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# $^{40}Ar/^{39}Ar$ age evidence for Altyn fault tectonic activities in western China

LIU Yongjiang[1], J. Genser[2], GE Xiaohong[1], F. Neubauer[2], G. Friedl[2], CHANG Lihua[1], REN Shoumai[3] & R. Handler[2]

1. College of Earth Sciences, Jilin University, Changchun 130061, China;
2. Institute of Geology and Paleontology, Salzburg University, Salzburg A-5020, Austrilia;
3. Statigraphic Research Center for Oil and Natural Gas, Ministry of Land and Resources, Beijing 100034, China

Correspondence should be addressed to Liu Yongjiang (e-mail: liuyj@email.jlu.edu.cn)

**Abstract** **Four $^{40}Ar/^{39}Ar$ age groups of mica, hornblende and K-feldspar were obtained from Proterozoic and early Paleozoic metamorphic rocks in the Aksay-Dangjin Pass area, western China. The samples away from the middle shear zone of the Altyn fault belt yield two plateau age groups in the range of 461—445.2 Ma and 414.9—342.8 Ma, respectively. They represent the tectono-thermal events that had been recorded in the rocks that were displaced by the Altyn strike-slip fault in late Ordovician-early Silurian and Devonian, respectively. These two age groups should be related to the closures of Northern and Southern Qilian Oceans. The deformed granitic gneiss from the northern belt gives a plateau age group of 178.4—137.5 Ma, which is interpreted as the active age of the Altyn fault in the middle-late Jurassic-early Cretaceous and should be related to the accretion of Lhasa block to the north. The sample from the middle shear zone of the Altyn fault belt yields two plateau ages of 36.4 and 26.3 Ma, respectively, suggesting the strike-slip movement with strong metamorphism at greenschist facies along the Altyn fault in the late Eocene. This event occurred in the most areas of the northern Tibet Plateau and should be in response in the north to the collision between Indian and Eurasian continents. The present study demonstrates that the Altyn fault is characterized by multiple pulse-style activities under the tectonic setting of convergence between the Indian and Eurasian continents.**

**Keywords: Altyn fault, $^{40}Ar/^{39}Ar$ age, tectono-thermal event, western China**

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As the northern boundary of the Tibetan Plateau the Altyn fault is a huge NEE strike-slip fault belt in the inner Asian continent. Its formation and evolution are closely related to the uplift of the whole plateau and the mass escape to the east. In recent years the Altyn fault has become a hot point of geological study in the Tibetan Plateau. The formation age of the Altyn fault was argued for a long time. Some researchers emphasized that the Altyn fault had commenced since early Paleozoic[1,2], some reported that the strike-slip activity began in Hercynian[3], Indosinian[4] and Jurassic[5], and others argued that the Altyn fault is a huge strike-slip fault formed in Cenozoic[6,7]. The present study attempts to set up a geochronological constraint on the Altyn fault evolution by the $^{40}Ar/^{39}Ar$ dating on samples from deformed rocks in the Aksay-Dangjin Pass area within the Altyn fault belt.

## 1 General geology

The research area is located in Xiaoebotu, Aksay and Dangjin Pass region, in which the Proterozoic, Ordovician and Silurian metamorphic rocks outcrop (Fig. 1). The Proterozoic Dakendaban Group is distributed widely in the Xiaoebotu-Aksay-Dangjin Pass area and consists of biotite plagioclase gneiss, dolomite marble, quartz schist, granitic gneiss, mica schist and amphibolite with the intrusions of pegmatitic and quartz veins. The lower Ordovician Wuligou Group consists of metamorphic intermediate-mafic volcanic, carbonitic and clastic rocks and mainly outcrop in the east and west of the research area. The lower Silurian Baluogenguole Group (originally Balonggonggaer System) in the south of the research area is composed of volcanic and clastic rocks.

The Altyn fault belt can be divided into three sub-belts along the profile of Aksay-Dangjin Pass according to the differences of metamorphism and deformation, which are from north to south: northern belt, middle shear zone and southern belt (Fig. 2). The northern belt is mainly composed of Proterozoic sequence of Dakendaban Group with the amphibolite facies metamorphism and weak overprinting of late greenschist facies metamorphism and deformation. The early deformation fabrics are mostly kept in the rocks. The southern belt consists of lower Silurian without or with very weak metamorphism, in which there are some middle-high grade metamorphic rocks of Proterozoic in the local area. The middle shear zone is located between southern and northern belts and composed mainly of lower Silurian sequences that suffered from the strong metamorphism of greenschist facies. The zone occurs as a dark green belt on the ground surface.

## 2 $^{40}Ar/^{39}Ar$ dating

All the dated samples are from the Xiaoebotu and Aksay-Dangjin Pass profile (Figs. 1 and 2). The lithology and petrology of the dated samples are listed in Table 1. The petrological features show that the samples from the middle shear zone (QA54) suffered from strong deformation and chloritizition. The samples away from the middle shear zone were weakly deformed and chloritizited. The preparation and analyses of all samples were finished in the Isotopic Dating Laboratory-ARGONAUT with a laser fusion $^{40}Ar/^{39}Ar$ dating system in the Institute of Geology and Paleontology, Salzburg University, Austrilia. The dated pure minerals were firstly separated from samples based on their grain sizes, then washed several times and

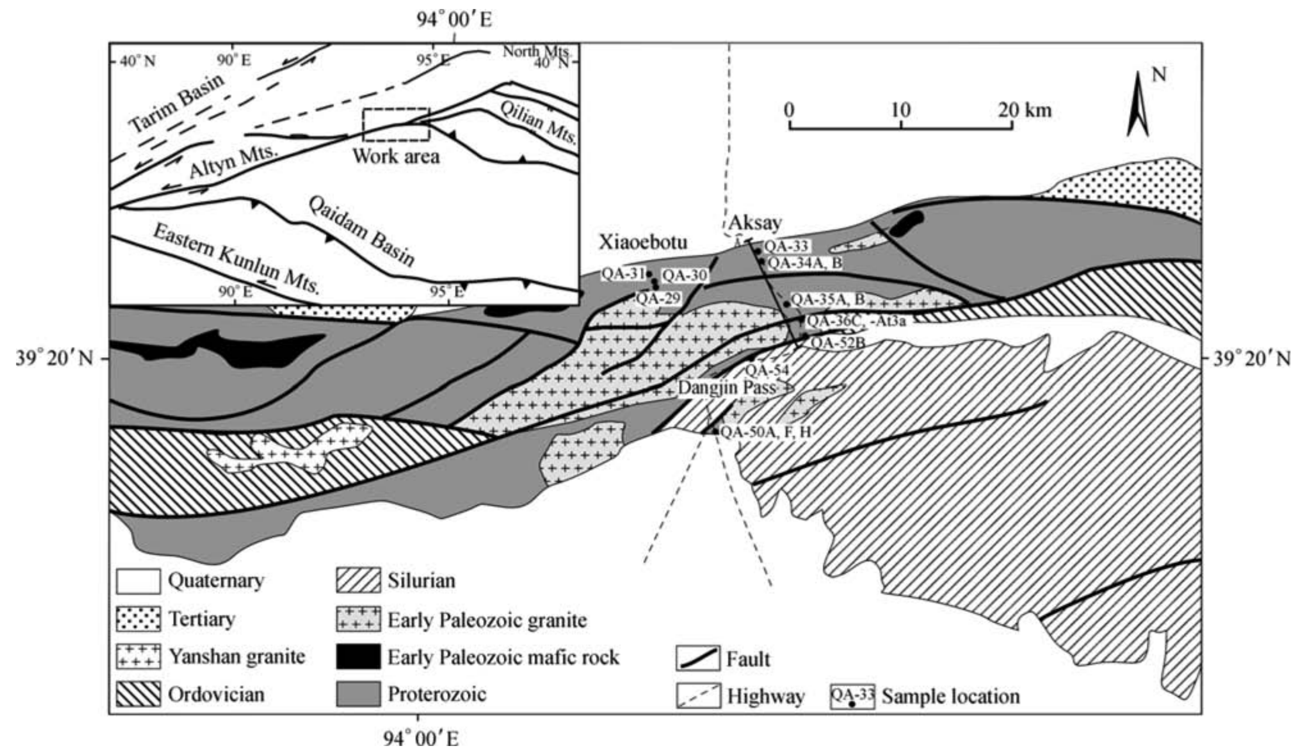


Fig. 1. Sketched geological map with sample locations.

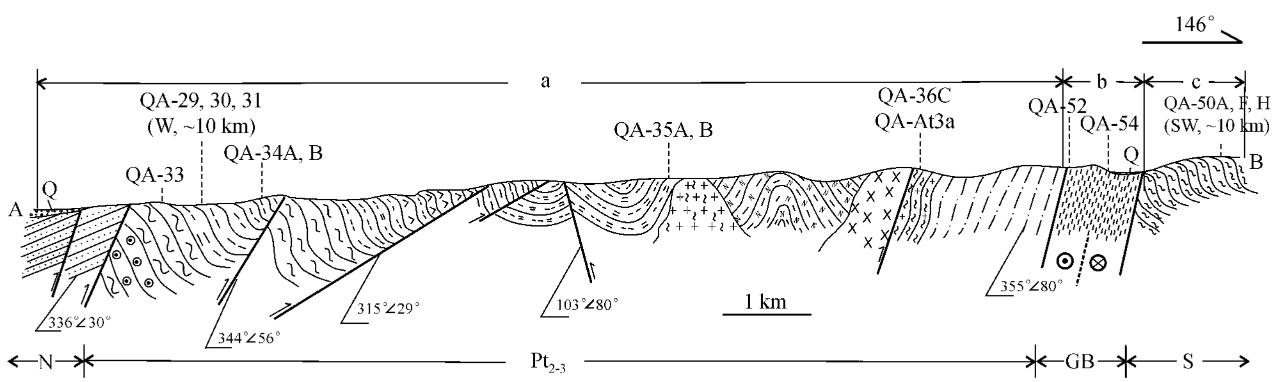


Fig. 2. Sketched tectonic profile (see Fig. 1 for the location). a, Northern belt; b, middle shear zone; c, southern belt GB, greenschist belt (Silurian); $Pt_{2\text{-}3}$, meso-neoproterozoic; S, Silurian; N, Neogene; Q, Quaternary; QA-54, sample location.

dried, finally irradiated. All the dated minerals are multiple grains (25—30) except for QA-35B that is a single muscovite grain. The sample fusion process was done by a laser system.

The samples from the northern belt yield two plateau age groups. One ranges from 461 to 445.2 Ma (Fig. 3), in which muscovite ages are in the range of 445.2—454.3 Ma, biotite ages 447.8—461 Ma. The spectra of samples QA-29, 30, 31, 33 show some lower temperature age steps (Fig. 3(a), (b), (c) and (d)) that could probably represent the late weak thermal disturbance. The other range from 178.4 to 137.5 Ma (Fig. 4), in which muscovite and biotite yield plateau ages of 178.4—164.3 Ma, and K-feldspar (QA-36C) yields a 137.5 Ma plateau age with obviously lower temperature stair-style spectrum that ranges in age from 30.1 to 119.8 Ma (Fig. 4(d)). This age group is obtained from the samples of mylonitized granitic gneiss (QA-At3a) and augen granitic gneiss (QA-36C) close to the middle shear zone in the northern belt (Fig. 2). The samples suffered from ductile deformation (Table 1) and this suggests that the ductile shear zone were developed in the sample location in the middle-late Jurassic-early Cretaceous. The present brittle fault structure in the location (Fig. 2) is developed on the basis of the reactivity of previous ductile shear zone.

The samples from the southern belt yield the plateau

Table 1 Petrology of the dated samples

| Sample | Lithology | Petrology |
|---|---|---|
| | | Northern belt |
| QA-At3a | mylonitized granitic gneiss | Mu + Pl + Q ± Chl. Quartz grains have undulatory extinction. Quartz and feldspar assemblages occur as lenses surrounded by muscovites and chlorites. In strong deformed zone quartz has ribbon fabric and is parallel to each other. |
| QA-29 | muscovite schist | Mu + Pl + Q ± Chl. Quartz and feldspar assemblages occur as lenses and bands without elongation of quartz grains. Muscovites are parallel to the foliations. |
| QA-30 | calcic biotite schist | Bt + Pl + Q. Biotites were weakly/not deformed with chloritizition and no orientation. The sample contains a lot of calcites. |
| QA-31 | mica schist | Bt + Mu + Pl + Q. Biotites are early generation with some alteration and no orientation. Muscovites are late generation and fine grained with good orientation. |
| QA-33 | garnet mica schist | Gt + Mu + Bt + Pl + Q. The sample was foliated as a whole. Garnet and muscovite are distributed parallel to the foliations. Biotite orientation has a small angle to the foliations; it may represent a secondary foliation. |
| QA-34A | biotite granite | Bt + Pl + Q. Deformation is very weak. |
| QA-34B | mica chlorite quartzite | Bt + Mu + Q + Chl ± Pl. Sample has well developed foliation. Micas are parallel to the foliation with chloritizition. Quartz grains show weak deformation. |
| QA-35A | garnet mica schist | Bt + Mu + Pl + Q + Gt. Micas are parallel to the foliations with deformation fabrics of some grains. Feldspar and quartz show weak orientation. Garnets occur as small grains. |
| QA-35B | granitic pegmatite | Mu + Pl + Q. The sample shows no deformation. |
| QA-36C | augen granitic gneiss | Mu + Bt + Kf + Pl + Q. The sample was deformed. The feldspar porphyroblasts were elongated, surrounded by micas and parallel to the foliations. Quartz grains were strongly elongated with orientation and subgrain nucleation. |
| | | Middle shear zone |
| QA-54 | greenschist | Chl + Pl + Q + Cc + Mu. The sample was strongly deformed. Most mica was chloritized with strain twin and mica-fish fabrics. Calcite grains were elongated. |
| | | Southern belt |
| QA-50A | biotite hornblende plagioclase gneiss | Bt + Hb + Pl + Q. The assemblages of hornblende and biotite are oriented and parallel to the foliation. Feldspars and quartz show no deformation. Calcite grains are distributed as bands. |
| QA-50F | garnet staurolite mica schist | Gt + St + Bt + Mu + Q + Pl ± Chl. The distribution of inclusions in garnet and staurolite is consistent with the foliation outside grains. Micas are parallel to the foliations, and some grains show kink fabrics. |
| QA-50H | garnet hornblende gneiss | Gt + Hb + Pl + Q ± Chl. Hornblende grains are oriented. Quartz and feldspar are very fine grained with no deformation. |

Gt, Garnet; St, staurolite; Bt, botite; Q, quartz; Pl, plagioclase; Chl, chlorite; Cc, calcite; Kf, K-feldspar; Hb, hornblende.

ages in the range of 414.9—342.8 Ma (Fig. 5), in which the muscovite plateau age (352.1 Ma) is consistent with the biotite ages (342.8—370.2 Ma). Sample QA-50A yields 414.9 and 396.7 Ma, two hornblende plateau ages (Fig. 5(a) and (b)) with out nice spectra.

The muscovite spectrum of sample QA-54 from the middle shear zone shows two obvious age plateaus with the ages of 26.3 Ma (48.3% release of $^{39}Ar$) in the lower temperature steps and 36.4 Ma (43.6% release of $^{39}Ar$) in the high temperature steps (Fig. 6). The high temperature plateau age (36.4 Ma) is close to the total fusion age (32.4 Ma). The sample was collected in the middle shear zone and suffered from strongly ductile deformation and metamorphism of greenschist facies (Table 1). This suggests that a ductile shearing happened with lower grade metamorphism in Oligocene along the middle shear zone in the Altyn fault belt. The younger age should represent a thermal overprinting event in 26.3 Ma, but the disturbance did not totally reset the argon isotopic system of 36.4 Ma.

## 3 Discussion of geological implication

The similar ages as the older group ages (461—445.2 Ma) obtained in the northern belt have been reported in the east of research area in the Qilian orogenic belt[8—10]. The same ages are also reported in other parts of the Altyn fault belt. Zhang et al. (1999)[11] reported 447—462 Ma U-Pb and Pb-Pb ages of zircons from aluminum-rich metamorphic rock samples in Tula in the western part of the Altyn fault belt and interpreted the age as a metamorphic age. Jolivet et al. (1999)[12] reported a 441 Ma U-Pb age of zircon and a 383 Ma $^{40}Ar/^{39}Ar$ age of muscovite from granite samples in the south of Milan in Xinjiang.

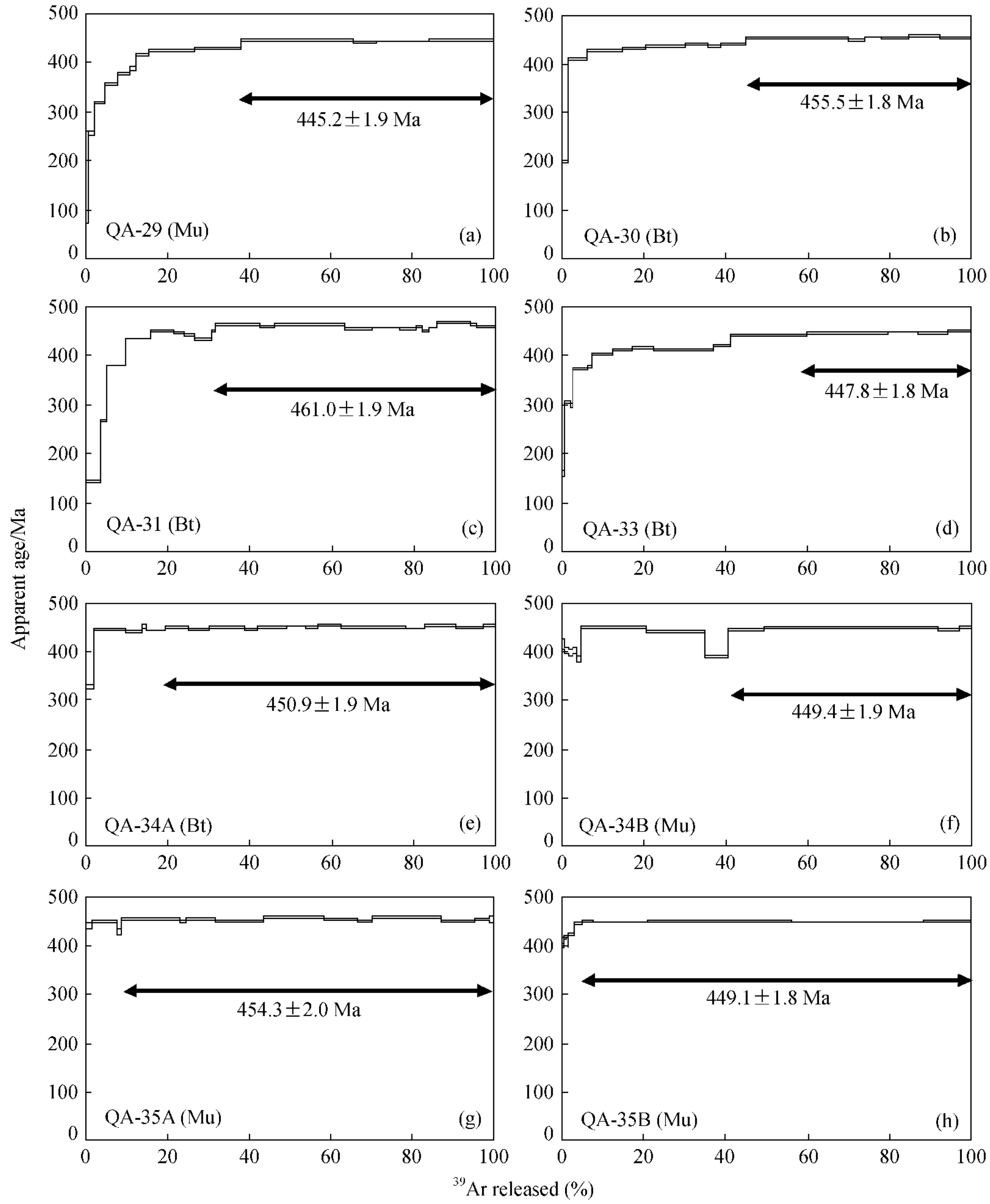


Fig. 3. $^{40}Ar/^{39}Ar$ dating spectra of samples from the north part in the northern belt (see Table 1 for mineral abbreviation).

Sobel et al. (2001)[13] obtained 453.4—382.5 Ma $^{40}Ar/^{39}Ar$ ages of micas from the samples of granite, granodiorite and granitic gneiss along the Mangnai-Ruoqiang profile. All the reported ages within the Altyn fault belt are consistent with the closure age of the Northern Qilian Ocean in middle-late Ordovician-early Silurian, and the tectonothermal events represented by the ages are probably related to the closure of the Northern Qilian Ocean[8—10].

The ages of 414.9—342.8 Ma from the southern belt are younger than the closure age of Northern Qilian Ocean. The southern belt should be structurally influenced by the Southern Qilian belt or the northern margin belt of Qaidam because of their location relationships. Recent researches support that the collision between Qaidam and Southern Qilian blocks occurred in early Paleozoic[14], therefore, the ages probably represent the tectonothermal events that happened during the continent-continent convergent process after the collision between Qaidam and Southern Qilian blocks.

The younger group ages (178.4—137.5 Ma), ob-

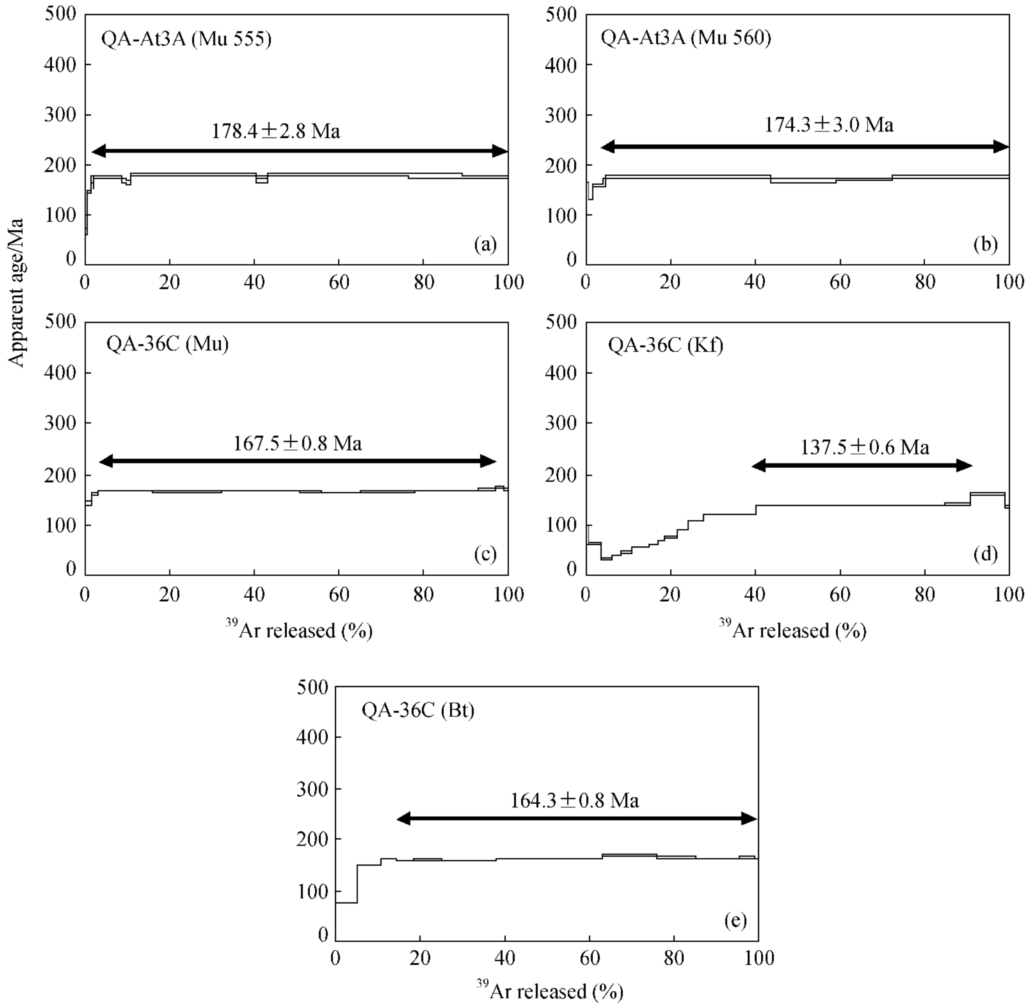


Fig. 4. $^{40}Ar/^{39}Ar$ dating spectra of samples from the south part in the northern belt (see Table 1 for mineral abbreviation).

tained in the northern belt, represent the tectonothermal event that happened in the middle Jurassic-early Cretaceous within the Altyn fault belt. Arnaud et al. (1999)[5] obtained 162.9—140 Ma ages by Rb/Sr and biotite $^{40}Ar/^{39}Ar$ methods from the samples of mylonitized granite and schist in the Altyn fault belt. Jolivet et al. (2001)[15] reported a number of zircon and apatite FT ages in Qilian, northern margin of Qaidam and Altyn fault belts, which are in the range of 135—172 Ma and represent a successive cooling process. Sobel et al. (2001)[13] reported a rapid cooling event in early Jurassic on the basis of K-feldspar $^{40}Ar/^{39}Ar$ dating data in the Mangnai-Ruoqiang profile. Mock et al. (1999)[16] dated the granite samples collected from Nacitai-Kunlun Pass in the Eastern Kunlun, and obtained the mica and K-feldspar $^{40}Ar/^{39}Ar$ ages that are mainly ranged from 120 to 146 Ma. He interpreted the ages to represent the ductile deformation in late Jurassic-early Cretaceous along the Xidatan strike-slip fault, which should be related to the accretion of Lhasa block to the north. Therefore, the tectonic event represented by the ages of 178.4—137.5 Ma happened not only in the Altyn fault belt, but also in the surround areas of the Qaidam Basin. This suggests that a regional tectonic event happened in late Jurassic-early Cretaceous in the large area of the northern Tibetan Plateau, which was controlled by the regional tectonic setting of the accretion of Lhasa block to the north along the Bangong-Nujiang suture.

The muscovite $^{40}Ar/^{39}Ar$ age of 36.4—26.3 Ma, obtained from sample QA-54 in the middle shear zone, suggests a re-active event of the Altyn fault belt in Oligocene. The cooling events of the similar ages have been reported in the northern area of Tibetan Plateau (40 Ma)[15], Eastern Kunlun (30 Ma)[16], Tianshan and Western Kunlun (20—25 Ma)[17]. Now most of researchers accept that the collision between Indian and Eurasian continents and the initiation of the Tibetan Plateau uplift happened in 40—50

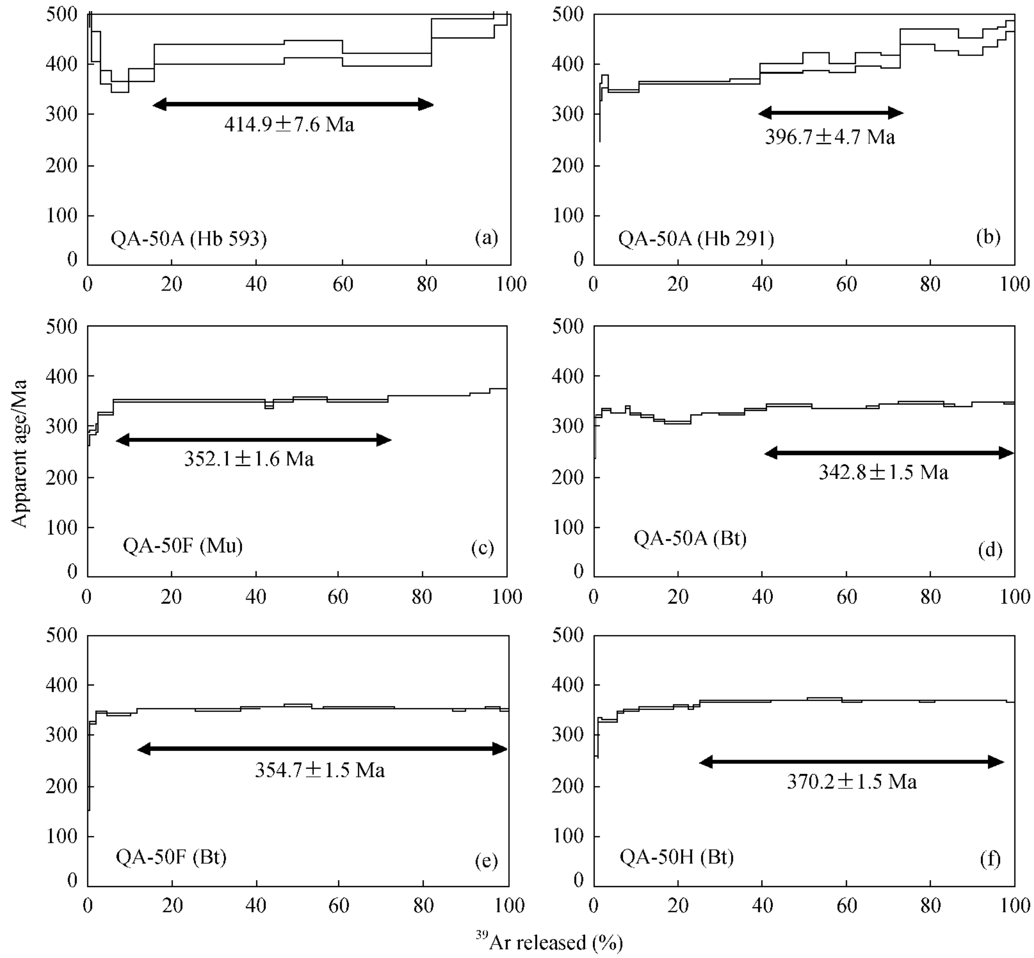


Fig. 5. $^{40}Ar/^{39}Ar$ dating spectra of samples from the southern belt (see Table 1 for mineral abbreviation).

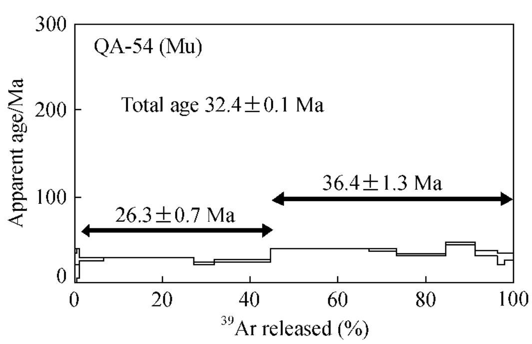


Fig. 6. $^{40}Ar/^{39}Ar$ dating spectra of the sample from the middle shear zone (see Table 1 for mineral abbreviation).

Ma[18—21]. We could deduce that the age of 36.4—26.3 Ma probably represents the tectonic response in the northern area of Tibetan Plateau to the collision between Indian and Eurasian continents.

## 4 Conclusions

The age groups of 461—445.2 Ma (northern belt) and 414.9—342.8 Ma (southern belt) should represent the tectonothermal events recorded in the rocks that were displaced by Altyn strike-slip fault in late Ordovician-early Silurian and Devonian, respectively. The former should be related to the closure of Northern Qilian Ocean, the latter to the continent-continent collision after the final closure of the ocean between Southern Qilian and the northern margin of Qaidam[22]. During the processes of the accretion of Lhasa block to the north along the Bangong-Nujiang suture and the convergence of Indian-Eurasian continents along the Yaluzangbu suture, the Altyn fault belt were active in the middle Jurassic-early Cretaceous (178.4—137.5 Ma) and Oligocene (36.4—26.3 Ma), respectively. The most likely active style was strike-slip movement with the lower grade metamorphism and the mountain uplift. These, together with the reports of the strike-slip activities in 89—92 Ma[23] and 223—226 Ma[4], suggest that the Altyn strike-slip fault belt is characterized by the multiple pulse-style activities under the tectonic setting of convergence between Indian and Eurasian continents.

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