Ore-Bearing Formations of the Precambrian in South China and Their Prospects

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Abstract In the Precambrian System of the Yangtze and Cathaysian plates six ore-bearing formations can be identified: the Cu-Pb-Zn-bearing formations in volcanic rocks of marine facies of the Neoarchean-Paleoproterozoic, Cu-Au-bearing formations and Pb-Zn-bearing formations in volcanic rocks of marine facies of the Mesoproterozoic, Pb-Zn-bearing formations in volcaniclastic rock and carbonate rock of the Neoproterozoic, Fe-Mn-bearing formations in the volcaniclastic rock of the Neoproterozoic, and Ni-Cr-serpentine-bearing formations in ophiolite and ultrabasic rock of the Meso- and Neoproterozoic. They were mostly formed in the marginal rift valleys of the Yangtze and Cathaysian plates, where occur stratabound and stratiform ore deposits, thermal deposits and porphyry polymetallic deposits. The six regions with ore-bearing formations have good prospects for ore deposits.

Key words: ore-bearing formation, Precambrian, Yangtze and Cathaysian plates, prospects

1 Evolution of Precambrian Tectonics

South China refers to the area including the Yangtze and Cathaysian plates and the Qinzhouwan-Hangzhouwan suture zone in between. Precambrian formations in this area occur mostly in the Jiuliling and Wuyi Mountain terranes and locally in the Qinzhouwan-Hangzhouwan suture zone (Ding, 2001) (Fig. 1).

1.1 Neoarchean-Paleoproterozoic craton-forming epoch

The Yangtze and Cathaysian cratons were formed roughly in the Neoarchean-Paleoproterozoic time. The strata are represented by the Mayuan Group in western Fujian, the Badu Group in southwestern Zhejiang, and the Xingzi Group in northern Jiangxi. The rock assemblage consists of medium- and high-grade metamorphic rocks such as gneisses, schists, plagioclase amphibolites and granulites, with the total thickness up to 3000–7000 m. The volcanics are dominated by basalts, dacites and rhyolites, indicating a bimodal feature. Recently, Sm-Nd isochron determinations have yielded an age of 2682±148 Ma for the intermediate-basic volcanites (plagioclase amphibolites) from the Mayuan Group in northwestern Fujian, an age of 1970 ± 85 Ma for the basic-ultrabasic lava from Donghua Village (Cheng, 1994), Youxi County of southern Fujian, and ages between 2199 Ma and 1878 Ma for the Badu Group in western Zhejiang. An U-Pb isotope age of 1869 Ma has also been obtained for the spilitic-keratophyric rocks of the Xingzi Group in northern Jiangxi (Hu et al., 1991). Base upon the study on metamorphism history of the rocks in western Zhejiang and Fujian, folding of the Paleoproterozoic strata with resultant appearance of the Precambrian craton was presumed to have taken place around 1990 Ma (Ma et al., 1992; Cheng, 1994).

1.2 Mesoproterozoic rifting epoch

Along with global rifting, the Yangtze and Cathaysian cratons began to break in the early Mesoproterozoic. These cratons were perhaps separated by the Nanhuai oceanic basin. Weakly metamorphosed tuffaceous sandstones and phyllites with more or less intercalations of intermediate-basic and spilitic-keratophyric lavas commonly occur in the flysch formation of the Yifeng Group in western Jiangxi, in the Shuangqiaooshan and Tongchang groups in northeastern Jiangxi, and in the Shangxi Group in southern Anhui. Ophiolites have also been found at Fuchuan, Shexian County of Anhui Province and at Zhangshudun, Yiyang County of Jiangxi Province. Intermediate-basic volcanic rocks are exposed at Youxi of central Fujian and at Longquan of southwestern Zhejiang. Numerous isotope ages indicate that Mesoproterozoic rifting took place between 1.6 Ga and 1.0 Ga.

In the terminal Mesoproterozoic between 13–1.0 Ga, the Nanhuai oceanic basin shrank and finally disappeared. The Sibao tectonic cycle (equivalent to the Greenville cycle) caused the Cathaysian and the Yangtze cratons to collide along the Huangzhouwan-Piangxiang-Qingzhouwan suture. This phase of collision represents the second stage of cratonization. Li Zhengxiang suggested that the South China plate was located on the northern margin of the Laurentia at that time (Li, 2000).
1.3 Neoproterozoic divergence and convergence
In the early Qinghaikouian period, the Yangtze and Cathaysian blocks began to diverge before long after their collision, resulting in the birth of the South China rift trough. The Qinghaikouian block accumulated in this trough is represented by a molasse-flyschoid-volcanic formation with an Rb-Sr isochron age of 818±84 Ma for the anesite at its top. The protoliths for the Chencai Group in the Jiangshan-Shaoxing belt are presumed to be basic lava, and intermediate-basic and acid volcaniclastic rocks. A Rb-Sr isochron age of 720 Ma has been obtained for the lava.

By the end of the Qinghaikouian period, the collision between the Yangtze, Cathaysian, North China, Indo-China and Tarim cratons ultimately made up a unified continental platform of China. This event is called, in a broad sense, the Jinning orogeny in China.

1.4 Latest Neoproterozoic erosion and deposition epoch
The divergence and subsequent amalgamation of the Yangtze and Cathaysian cratons caused the crust of South China to be well consolidated, and thus provided a stable basement for the covering sediments of the Sinian System.

The Nanhuai marine trough in South China received a formation of carbonaceous-manganese-siliceous sediments, jaspilites, black shales, phosphorites and ice-rafting deposits, indicating a stabilized continent. Sedimentation in southern and central Jiangxi, typically in the Xinyu area, was characterized by terrigenous clastic rocks involving magnetite-bearing quartzite, carbonaceous phyllite and manganese-bearing dolomite occasionally with basic or intermediate-acidic lavas. Such platform-type broad sea sediments indicate the cessation of violent crustal movements.

2 Characteristics of Ore-bearing Formations
Recently, some Precambrian ore-bearing formations have been identified in the Yangtze and Cathaysian plates. Some deposits are syn-sedimentary, such as massive sulfides, and the others are formed by transformation and superimposition on pre-existing source beds during tectonism, metamorphism and magmatism. However, both types of deposits are stratabound.

2.1 Neoproterozoic Cu-Pb-Zn-bearing marine volcanic formations
The Neoproterozoic copper-lead-zinc-bearing marine volcanic formations are widespread in the Longquan-Suichang district within the Wuyi terrane of the Cathaysian plate. Typical polymetallic deposits are represented by those at Wu’ao, Longquan County and at Geping, Suichang County in Zhejiang Province. The ores are hosted by metamorphic rocks of the Badu Group. The No. 1 mineralized zone of the Wu’ao deposit extends 1000 m in length, 1200 m in width, and 2–44 m in thickness with the main ore body being 700 m in length, 650 m in width, and 10.22 m in thickness, and dipping NNE at angles between 5° and 20°. The ore grades average 2.04% for Pb, 2.64% for Zn, 0.165% for Cu, and 31.47 g/t for Ag. The deposit has been proved to be of a medium size.

Neoproterozoic and Paleoproterozoic volcanogenic massive sulphides are important sources for the polymetallic deposits in Canada and account for 65% of the copper-lead-zinc ores in the country. Examples in China include the
Hongtoushan medium-scale copper deposit and the Qingchengzi large lead-zinc deposit in Liaoning Province, the Zhongtiaoshan large copper orefield in Shanxi Province, the Lalachang large copper deposit and the Dahongshan large copper-iron deposit in the Kangtai axis on the southwestern margin of the Yangtze plate, all of which are hosted in Neorheean-Paleoproterozoic volcano-sedimentary rift formations and could be taken as references in prospecting of similar deposits in this area.

2.2 Mesoproterozoic Cu-Au-bearing marine volcanic formations

Ore-bearing formations are widely distributed in the Yangtze and Cathaysian plates with clusters of very important copper-gold deposits and ore belts. The gold deposits at Huangjindong of Liuyang County, at Jinkeng of Xiushui County, at Jinshan of Dexing City, at Jimjiawu of Jingdezhen City, at Shuangqishan in the Wuyiyan terrane of the Cathaysian plate and at Huangshan of Zhuji County, the Au-Cu-polymetallic deposit at Yinzhan of Dexing City, and the Dexing copper orefield are all associated with Mesoproterozoic marine volcanic fylch formation. However, the reworking and superimposition of later tectonic shearing and magmatic intrusion have also played a very important role in the formation of these deposits.

The medium-sized Xiqiu copper deposit at Shaoxing City of Zhejiang Province occurs in the Mesoproterozoic Pingshui Formation in the Changshan-Zhuji uplift, where the ore-bearing formations contain volcanic rocks up to 83.2% and can be divided into four sedimentary cycles. The ore layers of this deposit are located at the top of the first cycle, and have been folded synchronously with the wall rocks. The main orebody is 1050 m long, 0.21–47.95 m thick, and extends more than 700 m to the depth. The average grades are 1.05% for Cu, 1.34% for Zn, 15.30% for S, 0.49 g/t for Au, and 10.9 g/t for Ag.

The Mesoproterozoic is an important metallogenic epoch for copper on the earth, and is responsible for many famous deposits such as those in East Africa and at Olympic Dam in Australia. In China, the important Mesoproterozoic copper ore belts include those in western Sichuan and eastern Yunnan. They are located on the western margin of the Yangtze plate and can be taken as good reference models for finding similar deposits in South China.

2.3 Mesoproterozoic Pb-Zn-bearing marine volcanosedimentary formation

A number of lead-zinc deposits of large or medium size have been found recently in the central Fujian rift volcanic zone of the Cathaysian plate. The deposits include, from southwest to northeast, those at Meixian and Fengyan of Youxi County, at Dongyan and Bawaiyang of Jian’ou County, at Xiaomei and Yinchang of Longquan County. The Dongyan Formation of the Mesoproterozoic Mamianshan Group is the principal host to the ores. The ore zone measures 800 m in length, 200 m in lateral extension, and 20 m in thickness with the single ore layers ranging from 1 m to 3 m in thickness. The ore layers are bedded, and are concordant and have been folded synchronously with the host strata. The average grades are 0.71%–1.69% for Pb, 2.97%–3.04% for Zn, and 30–34 g/t for Ag. The ores are massive, mottled, disseminated and striped in structure. The metallic minerals are dominated by sphalerite, galena, chalcopyrite, pyrite and pyrrhotite. Tens of deposits are distributed along the rift volcanic zone in central Fujian to form an important metallogenic belt.

The Mesoproterozoic is the worldwide lead-zinc metallogenic epoch. The large-size Mesoproterozoic lead-zinc deposits in rift belts on the northern margin of North China platform are represented by those at Huoqeqi, Langshan, Dongshengmiao, Jiashengpan, Tanyaokou, et al. The discovery of Mesoproterozoic lead-zinc deposits in a rift belt of central Fujian has made it possible to make metallogenic comparisons between this belt of South China and the rift belts in North China. Such comparisons would be helpful to prospecting in South China.

2.4 Neoproterozoic Pb-Zn-bearing volcanioclastic and carbonate formations

The Neoproterozoic lead-zinc-bearing volcanioclastic and carbonate formations are mainly distributed in the Yiyang-Nancheng-Yudu rift belt of the western Wuyi massif, in the volcanic belt from Dengshan of northeastern Jiangxi Province to Jingtian of Shexian County, Anhui Province, in the Neoproterozoic basins along the Qingshouwan-Huangzhouwan suture, in Neoproterozoic basins in northwestern Zhejiang Province and the northern Wuyi area, and in some other places. In the Yinkeng mining district of Yudu County, for instance, lead-zinc ore beds within the Neoproterozoic Qingbaikouan system are largely controlled by thick tuffaceous sediments of the Kuli Formation, and tuffaceous sandstones and shales with intercalated siliceous dolomite of the Shangshi Formation. Siliceous dolomite of the Shangshi Formation is the main host to the ores, and is 2–3 m in thickness and more than 4000 m in extension. The partly hidden ore layers have been folded synchronously to the host strata. The grades of ore average 6.5% for Pb + Zn, 1.1 g/t for Au, and 53.19 g/t for Ag.

2.5 Fe-Mn-Cu-bearing formations of the Sinian Period

Manganese-bearing sedimentary formations represented by the Xiangmen and Nantuo formations were deposited in basins on the northern margin of the Jiangnan block and
in Hunan and Guangxi Provinces on the Yangtze plate. In contrast, the iron-bearing Xiafang Formation, which is represented by the Xinyu-type iron deposit, was distributed in the area east of the Pingxiang-Chenzhou fault and south of the Pingxiang-Shaoxing fault. Generally, manganese and phosphorus are distributed close to the Yangtze plate, while iron close to the Cathaysian plate. In addition, the Guoqiao sandstone-hosted copper ores on the northern margin of the Jiangnan block also occur in equivalent strata, or called the copper-bearing sandstone formations. In response to the uplifting and weathering of the Neoproterozoic Rodinia super-continent for 100–200 million years, life activities were apparently intensified in marginal basins and rift areas. Sedimentation of manganese, iron, phosphorus, and sandstone- or shale-hosted copper ores also began. Therefore, further researches on these formations may promote a breakthrough in ore prospection.

2.6 Mesoproterozoic and Neoproterozoic Ni-Cr-bearing serpentinite in the ophiolite-ultrabasic succession

Two remarkable ophiolite belts have been discovered in the northeastern section of the Qinzhouwan-Hangzhouwan tectonic suture. One is the NNE-trending Zhangshudun (Yiyang County)-Fuchuan (Shexian County) belt; the other is the approximately E-W-trending Pingxiang-Shaoxing belt. The former is located on the northern boundary of the Qinzhouwan-Hangzhouwan suture, i.e. the Jiangxi-Anhui-Zhejiang fault, while the latter on the southern boundary of that suture, namely, the northern margin of the Cathaysian plate.

Three huge serpentinite deposits have been found in the Zhangshudun (Yiyang County)-Fuchuan (Shexian County) ophiolite-ultrabasic rock belt. These deposits are represented by Xiwang in Dening City, Zhangshudun in Yiyang County, and Fuchuan at Shexian County. The usable associated metals include nickel, chromium and cobalt. The Xiwan serpentinite was formed by post-magmatic metasomatism of peridotite, pyroxene peridotite and olivine pyroxenite. The orebody, 3300 m long and 200–500 m thick, trends N-S, dips towards the east at 55–80° and extends further down from the depth of 250 m controlled by drilling. The serpentinite of commercial values amounts to 324 million tons with the MgO content averaging 36%. The associated nickel amounts to 162.8 thousand tons (reaching a medium size, mainly consisting of nickel silicate, average grades 0.2% for Ni and 0.005% for Co) and chromium amounts to 152.2 thousand tons (average grade 0.187%).

The serpentinite ore is under exploitation at Baishishantou of Longyou County in the Pingxiang-Shaoxing ophiolite-ultrabasic rock belt.

As a summary, the above ore-bearing formations share the following characteristics:

1. They are deposited in continental margin or rift environments.

2. Polymetallic ores are mostly associated with marine bimodal volcanic rocks. The volcanic rocks are Na-rich, and the copper mineralization is associated with basic end members.

3. Mineralization tends to occur in transitional zones between volcanic and sedimentary rocks.

4. Submarine exhalites are widely distributed. Laminated sulfides are commonly associated and intercalated with jaspilites, carbonaceous-pelitic-siliceous rocks, exhalative carbonates (laminated marble), barite and anhydrite.

5. Wall rock alteration is commonly seen in both the footwalls and hanging walls of the deposits, and is typified by silification, sericitization, illitization, baritization, anhydritization, chloritization, epidotization, and carbonate alteration.

3 Promising Regions for Ore Exploration

The above 6 Precambrian ore-bearing formations in the Yangtze and Cathaysian plates of South China contain syngenetic ore layers, which are favorable loci for late-stage superimposition. Based upon regional analysis, the following areas can be taken as targets for further prospecting.

1. The central part of the Wuyi terrane, i.e., the area to the west of the line from Nanping, through Jian’ou, Jianyan, Songzheng, Longquan and Suichang to Longyou, where there are developed Neoarchean-Paleoproterozoic Cu-Pb-Zn-bearing volcanic formations metamorphosed to medium and high grades. These formations extend NE for 300 km, and have undergone intense metamorphism, tectonism and magmatism. Apart from stratabound deposits dominated by syngenetic deposits such as the Wuo and Shuiji types found, respectively, in Longquan and Jiangyang counties, superimposed or even porphyry-type deposits also deserve great attention during prospecting.

2. The Mesoproterozoic volcanic belt from Yuting, Xiuning County to Shuizhukeng, Shexian County, which is developed in the northeastern margin of the Jiangnan Precambrian block. It extends E-W for 70 km with a width of 0.5–2 km and is dominated by bimodal volcanites of the splite-keratophyre series. Two small-sized copper deposits at Huangtuling and Shuizukeng have been discovered. It is worth further exploration.

3. The Mesoproterozoic volcanic belt from Wanzai to Yifeng, which is located on the southwestern margin of the Jiuling massif and extends ENE to E-W for more than 100
km. The Sm-Nd isochron age of the basalt is 1038.3 Ma. Ten copper occurrences have been discovered in the Huangmao-Luocheng area of Wanzai County and the Fangxi-Pengqiao-Yaxi area of Yifeng County. Four or five copper-bearing mineralized layers occur along interbedding fracture zones, each being 1–2 m in thickness. Besides the stratabound copper-gold deposits, attention should also be paid to porphyry copper deposits and tripled copper-polymetallic deposits as of the Tongchang and Cunqian types in Deying County.

(4) The Mesoproterozoic volcanic belt from Zhongfuan, Yiyang County through Tongchang, Deying County to Meilin, Wuyuan County, which is located to the northwest of the Northeastern Jiangxi fault, and extends nearly NNE for about 110 km. Ores in this belt are stratabound in a flysch formation containing volcanic rocks. As immediate wall rocks of porphyry copper deposits, this formation has received great attention for the large number of Cu-Au-Ag deposits. Therefore, tracing in a NNE direction from the Tongchang orefield to southern Anhui Province is probably rewarding.

(5) The Meso-Neoproterozoic volcanic belt of central Fujian, which lies on the eastern margin of the Wuyi massif. Mesoproterozoic metamorphic rocks of this belt extend NNE for 300 km. In recent years, discoveries have been made of the Pb-Zn deposits at Meixian and Fengyan and the gold deposits at Shuangqishan and Wangmushan. Therefore, further exploration in this belt is suggested.

(6) The northern Wuyi Meso-Neoproterozoic volcanic belt, which is located on the northern margin of the Wuyi massif and extends nearly E-W for 90 km. Orebodies of the Tiehajie copper deposit and the Lijuia gold deposit are hosted in a formation dominated by grayish green phyllites with intercalations of siliceous exhalites and marble. The Zhoutan Formation, as a whole, is dominated by gneisses and granulites, but a considerable amount of amphibolite occurs in its middle and lower parts.

(7) The Yudu-Jinxi Neoproterozoic volcanoclastic and carbonate belt of central Jiangxi, which extends NE-NNE for 280 km. The ore-bearing Shangshi Formation is composed of interbedding and weakly metamorphosed light gray or grayish white tuffaceous sandstone, tuffaceous siltstone, tuffite, tuffaceous slate with intercalations of carbonaceous phyllite and siliceous dolomite in the upper parts. The discovery of the Qiaoziding Pb-Zn-Au-Ag stratabound deposit at Yinkeng, Yudu County, encourages further prospecting in central and southern Jiangxi Province.

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