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Ar^{39}/Ar^{40} dating of three typical gold deposits in southern Qinling and its implication①

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[Abstract] Three types of gold deposits, which are the disseminated ore, auriferous quartz vein, and ore hosted in ductile shear zone have been identified in southern Qinling. The dating of the Baguamiao gold deposit in Fengxian, Xiaogouli gold deposit in Chengxian and Shangjiagou gold deposit in Kangxian gave rise to plateau ages (131.91 ±0.89) Ma, (197.45 ± 1.13) Ma and (161.59 ±0.56) Ma respectively, consistent with the isochron ages. It is indicated that the metallization occurred in late Indosinian and early Yanshannian. The Ar^{39}/Ar^{40} dating affirms their metallogenic ages ranging from (131.91 ±0.89) Ma to (197.45 ±1.13) Ma which couple with the epoch in which the continent-continent collision and intracontinent orogene took place. Consequently, it is suggested that the collision-orogene, magmatic intrusion and location of gold deposits constitute an organic successive process. In line with the tectonic event, the large-scale metallization symbolizes the different representation of the same continental dynamics in the evolution of regional tectonics.

[Key words] southern Qinling; gold deposit; plateau age; isochron age
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1 INTRODUCTION

Qinling orogenic belt abuts North China platform with Shangzhou-Danfeng geosuture in the north and neighbors Yangtze platform with Mianxian-Lueyang geosuture in the south[1, 2]. In Paleozoic the three tectonic units corresponded to active continental margin of southern margin of North China plate, passive continental margin of northern margin of Yangtze plate and Qinling micro-plate respectively. Gold deposits in southern Qinling are mainly distributed within the Qinling micro-plate south to Shangdan fault and north to Mianxian-Lueyang fault. Mainly hosted in Devonian sediments, gold deposits are spatially associated with Sedex Pb-Zn deposits[3~5]. In 1980s~ 1990s, the great advance was made in the prospecting of gold deposits. The twenty mid-large gold deposits were discovered in Devonian Pb-Zn metallogenic belt and its periphery. The Baguamiao gold deposit in Fengxian, Shaanxi and Shuangwang gold deposit in Taibai, Shaanxi are the two super large ones. Meanwhile, the significant progress was made in the geological investigation and geological study on gold deposits, geology and geodynamics background of overseas gold deposits hosted in sedimentary rocks as well as relations between Au mineralization and magmatism[2, 4, 6~9]. For short of systematic and reliable dating data, it is difficult to establish the relations between formation of gold deposits and evolution of regional tectonics. Jointly Financed by State Key Basic Researching Project (No. G1999043213) and State Science and Technology Project (No. 96-914-01-04), we spent four years investigating metallogenic environment and Ar-Ar dating of the above-mentioned three typical gold deposits to clarify the relations between Au mineralization and evolution of regional tectonics.

2 TYPES OF GOLD DEPOSITS AND GEOLOGY OF TYPICAL GOLD DEPOSITS IN SOUTH QINLING

Based on geology of gold deposits, gold deposits in southern Qinling are classified into three types, sediment-hosted disseminated type such as Baguamiao gold deposit in Fengxian and Shuangwang gold deposits in Taibai, auriferous quartz vein such as Xioagouli gold deposit and Sanyangba gold deposit in Chengxian, and ductile shear zone-controlled gold deposits such as Shangjiagou gold deposit in Kangxian and Maanqiao gold deposit in Zhouzhi etc. They are mainly distributed in the deformed structural zones in south side and north side of Qinling micro-plate.

2.1 Disseminated type gold deposit

The Baguamiao super large gold deposit is the typical one which is located in the northern part of Taibai basin (Fig. 1). The country rocks are lithologically Xinghongpu Formation metamorphosed fine clastic rocks of Mid-Upper Devonian, mainly carbonaceous and calcareous sericite phyllite. Controlled

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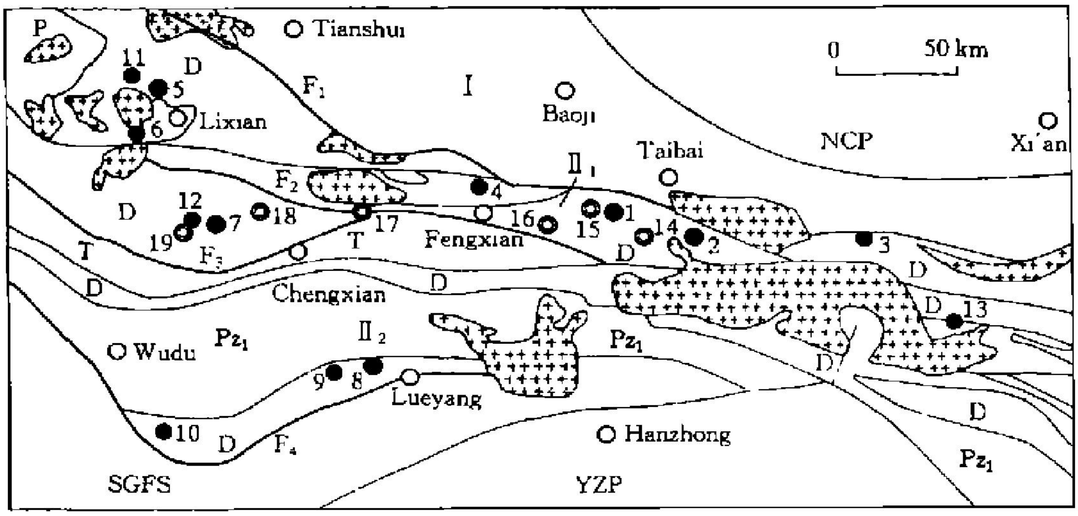

Fig. 1 Geological map of southern Qinling showing distribution of gold deposits

T —Triassic; P —Permian; D —Devonian; P_{z_1} —Lower Paeozoic; ηγ —Adamellite; F_1 —Shanzhou-Danfeng fault; F_2 —Lixian-Shanyang fault; F_3 —Lintan-Zhenan fault; F_4 —Lueyang-Maqu fault; I —Northern Qinling fold belt; II_1 —Northern part of southern Qinling fold belt; II_2 —Southern part of southern Qinling fold belt; ● —Gold deposit: 1 —Baguamiao in Fengxian; 2 —Shuangwang in Taibai; 3 —Maanqiao in Zhouzhi; 4 —Pangjiahe in Fengxian; 5 —Liba in Lixian; 6 —Jinshan in Lixian; 7 —Xiaogouli in Chengxian; 8 —Jianchaling in Lueyang; 9 —Shangjiagou in Kangxian; 10 —Liehecun; 11 —Zhaogou in Lixian; 12 —Sanyangba in Chengxian; 13 —Zhenghe; □ —Pb-Zn deposits: 14 —Yinmusi; 15 —Bafangshan; 16 —Qiandongshan; 17 —Luoba; 18 —Changba-Lijiagou; 19 —Dengjiashan; NCP —North China Platform; YZP —Yangtze Platform, SGFS —Songgan Fold System

by brittle-ductile faults, orebodies extend in accordance with strata as stratified and lenticular bodies as well as stockwork. The mineralization is clearly divided into three stages: 1) mineralization stage in regional metamorphism in which the bedding quartz-carbonate veins with Au content 1×10^{-6} (or g/t) more or less were formed; 2) quartz-carbonate-gold mineralization stage in which the extensively-distributed quartz-veins with Au content $2 \times 10^{-6} \sim 5 \times 10^{-6}$ were formed; 3) quartz-pyrite(pyrrhotite)-gold mineralization in which the superimposition of NE-trending densely-distributed quartz veins on the early-formed orebodies plays the positive role in the formation of rich ores. The ore types are quartz veins with minority sulfides and Au content 5×10^{-6} more or less. The Au-carrying minerals are mainly pyrite and pyrrhotite. The other sulfides are not commonly present. Gangue minerals are mainly sericite, quartz, ankerite and calcite etc[10, 11].

2.2 Auriferous quartz vein type gold deposit

It is the new type of gold deposit in southern Qinling. Xiaogouli gold deposit is a typical example. It is located in periphery of Changba, Dengjiashan super large and large Pb-Zn deposits, western Xicheng basin. Its country rocks are Xihanshui Formation epimetamorphic fine clastic rocks of Upper Devonian. Orebodies are complex quartz veins, trending east-west in accordance with strata, 1~ 3 m thick. They contain minority carbonate and a few sulfides. Native gold commonly occurs in quartz veins with Au content $6 \times 10^{-6} \sim 12 \times 10^{-6}$.

2.3 Ductile shear zone-hosted type gold deposit

The Shangjiagou gold deposit is a typical one which is located in the fourth member silty phyllite and slate (sericite quartz shiest locally) of Middle Devonian Sanhekou Group. Controlled by Sanguan-Hentansi brittle-ductile shear zone, orebodies strike east-west, deeply dipping south, featuring silicified auriferous mylonite, 300 m in length, 20~ 30 m in width, with Au content 2.3×10^{-6}. The mineralization is divided into three stages. In the main metallization stage, the massive smoky (fine pyrite-bearing) quartz veins were formed. The main ore minerals are quartz and pyrite. Hydrothermal alteration is characterized by silicification, sericitization, pyritization, bleaching and carbonitization.

3 SAMPLING AND DATING METHOD

The samples for observation of fluid inclusions, temperature measurement, and chemical composition determination were collected from quartz veins related to Au mineralization in Baguamiao, Shangjiagou and Xiaogouli gold deposits. Under the premise of freshness, purity and no presence of secondary inclusions, one sample was chosen from each gold deposit for Ar-Ar dating. The sample BGM-1 was collected from NE-trending quartz vein overlapping on early-formed orebodies in the Baguamiao gold. NE-trending quartz veins are characterized by several millimeter to several centimeters in thickness, rare presence of sulfides and intensive hydrothermal alteration beside them with Au content $5 \times 10^{-6} \sim 12 \times 10^{-6}$. The sample PD-4 of the Xiaogouli gold deposit was collected from EW-trending quartz vein with visible gold. The sample SJG-2 of the Shangjiagou gold deposit was collected from EW-trending coarse-grained quartz vein outside ductile shear zone (intense silicification), 1~ 2 m thick, with minority sulfides.

The analysis was carried out in Institute of Geology, Sinian Academy. At first, the samples were put in reaction pile for fast-neutron irradiation, which takes 60~ 80 h with integration flux of 1×10^{18}~ 3×10^{18} cm^{-2}. Then they were heated by step. Secondly, the samples were put in RGA-10 gas-source mass spectrometer and Ar-separating system for extraction and purification of Ar. Finally, the samples were put in RGA-10 gas-source mass spectrometer for stable isotope analysis[12]. It should be noted that the purifying time was long enough, and the data were deducted to revise Cl and interference of ^{40}Ar. The careful observation of the procedure could guarantee the precision of the results.

Step heating method is adopted to extract Ar for mass spectrum analysis. Table 1 shows neutron activation irradiation coefficients, Ar isotope ratio at different temperature, percentage of separated ^{39}Ar and the apparent age. Based on the related data, the $^{40}Ar/^{39}Ar$ age spectrum and isochron were plotted, as shown in Fig. 2.

4 ANALYTICAL RESULTS

The step heating indicates that the lowest

Table 1 Ar-Ar dating data of quartz veins of three gold deposits

Sample	Heating stage	t/ ℃	$(^{40}Ar/^{39}Ar)_m$	$(^{36}Ar/^{39}Ar)_m$	$(^{37}Ar/^{39}Ar)_m$	$(^{38}Ar/^{39}Ar)_m$	$^{39}Ar_k$ / 10^{-12} mol	$(^{40}Ar^*/^{39}Ar_k)$ ±1σ	$^{39}Ar_k$ /%	Apparent age ±1σ/ Ma
BGM-1	1	430	46.667	0.118 5	1.889 4	0.229 6	0.313	11.95±0.18	2.46	245.27±2.82
	2	550	28.606	0.069 7	1.471 6	0.177 9	0.482	8.20±0.07	3.79	171.90±0.78
	3	640	12.269	0.020 2	0.657 3	0.102 5	1.380	6.37±0.01	10.85	134.83±0.17
	4	720	10.533	0.014 7	0.566 8	0.116 0	1.740	6.24±0.01	13.68	132.31±0.15
	5	800	7.670	0.005 1	0.299 5	0.055 1	4.080	6.16±0.01	32.10	130.69±0.12
	6	900	9.385	0.011 2	0.513 0	0.092 7	2.080	6.12±0.01	16.32	129.72±0.17
	7	1 000	14.937	0.029 1	1.119 3	0.172 2	0.916	6.44±0.02	7.20	136.44±0.23
	8	1 100	24.364	0.052 7	1.916 9	0.366 4	0.637	9.01±0.05	5.01	187.95±0.69
	9	1 200	35.825	0.082 5	3.067 8	0.541 2	0.449	11.83±0.11	3.53	243.09±1.76
	10	1 350	45.096	0.105 1	2.599 4	0.605 1	0.364	14.42±0.17	2.86	292.09±3.19
	11	1 550	59.091	0.144 6	2.951 2	0.504 1	0.280	16.81±0.28	2.20	336.31±6.06
PD-4	1	430	44.444	0.104 9	1.342 6	0.166 7	0.375	13.67±0.14	3.28	278.05±2.51
	2	560	27.799	0.056 0	0.959 1	0.115 7	0.621	11.39±0.05	5.43	234.58±0.86
	3	640	20.118	0.035 5	0.877 5	0.109 5	0.784	9.72±0.03	6.85	202.10±0.42
	4	720	16.146	0.022 9	0.700 3	0.087 5	1.110	9.44±0.02	9.74	196.46±0.29
	5	800	11.783	0.008 3	0.466 0	0.049 7	3.640	9.36±0.01	31.85	194.90±0.20
	6	900	12.685	0.011 1	1.153 4	0.080 6	2.500	9.49±0.01	21.90	197.45±0.23
	7	1 000	16.914	0.024 7	1.513 5	0.130 9	0.939	9.76±0.02	8.21	202.72±0.34
	8	1 150	26.621	0.049 5	2.227 0	0.228 7	0.679	12.24±0.05	5.94	250.88±0.88
	9	1 300	36.946	0.076 4	2.824 7	0.359 6	0.470	14.73±0.10	4.11	297.85±1.92
	10	1 500	55.639	0.127 8	3.716 7	0.646 6	0.308	18.39±0.22	2.69	364.85±5.14
SJG-2	1	450	41.143	0.097 1	1.280 6	0.234 3	0.406	12.66±0.12	3.29	258.92±2.03
	2	560	26.493	0.056 0	1.222 2	0.175 4	0.621	10.11±0.05	5.04	209.69±0.72
	3	670	11.719	0.014 1	0.565 7	0.079 7	1.480	7.60±0.01	12.05	159.91±0.17
	4	760	10.160	0.008 6	0.424 1	0.061 0	2.170	7.65±0.01	17.61	160.88±0.16
	5	850	9.915	0.007 6	0.372 5	0.056 8	2.740	7.68±0.01	22.22	161.36±0.15
	6	930	10.807	0.016 0	0.578 2	0.078 3	1.870	7.72±0.01	15.16	162.33±0.17
	7	1 000	13.347	0.018 9	0.910 0	0.111 6	1.160	7.83±0.01	9.45	164.50±0.21
	8	1 100	24.161	0.045 3	1.706 6	0.206 4	0.691	10.96±0.04	5.61	226.29±0.67
	9	1 200	33.258	0.070 1	1.911 1	0.242 1	0.512	12.78±0.08	4.16	261.12±1.37
	10	1 350	41.716	0.094 7	1.887 1	0.224 9	0.392	14.01±0.12	3.18	284.51±2.28
	11	1 550	58.475	0.144 1	2.410 6	0.296 6	0.273	16.29±0.24	2.22	326.87±5.04

Conotation: sample weighs 0.45 g, irradiation coefficient $J=0.012\ 19$. Instrument: RGA-10 Gas Source Mass Spectrometry made by U.K. VSS Corp, $\lambda=5.543\times10^{-10}\ a^{-1}$. Sampling representation: BGM-1 for quartz-pyrite (pyrrhotite)-gold mineralization in NE-trending quartz veins; PD-4 for quartz-sulfides stage; SJG-2 for quartz-pyrite mineralization stage amount of ^{39}Ar is released at low-temperature (430~560 ℃) and high-temperature(1 100~1 550 ℃); the apparent ages are of no geochronological significance. At the other five stages, the great volume of ^{39}Ar is released. Baguamiao, Xiaogouli and Shangjiagou gold deposits release ^{39}Ar volume 80.15%, 78.55% and 76.49% respectively; the $^{40}Ar/^{39}Ar$ age spectrum forms a flat saddle (Fig. 2). At the saddle, the apparent age forms a plateau. The plateau ages of the Baguamiao, Xiaogouli and Shangjiagou gold deposits are respectively (131.91 ±0.89) Ma, (197.45 ±1.13) Ma and (161.59 ±0.56) Ma which represent the ages when quartz veins were formed. Because the plateau age is made up of five continuous heating data, isochron ages can be obtained based on the data.

The $^{40}Ar/^{36}Ar$ vs $^{39}Ar/^{36}Ar$ isochron ages of the Baguamiao, Xiaogouli and Shangjiagou gold deposits are (129.45 ±0.35) Ma, (193.24 ±0.93) Ma and (160.00 ±0.85) Ma respectively, with correlation coefficients r over 0.999, which indicates that the plateau age is consistent with the isochron age with error less than 5 Ma. The initial $^{40}Ar/^{39}Ar$ values (301~308) are close to Nier value(296.5 ±5). Because western Qinling had not been involved in the large scale tectonic movement and heat event since Yanshannian movement (metallization), Ar losing could be excluded. The above-mentioned discussion indicates that the isochron ages and plateau ages of the Baguamiao, Xiaogouli and Shangjiagou gold deposits are precise and reliable. Accordingly, the Ar-Ar ages represent the metallogenic ages of gold deposits in western Qinling.

5 IMPLICATION OF Ar-Ar DATING FOR METALLOGENESIS

Since the discovery of the Shuangwang gold deposit in 1980s, over twenty super large, large and middle gold deposits have been discovered in southern Qinling where is now an important gold belt in

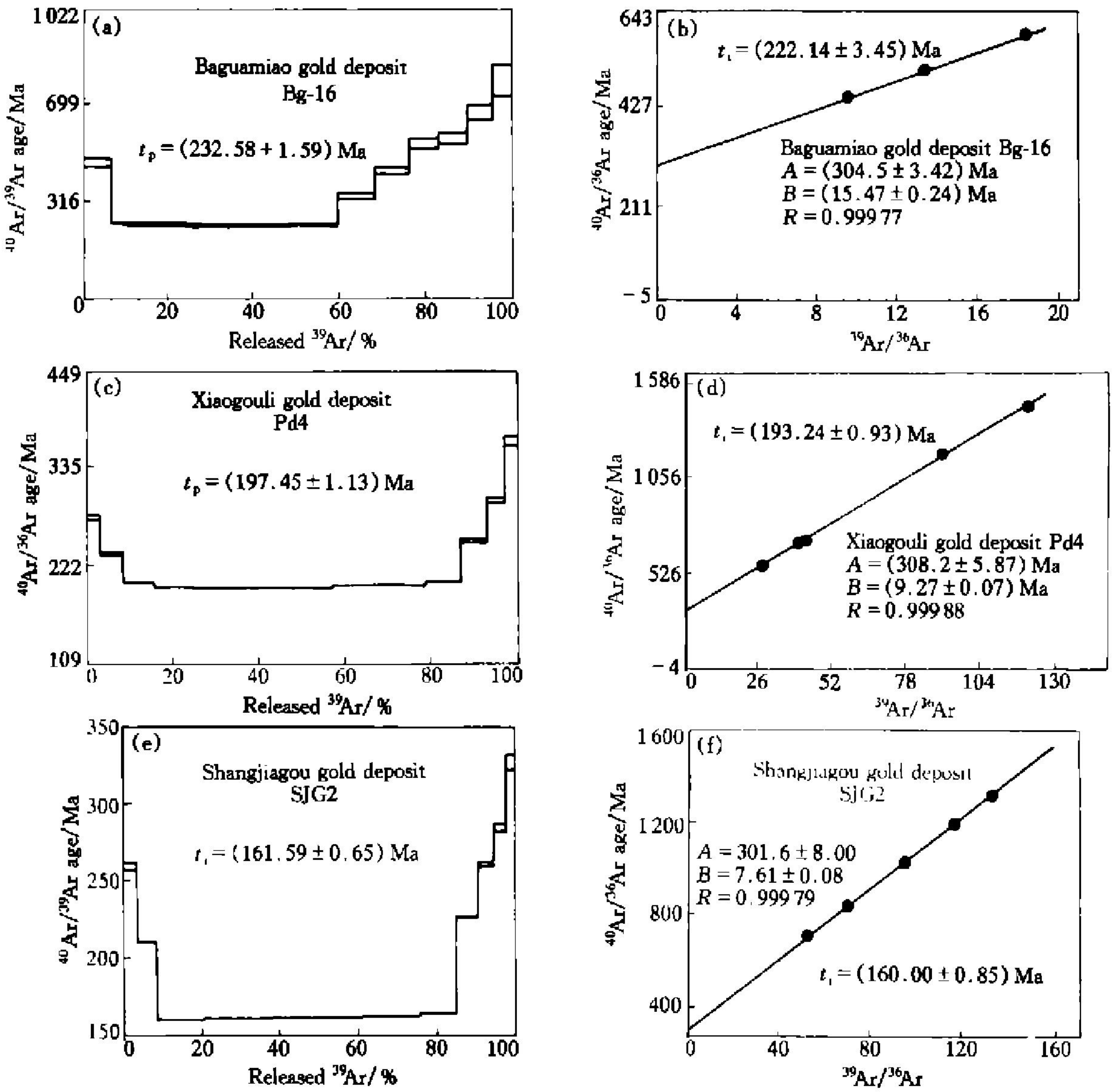

Fig. 2 Plateau age (left) and isochron age(right) of Au-bearing quartz veins of Baguamiao, Xiaogouli and Shangjiagou gold deposits

China. The large amount of comprehensive geological and geochemical researching work has been done so far, but as lack of geochronological data, the relations between metallization and evolution of regional tectonics is still controversial. Based on the Rb-Sr dating of fluid inclusions of quartz, arsenopyrite and pyrite, the isochron age of Liba gold deposit is (171.6 ± 26.9) Ma. According to $^{40}Ar/^{39}Ar$ dating of pyrite of the second and fourth metallogenic stages[13], the $^{40}Ar/^{39}Ar$ ages of two metallogenic stages are respectively (183.09 ±20.66) Ma and (168.00 ±16.20) Ma. These data indicate that gold deposits of southern Qinling were formed in early Yanshannian, but the error of these dating methods is considerably high ($^{40}Ar/^{39}Ar$ dating error of the Shuangwang gold deposit is up to 20 Ma more or less). There is no detailed introduction of analytical methods, precision and reliability of data. LIU[14] (1996) and HUANG[15] (2000) obtained the Rb-Sr isochron age based on the five data with correlation parameter r = 0.002 439. Its reliability and precision are far from credibility. A lot of data of various dating methods confirm that the felsic intrusives in southern Qinling were massively emplaced in Indosinian-early Yanshannian. The Rb-Sr ages and U-Pb ages range from190 Ma to 220 Ma[1, 16]. Based on Ar-Ar ages 129.45~ 197.45 Ma we dated (Table 1, Fig. 2), it is suggested that gold deposits were formed in Yanshannian, and that the regional metallization process lasted 60~ 70 Ma. It is convinced that the location of gold deposits is slightly later than emplacement of intrusives. Accordingly, it can be accepted that Indosinian-Yanshannian tectonic-thermal event is responsible for the formation of Xiaogouli gold deposit and the early-formed orebodies (quartz-carbonate veins) of the Baguamiao gold deposit. The age (197.45 ±1.13) Ma of the Xiaogouli gold deposit represents the upper age limit, and the age (131.91 ±0.89) Ma of NE-trending quartz veins of the Baguamiao gold deposit represents the lower age limit. ZHANG[2] (1996) pointed out that Mianxian-Luoyang geosuture was closed and transformed into intracontinent orogene. As a result of intensive deformation of rocks in the geosuture, several parallel thrusting nappes (Mianxian-Lueyang tectonic mélange belt) were formed. The Shangjiagou gold deposit in Kangxian, Gansu, is located in a regional ductile shear zone in the northern side of this tectonic belt. The Xiaogouli gold deposit and Baguamiaogold deposit are also located on the rim of Xicheng orefield and Fengtai orefield. The metallogenic ages of the Shangjiagou, Baguamiao and Xiaogouli gold deposits are respectively 160Ma, 130 Ma, and 193~ 197 Ma, which indirectly supports the fact that the intracontinent orogene took place in Mesozoic.

Based on geochronology and historic evolution of regional geology, it is summarized that multi-period and multi-epoch metallization is the premise for the formation of large or super large gold deposits. As a typical example, the Baguamiao super large gold deposit witnessed three-epoch mineralization. In the first mineralization epoch, the bedding quartz-calcite veins with Au content 1×10^{-6} was formed in regional metamorphism. The preliminary study indicates that bedding quartz vein of the Baguamiao gold deposit gains $^{40}Ar/^{39}Ar$ plateau age (232.58 ±1.59) Ma and isochron age (222.14 ± 3.45) Ma. Bedding quartz vein of Liba gold deposit in Lixian gains $^{40}Ar/^{39}Ar$ plateau age (210.60 ±1.26) Ma and isochron age (205.02 ±3.54) Ma. It is convinced that the late-superimposed mineralization took place in late Indosinian. In the second epoch, under the large-scale fluid process, the large-dimensioned quartz veins such as those in the Xiaogouli gold deposit were formed in early Yanshannian. In the third mineralization epoch (130 Ma) Au is highly enriched in and near NE-trending quartz veinlets to form rich ores.

6 CONCLUSION

The Ar-Ar dating of the three typical gold deposits in Qinling offers metallogenic age 129.45 ~ 197.45 Ma, corresponding to early Yanshannian. The studies on gold deposits of different type and different scale reveal that multi-epoch and multi-stage mineralization is the prerequisite for formation of super large and large gold deposits. It is known from the determined metallogenic age that the metallization in southern Qinling lasted 60~ 70 Ma.

The main types of gold deposits were formed in early Yanshannian, slight later than continent-continent collision and orogene in Mesozoic. The temporal succession of mineralization and orogene indicates that metallization is consistent with tectonic event, and collision orogene → magmatic intrusion → location of mineral deposits constitute a systematic, organic and successive process. The orogenic renovation period corresponds to massive metallogenic period.

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