Studies on $^{40}Ar/^{39}Ar$ thermochronology of strike-slip time of the Tan-Lu fault zone and their tectonic implications

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Received October 11, 2000

Abstract Samples of mylonite, ultramylonite and phyllonite were collected from 5 localities in the Anhui part of the Tan-Lu fault zone for $^{40}Ar/^{39}Ar$ chronological studies. Among them 4 samples from 3 localities on the eastern margin of the Dabie orogenic belt yielded $^{40}Ar/^{39}Ar$ plateau ages of 128—132 Ma; and 2 samples from the western margin of the Zhangbalin uplift and eastern margin of the Bengbu uplift gave the same $^{40}Ar/^{39}Ar$ plateau ages of 120 Ma. Isochron analyses and other lines of evidence suggest that the data are reliable. The data are interpreted as cooling ages of sinistral strike-slip deformation of the Tan-Lu fault zone. The younger ages from the north might be related to slower strike-slip rising. These results indicate that the large-scale left-lateral displacement in the Tan-Lu fault zone took place in the Early Cretaceous, rather than in Late Triassic (Indosinian) as proposed by some geologists. Therefore, this fault zone is an intracontinental wrench fault rather than a transform fault or suture line developed during formation of the Dabie orogenic belt.

Keywords: Tan-Lu fault zone, mylonite, $^{40}Ar/^{39}Ar$ age, Early Cretaceous, the Dabie-Jiaonan orogenic belt.

Sinistral displacement timing and tectonic models of the Tan-Lu fault zone, the largest fault in eastern China, are still controversial. There are two representative points about the displacement timing. One proposes the displacement from the Late Jurassic to the Early Cretaceous[1—4] while another insists on the strike-slip movement of the Late Triassic Indosinian[5—7]. Three main points have been suggested about the tectonic models. One considers the fault zone as an intracontinental wrench fault developed during oblique subduction of the Izinagi Plate and belonging to circum-Pacific tectonics[8,9]. Another proposes a transform model related to continent-continent collision of the North China and Yangtze plates[10—12].The third suggests that the fault zone represents NNE-trending plate boundary of the Yangtze Plate[5], i.e., oblique suture line between the North China and Yangtze plates. The main reason leading to the debates is lack of direct evidence for displacement time of the Tan-Lu fault zone. Inference about the displacement time by different researchers are debatable. To solve the key problem, we sampled mylonite, ultramylonite and phyllonite from the Anhui part of the fault zone for $^{40}Ar/^{39}Ar$ thermochronological analyses. It is the first time to obtain $^{40}Ar/^{39}Ar$ ages from the strike-slip mylonite series in the Tan-Lu fault zone, which is very important to understand its horizontal displacement time as well as tectonic model.

1 Geological setting and sample

The Tan-Lu fault zone in Anhui strikes in NE on the eastern margin of the Dabie orogenic belt and extends from Susong, Taihu, Qianshan, Tongchen to Lujiang. After passing Chaohu Lake, it occurs on the western boundary of the Zhangbalin uplift in NNE strike. To the north of Jiashan, the fault zone goes along the eastern margin of the Bengbu uplift and then extends into Jiangsu Province (fig. 1). The fault zone sinistrally offsets the Dabie orogenic belt to the Jiaonan orogenic belt with a displacement of 550 km. The NNE-striking Zhangbalin uplift belt between the two orogenic belts is curved remnant of the original orogenic belt which preserves high-pressure metamorphic products such as blueschist and white schist.

The Anhui part has the best exposures of mylonite series in the whole Tan-Lu fault zone. Protomylonite, mylonite, ultramylonite and phyllonite extensively occur in this part of the fault zone. Steep NE-NNE striking mylonitic foliations and horizontal elongation lineation are well developed in the mylonite series. Sinistral moving in the mylonite series can be easily determined by means of shear sense indicators in the field. In microscopic aspects, the mylonite series contain a great amount of very fine quartz grains produced by dynamic recrystallization, oriented and elongated quartz porphyritic crystals, oriented minerals such as hornblende and mica as well as extensive undulatory extinction and local core-mantle structures of quartz grains. The mylonite series occur in pre-existing high amphibolite facies metamorphic rocks. Low greenschist facies retrograde metamorphism was associated with development of the mylonite series, leading to extensive replacement of chlorite to previous hornblende and biotite. According to observation in the field and under microscope, the fault zone only has one phase of NE-NNE strike-slip ductile shear belts. Although the Tan-Lu shear zone is a composite

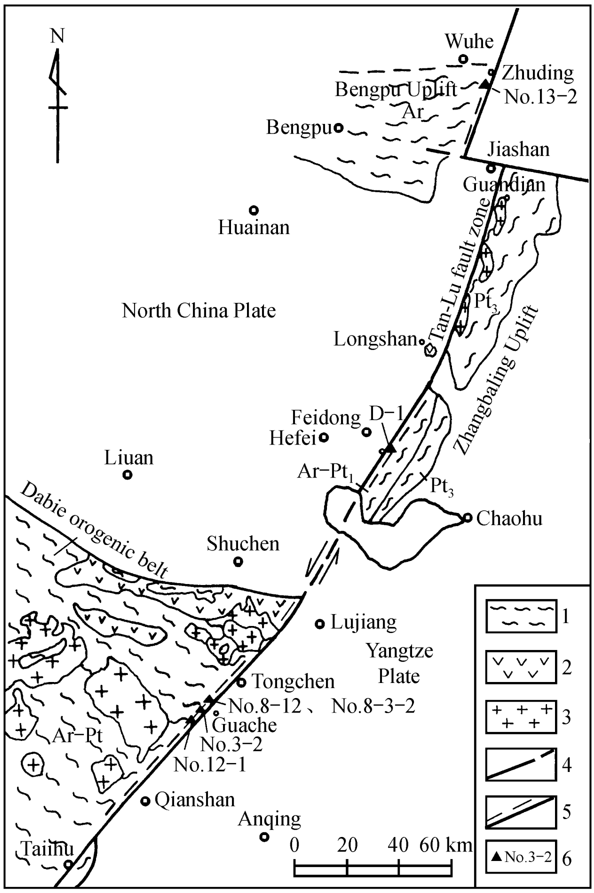

Fig. 1. Sampling location map in the Anhui part of the Tan-Lu fault zone. 1, Metamorphic basement rocks; 2, Mesozoic volcanic rocks; 3, Yanshanian intrusion; 4, fault; 5, mylonite belt; 6, sampling localities and number.

zone consisting of several small mylonite belts with the same extension and structural nature, their structural relationship shows synchronous development. After the ductile shear belts rose to the surface or near the surface during or after formation, later structures only show local brittle fault overprinting. Therefore, if mylonite samples are collected away from the later faults, their isotopic ages can give the earliest strike-slip time of the Tan-Lu fault zone.

Mylonite series in a ductile shear zone is usually formed at depths of more than 15 km. Even not considering shear heating effect, normal geothermal gradient (30℃/km) can cause a temperature higher than 450℃ at this level. The temperature scope can not only cause low greenschist facies metamorphism, but also exceed closure temperatures of Ar isotope system in K-bearing minerals[13], therefore resulting in total reset of the Ar system. It is concluded accordingly that formation time of mylonites can be determined by means of $^{40}Ar/^{39}Ar$ dating. The best method of $^{40}Ar/^{39}Ar$ dating of mylonites is using single K-bearing minerals such as hornblende, biotite and muscovite, which has been proved by many examples from China and abroad[14—16]. Due to intense shear deformation, the mylonites in the Anhui part show very strong mylonitization and grain-size reduction. The syn-deformational low greenschist facies metamorphism produced extensive chloritization on ideal dating minerals such as hornblende and biotite. Syn-deformational muscovite grains are very fine. Therefore, it is difficult to separate single minerals from the mylonites for $^{40}Ar/^{39}Ar$ dating. Whole-rock samples of the mylonite, ultramylonite and phyllonite are therefore used in this $^{40}Ar/^{39}Ar$ dating. Main disadvantage using a mylonite whole-rock sample for isotopic dating is that the dating result is supposed to be a mixed cooling age if the whole-rock contains different K-bearing minerals with different closure temperatures and experienced slow rising after its formation. However, if the whole-rock mainly consists of one type of K-bearing mineral and suffered rapid uplifting after formation, the effect mentioned above is minute. Some successful $^{40}Ar/^{39}Ar$ dating using mylonite whole-rock samples has been reported[17—23]. It has been published many times that deformation times were obtained from Rb-Sr whole-rock isochron ages of mylonites[17—19]. Whole-rock $^{40}Ar/^{39}Ar$ dating of deformed rocks such as slate, phyllite, schist and gneiss in ductile shear zones can often yield reliable deformation ages[20—22]. Dallmeyer et al.[23] selected whole-rock samples of phyllonite, ultramylonite and mylonitic rocks from the ductile shear zones in the Apuseni Mountains, Romania for $^{40}Ar/^{39}Ar$ dating and the obtained whole-rock ages are in agreement with $^{40}Ar/^{39}Ar$ mineral ages which all indicate the deformation time. Therefore, it has been proved in theory and practice that $^{40}Ar/^{39}Ar$ dating of mylonite whole-rock samples carefully selected from a ductile shear zone can give a reliable deformation age.

Samples No.8-12(ultramylonite), No.8-3-2(mylonite), No.3-2(ultramylonite) and No.12-1 (mylonite) are respectively from the Guache area, Tongchen County in an NE-striking Tan-Lu ductile shear zone on the eastern margin of the Dabie orogenic belt (fig.1). The three sampling localities are 3 km apart from each other along the strike. Attitudes of mylonite foliations for the three localities are 135° ∠75°, 140° ∠70° and 140° ∠60° respectively, and mylonites all have nearly horizontal elongation lineation. The ductile shear zone is as wide as 2.5 km. It overlies on the Dabie Group of the Dabie orogenic belt. The Qianshan Basin of the Late Cretaceous to Eogene appeared to the east of the shear zone. Original NWW-striking gneissosity of the Dabie Group is curved to NEE-NE near the shear zone. Sample D-1(mylonite) is from the north bank of Shibagoung dame in Shanwangji, Feidong County on the western side of the Zhangbalin uplift belt. Its protolith is metamorphosed Donggang granite. Mylonite foliation at the sampling localities is 295° ∠75° and elongation lineation is horizontal. Sample No.13-2 (phyllinote) was collected from an NNE strike-slip ductile shear zone in the Dagongshan gold deposit on the eastern margin of the Bengbu uplift belt. The sample has mylonite foliation of 95° ∠70° and horizontal elongation lineation. Details of the samples are shown in table 1. To avoid effect of calcite on the dating, calcite-bearing samples No.8-12 and No.13-2 were soaked in hydrochloric acid for several days.

Table 1 Description of mylonite samples from the Anhui part of the Tan-Lu fault zone[a)]

Sample No.	Sampling location	Rock type	Mineral assemblage	Protolith
8-12	Hulaowu, northern Tongpu, Tongchen	ultramylonite	Qz(85%)+Chl(12%)+Cal(3%)	biotite schist
8-3-2		mylonite	Qz(75%)+Pl(15%)+Ms(5%) +Chl(5%)	granitic gneiss
3-2	western Tongpu, Tongchen	ultramylonite	Qz(85%)+Chl(10%)+	biotite schist
12-1	western Niunan, Tongchen	mylonite	Qz(75%)+Pl(10%)+Chl(10%) +Bi(3%)+Epi(2%)	plagioclase amphibolite
D-1	northern bank of Shibagong dame in Shanwangji,Feidong	mylonite	Qz(65%)+Pl(30%)+Ms(5%)	granite
13-2	Xingzhuang, southern Zhudian, Wuhe	phyllonite	Qz(70%)+Ta(15%)+Chl(10%) +Cal(5%)	plagioclase amphibolite

a) Qz, quartz; Chl, chlorite; Pl, plagioclase; Cal, calcite; Ms, muscovite; Bi, biotite; Epi, epidote; Ta, talc.

2 Results and geological interpretation

This $^{40}Ar/^{39}Ar$ analysis was carried out in Institute of Geology and Geophysics, Chinese Academy of Sciences. The used test approaches and relative date are similar to whose described by Hu et al.[24]. 4 whole-rock samples from the western margin of the Dabie orogenic belt yielded $^{40}Ar/^{39}Ar$ plateau ages (fig. 2) of 128.35±0.64 Ma(No.8-12),130.61±0.88 Ma(No.8-3-2),124.67 ±0.73 Ma(No.3-2) and 132.1±0.53 Ma(No.12-1) respectively, which all belong to the Early Cretaceous. It is worth to point out that samples No.8-12 and No.8-3-2 from the same quarry gave ages (128.35±0.64 Ma, 130.61±0.88 Ma) consistent in errors, showing reliable results. The younger age (124.67±0.73 Ma) of sample No.3-2 might be due to clear weathering on the sample. A $^{40}Ar/^{39}Ar$ plateau age of mylonite whole-rock (D-1) from the Tan-Lu fault zone on the eastern side of the Zhangbalin is 120.48±0.75 Ma (fig. 2). Phyllonite whole-rock sample (No.13-2) from the fault zone on the eastern margin of the Bengpu uplift belt yielded a $^{40}Ar/^{39}Ar$ plateau age of 120.96±0.66 Ma (fig.2). The two ages also belong to the Early Cretaceous.

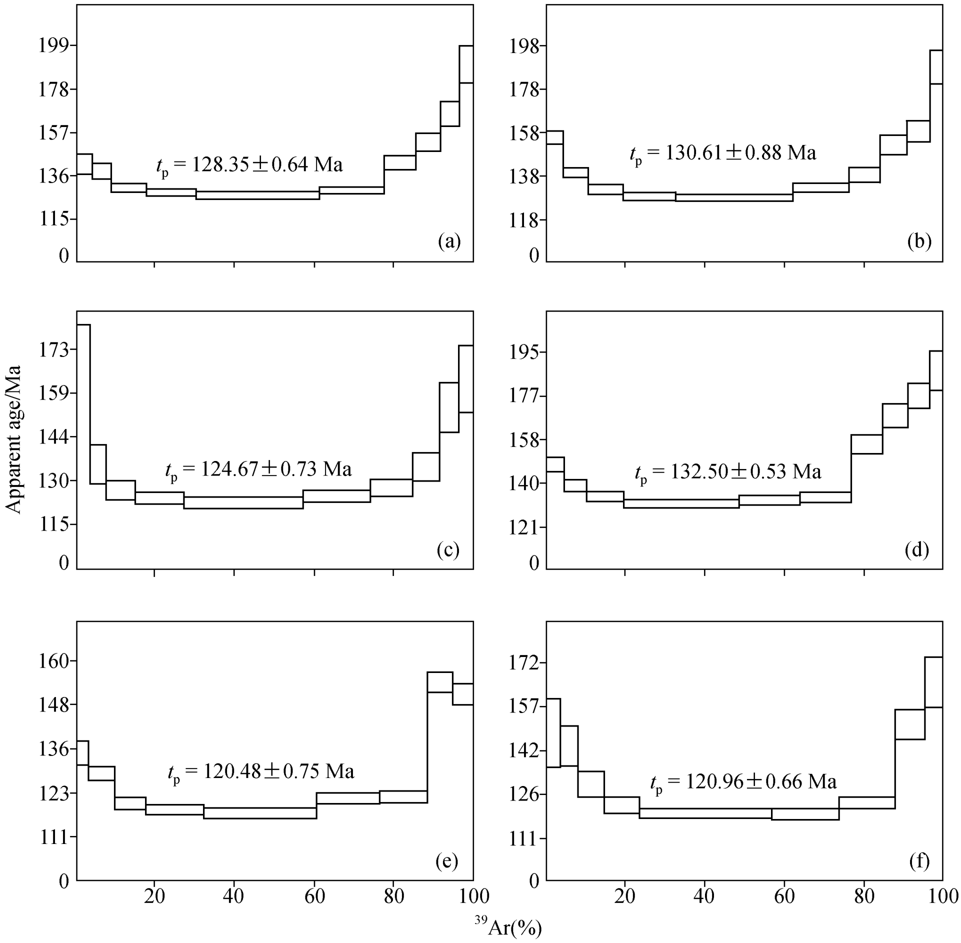

Fig. 2. $^{40}Ar/^{39}Ar$ age spectra of mylonite whole-rocks from the Anhui part of the Tan-Lu fault zone. (a) No. 8-12, ultramylonite whole-rock; (b) No. 8-3-2, mylonite whole rock; (c) No. 3-2, ultramylonite whole-rock; (d) No. 12-1, mylonite whole-rock; (e) D-1, mylonite whole-rock; (f) No. 13-2, phyllonite whole-rock.

The 6 samples have relatively consistent plateau ages in the middle portions (ca.80%) of ^{39}Ar released. The low and high temperature parts (each less than 10%) show older apparent ages. The plateau shapes may reflect existence of exceed argon. The exceed argon might be caused by small parts of porphyritic crystals of inherited feldspar or quartz. To check effect of the exceed argon on the plateau ages, $^{40}Ar/^{36}Ar$-$^{39}Ar/^{36}Ar$ isochron analysis was carried out in this work (table 2). It is found from table 2 that the data for each sample fit on a good isochron line with good correlation of 0.99973—1.00000, difference between the isochron age and corresponding plateau age is less than 3 Ma, and $^{40}Ar/^{36}Ar$ initials between 300.9±4.67 and 308.0±6.44 are not too different from the atmospheric value of 295.5. It is inferred therefore that effect of exceed argon on the obtained middle plateau ages is negligible and the plateau ages are geologically significant. It is suggested that $^{40}Ar/^{39}Ar$ systems in the mylonite series were totally reset during development of the Tan-Lu strike-slip ductile shear zone at deep levels, and the systems at the sampling localities were not disturbed by later structures. Therefore, the samples record cooling ages of the fault strike-slip deformation.

Table 2 Plateau ages, isochron ages, correlations (γ) and $^{40}Ar/^{36}Ar$ initials of samples

Sample No.	8-12	8-3-2	3-2	12-1	D-1	13-2
Plateau ages/Ma	128.35±0.64	130.61±0.88	124.67±0.73	132.50±0.53	120.48±0.75	120.96±0.66
Isochron ages/Ma	125.17±0.26	127.02±0.65	121.55±0.39	129.83±0.15	116.85±0.63	119.07±0.49
Correlation(γ)	0.99998	0.99985	0.99992	1.00000	0.99973	0.99989
$^{40}Ar/^{36}Ar$ initials	304.4±2.08	308.0±6.44	303.6±3.04	303.5±0.69	305.0±5.49	300.9±4.67

The plateau ages of mylonite samples from 5 localilies in the Anhui part of the Tan-Lu fault zone actually record cooling ages of their passing closure temperature due to later rising of the ductile shear zone, i.e. cooling ages of the strike-slip ductile deformation of the Tan-Lu fault zone. The cooling ages of the strike-slip ductile deformation on the eastern margin of the Dabie orogenic belt range from 128 Ma to 132 Ma (not considering the clearly weathered sample No.3-2), while the two cooling ages from Zhangbalin and Bengpu uplift blets are consistently 120 Ma. Apart from test errors, the difference of cooling ages from the two parts may suggest slower strike-slip rising in the northern section. In summary, the $^{40}Ar/^{39}Ar$ dating results indicate that cooling ages of the strike-slip deformation in the Anhui part of the Tan-Lu fault zone are middle Early Cretaceous, and the large-scale strike-slip movement of the fault should take place in earlier Early Cretaceous.

3 Tectonic implications

These $^{40}Ar/^{39}Ar$ dating results of the strike-slip mylonite whole-rocks from the Anhui part of the Tan-Lu fault zone provide strong evidence for the long-time controversial strike-slip timing of the fault zone. The results prove that the large-scale left-lateral displacement of the Tan-Lu fault took place in the Early Cretaceous rather than in the Late Triassic.

To further test reliability of the $^{40}Ar/^{39}Ar$ dating, volcanic rocks of the Maotangchang Formation at Longshan, Feidong County on the western side of the Zhangbalin uplift belt (fig.1), which was controlled and triggered by the strike-slip movement of the Tan-Lu fault, were collected for K-Ar dating. The whole-rock sample was analyzed in Institute of Geology, State Bureau of Seismology. The sample yielded a K-Ar age of 119 Ma. U-Pb zircon age of 128±1 Ma[25] (Early Cretaceous) was obtained from the Guangdian granite in the north of the Zhangbalin uplift belt which is triggered by the Tan-Lu fault zone and extends along the fault zone. Dou et al.[4] reported a $^{40}Ar/^{39}Ar$ biotite age of 100±2.3 Ma (Early Cretaceous) from a deformed rock (mica quartz schist) in the Yilan-Yitong ductile shear zone, the northern part of the Tan-Lu fault zone, and interpreted it as a cooling age of the strike-slip deformation. These isotopic dating results all support that the strike-slip movement on the Tan-Lu fault zone happened during the Early Cretaceous, and testify the $^{40}Ar/^{39}Ar$ dating results of mylonite whole-rocks in this work.

Isotopic ages of high-pressure and ultra-high-pressure metamorphism[26,27] as well as deformation ages of the deformed rocks[28,29] in the Dabie orogenic belt all suggest that the continent-continent collision between the North China Plate and the Yangtze Plate took place in the Indosinian (Late Triassic). Li et al.[30]obtained a $^{40}Ar/^{39}Ar$ muscovite age of 210 Ma from mylonite in a syn-collision ductile thrusting belt of the Dabie orogenic belt at Bixiling, Yuexi County. It is obvious that the Tan-Lu fault zone and Dabie orogenic belt were formed in different times. The former was developed after collision along the latter, and made the latter offset sinistrally for about 550 km. So the Tan-Lu fault zone is not a transform fault or suture line developed during collision of the Dabie-Jiaonan orogenic belt. If so, the Tan-Lu fault zone should show syn-collision thermochronological information. The dating results in this work suggest that the Tan-Lu fault zone is an intracontinental wrench fault zone developed due to oblique, high-speed subduction of the Izanagi Plate to the East Asian continent[31] in the Early Cretaceous, and therefore belongs to circum-Pacific tectonics. The Tan-Lu fault zone does not have relationship in tectonic mechanism with the Dabie-Jiaonan orogenic belt, the representative of the earlier paleo-Tethys tectonics. Superimposition of the two huge tectonic systems in East China represents the change and transfer of the earlier paleo-Tethys tectonic domian into the later circum-Pacific domain. Detailed discussion can be found in another paper[3].

Acknowledgements This work was supported by the National Natural Science Foundation of China (Grant No.49872074).

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