 1). Diopside generally has characteristic peaks at 660—666, 380—390 and 315—330 cm^{-1} 1). As shown in Fig. 3(a) and 3(b), pyroxenes

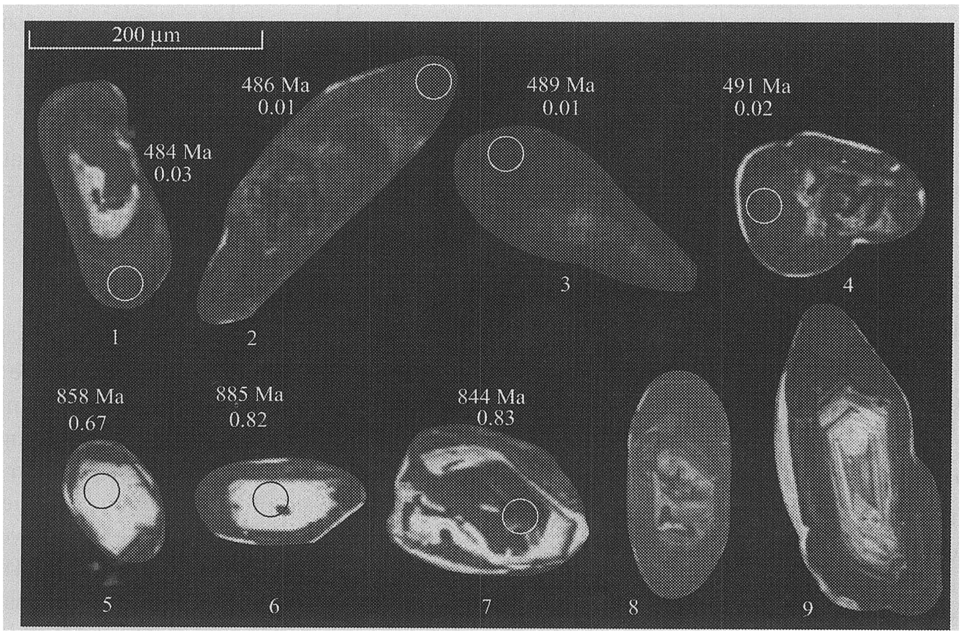

Fig. 2. CL images of typical zircons from granitoid gneiss. Circles are SHRIMP analysis spots, age and TH/U value of every analysis spot are denoted at upper location of every grains whose number is denoted at lower location.

1) Renishaw Raman Spectral Database, Inorganic Materials Volume, Gloucestershire: Renishaw plc.

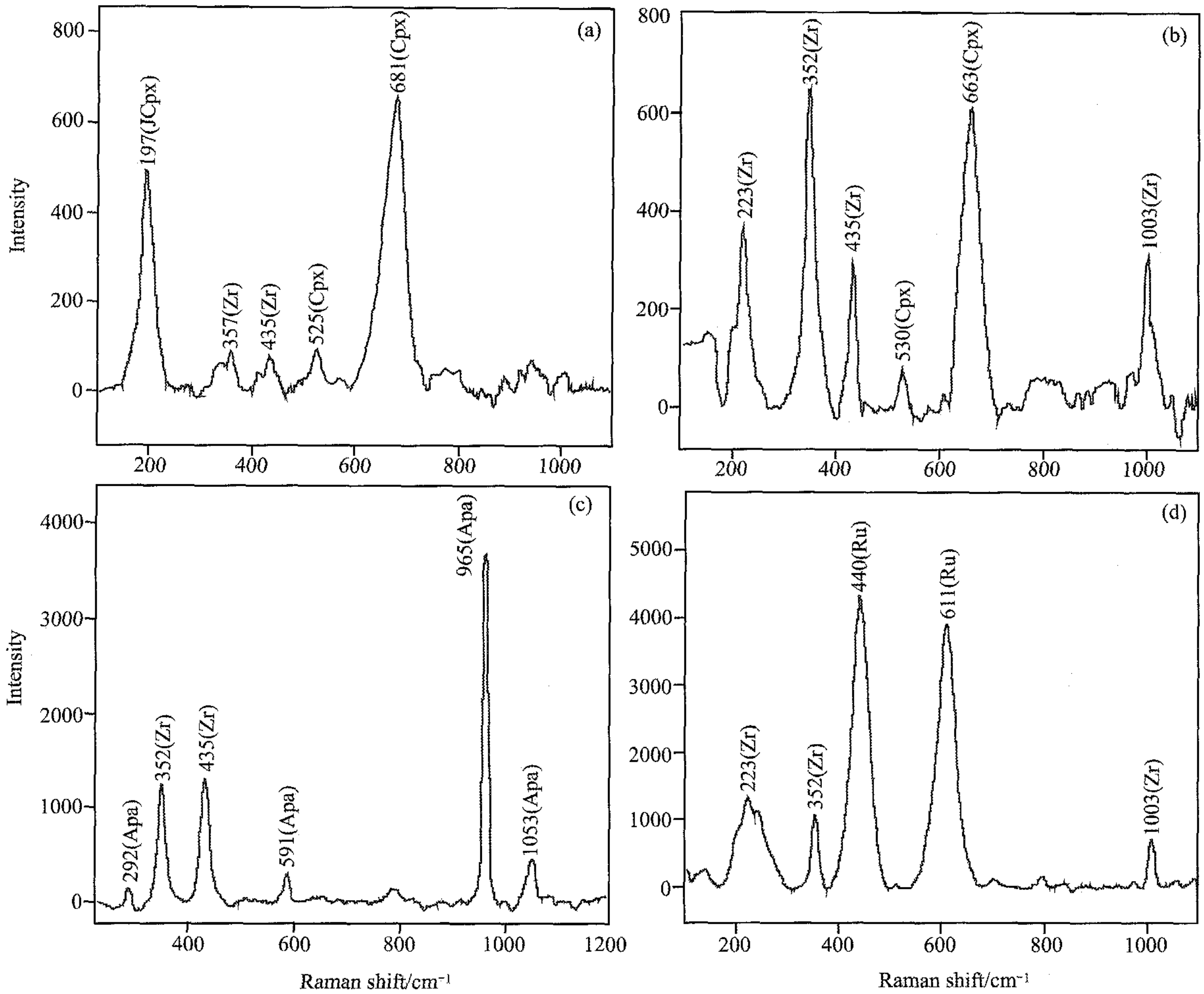

Fig. 3. The laser Raman spectra of main minerals included in the mantle of zircons.

included in zircons have the characteristic peaks at 681 or 663 cm^{-1} and relatively subordinate peaks at 525 or 530 cm^{-1}, especially the relatively subordinate peak at 197 cm^{-1} can be observed in Fig. 3(a). Based on these features, pyroxenes included in zircons should be jadeite rather than omphacite or diopside. Though both phlogopite and biotite have main peaks at 195—197 cm^{-1} and 665—685 cm^{-1} [1)], but phlogopite should also have subordinate peaks at 730—737 cm^{-1} and 772—777 cm^{-1} [1)], and biotite also has subordinate peaks at 545—576 cm^{-1}, 700—707 cm^{-1} and 739—751 cm^{-1} [1)]. Therefore, spectra in Fig. 3(a) and 3(b) are distinctively different from those of phlogopite and biotite.

Though coesite inclusion has not been observed in zircons at present, the research on UHP metamorphism[4] of the rock and the internal texture on CL images show that mineral inclutions of jadeite, rutile, quartz and apatite observed in mantle part of zircons are at least formed during HP metamorphism, whereas, quartz, apatite and feldspar in the cores may be the relict of magmatic mineral inclutions.

5 U-Pb zircon dating

SHRIMP U-Pb dating analyses from 21 spots of 21zircon grains are presented in Table 1 and Fig. 4. All data distribute along the concordant line and the adjacent areas below the line, and could be grouped into 5 clusters. The first cluster at the lowest position of the concordant line, composed of five mantle spots, yields ages from 484 to 491 Ma and a $^{206}Pb/^{238}U$ weighted average age of 487± 10 Ma (2σ), and the corresponding Th/U ratios of these spots are between 0.01 and 0.03, consistent with that of metamorphic zircons (<0.1[23]). Combining with the previous research about the rock[4], the CL investigations and mineral inclusions, the age of 487±10 Ma should repre-

1) See the footnote on page 2529.

sent the metamorphic age of the rock.

Another cluster at the upper position of the concordant line, composed of five residual core spots, yields $^{206}Pb/^{238}U$ ages varying in a large extent from 809±19 to 885±21 Ma due to the large scatteration of the analysis data. Though the possible alteration for some lower spots during metamorphism is not exclusive, the upper position of the spots, the existence of magmatic zoning and the Th/U ratios (between 0.42 and 0.83, belonging to magmatic zircons (>0.4))[24−28], indicate that the protolith age of the UHP metamorphosed granitoid gneisss should be between 809±19 and 885±21 Ma.

The other three clusters yield ages of 550—577, 612—645 and 711—738 Ma, and the age intervals between the five clusters are not larger than 100 Ma. Considering the complex of internal texture of zircons and the involvement of the spots in different zones, these ages may be a kind of mixture ages, and have no geological significance.

6 Discussion and conclusion

The metamorphic age of 487±10 Ma for the UHPM granitic gneisses which are direct country rocks of ultra-high garnet-bearing lherzolites at Yinggelisayi in the southern Altyn Tagh is firstly gained on the basis of the studies of the CL images, inclusion mineral assemblage and the high accuracy SHRIMP *in situ* U-Pb dating.

The whole-rock-garnet-omphacite Sm-Nd isochron age (500±10 Ma) and single zircon U-Pb age (503.9±5.3 Ma) of eclogites at the western Jianggesayi in Altyn (see Zhang Jianxin et al.)[14] were regarded as the peak meta-morphic age of high pressure rocks in this region.

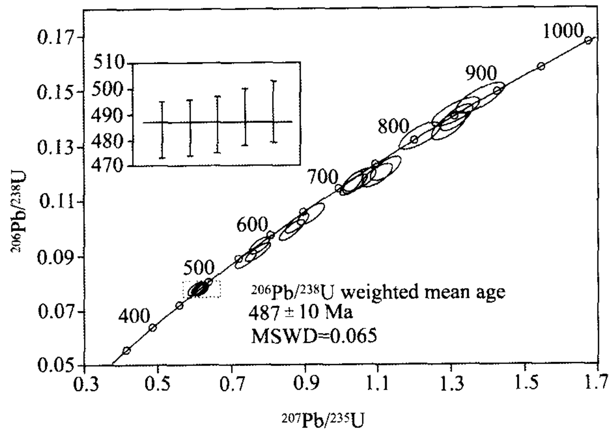

Fig. 4. SHRIMP U-Pb Concordia diagram for the zircon.

Recently the new ultra-high pressure metamorphism evidence was discovered in the eclogites at Jianggesayi area[3,29]. The determination of the metamorphic age (487±10 Ma) of UHPM rocks at Jianggesayi therefore indicates that both eclogites at the Jianggesayi area in western Altyn and garnet-bearing lherzolites and their direct country rock-granitic gneisses at Yinggelisayi area in eastern Altyn constitute a ultrahigh pressure belt in the south margin of the Altyn Tagh.

In addition, the magmatic crystallization age (varying from 809±19 to 885±21 Ma) of the protolith is also obtained in this study, which is generally consistent with the time of Neoproterozoic magmatic activity in the northern Yangtze plate[30,31]. However, much more studies to determine the genetic relationship between both magmatic activities are necessary. The geochemical features demonstrate that the protolith of the granitic gneiss proba-

Table 1 SHRIMP analysis data of zircons from Yinggelisayi granitic gneiss in Altyn Tagh[a)]

Spot	U/μg • g^{-1}	Th/μg • g^{-1}	Th/U	$^{206}Pb_c$ (%)	$^{206}Pb^*$/μg • g^{-1}	Isotopic ratios						Age/Ma	
						$^{207}Pb/^{206}Pb$	±%	$^{207}Pb/^{235}U$	±%	$^{206}Pb/^{238}U$	±%	$^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb$
1.1	1040	13	0.01	0.08	70.5	0.05680	1.0	0.617	2.6	0.0788	2.4	489±11	484±23
2.1	580	99	0.18	0.09	52.4	0.06308	1.1	0.915	2.7	0.1052	2.5	645±15	711±23
3.1	659	138	0.22	0.14	66.3	0.06483	1.1	1.046	2.7	0.1170	2.4	713±16	769±24
4.1	1134	200	0.18	0.10	114.0	0.06393	0.68	1.028	2.5	0.1166	2.4	711±16	739±14
5.1	899	21	0.02	0.01	60.4	0.05692	0.92	0.614	2.6	0.0782	2.4	485±11	488±20
6.1	1287	1035	0.83	0.05	155.0	0.06802	0.61	1.312	2.5	0.1399	2.4	844±19	869±13
7.1	1089	10	0.01	0.00	73.2	0.05644	0.84	0.609	2.6	0.0783	2.4	486±11	470±19
8.1	727	22	0.03	0.11	48.8	0.05725	1.0	0.616	2.6	0.0780	2.4	484±11	501±23
9.1	387	195	0.52	0.60	39.7	0.06410	2.1	1.048	3.2	0.1186	2.4	723±17	744±44
10.1	1238	150	0.13	0.10	99.7	0.05974	0.79	0.771	2.5	0.0936	2.4	577±13	594±17
11.1	1254	857	0.71	0.08	148.0	0.06855	0.59	1.295	2.5	0.1370	2.4	828±19	885±12
12.1	1083	831	0.79	0.15	83.1	0.06005	0.92	0.738	2.6	0.0891	2.4	550±13	605±20
13.1	277	220	0.82	0.28	35.1	0.06800	1.9	1.380	3.2	0.1472	2.6	885±21	868±40
14.1	218	88	0.42	0.37	25.1	0.06590	2.1	1.214	3.2	0.1337	2.5	809±19	802±43
15.1	1144	249	0.22	0.15	98.0	0.06284	1.0	0.863	2.7	0.0996	2.5	612±14	703±22
16.1	804	194	0.25	0.08	63.3	0.06099	1.1	0.770	2.7	0.0915	2.4	565±13	639±24
17.1	850	17	0.02	0.23	57.9	0.05570	1.9	0.607	3.2	0.0791	2.5	491±12	440±43
18.1	1387	1003	0.75	0.05	142.0	0.06676	0.58	1.097	2.5	0.1192	2.4	726±17	830±12
19.1	945	207	0.23	0.11	83.2	0.06231	0.86	0.879	2.6	0.1023	2.4	628±14	685±18
20.1	147	95	0.67	0.45	18.1	0.06690	2.3	1.314	3.4	0.1423	2.5	858±20	836±48
21.1	961	815	0.88	0.08	101.0	0.06663	0.99	1.118	2.6	0.1217	2.4	740±17	826±21

a) $^{206}Pb_c$ represents the common ^{206}Pb percentage in total ^{206}Pb, $^{206}Pb^*$ represents radiogenetic lead, and error is at 1σ level.

bly results from anatexis of middle or upper crustal rocks[4]1). This study therefore suggests that the ultrahigh pressure metamorphic rocks in the Altyn orogen are the products of deep-subduction of the continental crust in the early Palaeozoic era (about 500 Ma).

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1) See the footnote on page 2528.