NOTES

^{40}Ar-^{39}Ar dating and geological implication of auriferous altered rocks from the middle-deep section of Q875 gold-quartz vein in Xiaoqinling area, Henan, China

WANG Yitian[1], MAO Jingwen[1], LU Xinxiang[2] & YE Anwang[3]

1. Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing 100037, China;
2. Institute of Geological Sciences, Henan Province, Zhengzhou 450053, China;
3. Lingbao Bureau of Geology and Mineral Resources, Henan Province, Lingbao 472500, China

Correspondence should be addressed to Wang Yitian (e-mail: wyt69@263.net)

Abstract **The ^{40}Ar-^{39}Ar age method is employed in this work to analyze the auriferous altered rocks from the middle-deep section of the Q875 gold-quartz vein in the Xiaoqinling area, and the results show that the main gold deposition of the Q875 occurred in ca. 128—126 Ma. As a typical gold-bearing quartz vein in this gold-rich area, the age data obtained from the Q875 also constrain on the metallogenic time of the lode gold deposits developed in the same geological settings. This geochronological study supplies new evidence for further understanding the timing of gold mineralization, the genesis of gold deposits and the geodynamic settings in Xiaoqinling area.**

Keywords: ^{40}Ar-^{39}Ar dating, auriferous altered rock, Q875 gold-quartz vein, lode gold deposit, metallogenic time, Xiaoqinling.

The Xiaoqinling area located on the south margin of the North China craton is an important area of gold production in China. A lot of research works around the lode gold deposits developed in this area have been carried out by many researchers, which lead to understanding more and more the gold deposits. However, the knowledge of the metallogenic time is still very different in the light of the achievements of different researchers. The earliest age data are 108—76 Ma[1], which is indirectly determined according to the crosscutting relationship between the gold-quartz veins and the dikes of diabase and minette, and ages of the latter are determined by the K-Ar age method. Liu[2] analyzed the metal minerals from Q505 quartz vein, and he gained 85 Ma and 673 Ma of ^{40}Ar-^{39}Ar total-fusion age for galena and pyrite, respectively, which make him believe that there are two metallogenic stages. Li et al.[3] analyzed the quartz of both quartz-pyrite stage and quartz-polymetallic sulfide stage of Q60 quartz vein, and gained a (161.5±17.9) Ma of Rb-Sr isochron age, and he suggests that the main ore-forming event occurred during 160—170 Ma. Shen et al.[4] and Li[5] suggest that the gold mineralization developed early than 1800 Ma in light of the lead isotopic compositions and comparison with the gold deposits developed on the north margin of the North China craton. Xu et al.[6] analyzed the sericite from altered rocks of Q507 quartz vein with the ^{40}Ar-^{39}Ar age method, and obtained a plateau age of (132.16±2.64) Ma, and he suggests that the gold minertalization developed after 132 Ma. Analyzing the quartz of Q303 quartz vein, Xue et al.[7] gain Rb-Sr isochron ages of 2382—2234 Ma and ^{40}Ar-^{39}Ar ages of 2046 Ma (plateau age) and 2005 Ma (isochron age), which make them believe that the main gold mineralization developed in Paleoproterozoic. Lu et al.[8] suggest that the ore-forming event occurs in the Indo-Chinese epoch according to their synthetic analysis and discussion. All the different age data mentioned above directly have influence on recognizing the source of metallogenic materials, the evolution of ore-forming fluids and metallogenic mechanism, and restrict further understanding the gold mineralization in this area. Therefore, it is necessary to select the typical samples for further dating to gain more reliable age data for answering the questions clearly.

In the 1990s, especially in recent years, many research works on the tectonic evolution and geodynamic features of the region of the Xiaoqinling, Qinling and East China have been carried out with a lot of important advances and breakthroughs, which lay a sound foundation for the further study on gold deposits. As the prospecting engineering is limited, the research works before in the Xiaoqinling area mainly focus on ore veins occurring in the surface and shallow section. In recent two and three years, the prospecting works performed in the middle-deep section make us have more chances to study the metallogenic geology in this area. Therefore in this work, we select the auriferous altered rocks from the middle-deep section of the Q875 gold-quartz vein to be studied with the ^{40}Ar-^{39}Ar age method to determine the timing of gold deposition, and combine the new advances in the regional tectonic evolution and deep process to synthetically analyze the gold mineralization. This study supplies new evidence for the metallogenic time, further understanding the genesis of gold deposits and geodynamic settings in the Xiaoqinling area.

1 Geological features of the ore vein

The Q875 quartz vein, a ore-bearing fault belt, occurs at Hongtuling-Heiyuzi where is southeast to the Wenyu granite, which is the main part of the Hongtuling gold deposit. The fault is located to the north of the core of Qishuping syncline, and controlled by both its north limb and Wulichun anticline. The fault belt is 3.7 km long, and 1—3.5 m wide. It is near west-east trending, and dips 160°—200° with a dip range of 30°—60°, which displays the flat wavy shape along both the strike and the dip. The fault belt shows the character of multi-deformation, which at least consists of deformations of compresso-shear, tenso-shear and compression. The mylonite, cataclasite and quartz veins are well developed in the fault belt, and the wall rocks mainly consist of the biotite-plagioclase gneiss, plagioclase-amphibole gneiss and granulitite of Archean Taihua group.

The prospecting works before show that the ore body of Q875 mainly occurs at the elevation range of 1178—1690 m, and the mining works are limited to this range. The middle-deep prospecting and mining engineering has been carried out in recent two or three years, and new ore body with average gold grade of 4.78 g/t has been found and mined at the elevation lower than 1000 m. At present, there are two tunnels of PD986 and PD848 (the number stands for the elevation of the tunnel portal). In PD986, the fault shows the attitude of 205°∠52°, and the width is 2.3 m. While the attitude of the quartz vein is 195°∠38°, and its maximum width is 0.96 m and the general width is about 0.65 m. In PD848, the attitude of the fault changes into 225°∠54°, and the width is about 1.5 m. Meanwhile, the width of the quartz vein also changes smaller than 0.6 m, and its attitude is 190°∠50°. The quartz vein is distributed discontinuously in the middle-deep part of the fault as shapes of irregular vein and lens, and the intersection angles come to form between the quartz vein and the fault. The main metallogenic alteration developed in the quartz vein is of pyritization and gold, and the altered mylonite, mylonite and cataclasite are developed in the part of the fault where there is no quartz vein. The wall-rock alteration is mainly developed as the altered mylonite (i.e. the auriferous altered rock), and the major alteration types are of silication, biotitization, pyritization, sericitization, carbonatization, and chloritization. The alteration intensity gets weaker and vanishes finally from the ore body to both sides.

The lode gold deposits in the Xiaoqinling area are mesothermal deposits, and the ductile shear belts strictly control the ore bodies. The early ductile shear belts are superimposed by the late ductile-brittle deformation to form the extensive dilatant spaces that make the quartz vein and ore-forming fluid be immigration and emplacement[9]. The mineralization process of lode gold deposits in the Xiaoqinling area can be divided into four stages, and from early to late they are (i) pyrite-quartz stage; (ii) quartz-pyrite stage; (iii) quartz-polymetal sulfide stage; and (iv) quartz-carbonate stage[10], and the metallogenic temperature decreases from the early stage to the late stage[11]. The gold enrichment mainly occurs in the second and the third stage; in other words, both the quartz-pyrite stage and the quartz-polymetal sulfide stage are the main ore-forming periods. The first and second metallogenic stages are well developed in Q875, and the gold deposition mainly occurs in the quartz-pyrite stage. The third and fourth stages are not well developed in Q875 just like most of other gold-quartz veins in this area.

2 Samples and analytical methods

Two samples used in this study were collected from the middle-deep section of Q875 fault belt, which are the auriferous altered rocks and the protolith is the plagioclase-amphibole gneiss. Sample 516HY5-1 was collected from PD986, and 519MJ2 from PD848. The main minerals of sample 516HY5-1 are biotite, quartz, plagioclase and pyrite. The quartz and plagioclase are distributed as lens and veinlet along the shear foliations composed of the fine-grained biotite. The pyrite, the main metal sulfide, is distributed in the rock, which is cubic crystal and its grain size is smaller than 0.1 mm. The chlorite and sericite are rare in the rock. All the minerals are of directive spread, and the shear indicators are well developed in the rock, such as the stretching linenation, S-C fabric and σ porphyroclastic. Under the microscope, the biotite appears as fine lepidosome, and its content is about 60%, which composes the S-C fabric. The content of quartz is about 20%, and subgrain and wavy extinction are well developed. There is a little calcite appearing as thread vein or aggregate, which implies that the carbonatization comes to form. The mineral composition and deformation feature of sample 519MJ2 are similar to those of sample 516HY5-1, while there are some differences between them. The grain size of biotite is rather smaller, and the content of quartz is rather high. The quartz stringers, whose thickness is smaller than 1 mm, are densely distributed along the shear foliations. The grain size of pyrite is bigger than that of sample 516HY5-1, and the maximum is up to 2 mm. The chalcopyrite can be seen occasionally. On the profile of Q875 fault, it can be recognized that both biotitization and pyritization are syngenetic, and their alteration intensities decrease at the same time from the core of the ore body to both sides. Besides, the biotite appearing as fine lepidosome under the microscope implies the character of thermal alteration. Therefore, it can be inferred that the biotite is a product of the same thermal alteration as the pyrite, the directly metallogenic mark. In addition, the big content and grain of biotite in the sample is easy for separation. So the biotite is selected to be the dating mineral in this study.

The two samples described above are crushed and selected first with the heavy liquid separation, and then the fresh biotite without alteration is separated out under the binocular microscope to 99% or greater purity. The biotite minerals are irradiated in a fast neutron flux in the H8 facility adjacent to the core of the 49-2 reactor, Chinese Institute of Atomic Energy. The fluence monitors are the ZBH-25 biotite of Chinese standard sample and the BSP-1 hornblende of international standard sample, whose ages are (132.7±2.1) Ma and (2060±18.6) Ma, respectively. The irradiated minerals are incrementally heated in the extreme high vacuum argon extraction system, the Laboratory of Argon-Argon Dating, Institute of Geology and Geophysics, the Chinese Academy of Sciences. Then, the purified argon is analyzed statically with the RGA-10 gas mass spectrometer. The mass spectrogram peak values of the argon isotopes are corrected with background correction, mass preferential correction, fractionation correction and memory effect correction, and ^{37}Ar is corrected with decay correction. Factors used to correct the effects of interfering neutron reactions are $(^{40}Ar/^{39}Ar)_K = 3.048\times10^{-3}$, $(^{36}Ar/^{37}Ar)_{Ca} = 2.644\times10^{-4}$, $(^{39}Ar/^{37}Ar)_{Ca} = 6.868\times10^{-4}$. The decay constant of ^{40}K of $\lambda = 5.543\times10^{-10}/a$ is used to calculate the ages at 1σ uncertainty.

3 Analytical results

The analytical results of argon isotopic compositions of the two minerals are shown in both table 1 and table 2.

The biotite of sample 516HY5-1 is incrementally heated with 11 stages, and the temperatures range from 420℃ to 1400℃. The differences of apparent ages from the fourth to the tenth stage (temperature ranges 720—1300℃) are fairly small, and they are calculated with the method of weighted mean to obtain the plateau age of (128.5±0.2) Ma (fig. 1(a)), and the percentage of released $^{39}Ar_K$ is up to 86.6%. The data are calculated with the linear regression analysis to obtain the isochron age of (128.3±0.3) Ma (fig. 1(b)), and the coefficient of correlation is 0.99995. The biotite of sample 519MJ2 is incrementally heated with 12 stages, and the temperatures

Table 1 Analytical results of ^{40}Ar-^{39}Ar isotopic data for biotite of sample 516HY5-1 from Q875 gold-quartz vein in Xiaoqinling area

Heating steps	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)	$^{40}Ar^*/^{39}Ar_K$	$^{39}Ar_K$ (%)	Apparent age t/Ma (±1σ)
1	420	8.3114	0.0175	0.1917	0.0232	5.29	3.135	1.6	56.5±0.7
2	550	6.9391	0.0076	0.1124	0.0401	12.20	4.682	3.7	83.7±1.0
3	640	7.8142	0.0065	0.0934	0.0344	21.22	5.863	6.4	104.2±1.2
4	720	8.0379	0.0025	0.0801	0.0218	36.65	7.270	10.9	128.3±1.5
5	800	7.9729	0.0023	0.0770	0.0201	68.66	7.253	20.5	128.0±1.5
6	880	8.1272	0.0028	0.0756	0.0189	65.65	7.271	19.6	128.3±1.5
7	1000	8.1140	0.0026	0.0775	0.0171	52.89	7.316	15.8	129.1±1.5
8	1100	8.3561	0.0034	0.0946	0.0250	33.86	7.327	10.1	129.3±1.5
9	1200	9.1489	0.0063	0.1128	0.0313	21.80	7.251	6.5	128.0±1.5
10	1300	10.5490	0.0109	0.1483	0.0468	10.55	7.300	3.2	128.8±1.5
11	1400	13.5290	0.0180	0.2065	0.0820	5.13	8.196	1.5	144.0±1.8

Analysis unit: Laboratory of Argon-Argon Dating, Institute of Geology and Geophysics, the Chinese Academy of Sciences. Analysts: Sang Haiqing and Wang Yingju. $W = 0.1218$ g, $J = 0.010137$.

Table 2 Analytical results of ^{40}Ar-^{39}Ar isotopic data for biotite of sample 519MJ2 from Q875 gold-quartz vein in Xiaoqinling area

Heating steps	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)	$^{40}Ar^*/^{39}Ar_K$	$^{39}Ar_K$ (%)	Apparent age t/Ma (±1σ)
1	420	16.4610	0.0136	0.1674	0.0318	7.14	12.430	2.1	211.4±2.4
2	550	7.7861	0.0118	0.1616	0.0305	12.36	4.292	3.7	75.8±0.9
3	640	8.7899	0.0114	0.2258	0.0331	10.16	5.421	3.1	95.2±1.1
4	720	9.7389	0.0104	0.2047	0.0347	11.55	6.655	3.5	116.2±1.4
5	800	8.6673	0.0045	0.1051	0.0189	23.15	7.319	7.0	127.4±1.5
6	880	7.9032	0.0020	0.0746	0.0151	57.53	7.286	17.2	126.9±1.5
7	960	7.9761	0.0023	0.0848	0.0169	77.94	7.252	23.4	126.3±1.5
8	1040	7.9779	0.0022	0.0847	0.0158	63.10	7.305	18.9	127.2±1.5
9	1120	8.5294	0.0044	0.1472	0.0286	31.54	7.214	9.5	125.7±1.5
10	1200	9.2391	0.0065	0.1220	0.0353	21.34	7.301	6.4	127.1±1.5
11	1300	10.5050	0.0109	0.1933	0.0628	10.55	7.261	3.2	126.5±1.6
12	1400	12.5170	0.0154	0.1855	0.0845	6.45	7.957	1.9	138.1±1.8

Analysis unit: Laboratory of Argon-Argon Dating, Institute of Geology and Geophysics, the Chinese Academy of Sciences. Analysts: Sang Haiqing and Wang Yingju. $W = 0.1213$ g, $J = 0.009998$.

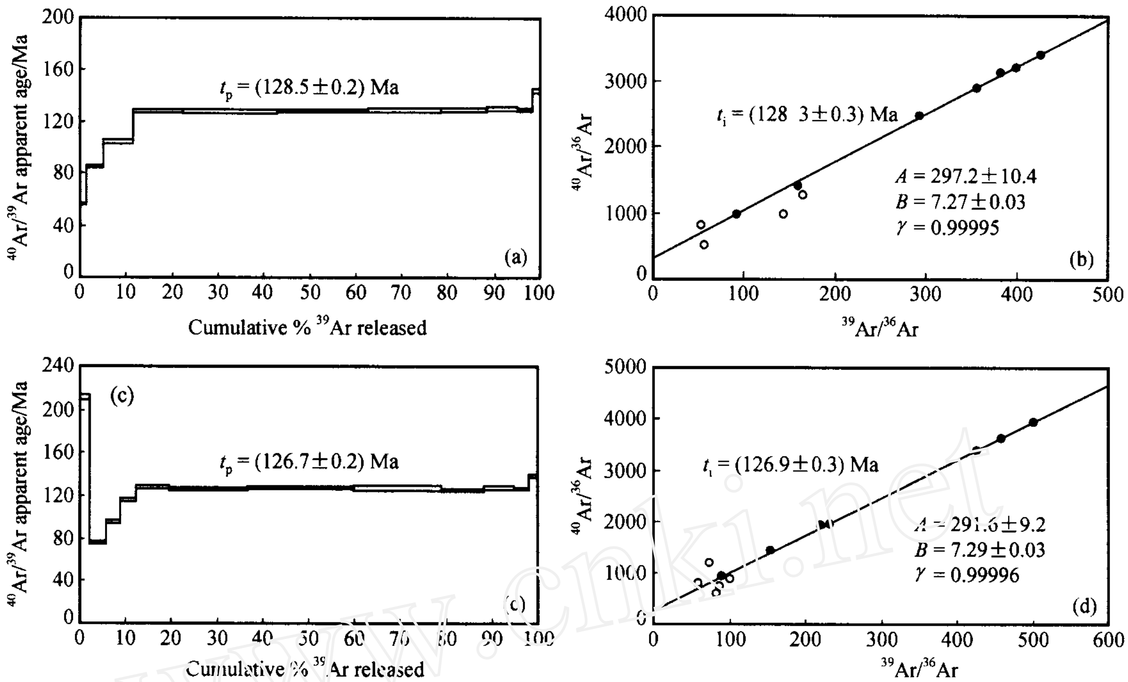

Fig. 1. Diagrams of ^{40}Ar-^{39}Ar plateau age and isochron age for biotites from the auriferous altered rock of the Q875 gold-quartz vein in Xiaoqinling area. (a) The plateau age diagram of sample 516HY5-1; (b) the isochron age diagram of sample 516HY5-1; (c) the plateau age diagram of sample 519MJ2; (d) the isochron age diagram of sample 519MJ2. The blank circles in the isochron age diagrams stand for the data not used for calculation.

range also from 420℃ to 1400℃. The apparent ages from the fifth to the eleventh stage (temperature ranges 800—1400℃) are calculated to obtain the plateau age of (126.7±0.2) Ma (fig. 1(c)), and the percentage of released $^{39}Ar_K$ is up to 85.6%. The isochron age calculated is (126.9±0.3) Ma (fig. 1(d)), and the coefficient of correlation is 0.99996.

The isochron ages of the two biotites are in accord with their plateau ages. Besides, their initial $^{40}Ar/^{36}Ar$ ratios of 297.2±10.4 for 516HY5-1 and 291.6±9.2 for 519MJ2 are consistent with the Nier's standard value of 295.5±5 within the error range, which indicate that the biotite does not contain excess argon, and also there is no notable argon loss. The data features mentioned above show that the ^{40}Ar-^{39}Ar age data of two biotites are precise and reliable.

4 Geological implication

On the plateau age spectra of two biotites (fig. 1(a), (c)), there appear some changes of argon isotopic composition causing the fluctuation of apparent ages in the low temperature range (≤540℃), which indicates loosing a little argon from the surfaces of mineral grains[12,13]. The two flat age spectra composed of the apparent ages in the middle-high temperature range imply that the argon isotopic compositions are stable inside the mineral grains. In other words, the argon loss from the surface does not extend into the interior of the mineral grain. Therefore, the data show that the biotites do not experience any thermal disturbance beyond their closure temperature after about 128—126 Ma, and the ages obtained are right their crystallization time. The K-Ar closure temperature of the biotite is generally regarded as (300±50)℃[14], which is consistent with the homogenization temperature (260—300℃)1) of the quartz-pyrite stage in the Q875. Actually, as the mesothermal lode gold deposits, the metallogenic temperatures of the quartz-pyrite stage (the second mineralization stage) of all the gold-quartz veins in Xiaoqinling area are mainly in the ranges[11,15]. Hence, the crystallization time of the biotite, the product of the same thermal alteration as the pyrite, is right the time of the gold mineralization of quartz-pyrite stage, i.e. the main gold deposition of Q875 occurred in ca. 128—126 Ma.

The age data obtained before in Xiaoqinling area are quite different from each other, and the data range from

1) Department of Geology, Beijing University of Science and Technology, the Ninth Gold Team of the Chinese Armed Police, Studies on the metallogenic geology and ore prospecting direction of Chucha-Luanshigou gold deposits in Henan Province (internal report in Chinese), 1992.

Paleoproterozoic to late Cretaceous. The early data are mainly of K-Ar ages[1], and their geological implications are usually uncertain because the age method cannot tell whether there exists the excess argon or argon loss. The ^{40}Ar-^{39}Ar total released age[2] is the average value of each apparent age so that the data are actually equivalent to those gained by the K-Ar method, and also its uncertainty is the same as that of the K-Ar age. Li et al.[3] put the quartz samples of different metallogenic stages together for Rb-Sr measurement, and the isochron age obtained is possibly a mixed age. From the view of the metallogenic temperature, the homogeneous temperatures of fluid inclusions in the quartz are generally lower than 350℃, which are far lower than the metamorphic temperature of the amphibolite facies in Paleoproterozoic, so it is impossible that the main gold mineralization develop in Paleoproterozoic[4,5,7]. However, the possibility of polymineralization cannot be ruled out at present, especially the existence of gold pre-enrichment under the hypometamorphic conditions in Precambrian.

Many researchers' achievements[16—19] show that the Qinling orogen results from the collision between the North China plate and the Yangtze plate in the Indo-Chinese epoch. In the Qinling area, both the widespread collision granites[19] and the rapakivi granites[20,21] within the Shangxian-Danfeng suture indicate that the two plates finally converge in the late Indo-Chinese epoch, and the intracontinental evolution or intracontinental orogenesis emerges from then on in this area. No doubt, the Xiaoqinling area can response to and record the orogenesis evolution as the marginal component of the Qinling orogen. In the collision process, the Xiaoqinling takes into form the Taihua nappe as the overthrust basement in the compression tectonic regime[17,22]. In the intracontinental process of post-collision, the Xiaoqinling develops as a metamorphic core complex in the extensive tectonic regime[9,23]. The synorogenic (intracontinental orogenesis) detachment tectonics parallel to the orogen developed in the Xiaoqinling metamorphic core complex occur in 135—123 Ma according to the study of isotope geochronology[23]. The age data obtained in this study are in the age range above, also similar to the ^{40}Ar-^{39}Ar plateau age of 132 Ma for the sericite from the altered rock of Q507[6]. Obviously, the geochronological data supply directly evidence for the time relationship between the gold mineralization and the tectonic evolution.

The deformations of the gold-bearing faults can be recognized and divided into three stages according to geological features in the field, and they are the early stage of ductile compresso-shear deformation, the middle stage of superimposition of brittle-ductile tenso-shear deformation and the late stage of superimposition of brittle compresso-shear deformation. The emplacement of quartz veins and the immigration of ore-forming fluids mainly occur in the process of the middle stage of brittle-ductile tenso-shear deformation, which are consistent with the tectonic features of deformation behavior, sense of movement (NNW), and tectonic level when the Xiaoqinling metamorphic core complex takes into form[23]. Therefore, it can be inferred that the middle stage of deformation superimposition of the ore-bearing fault results from the regional extensive tectonics. Kerrich and Wyman[24] document that the intensive decompression partial melting will take place at depth due to the decreasing of the compressive stress during the transformation from the compressive regime to the extensive regime in orogen, and the fluids produced will migrate upwards. Meanwhile, the tectonic behavior of shallow faults transfers as well, which supply tunnels for shallow fluids moving downwards. Then, the intensive polygenetic fluid activities will occur inside the obduction plate during the transformation of the tectonic regime, which can lead to the mineralization on a large scale. Therefore, we suggest that the age data obtained in this study constrain on the time of the main gold deposition in Q875 quartz vein, as well as on the metallogenic time of the lode gold deposits developed in the same geodynamic settings in Xiaoqinling area.

In East China, the large-scale lithosphere delamination develops in Yanshanian, which results in lithosphere thinning and asthenosphere upwelling[25]. The widespread volcanic rocks and granites indicate that the delamination occurs in ca. 160—120 Ma[26]. This tectonic phase is exactly the peak time of the crust-mantle interaction when the deep-seated fluids, including magmatic fluids and metamorphic dehydration fluids, come to produce, migrate and accumulate in large [27]. There develop a lot of gold deposits in Xiaoshan and Xiong'ershan metamorphic core complexes, which are located on the south margin of the North China craton as well. The metallogenic time of the gold deposit is 130 Ma in the Xiaoshan area, and the typical Qiyugou gold deposit in Xiong'ershan emerges in 125 Ma[29]. While in the Jiaodong gold-rich area located on the east margin of North China, the age of main mineralization of lode gold deposits is about 122—123 Ma[30,31]. All the data of isotope geochronology coincide with the time range of the lithosphere delamination in East China, which implies the time relationship between the mineralization in the south and east margin of the North China craton and the deep-seated tectonic process in East China.

5 Conclusions

The main gold deposition of the Q875 quartz vein occurred in ca. 128—126 Ma, and the age data as well constrain on the metallogenic time of the lode gold deposits developed in same geological settings in the Xiaoqinling area.

The age data of tectonic deformation and gold mineralization further prove that the development and evolution of the typical extensive tectonics of Xiaoqinling metamorphic core complex affect and control the occurrence and distribution of gold deposits.

More and more geochronological studies supply new important evidence for the temporospatial coupling relationship between the gold mineralization in the periphery of the North China craton and the regional tectonic evolution and the deep-seated tectonic process.

Acknowledgements The authors would like to thank Liu Shulin, the vice president of the Lingbao Bureau of Geology and Mineral Resources, Henan Province, and Li Yongge, Bai Zhengquan, Li Shuhui, Shi Lihong, Tian Tao and Zhang Jianbin from the bureau for their generous assistance and cooperation in the field work. The manuscript has benefited from a valuable discussion on the analytical results with Prof. Sang Haiqing. This work was supported by the State Key Basic Research Program of China (Grant No. G1999043211).

References

1. Chao, Y., Discussion on the metallogenic epoch of gold deposits in Xiaoqinling, Shanxi Geology (in Chinese), 1989, 7(1): 52.
2. Liu, C., New knowledge of the metallogenic epoch of gold deposits in Xiaoqinling, Henan, Henan Geology (in Chinese), 1992, 10(3): 195.
3. Li, H., Liu, J., Wei, L., Chronology Study and Its Geological Application of the Fluid Inclusion in Thermal Deposits (in Chinese), Beijing: Geological Publishing House, 1993, 92—105.
4. Shen, B., Luo, H., Li, S. et al., Geology and Mineralization of the Archean Greenstone Belt in the North China Craton (in Chinese), Beijing: Geological Publishing House, 1994, 1—102.
5. Li, J., A primary discussion on the metallogenic epoch of China's gold deposits, Progress in Precambrian Research (in Chinese), 1997, 20(1): 17.
6. Xu, Q., Zhong, Z., Zhou, H. et al., $^{40}Ar/^{39}Ar$ dating of the Xiaoqinling gold area in Henan Province, Geological Review (in Chinese), 1998, 44(3): 323.
7. Xue, L., Pang, J., Wang, X. et al., Rb-Sr and ^{40}Ar-^{39}Ar dating of fluid inclusion of the No.303 quartz vein in Xiaoqinling region, Geochimica (in Chinese), 1999, 28(5): 473.
8. Lu, X., Yu, X., Dong, Y. et al., Metallogenic epoch of gold deposits in the Xiaoqinling-Xiong'ershan area, Gold Geology (in Chinese), 1999, 5(1): 11.
9. Hu, Z., Qian, Z., Yan, G. et al., Xiaoqinling Detachment-metamorphic Core Complex and Gold Deposits (in Chinese), Xi'an: Shaanxi Press of Science and Technology, 1994, 21—122.
10. Luan, S., Chen, S., Main ore-controlled factors and metallogenic model of the gold deposits in Xiaoqinling, Contributions to Geology and Mineral Resources Research, 1990, 5(4): 1.
11. Jiang, N., Hydrothermal fluid evolution associated with gold mineralization at the Wenyu Mine, Xiaoqinling district, China, Resource Geology, 2000, 50(2): 103.
12. Zhang, Z., Application and limitation of the isotope chronology methods, Modern Approaches to Study the Lithosphere (eds. Zhang, B., Hong, D., Wu, X.) (in Chinese), Beijing: Atomic Energy Press, 1997, 186—200.
13. Faure, G., Isotope geochronology and its applications to geology, Earth Frontiers, 1998, 5(1—2): 17.
14. Wang, Z., Lu, H., $^{40}Ar/^{39}Ar$ geochronology and exhumation of mylonitized metamorphic complex in Changle-Nanao ductile shear zone, Science in China, Ser. D, 1997, 40(6): 641.
15. Wang, D., Zhang, H., Hua, X. et al., The main ore-control conditions of gold deposits and the prognosis of blind ore in Xiaoqinling, Henan, Contributions to the Project of Regional Metallogenetic Conditions of Main Gold Deposit Types in China, III-The Xiaoqinling Area in Henan and Shaanxi Provinces (ed. Shenyang Institute of Geology and Mineral Resources) (in Chinese), Beijing: Geological Publishing House, 1989, 47—83.
16. Li, S., Hart, S. R., Zheng, S. et al., Timing of collision between the North and South China blocks: Sm-Nd isotopic age evidence, Science in China, Ser. B, 1989, 32: 1391.
17. of the North China block and South China block: evidence from the Sm-Nd isotopic age, Science in China, Ser. D (in Chinese), 1989, (3): 312.
18. Wang, Q., Sun, S., Li, J. et al., The tectonic evolution of the Qinling Mountain belt, Scienta Geologica Sinica (in Chinese), 1989(2): 129.
19. Zhang, G., Meng, Q., Yu, Z. et al., Orogenesis and dynamics of the Qinling orogen, Science in China, Ser. D, 1996, 39(3): 225.
20. Zhang, G., Meng, Q., Yu, Z. et al., Orogenic process and its dynamic features of Qinling orogen, Science in China, Ser. D (in Chinese), 1996, 26(3): 193.
21. Lu, X., Dong, Y., Chang, Q. et al., Indosinian shahewan rapakivi granite in Qinling and its dynamic significance, Science in China, Ser. D, 1996, 39(3): 266.
22. Lu, X., Dong, Y., Chang, Q. et al., The Shaohewan rapakivi granite of Indo-Chinese epoch in Qinling and its dynamic implication, Science in China, Ser. D (in Chinese), 1996, 26(3): 244.
23. Wang, Y., Hu, Z., Tectonic facies analysis on the Xiaoqingling gold deposits, Collision Orogenic Belts of China (eds. Chen, H., Hou, Q., Xiao, W.) (in Chinese), Beijing: China Ocean Press, 1999, 224—232.
24. Zhang, J., Zheng, Y., Liu, S., The Xiaoqinling Metamorphic Core Complex: Structure, Genetic Mechanism and Evolution (in Chinese), Beijing: China Ocean Press, 1998, 12—63.
25. Kerrich, R., Wyman, D., Geodynamic setting of mesothermal gold deposits: An association with accretionary tectonic regimes, Geology, 1990(18): 882.
26. Deng, J., Zhao, G., Zhao, H. et al., Yanshanian igneous petrotectonic assemblage and orogenic-deep processes in East China, Geological Review (in Chinese), 2000, 46(1): 41.
27. Dong, S., Wu, X., Wu, Z. et al., On tectonic seesawing of the East Asia continent, Geological Review (in Chinese), 2000, 46(1): 8.
28. Mao, J., Wang, Z., A preliminary study on time limits and geodynamic setting of large-scale metallogeny in East China (in Chinese), Mineral Depoists, 2000, 19(3): 289.
29. Zu, J., Zhang, T., Xue, L., Determination of the ore-forming age of gold deposits in Xiaoshan, western Henan and its geological significance, Geological Review (in Chinese), 1999, 45(4): 418.
30. Yang, J., Zhou, X., The Rb-Sr isochron of ore and pyrite sub-samples from Linglong gold deposit, Jiaodong Peninsula, eastern China and their geological significance, Chinese Science Buletin, 2000, 45(24): 2272.
31. Yang, J., Zhou, X., Rb-Sr isochron ages of pyrite and ore from Linglong gold deposits and their geological significance, Chinese Science Bulletin (in Chinese), 2000, 45(14): 1547.
32. Yang, J., Zhou, X., Rb-Sr, Sm-Nd, and Pb isotope systematics of pyrite: Implications for the age and genesis of lode gold deposits, Geology, 2001, 29: 711.

(Received May 27, 2002)