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Cenozoic Mineralization in China, as a Key to Past Mineralization and a Clue to Future Prospecting

WANG Denghong[1], CHEN Yuchuan[2], XU Jue[1],
YANG Jianmin[1], XUE Chunji[2] and YAN Shenghao[2]

1 Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing 100037

2 Chinese Academy of Geological Sciences, Beijing 100037

Abstract Many Cenozoic metal deposits have been found during the past decade. Among them, the Fuwan Ag deposit in Guangdong is the largest Ag deposit in China. Besides, the largest Cu deposit of China in Yulong, Tibet, the largest Pb-Zn deposit of China in Jinding, Yunnan, and the largest Au deposit of China in Jinguashi,Taiwan, were also formed in the Cenozoic. Why so many important "present" deposits formed during such a short period of geological history is the key problem. The major reason is that different tectonic settings control different kinds of magmatic activity and mineralization at the same time. In southwestern China, porphyry-type Cu deposits such as Yulong were formed during the early stage of the Himalayan orogeny, sediment-hosted Pb-Zn deposits such as Jinding were formed within intermontane basins related to deep faults, and carbonatite-related deposits such as the Maoniuping REE deposit and alkalic magmatic rock-related deposits such as the Beiya Au deposit originated from the mantle source. In southeastern China, the Fuwan Ag deposit was related to continental rifting which was triggered by the mantle plume. In Taiwan, the Jinguashi Au deposit was formed during the subduction process of an oceanic plate beneath a continental plate. Besides, the features such as the diversification, inheritance, large size, deep source of metals and fluids of the Cenozoic (Present or Recent) mineralization can be used as a key to the search for past deposits.

Key words: Cenozoic metallic mineralization, minerogenetic series, Yulong Cu deposit, Jinding Pb-Zn deposit, Fuwan Ag deposit, Jinguashi Au deposit, China

1 Importance of Cenozoic Mineralization in China

Compared with other eras of the geological history, the Cenozoic Era is the shortest but one of the most important eras, because most of the porphyry copper deposits and most of the epithermal gold-silver deposits and a lot of other kinds of important deposits formed at this stage within a limited areal extent in the world. However, scanty few work has been done on Cenozoic mineralization in China, even though more and more deposits have been found recently by carrying out some special prospecting programmes such as the Sanjiang Programme and the WSYP (west margin of the Yangtze Platform) Programme. Among those deposits, the Xifanping porphyry copper deposit and gold deposits such as the Pianyanzi, Huangjintaizi, and Baijintaizi deposits along the Daduhe River in Sichuan and the Beiya gold deposit and Baiyangping polymetallic deposit in Yunnan Province are well-known. Some of these deposits belong to new types. For example, the Pianyanzi gold deposit in Kangding, Sichuan, is of sellaite type, with Au contents in sellaite ranging from 19.23 to 3635.70 g/t (muscovite from a gold vein yield a K-Ar age of 9.55 Ma, after Luo Hongshu et al., 1987).

In the Cenozoic, the continental geology changed so greatly that the New-Tethys closed and the Himalayan Mountains uplifted in the southwest of China, while some of the Mesozoic mountains formed by the Yanshanian movement sank and were transformed into basins in the east of China. Such continental tectonism marked by "uplift in the west and subsidence in the east" not only resulted in the formation of the roof of the world by junction between the Himalayan terrane and the Zangdian (Tibet-Yunnan) terrane and massive uplift of the Qinghai-Tibet Plateau in the west and gave rise to volcanic belts and a number of volcanic-sedimentary basins along the east coast of China, but also contributed a lot to the formation of endogenetic deposits marked by the concentration of gold, copper and other mantle materials and fluids into mineral deposits and affected the formation of oil and gas traps. This minerogenic pattern is closely related to the continental tectonic framework of uplift in the west and subsidence in the east of China, with plate tectonism only influencing the east margin of China. In the uplift region, different kinds of deposits can be raised to a high level near the ground surface and easy to find after strong fluid activity, shearing, overthrusting and erosion; while in the subsidence region, deposits are relatively difficult to find because they are buried and covered by sedimentary rocks.

In general, the Cenozoic Era is an important stage of large-scale mineralization, with the largest Cu deposit (Yulong in Tibet) (Li et al., 1981), largest Au deposit (Jinguashi in Taiwan), largest Ag deposit (Fuwan in Guangdong) (Zhang et al., 1997; Liang et al., 1998; Zhang et al., 1999), and largest Pb-Zn deposit (Jinding in Yunnan) formed at this stage. On the other hand, it is very likely to find new types of deposits because of the extension and complexity of the Himalayan movement. Most of the Cenozoic deposits in China were formed intracontinentally at the continental stage of evolution, making up a unique system of continental mineralization. Only some deposits were formed within an environment similar to that of the mid-oceanic ridge, such as the Luobusha-type chromite deposits in Tibet (Wang et al., 1987), or formed in a subduction zone, such as the Jinguashi-type gold deposits in Taiwan. More and more Carlin-type gold deposits and other epithermal gold-silver deposits are expected to be discovered in rifted areas in the east of China, because strong magmatism and fluid mineralization originating from the mantle occurred there. And in the western uplift region of China, it is more possible to find deposits formed by overthrusting combined with fluids activity, deposits formed directly by mantle-derived fluids within deep fault zones, porphyry-type and alkalic rock-type deposits formed by hypabyssal magmatism, or deposits formed by metamorphism and/or anatexis of crustal materials.

2 Major Characteristics of Cenozoic Metallic Mineralization in China

2.1 Diversification

On a global scale, copper and gold mineralization is the most important in the Cenozoic, but in China, various types of deposits of a certain size have been found and proved to be formed at the Himalayan stage (Table 1), including deposits of Li, Be, Nb, Ta, Cs, Rb, B, Cu, Pb, Zn, Au, Ag, W, Sn, REE, Cr-Fe, U, nonmetals, gem, oil and gas, and so on. Host rocks are also highly varied, including porphyry, pegmatite, sedimentary rocks, metamorphic rocks and so on. These deposits are formed by different kinds of fluids originating from the crust, mantle, or crust-mantle mixing source and by different processes such as crystallization differentiation, fluid metasomatism, overthrusting-shearing and so forth.

2.2 Inheritance

According to the available data, the endogenetic mineralization in western China started in the Yanshanian Stage and reached the peak in the Himalayan Stage, while the endogenetic mineralization in eastern China peaked in the Yanshanian Stage and continued into the Himalayan Stage. As to the subduction zone along the east coast of China, mineralization mainly occurred in the Yanshanian Stage on the continental side, but peaked in the Cenozoic (especially from the Neogene to Quaternary) in Taiwan.

2.3 Large size

As stated above, all the largest deposits of copper, gold, silver, lead and zinc were formed in the Cenozoic.

2.4 Deep source of metals and fluid

Although the Himalayan movement affected the superstructure strongly, some newly obtained helium isotopic data (Fig. 1), combined with other data such as lead isotope data, show a contribution of mantle fluids and mantle materials to the formation of the Jinding Pb-Zn deposit and Fuwan Ag deposit, which

Table 1 Isotopic ages of major Cenozoic deposits in China

District	Deposit	Major element	Samples	Method	Age, Ma	References
Kangding, Sichuan	Pianyanzi	Au	Muscovite from vein	K-Ar	9.55	Luo Hongshu et al., 1987
Mianning, Sichuan	Maoniuping	REE	Zircon from katnosite	U-Pb	12.2	Yuan Zhongxin et al., 1995
Mianning, Sichuan	Maoniuping	REE	Zircon from katnosite	U-Pb	22.4	Yuan Zhongxin et al., 1995
Mianning, Sichuan	Maoniuping	REE	Biotite from vein	K-Ar	40.3	No.109 Geological Party of Sichuan
Mianning, Sichuan	Maoniuping	REE	Ternovskite from vein	K-Ar	31.7	No.109 Geological Party of Sichuan
Kangding, Sichuan	Huangjinping	Au	Muscovite from vein	K-Ar	26.8–20.8	Fudeming,1996
Shimian, Sichuan	Pushagang	Au	Muscovite from phyllonite	K-Ar	15.4–21.2	Fudeming,1996
Siman, Sichuan	Pushagang	Au	Phyllonite-type ore	K-Ar	17.0±0.28	This work
Mianning, Sichuan	Chapuzi	Au	Au-bearing granite porphyry	K-Ar	31.9	Fudeming,1996
Xiangyun, Yunnan	Machangqing	Au	Ore-bearing porphyry	K-Ar	31–48	Fudeming,1996
Xiangyun, Yunnan	Machangqing	Au	Ore-bearing porphyry	Rb-Sr	34	Fudeming,1996
Heqing, Yunnan	Beiya	Au	Zircon from mineralized porphyry	U-Pb	61	Fudeming,1996
Heqing, Yunnan	Hongnitang	Au	Ore-bearing syenite-porphyry	K-Ar	47.75±1.07	This work
Heqing, Yunnan	Wandongshan	Au	Ore-bearing syenite-porphyry	K-Ar	35.98±1.43	This work
Heqing, Yunnan	Wandongshan	Au	Sericite from mylonite-type ore	K-Ar	27.76±0.60	This work
Chuxiong, Yunnan	Xiaoshuijing	Au	Sericite from lamprophyre	K-Ar	50.95±0.89	This work
Yao'an, Yunnan	Yao'an	Au	Ore-bearing syenite-porphyry	K-Ar	31–50	Fudeming,1996
Yanyuan, Sichuan	Xifanping	Cu	Hornblende from Cu-bearing monzonite-porphyry	Ar-Ar	49.57(total fusion), 47.52(plateau), 46.75(isochron)	Luo Yaonan et al., 1996
Yanyuan, Sichuan	Xifanping	Cu	Hornblende from rock body No. 56	K-Ar	33.5–32.2	Xushijin et al.,1997
Yanyuan, Sichuan	Xifanping	Cu	Biotite from monzonite porphyry	K-Ar	34.6	Xushijin et al.,1997
Ninglang, Yunnan	Luobodi	Cu	Porphyry	Rb-Sr	52.76	Hu Shouquan et al., 1998
Yanyuan, Sichuan	Xifanping	Cu	Cu-bearing monzonite porphyry	K-Ar	51.9	Chengdu Institute of Geology and Mineral Resource
Gaoming, Guangdong	Fuwan	Ag	Fluid inclusions in quartz from vein	Rb-Sr	66.34±3.4	No. 757 Geological Party
Gaoming, Guangdong	Fuwan	Ag	Fluid inclusions in quartz from vein	Rb-Sr	65±2.5	Liang Huaying et al., 1998
Gaoming, Guangdong	Changkeng	Au	Silicified wall-rock	K-Ar	136.8±11.3	Du Jun'en et al., 1996

Note: Age data of this work were obtained at the Institute of Geology, Chinese Academy of Geological Sciences.

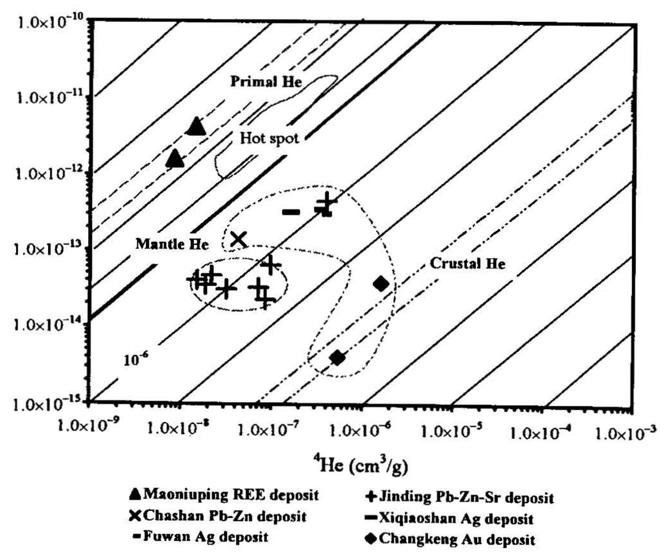

Fig. 1. Helium isotopic composition of Cenozoic ores in China.

were once taken for granted as having originated from the crust source.

2.5 Environment of mineralization

The Himalayan mineralization in the mainland of China was influenced by continental tectonism, which is prominently manifested by uplift in the west and subsidence in the east in the Cenozoic. Both the uplift and the subsidence are so strong that the continental topography of China has changed violently, with the Neo-Tethys changing into the roof of the world in the west and part of mountains formed by the Yanshanian movement changing into basins in the east (Dong et al., 2000). Such a great change in the Cenozoic is rare in the world.

3 Minerogenetic Series of Cenozoic Deposits in China

After the concept of "minerogenetic series" was put forward (Cheng et al., 1979), this concept was studied and perfected progressively (Cheng et al., 1983; Tao, 1989; Zhai, 1992; Zhang et al., 1993; Song, 1996; Chen, 1998). And Chen et al. (1999) point out that the minerogenetic series refers to a series of deposits which have genetic relationship with each other and formed in a certain geological stage and in a certain geological setting. A lot of important minerogenetic series in China were formed by Cenozoic endogenetic mineralization, including:

(1) The Cr-Pt minerogenetic series related to Tertiary ultrabasic rocks in the Yarlung Zangbo subduction zone. Typical deposits include the Luobosa deposit in Qusum and the Dongqiao deposit and Xiangkashan deposit in Amdo;

(2) The saline lake-type Cs-Li-B minerogenetic series related to hot spring activity in the intracontinental basins of the Qinghai-Tibet Plateau;

(3) The Cu-Mo-Sn-W-Pb-Zn-Au-Ag minerogenetic series related to Himalayan hypabyssal intermediate-acid intrusive rocks in the Sanjiang belt. This series can be divided into two subseries: the Cu-Mo-Au-Ag subseries and the Sn-Nb-Ta-Rb-U subseries. The former includes a lot of porphyry-type Cu-Mo deposits such as the Yulong, Narigongma, and Malasongduo deposits in Tibet, and the Machangqing and Xuejiping deposits in Yunnan, as well as some deposits formed in contact zones; the latter includes the large Lianglishan Sn deposit in Lianghe County and the medium-sized tin-rare metal deposit in Xiqi County.

(4) The Pb-Zn-Sr-Cu-Au-Ag-Hg-As minerogenetic series related to Meso-Cenozoic downwarping, overthrusting, detachment and fluid mineralization within the Lanping-Simao basin and other basins in the Sanjiang fold system. Typical deposits include the Jinding Pb-Zn deposit in Lanping, large Maocaopo Hg deposit in Sidian and large Shuiyinchang Hg deposit in Baoshan, and large Shihuangchang As deposit in Dali. These deposits have an obscure relationship with intrusions but have a close relationship with different kinds of fluids, which may have not only leached ore-forming materials from host rocks during long-distant movement but also provided favourable positions such as the structural dilated space for deposition of ores. Although their host rocks are highly varied, the Tertiary is the most important, which is a metallogenic epoch of the Cenozoic. For example, the syndepositional fault controlling the Eogene basins contributed to the formation of dozens of superlarge, large and medium-sized deposits, in the Lanping-Jinding, Sanshan-Hexi, Baiyangping and other metallogenic belts by its transformation into huge thrusting-detachment zones in its late stage of evolution. Some other deposits, such as the sandstone-type Denghaishan deposit, mudstone-type Jiata deposit and vein-type Yaojiashan copper deposit, might be included in this minerogenetic series.

(5) The nonferrous-rare metal-gold minerogenetic series related to Meso-Cenozoic granite- pegmatite along the Xianshuihe strike-slip fault belt or in the Songpan-Garzê fold belt. Typical deposits are located in the contact zones of the Cenozoic Zheduoshan granite complex or along the large-scale strike-slip faults or nappe structures within or near the Zheduoshan complex, such as the Pianyanzi gold deposit in the east exocontact zone of the Zheduoshan granite complex, the Nonggeshan Pb-Zn-Ag-Cu deposit in the west contact zone, and the Selaha W-Sn deposit within the Zheduoshan granite complex.

(6) The Au-Ni-Sb-Be-Pb-Zn minerogenetic series related to Meso-Cenozoic mantle-derived fluid and magmatism in the Honghe-Ailaoshan deep fault zone in Yunnan Province, including such large and medium-sized Au (Ag) deposits as the Jinchang gold deposit in Mojiang, Laowangzhai gold deposit in Zhenyuan and Daping Au (Ag) deposit.

(7) The Au-Cu-Ag minerogenetic series related to Himalayan shearing and fluid mineralization on the northwest margin of the Yangtze platform. There are two sub-series of deposits: one is the shear zone-type gold deposits hosted within the old crystalline basement along the Dadu River (such as the Huangjinping, Baijintaizi, and Sandiao gold deposits); the other is the polymetal deposits located in the front of nappe structures, such as the Tianwan Cu-Ag-Au deposit and Tianping gold deposit.

(8) The REE-U-F minerogenetic series related to alkali granite and/or mantle fluids in the central part of the west margin of the Yangtze platform, including the Maoniuping deposit and Daluxiang deposit in Sichuan Province.

(9) The Pb-Zn-Cu-Au-Ag minerogenetic series

related to alkaline and subalkaline magmatism on the southwest margin of the Yangtze platform. Typical deposits of this series include the Xifanping, Yao'an, Beiya, Laojie, Tongchang, Huangkuangchang, and Chang'anchong deposits. They are associated with alkalic complexes with their rock-forming ages ranging from 55 to 25 Ma B.P., earlier than those of the alkalic complex rocks of the REE-U-F series at Maoniuping.

(10) The rare metal-gem-nonmetal minerogenetic series related to metamorphism in western Yunnan, including the Heishitou gem deposit, Puladi and Yimaluo rare metal-gem deposits.

(11) The Au (Ag-Mo) minerogenetic series related to Meso-Cenozoic tectono-magmatism in the Jiaodong area, Shandong Province. Although most of the well-known gold deposits in Shandong were formed in the Yanshanian Stage, some old deposits have been proved to be formed in the Himalayan Stage, e.g. the Jiehe gold deposit was formed 46 to 44 Ma ago. Moreover, some gold deposits being prospected are possible to be formed in the Cenozoic. The examples are the Fayunkuang gold deposits and Pengjiakuang gold deposit in the Jiaolai basin, which occur in Cretaceous conglomerates and in the contact zone between the Cretaceous conglomerates and the Precambrian basement rocks respectively.

(12) The Au-Ag-Pb-Zn minerogenetic series related to Meso-Cenozoic granite-trachyte in the Guangzhou-Sanshui basin. Based on present studies, the large Karlin-type Changkeng gold deposit was formed in the Yanshanian Stage, the superlarge Fuwan silver deposit formed at the beginning of the Cenozoic, and the trachite-hosted Xiqiaoshan silver deposit formed in the Middle-Late Tertiary in the Guangzhou-Sanshui basin. Other Ag-Pb-Zn polymetallic deposits such as the Chashan, Hengjiang and Fengwei deposits also belong to the series, but chronological studies are still being carried out.

(13) The gem minerogenetic series related to Cenozoic alkali basalts in eastern China, including the Penglai sapphire deposit in Hainan Province, Cangle sapphire deposit in Shandong Province and Kuandian sapphire deposit in Liaoning Province.

(14) The Au-Cu-Ag minerogenetic series related to Cenozoic, especially Quaternary, intermediate-acid volcanic rocks in the Taiwan subduction zone, including the Jinguashi gold-copper deposit and other gold deposits at Jiufen, Pingfengshan, Wudankeng and so on.

Of course, the above fourteen minerogenetic series can not contain all of the Cenozoic deposits in China, because there are a lot of other important endogenetic minerogenetic series formed in the Cenozoic, e.g. uranim deposits in South China and Xinjiang.

4 Present Mineralization is the Key to Looking for Past Deposits

One purpose of the researches on Cenozoic endogenetic mineralization is to provide examples for the researches on endogenetic mineralization in the early evolution stage of the Earth, that is to say, "the present is the key to past". Based on the present studies of Cenozoic mineralization and according to the characteristics of Cenozoic endogenetic mineralization in China, we should pay more attention to the difference in different areas. For example, it is highly possible to find new deposits along the Tancheng-Lujiang fault belt and its both sides in eastern China and along the deep fault zones on the north margin of the North China Platform, because the Mesozoic mineralization continued into the Cenozoic in these areas. The possibility is more obvious in basins that began to form in the Mesozoic and continued into the Cenozoic, e.g. the Jiaolai basin in Shandong and the Sanshui basin and Luoding basin in Guangdong. In these basins, the ore prospects are good, because some metal deposits or ore veins have been found to cut the Cretaceous strata in the interiors of the basins and on the interface between the basins and the basement. It is worthwhile to point out that the Meso-Cenozoic volcanic regions with clear volcanic edifices in North China also have good ore prospects but little work has been done by now. For example, the Oubalage Cu-Au deposit in Inner Mongolia, which is characteristically similar to those volcanogenic Cu-Au deposits in Colorado, USA, is related to a small porphyry body and located at the intersection of ring structure and radiating structure of continental volcanic rocks, showing a good prospect for looking for epithermal deposits.

In northwestern China, some small mantle-derived subalkaline bodies intruded after the Hercynian orogeny may provide new clues for looking for Mesozoic and Cenozoic deposits. In southwestern China, the continuous northward motion of the Indian plate resulted in the rapid uplift of the Himalayan Mountains and their nearby high mountains and at the same time, the stability of the mantle and asthenosphere beneath the Himalayas was disturbed by some subducted blocks, thus stimulating upwelling of some mantle materials, among which only those magmas rich in fluids or highly mobile magmas may have penetrated the thickening crust and reached or approached the surface. Therefore, the small mantle-derived bodies, especially the alkali complexes, are also an important indication of ore searching. Most of the known Cenozoic deposits in southwestern China have a close space-time relationship with alkali complexes. So, generally, there is a good prospect for finding new Cenozoic deposits in China. Considering the present limited research and good prospect, it is necessary to study the Cenozoic metallogeny in China further.

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About the first author

Wang Denghong Born in 1967; graduated from the Chengdu College of Geology in 1989; got the Master and Ph.D. degrees of economic geology from the Chinese Academy of Geological Sciences (CAGS) in 1992 and 1995 respectively. Now He is research professor of the Institute of Mineral Deposits, CAGS; majoring in economic geology and mantle plume. Tel: 010-68327214.