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$^{40}Ar/^{39}Ar$ Dating of the Shaxi Porphyry Cu-Au Deposit in the Southern Tan-Lu Fault Zone, Anhui Province

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Abstract: Four samples of plagioclase and biotite from the Shaxi porphyry in the lower part of the Yangtze metallogenic belt were analyzed for age determination with the $^{40}Ar/^{39}Ar$ method. The results yield reproducible ages of 126 Ma to 135 Ma with a high level of confidence according to the agreement between isochron and plateau ages. The four Ar-Ar ages are relatively consistent within the analytical error. These ages are also consistent with, but more precise than, previous K-Ar and Rb-Sr ages and thus provide better constraints on the time of porphyry formation and associated Cu-Au mineralization along the middle to lower part of the Yangtze metallogenic belt. The ages of 126 to 135 Ma are interpreted to represent the intrusive time of the Shaxi porphyry, so that the Cu-Au mineralization should have occurred later due to the post-magmatic hydrothermal event.

Key words: Shaxi porphyry-type Cu-Au deposit, $^{40}Ar/^{39}Ar$ dating, Yangtze metallogenic belt, Tancheng -Lujiang fault belt, East China

1 Introduction

The middle-lower part of the Yangtze Valley is one of the most important areas for Jurassic-Cretaceous poly-Cu-Fe-Au deposits in China (Chang et al., 1991; Zhai et al., 1996; Pan and Dong, 1999). Although porphyry Cu-(Mo-Au) deposits are the world's primary source of these metals, porphyry Cu deposits in this poly-metallogenic belt are a major source of Cu. The Shaxi porphyry Cu-Au deposit is one of the important discoveries during the 1970s. It is located in the northwestern Luzong volcanic basin, the central part of Anhui Province, east-central China, where the Tan-Lu (Tancheng-Lujiang) fault passes through the ore district. According to Chang et al. (1991) and Zhai et al. (1996), the eastern part of the Yangtze Craton in eastern China is an important Fe-Cu metallogenic province, whose metallogeny was controlled by faults and aulacogens in the continental plate during the Jurassic. The dominant WNW and E-W trending deep fault system controlled the distributions of Cu mineralization. A series of igneous rocks in this region can be grouped into two associations according to their relationship to the metal genesis. The first one is a Fe-related group, whereas the second one is a Cu-related group.

This paper is focused on the second group in order to understand the relationship between its petrogenesis and Cu mineralization, particularly age determination of porphyrite in association with the Shaxi Cu-Au deposit. Previous geochronological studies of igneous rocks in the Lower Yangtze Valley, including K-Ar and Rb-Sr dating, suggest that different rock associations were formed in the same time span about 160 to 105 Ma (Bureau of Geology and Mineral Resources of Anhui Province, 1987; Chang et al., 1991; Zhao et al., 2004; Di et al., 2005; Xu et al, 2005). This study provides more accurate Ar-Ar ages from fast neutron activation techniques for biotite and plagioclase separates. The results are important for understanding the forming processes of both intrusives and Cu-Au deposits in the region.

2 Geological Setting

The Shaxi porphyrite intrusive is a small intrusion with an outcrop area of approximately 1 km^2, but it is heavily copper mineralized and accompanied by Au mineralization (Yang, 1996; Yang et al., 2001b, 2002,

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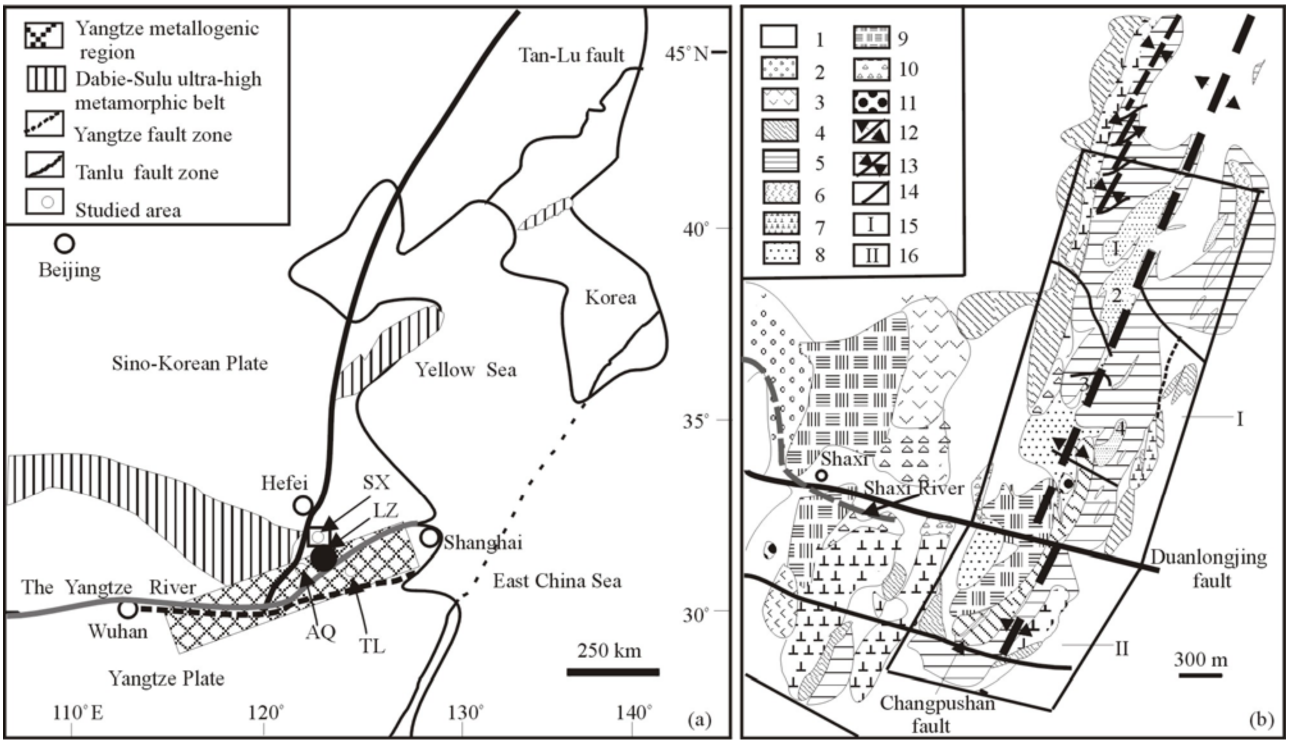

Fig. 1. The regional geological and tectonic map of the studied area.
(a) The regional geological and tectonic map along the middle-lower Yangtze metallogenic belt (after Chang et al., 1991).
SX – Shaxi-Changpushan porphyry Cu-Au deposit; AQ – Anqing magmatic Cu-Mo ore field; TL – Tongling skarn Cu-Au ore field.
(b) geological map of the Shaxi porphyry copper (gold) deposit, Central Anhui (after the No. 327 Geological Party, 1982).
1. Quaternary system; 2. red sedimentary rocks of the Kz-Cz series; 3. volcanic rocks of Kz; 4. clastic rocks of Kz; 5. clastic rocks of Pz; 6. middle and deep facies of diorite; 7. hypabyssal porphyry dioritoid; 8. ore-bearing quartz porphyry diorite; 9. subvolcanic rocks; 10. intrusive breccias; 11. explosion breccias; 12. extrapolated axis of anticline; 13. secondary axis of syncline; 14. fault; 15. region with drilling holes (including ZK3301and ZK3307); 16. range of deposits: I - the Shaxi porphyry copper (gold) ore deposit; II - the range of a prospecting area of porphyry copper-gold deposit with similar mineralization of that in Shaxi (after Yang et al., 2001b).

2006; Yang and Lee, 2005). Figure 1a shows the general information about the regional tectonic setting along the middle-lower Yangtze metallogenic belt, and Fig. 1a is a geological map of the Shaxi porphyry copper (gold) deposit.

The studied region is located on the northern margin of the Yangtze Craton (Ren, 1980), but still south of the Dabie ultrahigh-pressure (UHP) metamorphic belt (Zhao et al., 2004a). The Dabie orogen was formed by Triassic subduction of the South China Block beneath the North China Block to result in continental collision (e.g., Zheng et al., 2003, 2005). The Dabie UHP metamorphic complex is truncated at its eastern end by the Tanlu fault, which offsets it by approximately 500 km northward to the Shandong Peninsular where it occurs as the Sulu orogen. Many studies have contributed to understanding of the geodynamics of the continental subduction and subsequent exhumation from various aspects of field geology, structural geology, mineralogy, petrology, geochemistry, geophysics, petrophysics and tectonics in the Dabie-Sulu orogenic belt (Zheng et al., 2003, 2005 and references therein). Zircon U-Pb dating by the TIMS (thermal ion mass spectrometer, upper intercept age) and SIMS (ion microprobe, $^{206}Pb/^{238}U$ age for zircon cores) has yielded a range of 620 to 880 Ma (mode range of 700 to 800 Ma) for protoliths of most UHP eclogites and orthogneisses in the Dabie-Sulu orogenic belt, corresponding to bimodal magmatism along the northern margin of the South China Block in response to the middle Neoproterozoic rifting tectonics (Zheng et al., 2004, 2006). Post-collisional igneous rocks are composed of voluminous coeval granitoids and minor mafic-ultramafic rocks that have emplacement ages of 117 to 135 Ma as established by different techniques of geochronology (e.g., Chen et al., 1995; Zhao et al., 2004b, 2005; Xie et al., 2006). Available results from element and isotope analyses indicate that the Early Cretaceous granitoids in the Dabie orogen have the geochemical characteristics similar to the subducted continent in many aspects. Therefore, they are petrogenetically considered as being generated by partial melting of the South China Block due to extension collapse of the collision-thickened orogen (Zhao et al., 2004b, 2005).

The whole district is affected by two multiple faults: the Tan-Lu fault which passes through the whole district, and the Fanshan-Tongling fault, which is also a regional deep fault belt controlling the distribution and mechanism of the porphyry intrusive (Dong, 1984; Chang et al., 1991). The Tan-Lu fault belt, as a major wrench fault to the northwest of the Pacific Ocean, cuts the eastern continental crust of northeastern Asia and crosses more than several thousands kilometers in eastern China (Xu et al., 1987). Its northern part enters the Kurtuhin fault belt in the far east of Russia (Salon, 1977). Xu et al. (1987) presented the fact that this fault system would be traced for more than 3600 km, extending intermittently to South China, with a strike from NE to NNE, assuming an "S-shaped or snake-shaped" curve. This fault is 10–50 km in width and shows a fractural down-warping zone with highly plastic deformed ductile shear zones at levels of the middle to lower crust, and there are a series of ductile shear zones also with NE or NNE trends which were developed in the slide formation of the major fault belt within or near the studied region (Wang et al., 1983; Yang, 1992; Zhang, 1992; Yang et al., 1998a, b; 2001a).

3 Petrography and Geochemistry

3.1 Petrography

Igneous rocks are widely distributed in the studied region with the characteristics of multiple magmatic activities. The period of the magmatic activity is clear from the field observation, where volcanic rocks in the deposit are overlying sandstones of the Xiangshan Group (middle-upper Jurassic) and have an intrusive contact with the lower Cretaceous red beds. Therefore, the volcanic activity was limited to the late Jurassic to early Cretaceous. The intrusive rocks in the Shaxi porphyry Cu-Au deposits are stocks, tongues, apophyses, ethmoliths and dikes, and include deep-shallow-ultra-shallow intrusive bodies. According to drilling and geophysical exploration (The No. 327 Geological Party, 1982; Yang et al., 2001b), all of the intrusive bodies have the same basement, and the ore bodies are resident in the upper part of the intrusive at 0–800 m depth. There are two active stages of igneous activity in this region. The early stage is an intrusive one, with different extents of Cu-Au mineralization, hosted mainly by quartz diorite porphyry and biotite quartz diorite porphyry with lesser amounts of amphibole diorite porphyry and breccia diorite porphyry. The late stage of magmatic activity is an injection accompanied with a large amount of basic, intermediate and intermediate-acid magmas with volcanic explosion and sub-volcano activity without any Cu-Au mineralization.

There are several kinds of intrusive rocks with porphyry copper mineralization in the Shaxi porphyry Cu-Au deposit. These are quartz diorite porphyry, biotite-quartz diorite porphyry and fine- to medium-grained porphyry diorite, which have a subhedral seriate texture.

Figure 2 shows the petrologic characteristics from observations of the intrusives from the Shaxi Cu-Au-bearing igneous intrusive in the lower part of the Yangtze metallogenic belt.

They contain phenocrysts of plagioclase and alkali-feldspar with sizes of 8–3 mm and 5–1.5 mm, respectively. Some feldspars are severely alterated to sericite, chlorite and kaolinite in the alteration zones (Fig. 2a, b). The diorites in this region contain amphibole, quartz, microcline, biotite, muscovite, apatite, sphene, pyrite, magnetite and rare rutile. The microcline occurs as subhedral crystals with cross-hatch twinning of microperthitic and contains plagioclase. The biotite is all subhedral (Fig. 2c); however, the amount of biotite is more than that of muscovite in the diorite porphyry samples. All the opaque minerals are distributed among the main rock-forming minerals. The plagioclase in the diorite porphyry usually occurs as subhedral poly-synthetically twinned crystals (Fig. 2d).

3.2 Geochemistry

Late Mesozoic igneous rocks associated with Cu-Au mineralization crop out widely in the Lower Yangtze region. They intruded into either the Neoproterozoic low-grade metamorphic rocks or the Paleozoic to Triassic sedimentary strata.

3.2.1 Major elements

Several rock associations were recognized in this region. The Luzong meso-volcanic rocks and some in the Tongling region with skarn Cu-Au mineralization fall into the shoshonite field in the K_2O vs. SiO_2 plot (Fig. 3). The K-enriched rock association contains shoshonite series and ultrapotassic rocks classified by high Na_2O+K_2O of 8.1% to 12.0%, high K_2O content of 4.1% to 8.5%, and with K_2O/Na_2O ratios of about 0.8 to 1.4 (Bureau of Geology and Mineral Resources of Anhui Province, 1987; Wang and Yang, 1996; Yang, 1996; Xing and Xu, 1999; Yang and Lee, 2005). They are basaltic trachyandesite, trachyandesite and syenite in composition. However, the rocks in the Shaxi porphyry Cu-Au deposit are of calc-alkaline series, and the rocks in the Anqing and Tongling areas are of high-potasssic calc-alkaline series. According to Chen et al. (2001), there exists a kind of rock series with Na-rich alkaline mafic association in this region showing low SiO_2 of 46–56% and high alkali content with Na_2O/K_2O ranging from 5.0–7.1% and Na_2O/K_2O ratios of 1.4 to 4.3 (Xing and Xu, 1999). The associations of high potassic calc-alkaline series or calc-alkaline series occurring in the area north of the Yangtze River consisting of monzonite and granite stocks, diorite, quartz diorite and granodiorite stocks are distributed along the Yangtze River. These rocks are closely associated with the mineralization of copper, iron, sulfur and gold ore deposits

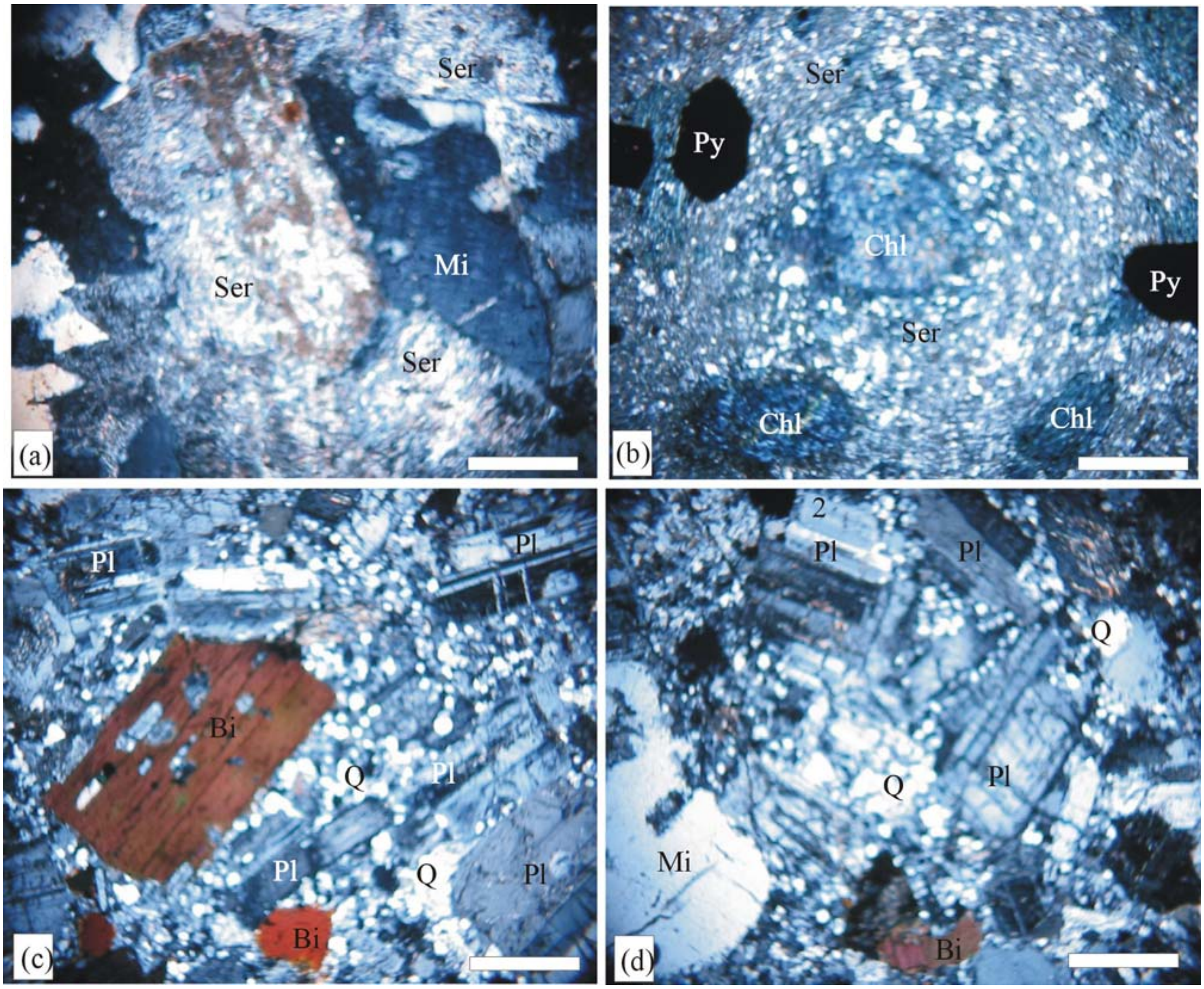

Fig. 2. Microscopic images of petrologic observation of the granitoids related to the Shaxi porphyry Cu-Au deposit.
(All the images are taken with the Laca microscope under the polarized light condition, the scale bar for each of the image is 0.20 mm. Abbreviations in the images: Am – amphibole; Bi – biotite; Mi – microcline; Pl – plagioclase; Chl – chlorite and chloritization; Py – pyrite; Q – quartz; Ser – sericite and sericitization).
1. Heavy alteration of sericitization and argillation in porphyrite from the Shaxi intrusive related to the porphyry Cu-Au deposit (ZK1405-21); 2. heavy alteration of sericitization and chloritization in porphyrite from the Shaxi intrusive (ZK1002-10); 3. regular shape of fresh biotite and plagioclase with zoning texture of porphyrite (Sample ZK 3303-07); 4. regular shape of fresh plagioclase with some smaller crystals of quartz and biotite, and one crystal of microcline can be identified from porphyrite (Sample ZK 3303-01).

(Chang et al., 1991), making the area an important metal production base in China. Intrusions distributed in the region south of the Yangtze River include granites and granodiorites, occurring as batholiths and stocks. They are S-type granites in terms of chemical composition and mineralogy (Chang et al., 1991).

3.2.2 REE

The total (REE+Y) contents range from 256 ppm to 79 ppm (with an average value of 115.93 ppm) in the intrusive rocks in the Shaxi area (Yang, 1996). Almost all of the samples have the characteristics of enrichment in LREE and depletion in HREE without Eu anomaly compared to those of REE data from the other regions adjacent to Shaxi, such as the Anqing, Tongling, Luzong and Chuxian areas (see Fig. 4). The REE patterns in the intrusive rocks from the Shaxi area are more similar to those of the lower crust rocks (Taylor et al., 1985).

3.2.3 Trace elements

The spidergram of trace elements in the Shaxi area is shown in Fig. 5, which has the characteristics of mantle compatible elements such as Sc, Cr, Co and Ni and some transitional compatible elements such as Ti, V, Mn, Fe and Cu, with strong fractionation compared to the average contents of trace elements of crust rocks and adjacent dioritoids along the Yangtze metallogenic belt (Thorpe, 1976; Taylor et al., 1985; Bureau of Geology and Mineral Resources of Anhui Province, 1987; Chang et al., 1991; Ren et al., 1991), especially those of Cu with very largely

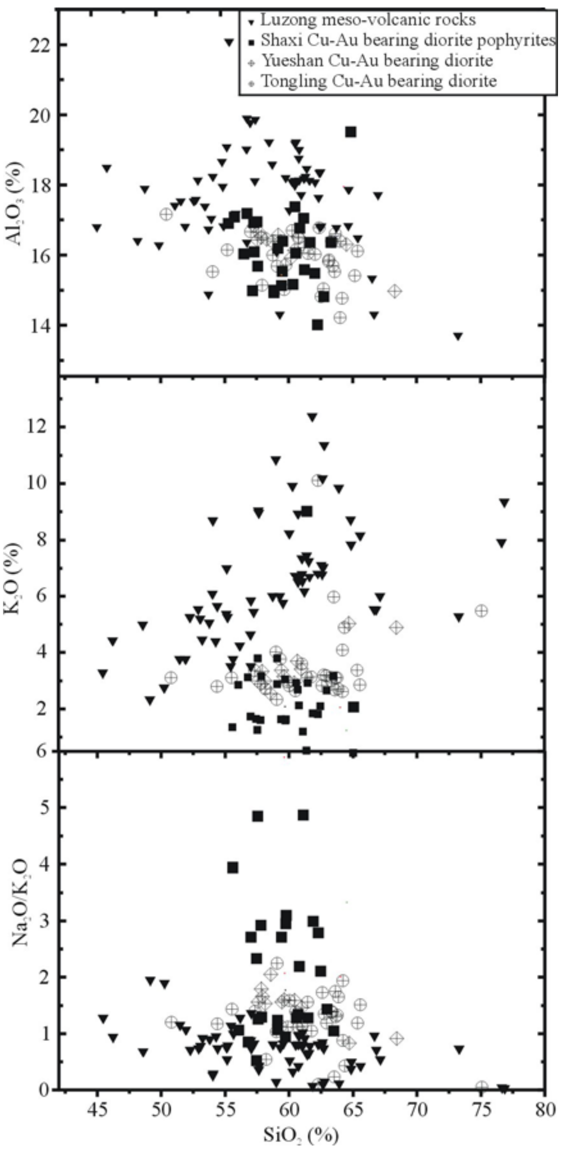

Fig. 3. SiO_2 vs. Al_2O_3, K_2O and Na_2O/K_2O diagrams showing variations of different igneous rock associations related to Cu-Au mineralization in Anhui Province (after Rollinson, 1993 and Rickwood, 1989; data are derived from the No. 327 Geological Party, 1982; the No. 321 Geological Party, 1990; Bureau of Geology and Mineral Resources of Anhui Province, 1987; Chang et al., 1991; Ren et al., 1991; Qiu, 1992; Yang, 1996; Wang and Yang, 1996; Yang et al., 2001b).

positive anomaly, which may be interpreted as an important cause for Cu mineralization in this region. The lithophile elements such as K, Rb, Th, Sr, Ba, Li and La are also enriched compared to the average contents of the crustal rocks and adjacent dioritoids (Bureau of Geology and Mineral Resources of Anhui Province, 1987; Chang et al., 1991; Ren et al., 1991), which manifests the regional geochemical anomalies of these elements and may be interpreted as an important cause for Cu mineralization in this region. The hydrothermal alteration to some of the

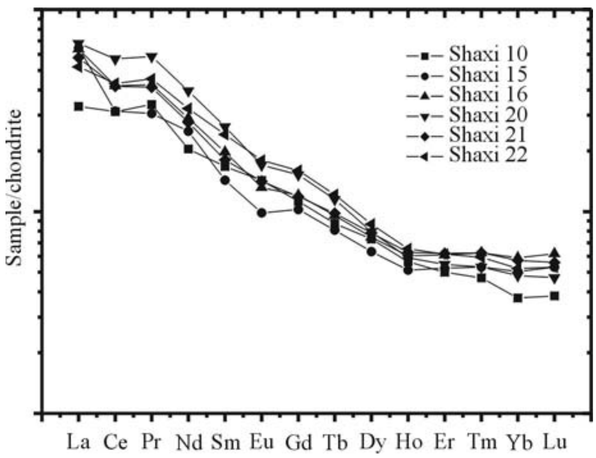

Fig. 4. Normalized REE patterns of the altered intrusive rocks in the Shaxi porphyry Cu-Au deposit (data from Yang, 1996).

Cu-related intrusive rocks is another cause for the increase of these elements.

4 $^{40}Ar/^{39}Ar$ Dating

4.1 Sample selection and experimental methods

Biotite and plagioclase are commonly used for the $^{40}Ar/^{39}Ar$ geochronometer. The fresh rocks selected for analysis in this study are porphyrites from the Shaxi intrusive. The rocks were crushed, separated using heavy liquid, and single biotite and plagioclase crystals were picked by hand under the binocular microscope to get pure monominerals mainly avoiding the intergrowths of minerals, fluid inclusions and alteration. Figure 2 (c, d) are the microscopic images of petrologic observation of the two selected porphyrite samples in the Shaxi porphyry Cu-Au deposit, showing the fresh minerals of both biotite and plagioclase suitable for the $^{40}Ar/^{39}Ar$ geochronometer in this study.

It is well known that obtaining meaningful ages from such spectra is very difficult because of the possibility of alteration of minerals. Although biotite is a common rock-forming mineral suitable for Ar-Ar dating, it is often affected by alteration related to unique geological localities. The capability to obtain reliable ages depends on delicate choice and preparation of the fresh minerals, which will be the extremely important for obtaining the true geological dating. In this work great efforts were made, e.g., high-resolution binocular microscope was hired to check the pure biotite after heavy liquid separation in order to avoid the affects of alteration. In this way the purification of minerals was ensured for the further measurement, which is essential to the $^{40}Ar/^{39}Ar$ geochronometer.

The preparation and conditions of the biotite and plagioclase samples and standard samples for analysis

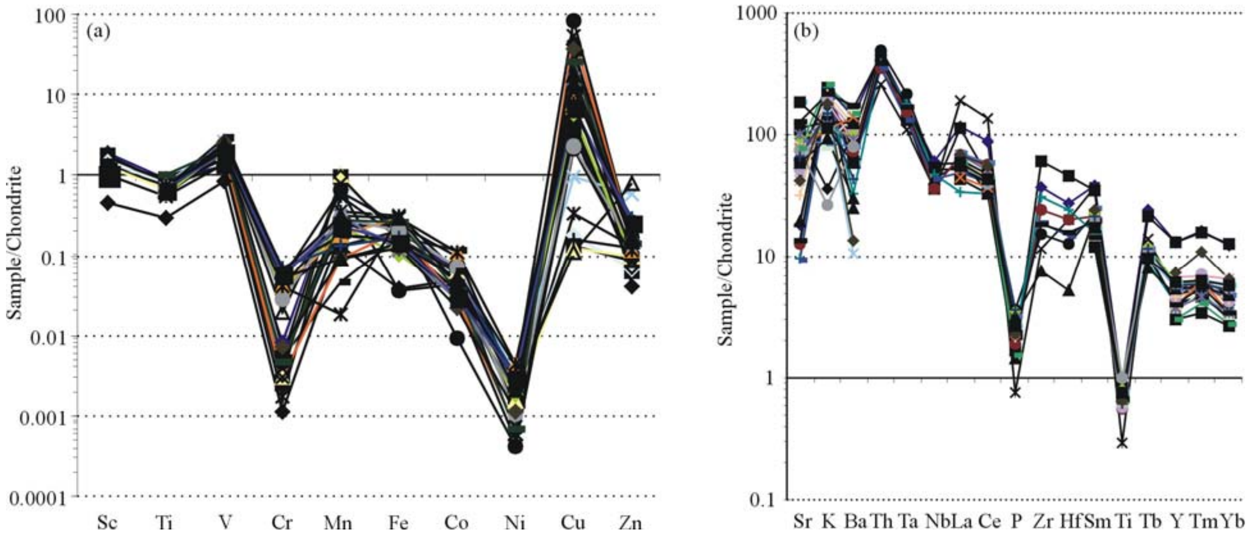

Fig. 5. Spidergrams in the Shaxi porphyry copper (gold) deposit (data from Yang, 1996).
(a) Transitional elements; (b) large lithophile elements.

with the fast neutron irradiation incremental heating for Ar extraction is described as follows: the separated monomineral samples were wrapped up in aluminum foil and placed in the central part of the B8 hole site of the 49-2 type reactor for fast irradiation with an irradiation time of 52 h 47 min, intermittent flux of neutrons 6.63×10^{12} n/cm^2·s and integrated flux of neutrons 1.26×10^{18} n/cm^2.

The standard samples used to monitor neutron fluxes included Chinese standard ones of ZBJ (hornblende) and ZBH-25 (biotite) with ages of 132.8±1.4 Ma and 132.7±1.2 Ma, respectively, and French B600 (biotite), Australia 77600 (hornblende) and international standard BSP (hornblende) with ages of 322 Ma, 414.5±3.7 Ma and 2060±8 Ma, respectively. The values of irradiation parameters J are 0.012826 (for sample ZK3303-07, biotite and plagioclase) and 0.012831 (for sample ZK3303-01, biotite and plagioclase), respectively.

The measurements were performed on an English RGA-10 Model gas-source mass spectrometer (VSS Company); the sample weights are from 0.14930 g to 0.1022 g. The decay constant λ is 5.54×10^{-10}/a in the static mode. The blanks of the whole system are $^{40}Ar=1.6\times10^{-14}$ mol and $^{36}Ar=1.2\times10^{-16}$ mol and the errors involved in the Ar measurement are within the range of 0.5% –1%.

4.2 Results of the $^{40}Ar/^{39}Ar$ dating

The gas released from the samples when heated in a tight container was analyzed on the mass spectrometer for Ar isotopes. Both biotite and plagioclase separates from two samples were analyzed and the results are shown in Table 1. Figures 6–9 show the apparent $^{40}Ar/^{39}Ar$ age spectra and the isochron ages for the 4 selected samples.

The Ar isotope data acquired at 11 heating stages range from 420°C to 1450°C for each sample, though the heating temperature steps were slightly different. The data points involved in plateau age calculation can satisfy such preconditions that the sample was formed under a chemically closed condition. The two biotite samples and two plagioclase samples represent ideal grains for $^{40}Ar/^{39}Ar$ dating, giving relatively reproducible ages with a high level of confidence ranging from 126 to 135 Ma according to the result of isochron age and plateau age analysis.

5 Discussion

It is desirable to identify apparent ages that are adversely influenced by alteration and to obtain meaningful ages from all rocks regardless of the conditions because many rocks are geologically unique and/or representative of key localities. However, it is difficult to obtain geologically meaningful ages from highly altered biotite using incremental step-heating. Even those biotites which appear pristine in thin sections can yield variable plateau and unexpected apparent ages (e.g., Lo and Onstott, 1989; Ruffet et al., 1991; Onstott et al., 1995; Roberts et al., 2001; Burgess et al., 2004). Biotite and plagioclase are the minerals most commonly dated by $^{40}Ar/^{39}Ar$ geochronology. However, secondary alteration of biotite to phases such as chlorite is a common and widespread occurrence in nature and has long been known to lead to a lowering of biotite ages (Mitchell and Taka, 1984; Kelley et al., 1997; Adams and Kelley, 1998; Haines et al., 2004). Although later thermal disturbance can also yield plateau ages, alteration and weathering of grains are often correlated with $^{40}Ar/^{39}Ar$ age spectra that are seriously disturbed.

From the results of biotite and plagioclase, it can be

Table 1 Data for $^{40}Ar/^{39}Ar$ dating from the Shaxi porphyry intrusive, Anhui Province

Heating stage	Temperature	$(^{40}Ar/^{39}Ar)_m$	$(^{36}Ar/^{39}Ar)_m$	$(^{37}Ar/^{39}Ar)_m$	$(^{38}Ar/^{39}Ar)_m$	$^{39}Ar_K\times10^{-12}$ mol	$(^{40}Ar^*/^{39}Ar_K)$	$^{39}Ar_K$ ±1 σ	t (Ma) ±1 σ
Sample ZK3303-07, biotite, J = 0.012826, weight = 108.1 mg									
1	400	24.244	0.0431	0.1112	0.0503	3.244	11.55±0.472	1.25	249.34±11.34
2	500	17.009	0.0287	0.0986	0.0430	4.848	8.572±0.023	1.88	188.19±4.70
3	600	10.082	0.0192	0.0638	0.0303	8.421	4.413±0.008	3.28	99.34±1.42
4	700	9.0322	0.0107	0.0692	0.0387	21.57	5.847±0.007	8.40	131.05±1.77
5	800	7.1621	0.0040	0.0330	0.0317	34.33	5.971±0.004	13.3	133.14±1.65
6	880	7.1631	0.0042	0.0303	0.0304	32.71	5.912±0.004	12.7	131.88±1.64
7	960	6.7105	0.0026	0.0247	0.0337	52.89	5.937±0.004	20.6	132.41±1.63
8	1040	6.6853	0.0028	0.0260	0.0365	41.29	5.860±0.004	16.0	130.76±1.62
9	1140	7.1818	0.0045	0.0351	0.0345	25.51	5.846±0.004	9.94	130.46±1.63
10	1300	7.6829	0.0060	0.0389	0.0402	19.02	5.892±0.005	7.41	131.44±1.68
11	1400	8.6727	0.0090	0.0421	0.0490	12.75	6.002±0.007	4.97	133.81±1.81
Sample ZK3303-07, plagioclase, J = 0.012826, weight = 149.3 mg									
1	420	33.137	0.0686	0.68121	0.25098	2.365	13.02±0.091	1.11	278.76±23.79
2	540	21.208	0.0496	0.93266	0.13087	3.454	7.473±0.038	1.62	188.13±6.30
3	660	13.289	0.0326	0.64155	0.08950	7.911	3.763±0.016	3.34	85.05±1.68
4	780	9.9710	0.0145	0.32557	0.04246	16.00	5.734±0.008	7.53	128.03±1.83
5	880	7.9326	0.0076	0.29386	0.02830	24.12	5.692±0.005	11.3	127.13±1.61
6	960	7.2052	0.0052	0.33906	0.02218	35.02	5.672±0.004	16.4	126.70±1.56
7	1040	7.1739	0.0050	0.42779	0.02210	32.00	5.714±0.004	15.0	127.61±1.57
8	1120	6.9550	0.0044	0.45492	0.02219	41.28	5.668±0.004	19.4	126.61±1.55
9	1200	7.0317	0.0047	0.71731	0.02740	29.21	5.668±0.004	13.7	127.04±1.57
10	1320	8.9710	0.0115	0.93129	0.03980	15.99	5.636±0.007	7.52	125.92±1.70
11	1450	13.320	0.0234	0.75508	0.08398	5.936	6.491±0.016	2.79	144.28±2.79
Sample ZK3301-01, biotite, J = 0.012831, weight = 102.2 mg									
1	420	17.130	0.0257	0.1409	0.0699	5.405	9.542±0.024	2.32	208.37±5.32
2	540	10.240	0.0219	0.0803	0.0599	10.55	3.784±0.009	4.53	85.54±1.30
3	660	8.5542	0.0084	0.0421	0.0413	19.25	6.076±0.006	8.26	135.45±1.79
4	780	7.7454	0.0054	0.0264	0.0267	25.51	6.141±0.005	10.9	136.84±1.72
5	880	8.1081	0.0067	0.0397	0.0322	34.33	6.122±0.005	14.7	136.44±1.75
6	960	8.6725	0.0088	0.0548	0.0433	26.21	6.073±0.006	11.2	135.39±1.81
7	1040	7.5254	0.0050	0.0399	0.0307	27.37	6.031±0.005	11.7	134.49±1.69
8	1140	7.7325	0.0058	0.0440	0.0315	39.90	6.024±0.005	17.1	134.34±1.70
9	1250	8.7790	0.0093	0.0480	0.0451	19.95	6.046±0.007	8.56	134.81±1.81
10	1350	9.5294	0.0117	0.0553	0.0460	15.77	6.073±0.008	6.77	135.38±1.89
11	1450	12.486	0.0216	0.0735	0.0735	8.583	6.136±0.014	3.68	136.73±2.44
Sample ZK3301-01, plagioclase, J = 0.012831, weight = 138.3 mg									
1	420	26.878	0.0578	0.60524	0.0953	4.011	9.929±0.058	2.38	216.35±12.17
2	540	10.107	0.0214	0.47937	0.0495	8.650	3.863±0.009	5.14	86.70±1.28
3	660	9.3469	0.0122	0.46373	0.0365	11.36	5.787±0.007	6.76	129.24±1.77
4	780	8.4848	0.0090	0.32217	0.0277	15.30	5.847±0.006	9.10	130.51±1.69
5	880	8.0000	0.0076	0.42457	0.0204	24.35	5.782±0.005	14.4	129.13±1.63
6	960	8.4651	0.0093	0.47780	0.0204	19.94	5.761±0.005	11.8	128.66±1.66
7	1020	7.7966	0.0068	0.54255	0.0199	27.36	5.839±0.004	16.2	130.34±1.63
8	1100	8.2291	0.0083	0.61051	0.0203	22.26	5.819±0.005	13.2	129.93±1.66
9	1200	8.6301	0.0095	0.79425	0.0224	16.92	5.857±0.006	10.0	130.73±1.70
10	1300	10.625	0.0166	0.93129	0.0302	11.12	5.785±0.009	6.62	129.19±1.89
11	1420	11.862	0.0206	0.77766	0.0458	6.742	5.839±0.011	4.0	130.35±2.12

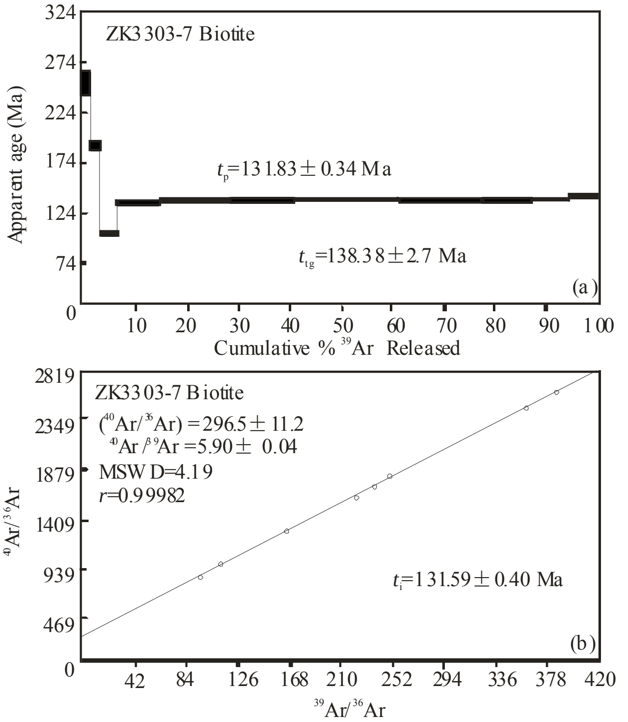

Fig. 6. The ^{40}Ar-^{39}Ar spectra and corresponding isochron diagrams of biotite in the Shaxi porphyrite intrusive, the southern Tan-Lu fault belt (Sample 3303-07).
(a) Spectral diagram; (b) isochron diagram.

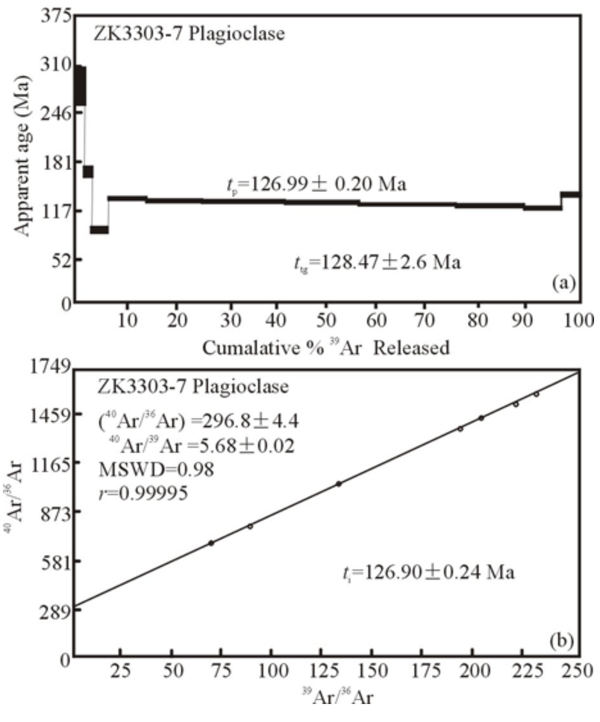

Fig. 7. The ^{40}Ar-^{39}Ar spectra (a) and corresponding isochron diagrams of plagioclase in Shaxi porphyrite intrusive, the south Tan-Lu fault belt (Sample 3303-07).
(a) Spectral diagram; (b) isochron diagram.

judged that these Ar-Ar ages can well represent the timing of the Shaxi porphyry emplacement, which can also be compared to the other ages by Ar-Ar, Rb/Sr and zircon U-Pb dating for many intrusives along the middle-lower Yangtze valley ranging from 140 to 122 Ma (Chen et al., 1985a, b, 1991, 1993, 1994; Zhou et al., 1987, 1988; McKee, 1988; Xu and Xing, 1994; Zhao et al., 2004a; Yang, 2006). The post-collisional magmatism in the Dabie orogen also occurred at 120 to 130 Ma (Chen et al., 1995; Zhao et al., 2004b, 2005; Xie et al., 2006). It is known that there is widespread occurrence of Early Cretaceous mineralizations in eastern China, but, significantly different settings of geotectonics are responsible for the same period of magmatism. Therefore, it remains to be resolved whether the Early Cretaceous magmatism along the middle-lower Yangtze Valley was triggered by mantle superwelling in response to the Pacific Superplume event (Zhao et al., 2004b, 2005) or it is related to subduction of the Pacific plate (Wu et al., 2005).

Recently, Xu et al. (2005) studied the Tongling skarn copper mineralized region and dated the main orebodies of the Dongguashan copper deposit with the Rb-Sr isotopic method, and they obtained the isochron ages of 136.5±1.4 Ma in the Qingshanjiao intrusive and 134±11 Ma of the later mineralized fluid inclusions in quartz vein. Di et al. (2005) studied the crystallization ages of the Xiaotongguanshan quartz monzodiorite and Shatanjiao quartz monzonite porphyry in the Tongling area using the SHRIMP zircon U-Pb method, and found that the crystallization age of the former is 142.8±1.8 Ma, that of the latter is 151.8±2.6 Ma. All the geochronology of the igneous rocks along the middle-lower Yangtze region indicates that these intrusives related to Cu-Au mineralization belong to the Late Jurassic-Early Cretaceous. It is believable that the ages from 126 to 135 Ma can represent the intrusive time in the Shaxi region, and the Cu-Au mineralization should have occurred later by a strong hydrothermal event of magmatism. These ages are also in accordance to the study of the movement of the Tan-Lu fault belt obtained by Ar-Ar dating such as Zhu et al. (2004), whose results of the $^{40}Ar/^{39}Ar$ ages of mylonite whole-rock and muscovite from the later Tanlu ductile shear zone suggest another sinistral strike-slip cooling event at 128 Ma. Thus the strike-slip faulting of the Tan-Lu fault belt would induce a large-scale intrusion and doming uplift within its adjacent Shaxi area. Such a case was studied by Wu et al. (2004) in the Tongling region, and they provided a mechanism of emplacement in the deep and found the fact that the left-lateral shear shown by the ductile shear zone and the rheomorphic fold reveals that the pluton emplacement and the deformation of surrounding rock are controlled by a NNE-striking left-lateral shear stress field.

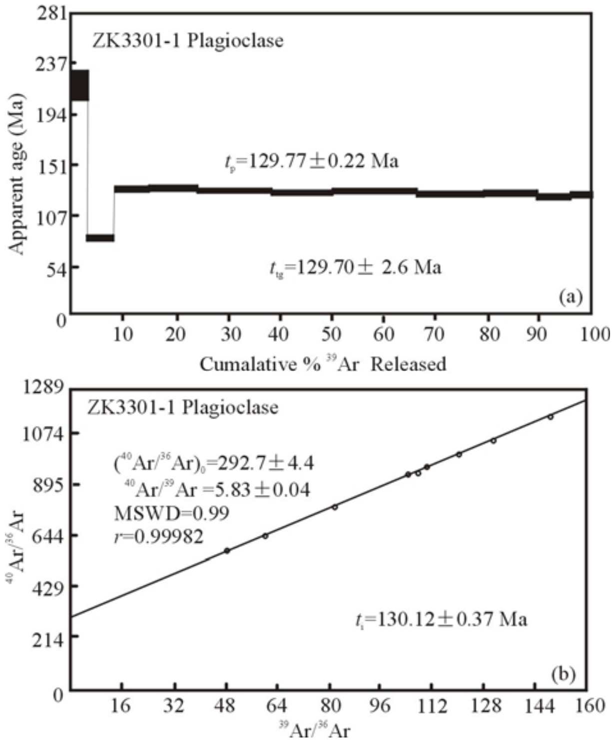

Fig. 8. The ^{40}Ar-^{39}Ar spectra and corresponding isochron diagrams of biotite in the Shaxi porphyrite intrusive, the south Tan-Lu fault belt (Sample 3301-01).
(a) Spectral diagram; (b) isochron diagram.

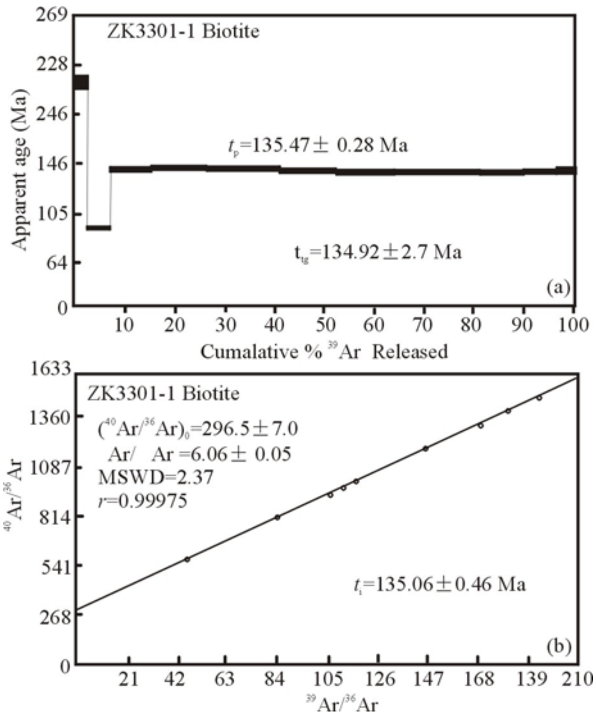

Fig. 9. The ^{40}Ar-^{39}Ar spectra and corresponding isochron diagrams of plagioclase in the Shaxi porphyrite intrusive, the south Tan-Lu fault belt (Sample 3301-01).
(a) Spectral diagram; (b) isochron diagram.

6 Conclusion

The Cu-Au mineralization in the Shaxi porphyry deposit occurs in a complex intrusive composed of quartz diorite porphyry, biotite-quartz diorite porphyry and fine- to medium-grained porphyry diorite along the lower part of the Yangtze metallogenic belt. The four reproducible Ar-Ar ages ranging from 126 to 135 Ma with a high level of confidence represent the formation ages of the Shaxi porphyry intrusive with Cu-Au mineralization. The ages constraining on the Cu-Au mineralization in the central Anhui Province are consistent with those of the majority of the adjacent acid intrusives with mass Cu-Au mineralization along the Yangtze metallogenic belt in the Yanshanian Period (Mesozoic).

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