Geotectonic Settings of Large and Superlarge Mineral Deposits on the Southwestern Margin of the North China Plate

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Abstract The geotectonic setting refers to the three-dimensional space and related events based on which a metallogenic system is formed and an ore-forming process takes place. This paper discusses the tectonic evolution of the southwestern margin of the North China paleocontinent and related geotectonic settings in which large or superlarge deposits are formed. Emphasis is put on the geodynamic conditions of the Jinchuan nickel-copper deposit, the Baiyin copper-polymetallic deposit and the Hanshan gold deposit. It is significant that the three deposits occur together as a "trinity" on the same paleocontinental margin. The Jinchuan nickel-copper deposit was formed during the early stage of rifting of the paleocontinental margin; the Baiyin copper-polymetallic deposit was formed during the splitting stage of a continental-margin arc. The continental-margin arc spitting resulted in an "island arc rift" in the early stage of evolution. The Hanshan gold deposit was formed within the Altun sinistral strike-slip fault system and its provenance is the "intraoceanic arc" volcanic rocks.

Key words: North China plate, tectonic evolution, Jinchuan nickel-copper deposit, Baiyin copper-polymetallic deposit, Hanshan gold deposit

1 Introduction

The plate margin, along which tectonic activities are complicated and intensive, and within which substance and energy exchanges of various spheres of mantle and crust take place easily and frequently, is often an important metallogenic province. There exist different metallogenic systems and assemblages on different plate margins (Tang, 1982; Zhai, 1993, 1999; Veto-Akos, 1997; Tang and Bai, 1999). Even on the same plate margin, metallogenic systems (assemblages) in different stages of different evolution processes are different, and this leads to diversity and multistage features of a metallogenic system. The geotectonic setting refers to the three-dimensional space and related events based on which a metallogenic system is formed and an ore-forming process takes place. The research method of integrating metallogenesis with tectonism and relating metallogenic systems with tectonic settings is an outstanding means not only for the research of mineral deposits but also in promoting the thinking mode of the research. With the help of this method we shall be able to understand the origin and development of deposits based on an integrated view as well as a historical view, thereby solving the problem "where to prospect for ore minerals".

The southwestern margin of the North China plate is a metallogenic belt of China (Tang and Bai, 1999), in which there have occurred the world-famous Baiyin copper-polymetallic deposit (large scale), Jinchuan Ni-Cu-Pt deposit (superlarge scale) and Hanshan gold deposit (large scale). It is especially remarkable that the three deposits occur as a "trinity" in the same metallogenic province. In what tectonic settings were these deposits formed? Under what tectonic conditions did the mineralization take place? What is actually implied in the phenomenon that the deposits occur as a "trinity" in the same belt and what significance does it have in ore prospecting? With these questions in mind and on the basis of the concept of metallogenic systems (assemblages), we focus our attention on the evolution history of the southwestern margin, and on the tectonic settings of the above-mentioned three deposits. Because the North Qilian tectonic belt is a suture between the North China plate and the Central Qilian-Qaidam plate, some other deposits in the suture, such as the Jingtieshan iron deposit and Ta'ergou tungsten deposit, are associated with the evolution of the Central Qilian-Qaidam plate margin. The tectonic settings of these deposits will not be discussed in this paper; special researches on them will be done in the future.

2 Geological Evolution History of the Early Precambrian on the Southwestern Margin of the North China Paleocontinent

The Longshoushan Group on the southwestern margin of the North China paleocontinent belongs to the active marginal belt of the Alxa continental nucleus, and its oldest age is 3,100 Ma, assigned to the middle Archean.

2.1 The Longshoushan Group being non-Smith strata

The oldest sequence on the southwestern margin of the North China plate (Fig. 1) is the well-known Longshoushan Group distributed in the southern Alxa landmass. It is cut by the Altun fault and Jinding fault in the west, extends via the Baiyin area to eastern Gansu Province, and is bounded on the south by the Longshoushan fault. The composition and evolution of the Longshoushan Group essentially and concretely

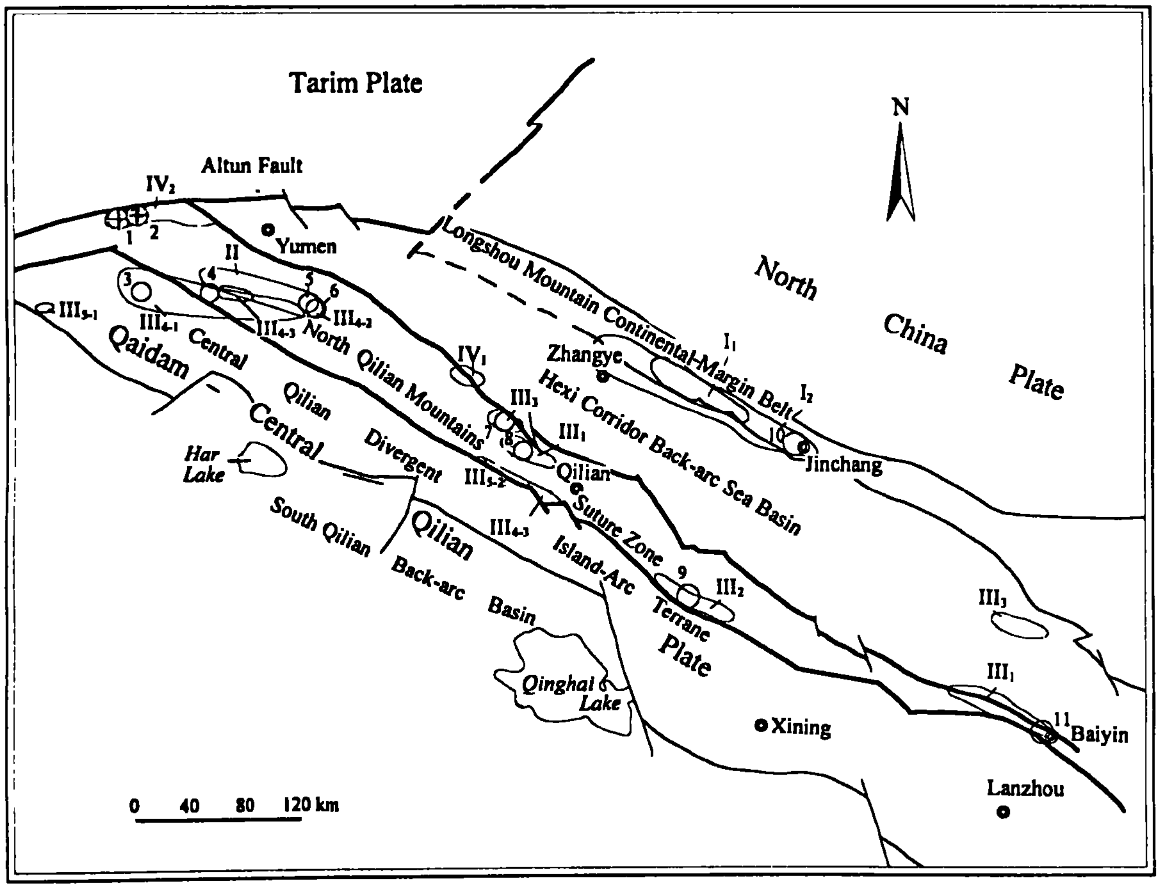

Fig. 1. Geotectonic framework and metallogenic system of the southwestern margin of the North China paleocontinent.

I – Middle Archean-Mesoproterozoic pre-rifting metallogenic system of the North China paleocontinent; I_1 – sea basin sedimentary metallogenic assemblage of the continental nucleus margin (Dongdashan iron metallogenic assemblage); I_2 – pre-rifting diapiric magmatic metallogenic assemblage (Jinchuan Cu-Ni metallogenic assemblage); II — Meso- and Neoproterozoic rifting metallogenic assemblage on the north margin of the Qaidam plate (Huashugou-Liugouxia iron metallogenic assemblage); III – Caledonian active continental margin metallogenic assemblage; III_1 – early-stage island arc rift metallogenic assemblage (Baiyin-Qingshuigou Cu-polymetallic metallogenic assemblage); III_2 – middle-late stage island-arc metallogenic assemblage (Honggou-Jiaolongzhang Cu-polymetallic metallogenic assemblage); III_3 – late-stage back-arc spreading basin metallogenic assemblage (Zhuzuiyaba-Jiugequan-Shijuli Cu-polymetallic metallogenic assemblage); III_4 – magmatic hydrothermal metallogenic assemblage associated with subduction; III_{4-1} – Ta'ergou–Xiaoliugou tungsten metallogenic assemblage; III_{4-2} – Huashugou-Liugouxia copper metallogenic assemblage; III_{4-3} – Dadonggou–Diaodaban lead-zinc metallogenic assemblage; III_5 – Oceanic crust residuals metallogenic assemblage; III_{5-1} – Dadaoerji chromium metallogenic assemblage; III_{5-2} – Yushigou chronic metallogenic assemblage; IV – collision orogenic metallogenic assemblage; IV_1 – residual basin metallogenic assemblage (Tianlu copper metallogenic assemblage); IV_2 – intracontinent orogeny, ductile shear metallogenic assemblage (Hanshan–Yingzuishan gold metallogenic assemblage). Deposits: 1. Yingzuishan gold deposit; 2. Hanshan gold deposit; 3. Liugouxia iron-copper deposit; 4. Ta'ergou tungsten deposit; 5. Huashugou (Jingtieshan) iron-copper deposit; 6. Xiaoliugou tungsten-molybdenum deposit; 7. Shijuli copper deposit; 8. Guomisi copper-polymetallic deposit; 9. Honggou copper-polymetallic deposit; 10. Jinchuan neckel-copper deposit; 11. Baiyin copper-polymetallic deposit.

reflect the evolution history of the southwestern margin of the North China paleocontinent. Since the 1950s, with the discovery, exploration and utilization of the superlarge Jinchuan Ni-Cu deposit, the Longshoushan Group, especially the Baijiazuizi Formation in it, has been paid close attention to because it is a direct host sequence of ore-bearing intrusion. The first author and other researchers have been protractedly and unremittingly engaged in researches not only on the Jinchuan ultramafic intrusion and the Jinchuan Ni-Cu deposit but also on the Longshoushan Group.

The former Xi'an College of Geology (now Chang'an University) and the No. 6 Geological Party of Gansu Provincial Bureau of Geology and Mineral Exploration and Development jointly compiled three sheets of geological map (scale 1:50000), which are arranged from south to north, and known as the *Geological Corridor Map*. Their research shows that the Longshoushan Group is a middle Archean–Early Paleozoic paleometamorphic body, and belongs to a linear marginal active belt of the Alxa continental nucleus (part of the North China paleocontinental nucleus) with complicated metamorphic and deformational structures. It is suggested that there existed not only a basement of the Longshoushan continental marginal rift in the Jixianian Period of the Mesoproterozoic, but also an active continental margin, along which the Caledonian Qilian Ocean underthrust towards the North China continent. After early extension and compression, as well as the orogeny, intracontinental subduction and extension in the late Caledonian and later stages, the Longshoushan terrain has obtained a complicated structural feature. In the Group, solid rheid structures formed by early spreading, such as A-type folds, rootless folds, bedding ductile shear zones, viscous boudinage structures and tectonic lens and syntectonic crystallized veins, are developed. The research also shows that because it has undergone multicyclic and multistage metamorphism and deformation, the Longshoushan Group is fragmented and its sequence is indistinct, so it belongs to the non-Smith sequence. Its four lithostratigraphic associations are isolated from each other by faults or other geologic bodies to become four independent tectonic microlithons. The four lithostratigraphic associations are as follows (Yang et al., 1997, complemented).

Association D: metamorphosed intermediate-acidic volcanic rocks, pyroclastic rocks, leucogranulitite, quartzite intercalated with quartz schist, and gneiss; thickness 2110–2419 m;

Association C: biotite schist, quartz schist, amphibolite, and granulitite intercalated with gneiss; thickness 1179–3237 m;

Association B: marble intercalated with gneiss, quartz schist, and amphibolite; thickness 928–3745 m;

Association A: onyx marble, ophthalmite (mylonite), migmatitic gneiss intercalated with amphibolite, marble, and mica schist; thickness 1627–2100 m.

Association A corresponds to the Baijiazuizi Formation and Dongdashan Formation. Its protolith is of clastic-carbonate-basic volcanic rock formation. The Baijiazuizi Formation contains more marble and the Dongdashan Formation contains more clastic rocks and BIF (banded iron formation), in which the Dongdashan iron deposit occurs. Association B corresponds to the Tamazigou Formation belonging to the carbonate rock formation. Associations C and D consist mainly of clastic rocks and intermediate-basic-intermediate-acidic volcanic formations.

2.2 Ages of the four lithostratigraphic associations of the Longshoushan Group

According to the data from previous researchers, the Sm-Nd pattern age of the association-A amphibolite is ca. 3,100 Ma, so it was formed in the middle Archean; the Sm-Nd pattern age of association-B amphibolite is 2721±40 Ma, so it was formed in the late Archean. According to Yang et al. (1997), the K-Ar isotopic age of biotite from associations C and D is 1600 Ma, and Sm-Nd isotopic age of zircon from associations C and D is 1508 Ma. Associations C and D underlie the Jixian System, so they should be formed in the Paleoproterozoic.

2.3 Variation trend of rock formation of the Longshoushan Group

From early to late, the general variation trend of rock formations of the Longshoushan Group is as follows:

(1) From middle Archean to late Archean, carbonate rocks increased but were absent in the Paleoproterozoic.

(2) Clastic rocks generally increased.

(3) Early (middle Archean) volcanic rocks were basic and belonged to the sodic alkali olivine basalt series and Neo–Paleoproterozoic) volcanic rocks were intermediate-basic and intermediate-acidic, and of bimodal igneous activity features (from regional geological surveying data).

(4) Middle Archean metamorphism corresponded to the higher amphibolite facies. Association A locally contained migmatite; late Archean metamorphism corresponded to the lower amphibolite facies and Paleoproterozoic metamorphism to the higher greenschist facies.

The above-described evolution trend reflects that the crust maturity of the Longshoushan Group increased from early to late.

2.4 Lithostratigraphic correlation between the Longshoushan terrain and the early Precambrian strata in the North China paleocontinent nucleus

The lithostratigraphic association A of the middle Archean Longshoushan Group corresponds roughly to the Qianxi and Anshan Groups of the inner-North China paleocontinent. Both the Qianxi Group and the Anshan Group are supracrustal metamorphic rock series belonging to amphibolite-granulite facies metamorphism consisting of monzogranulite, hypersthene granulite intercalated with garnet leucogranulitite, hypersthene plagioclase gneiss, magnetitic quartzite intercalated with piriklazite, plagioclase diopside granulite, and two-pyroxene plagioclase amphibolite. Their primary rocks belong to volcano-sedimentary rock series, and consist mainly of tholeiite, dacite as well as graywacke, alumina rocks, and BIF with huge thickness. They are common in having basic volcanic activity. Their differences lie in that association A of the Longshoushan Group is migmatized while the Qianxi and Anshan Groups are not; the latter have experienced intensive granite magmatic activity, but mesogenetic magmatism is absent in the Longshoushan area.

Late Archean strata occur extensively within the North China paleocontinent, and many important geological events took place during the late Archean, which was a key period for the formation of the Archean crust. Considering the characteristics of the provenance, primary rock formation of the strata and magmatic activity of the stage, late Archean strata can be roughly grouped into the sedimentary type and volcano-magmatic type (Ma Xingyuan, et al., 1987; Wu Jiashan, 1998). Sedimentary type strata consist mainly of aluminous, carbonaceous and calcareous sedimentary rocks, with minor intermediate-acidic magmatic rocks; volcano-magmatic type crustal primary rock formations consist mainly of volcanic rocks and pyroclastic rocks, with a bimodal feature, and sedimentary rocks increase gradually towards the upper part, These show the characteristics of a greenstone belt. The primary rocks of the late Archean rocks in the Longshoushan area (association B of Longshoushan Group–Tamazigou Formation) are mainly carbonate rocks, only with small amounts of clastic rocks and intermediate-basic volcanic rocks. The carbonate rocks contain rich carbonaceous matter. Thus, the late Archean rocks of the Longshoushan area should belong to the sedimentary crust, and generally belong to active sedimentary rocks in a chasmic sea environment of continental margins.

2.5 No greenstone features being shown in the Longshoushan Group, and no greenstone belt on the southwestern margin of the North China paleocontinent.

Some researchers consider that the Longshoushan Group has features of a greenstone belt (Pan, 1986); we do not agree with this view, and our main reasons are as follows:

(1) Greenstones bear obvious characteristics of volcanic activity no matter whether they are of bimodal type or island-arc type (Condie, 1976), whereas the study area, whether in the middle Archean or in the late Archean, was dominated by sedimentary rocks.

(2) Carbonate rocks are absent in greenstone, but there are abundant carbonate rocks in the study area.

(3) Most of greenstones are interrupted by magmatic rocks and alternate with granite (Kang, 1976; Wang and Liu, 1980). But in the study area, early Precambrian rocks generally occur in belts and are frequently interrupted by faults.

(4) A greenstone belt has a green appearance, but the rocks in the study area show a gray color.

2.6 The "opening-closing" cycle reflected by primary rock formation of the Longshoushan Group

From an analysis of the above-described formation, middle Archean rocks in the Longshoushan area should belong to the clastic rock–magnesium-rich carbonate rock–intermediate-basic volcanic rock formation (Fig. 2). And based on this we can infer that early spreading took place in the end of middle Archean. The grounds for the inference are as follows: limited granite is distributed in the study area, migmatite occurs only along association A, and association A contains abundant bedding rheomorphic structures (see the above description). The essential causes that metamorphic rocks, migmatite and migmatitic granite occur together in certain regular stratohorizons lie in that spreading took place in the end of middle Archean (early period of the Fuping Movement), when nearly flat-lying peel faults were formed and ductile deformation, migmatization and granite magmatism took place in the deep rock strata. The available data show that the isotopic age of migmatites and granites mainly ranges 1984–2065 Ma and the average Sm-Nd age of basic rock veins penetrating migmatites is 2667 Ma (average from 6 samples, regional geological data, 1995). Therefore, the former age (1984–2065 Ma) should be the age of a thermal event in the late stage of forming migmatites; and based on the later age (2667 Ma), it can be deduced that migmatization took place in the end of the late Archean. With the spreading, the Longshoushan area in the late Archean was extended to a chasmic sea, where carbonate rocks with a huge thickness were deposited and, at the same time, weak volcanic activities took place (Fig. 2). At the end of the late Archean, the general tectonic regime changed from extensional to contractional, and the marginal sea was closed. In the Paleoproterozoic, clastic rock formations, and intermediate-basic and intermediate-acidic volcanic rock formations were formed; and by the end of the Paleoproterozoic extensive granite vein activities took place in the study area, which caused further welding and solidification of the Longshoushan Group (Fig. 2). The above describes the first "opening-closing" cycle of this area.

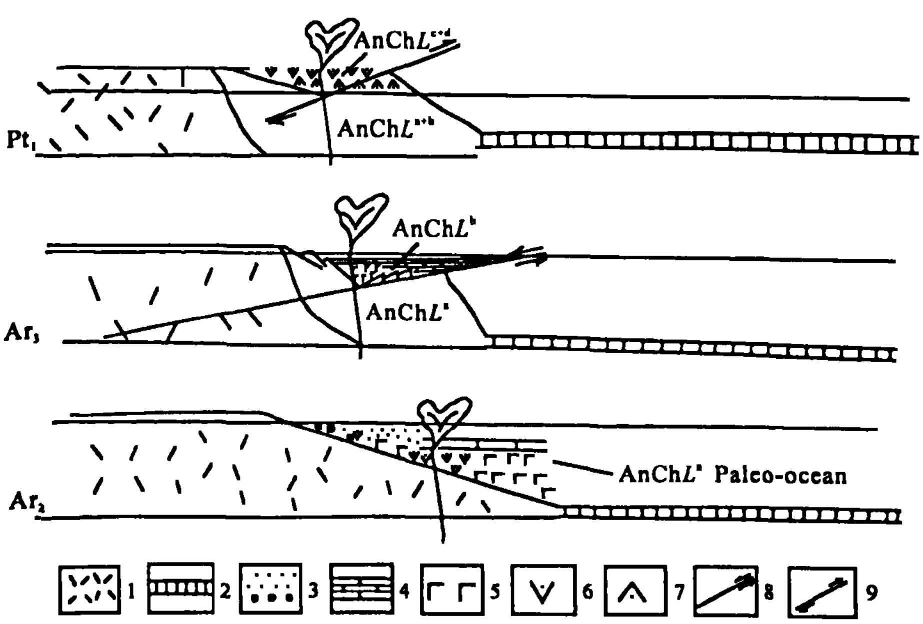

Fig. 2. Early Precambrian tectonic-depositional evolution in the Longshoushan area.
1. Continental crust; 2. oceanic crust; 3. sand-mud-gravel; 4. calcareous matter; 5. basic volcanic rocks; 6. intermediate-basic volcanic rocks; 7. intermediate-acidic volcanic rocks; 8. peel fault; 9. thrust fault. AnChL – Longshoushan Group of the Precambrian Changchengian System; subscripts a–d represent the formations.

3 Mesoproterozoic Tectonic Setting of the Southwestern Margin of the North China Paleocontinent and Formation of the Jinchuan Nickel-Copper Deposit

At the early stage of the Mesoproterozoic, the southwestern margin of the North China paleocontinent was in an uplifted background, and at the late stage, it was a rift setting. The host rock of the Jinchuan Ni-Cu deposit—the Jinchuan ultrabasic intrusion was formed in the upwelling setting before rifting. The age of the intrusion is 1508±31 Ma.

3.1 The southwestern margin being in an upwelling background and deposition absent in the Changchengian Period

The Lüliang Movement caused the southwestern margin to be welded and solidified. In the Changchengian Period, deep magmatism was strong in the area. The upper part of the area was uplifted and turned into a denudation area. Intensive melting took place in the deep strata. The Sm-Nd isochron age of the Jinchuan intrusion is 1508±31 Ma (Tang et al., 1995), and the Sm-Nd age of the Zangbutai intrusion in the same tectonic belt is 1511 Ma. The uplifting caused by deep magmatism often resulted in rifting. The Jinchuan Ni-Cu deposit is just associated with the early rifting taking place on the continental margin.

3.2 Rifting of the Longshoushan area in the Jixianian Period

The Longshoushan area was steadily uplifted in the

Changchengian Period. In the Jixianian Period, the upper crust of the area gradually became thin, entering the rifting stage, and a rift based on the Longshoushan terrain was formed. Within the rift, the Dunzigou Group (*JxD*) containing abundant volcanic materials was deposited. The lower part of the Dongzigou Group, dominated by clastic rocks, belongs to a rift molasse formation, which mainly consists of metaconglomerate, metaquartzose sandstone and quartzite, and the gravel came from the Longshoushan terrain. The middle part of the group consists mainly of carbonate rocks, and its main components are limestone and dolomite, with sandy dolomite in the late stage; the upper part is mainly composed of muddy rocks, generally dark green-grayish green thin-bedded silty chlorite-sericite phyllite. The above stratigraphic sequence reflects the whole process from opening to closing of the Longshoushan rift. The lower-part rocks formed in the initial stage of the rift belong to the river facies; the crystallized dolomite and stromatolite widespread in the middle part reflect an intertidal zone environment, and the limestone reflects a shallow sea continental shelf environment. Occurrence of the upper part muddy rocks marked the closure of the rift. Additionally, a large quantity of basic volcanic rocks bearing geochemical characteristics of rift volcanic rocks were discovered in the Hongwajing, Xuanmaotou and Zangbutai areas (1:50,000 regional geologic survey data, 1995). The above description shows that another opening-closing cycle took place on the southwestern margin of the North China paleocontinent during the Jixianian Period.

4 Tectono-sedimentation in the Longshoushan Area during the Neoproterozoic

With the closure of the Longshoushan rift in the Jixianian Period and under the influence of the Jinning Movement (early stage), the Longshoushan area was uplifted once again and the Qingbaikou System is absent in this area. The uplifting may be related to subduction-orogeny of the Old Qilian Ocean. Influenced by the tectono-thermal event, the Jinchuan intrusion was partially metamorphosed. The Qingbaikou Period is a key period for the southwestern margin of the North China paleocontinent to change from a passive continental margin to an active one and also a period for the turning of extensive mechanism to compressive mechanism caused by thrusting. Affected by the global climate in the Sinian Period, ocean-glacial sediments were formed in the littoral zone, and after ablation, shallow-sea carbonate rocks were deposited. The ocean-glacial sediments and the carbonate rocks together comprise the Hanmushan Group (*ZH*, *Z*). Its lower part (glacial sediments) is called the Shaohuotonggou Formation (*Zs*, Z_1), which is parallelly unconformable over the Dunzigou Group (*JxD*), and consists mainly of grayish green and purplish red moraine-breccia, moraine pebble-bearing phyllite and pebble-bearing silty slate. The upper part of the Hanmushan Group, named the Caodaban Formation (*Zc*, Z_2), being conformable to the Shaohuotonggou Formation and locally with phosphoric layers, consists mainly of limestone intercalated with calcareous phyllite. The whole-rock Rb-Sr isochron age of the phyllite is 593±39 Ma. In general, it still belonged to the passive continental margin. In the Paleozoic Era, the study area stepped into a new active stage, when the Qilian Ocean was thrust toward the North China plate and a series of active continental margin structures were formed.

5 Caledonian Tectonic Evolution of the Southwestern Margin of the North China Plate and Formation of the Baiyin Orefield

In the early Early Paleozoic, the southwestern margin of the North China plate was an Andean type active continental margin. In the middle stage, a trench-arc-basin system and biserial arcs (continental-margin arc and oceanic crust island arc) were formed. In the late stage, the Qilian Ocean disappeared, and the back-arc basin shrank; in the terminal stage, the southwestern margin collided with the Central Qilian–Qaidam plate, forming an orogenic belt. The Baiyin polymetallic orefield is associated with the opening of the continental-margin arc (island arc rifting). The provenance of the Hanshan gold deposit is related to the oceanic crust island arc (Figs. 1 and 3).

5.1 Formation and Evolution of the Baiyin–Qingshuigou–Changma continental-margin arc

5.1.1 Characteristics of the basement of the arc

The northward subduction of the Qilian Ocean changed the southwestern margin completely from a passive continental margin into an active continental margin. The main indication for that is the Heicigou Formation (Є*h*, Є$_2$), which is composed of intermediate-basic calc-alkaline volcanic rocks and developed along the continental margin. Because of the tectonic mixing, the Heicigou Formation is now mainly distributed in the North Qilian orogenic belt. The active sediments consist mainly of pyroclastic rocks, intermediate and basic lava intercalated with fine clastic rocks and minor marine fossil-bearing carbonate rock lenses. The rock sequence is distributed, from east to west, in the areas such as Huitulaochi-Shengjialiang in Baiyin City, Shiqingdong in Yongdeng County, Heicigou in Tianzhu County, Dayehekou-Yingzuishan in Sunan County and Changma in Yumen City. Lithofacies reconstruction shows that the Heicigou Formation belongs to the sea-floor slope volcanosedimentary formation dominated by explosive volcanism. To the north of the rock sequence (the Heicigou Formation), i.e. the side near the North China paleocontinent, there is distributed mainly the Dahuangshan Formation (Є*d*, Є$_{2\text{-}3}$), which was formed at the same time with the Heicigou Formation but different in facies. The Dahuangshan Formation consists of grayish green and purplish red epimetamorphic rhythmic fine clastic rocks, intercalated with argillite and a few limestone lenses, distributed most completely in Dakouzigou of Dahuangshan Mountain in Shandan County. Wavy wash structures, molds and crossbeds are often found in sandstone, reflecting the features of a flysch formation. Based on the fossils, the Dahuangshan Formation was formed in the middle–late Cambrian, and is a diachronous stratigraphic unit and belongs to quasi-stable clastic sediments of neritic shelf facies. The above-described spatial arrangement of the Heicigou and Dahuangshan formations gives a vivid picture for the activities of the southwestern margin in the middle-late Cambrian as follows: the continental side is dominated by quasi-stable clastic sediments, and the oceanic side mainly of active sediments and strong volcanic activities. Through reconstruction of the tectonic setting, it is considered that in the early Early Paleozoic, the southwestern margin should be an Andean-type continental margin (Fig. 3).

It is obvious from the above description that the basement of the Baiyin volcano-arc is located in a transitional zone between ocean and continent. Studies of the acidic volcanic rocks of the Baiyin area (The Heicigou Formation locally contains acidic volcanic rocks) (Xia et al., 1998), and the Archean granulite of

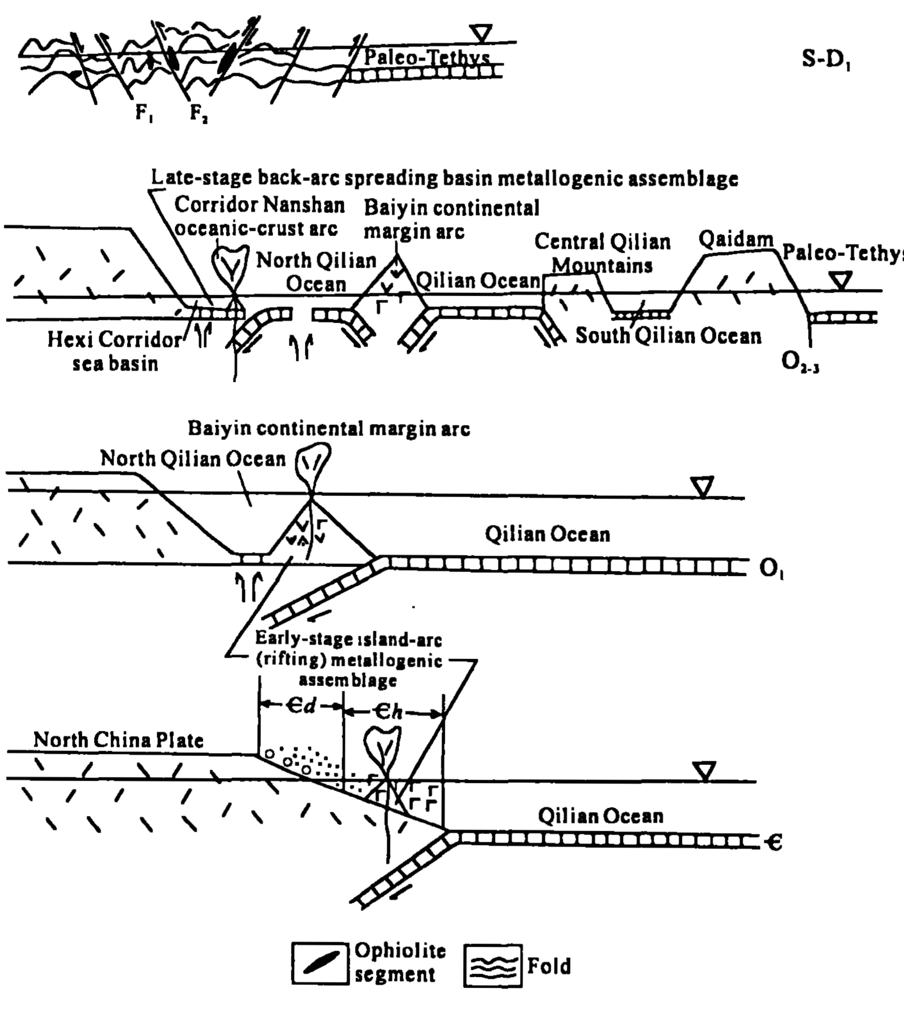

Fig. 3. Caledonian tectonic evolution on the southwestern margin of the North China paleocontinent.

F$_1$ – Longshoushan fault; F$_2$ – Corridor Nanshan fault; Є*d* – Dahuangshan Formation; Є*h* – Heicigou Formation; other symbols same as in Fig. 2.

North China (Shen, 1992) show that the two have similar chondrite-normalized patterns. This implies that the deep part of the Baiyin volcano-arc basement may be a part of the North China paleocontinent. Because of back-arc spreading, it is now located on the north margin of the Central Qilian divergent island arc. In view of the volcano-sedimentary rock association around it and the pillow structure of the basic volcanic lava, the Baiyin arc should be a product of subaquatic volcanic eruption.

5.1.2 Features of the volcanic rock of the arc

Xia et al. (1998) have made a thorough research on the volcanic rock distributed in the Baiyin–Qingshuigou–Changma area. Their research results show that the volcanic rock of this area has a bimodal feature and its microelement ratio spider diagram shows features of "large swellings" (i.e., rich in Sr, K, Rb, Ba, Th, Ta, Nb, Ce, P and Zr). Based on that, they think that the volcanic rock is a product of a rifting environment. But regionally, the volcanic rock belt consists essentially of intermediate-basic calca-alkline volcanic rock, and intermediate-acid volcanic rock is limited in three areas, i.e., Baiyin, Qingshuigou and Changma. This implies that volcanic activities of the southwestern margin in the early stage of the Early Paleozoic did not take place homogeneously along the margin but were concentrated in sections. In the longitudinal direction, the volcanic rock differs in nature with different distances from the Benioff line. Generally, the crust is thinner near the Benioff line, where basic magma is often formed and weakly contaminated by crustal materials. But in places far away from the Benioff line, the continental margin crust is thicker, where the up-going basic magma is greatly contaminated by crustal materials. And, because of greater pressure of the crust, the basic magma ascends slowly, and the thermal energy produced during the up-going process will cause anatexis in the lower part of the continental crust, forming silica-rich magma. The silica-rich magma first goes up and erupts to form acid volcanic rock series, and then the lower basic magma erupts to form basic volcanic rocks in the upper location, comprising the so-called bimodal rock suite (spilite-keratothyre sequence). So the occurrence of the bimodal rock suite in this area does not mark continental rifting, but marks splitting of the continental-margin arc from the continent, and marks the initial stage of the Andean-type continental margin evolving into a trench-arc-basin system. In this area, the bimodal suite is locally distributed in the continental-margin arc zone, and the whole regionally is still dominated by intermediate-basic calca-alkline volcanic rocks (Zhao, 1996). As mentioned above, the Longshoushan rift formed on the southwestern margin of the North China paleocontinent in the Mesoproterozoic Jixianian Period had already been closed in the early stage of late Archean, but no granite magmatism occurred and granite of the same period was absent in the Earth's surface. With low consolidation grade and low maturity, this type of tectonically weak zone is one of the principal causes that volcanic magmatism of the late stage of late Archean could take place far away from the Benioff zone and the bimodal suite could be formed. Jixianian strata have already been discovered in the Baiyin area, which confirms the reliability of the above deduction.

Another reason for discussing the consideration that the volcanic rock is a product of rifting is that many geochemical characteristics of the volcanic rock cannot be derived by typical rifting. For example, the <FeO>/MgO-SiO_2 diagram of the volcanic rock shows that part of it belongs to the calca-alkline series, and part belongs to the tholeiite series. The contents of Al_2O_3 and <FeO> of the volcanic rock are medium, but rift tholeiite generally contains rich iron and meager aluminum (Condie, 1982). More importantly, the TiO_2 content of rift tholeiite is 2.2×10^{-2}, that of oceanic ridge tholeiite is 1.5×10^{-2}, and that of island arc is 0.83×10^{-2} (Condie, 1982). But the TiO_2 contents of both tholeiite and calca-alkline rocks from Xia (1998) are lower than 0.96×10^{-2}. In addition, the Cr content of the basic volcanic rock (tholeiite) in the belt is generally 29.2×10^{-6} to 130×10^{-6}, which is far from that of continental rift tholeiite (160×10^{-6}) and close to that of island arc tholeiite (50×10^{-6}). To sum up, the volcanic rock in the Baiyin area and other related areas should be an island arc volcanic rock, while some of its features characteristic of rifts are derived from splitting of the continental-margin arc from the continent. This type of tectonic setting can be called island arc rifting.

5.2 Formation and evolution of the Ordovician oceanic crust-type island arc

The uninterrupted northward subduction of the Qilian Ocean separated the above-described Baiyin-

Qingshuigou-Changma continental-margin arc away from the southeast margin of the North China paleocontinent, during which time the North Qilian Ocean was formed (Figs. 1 and 3). The spreading of the North Qilian Ocean caused the continental-margin arc to drift far away from the continental margin and joined the Qilian Ocean. In the course of drifting, a great deal of segments of the residual arc were left in the North Qilian Ocean. Intermediate-acidic volcanic rock series (Chelungou Group, *OC*, O_1) are found in the residual arcs distributed in the Chelungou area of Tianzhu County. The spreading and northward intraoceanic subduction also resulted in the formation of an intraoceanic island arc. The intraoceanic island arc (or called the oceanic crust arc) is distributed along the area north of Baiyin City-Shihuigou of Yongdeng County-Corridor Nanshan-Hanshan of the Changma region, striking WNW in a length of 800 km. The intraoceanic arc consists mainly of intermediate-basic volcanic rock and pyroclastic rock of the Yingou Group (OY, O_1). What needs to be further explained is that although the Yingou Group consists mainly of volcanic rock and ophiolite, its components and the implication reflected by each component are complicated. In the Group, there are ophiolite and volcanic rocks that reflect the existence of the Qilian Ocean, e.g., the Yushigou ophiolite; those reflecting the existence of the North Qilian Ocean, e.g., the Dachadaban ophiolite; and the volcanic rocks reflecting the existence of the island arc, such as the Corridor Nanshan volcanic rock. There have been many researches about the ophiolite and volcanic rocks that reflect the existence of the Qilian Ocean and the North Qilian Ocean, and we will have additional discussions about them in future. Here we shall focus on the features of the Yingou Group volcanic rock that reflects the island arc process. It has already been clear that the volcanic rock of the Yingou Group in the early stage consisted of boninite, characterized by high-Mg and high-Si contents. Besides, there was tholeiite in Shihuigou of Yongdeng County, and island arc calca-alkline volcanic rock in a little later stage, in which pyroclastic rock and sedimentary rock (Zhongbao Group OZ, O_{1-2}) comprised a very high percentage. In the late stage of the island arc evolution, trachyte, leucotephrite, leucite analcitite and leucite trachyte occurred. These rocks belong to the arc alkaline dorgalite series, and also are components of the Zhongbao Group. They are an important marker for maturity of oceanic crust-type island arc. In the Hanshan area of Yumen City, the lower part of the oceanic crust-type arc consists of basaltic lava with pillow structure developed in it, representing the basement of the oceanic crust arc. The middle part is mainly composed of andesitic lava and andesitic tuffaceous slate, locally intercalated with sediment-tuffs and tuffaceous sandstone. The upper part consists mainly of andesitic lava including rhythmic occurrence of poly-, less- and non-porphyritic andesites, and is the principal part of the arc. The ore source of the Hanshan gold deposit is just the maturing oceanic crust island arc volcanic rocks.

By the way, due to the extension and subduction of the Qilian Ocean, off the north side of the above-described oceanic crust island arc in the late Early Paleozoic, a new extensional basin was formed. Back-arc basin type ophiolites, such as the Laohushan ophiolite, Jiugequan ophiolite and Yushugoushan ophiolite, were formed, and the associated deposits include the Jiugequan and Zhuzuiyaba copper deposits (Fig. 1). At the end of the Early Paleozoic, the above-mentioned island arc and continent began to collide, and sandstone (Angzanggou Formation, S*a*, S_1) was formed in the Silurian, and the related sedimentary mineral resource is the Tianlu copper deposit (Figs. 1 and 3).

6 History of the Qilian Mountains and Formation of the Hanshan Gold Deposit

In the Late Paleozoic, the Qilian Ocean and North Qilian Ocean disappeared successively; the Qaidam-Central Qilian plate and North China plate collided and welded, entering into the intraplate movement stage. The Tethys replaced the original Qaidam-Central Qilian plate. After having experienced lifting and leveling in turns, the Qilian Mountains were finally formed in the Pleistocene. The Hanshan gold deposit was formed in the late stage of the intracontinent orogenic movement.

At the end of the Caledonian Movement, with the North China plate colliding with the Qaidam plate, the high Old Qilian Mountains were formed. In the early Late Paleozoic, the mountains were leveled to ground and a huge piedmont molasse formation (Laojunshan conglomerate, more than 3000 m thick) was accumulated in the piedmont depression in the north part of the mountains. The former position of the

Qaidam-Central Qilian plate was occupied by the Tethys along with the collision of the Qaidam-Central Qilian plate with the North China plate. The welded and leveled Old Qilian Mountains stood along the Tethys shore, and a basin-and-range landscape emerged there. In the Tertiary, the Tethys closed and another orogenic movement took place; high mountains were formed again in this area, and then again was peneplaned. About 1000 m thick molasse was accumulated on the south margin of the Corridor basin (Ge, 1996). In the Neogene, the Indian plate collided with the Qinghai-Tibet plate, and northward subduction of the Ampferer type continued, resulting in a north-south strain on this area. At the same time, the Pacific plate was thrust toward the Eurasian continent in a Benioff-type subduction. These processes subjected this area to a retraction stress with WNW-dominant tectonic lines, and also caused an Ampferer-type subduction along the interfaces of the main Caledonian blocks (for example, the Corridor basin underthrusting toward the Qilian Mountains) and ductile shear (e.g., the Altun sinistral ductile shear strike-slip fault). Then the whole Qilian area was gradually elevated. The fluid dynamics of the Hanshan gold deposit is associated with the Altun fault. From the end of early Pleistocene to middle Pleistocene, the Qilian Mountains were drastically uplifted. In the terminal Pleistocene, the retraction process was even more extensive and the Qilian Mountains were shortened in the horizontal direction and further elevated by thrusting, forming a new "V"-type structure. Then the Qilian Mountains became 4000–5000 m high.

7 Conclusions

The geotectonic setting is one of the major factors determining the metallogenesis and metallogenic patterns. A plate margin is often an important metallogenic belt. The North China paleocontinental margin was an active continental margin in the middle Archean, and in a chasmic sea environment in the late Archean. The chasmic sea was and an epeirogenic movement took place in the Paleoproterozoic. It was an upwelling environment in the Changchengian Period, and ultrabasic magmatism occurred in the deep part, resulting in the Jinchuan superlarge magmatic deposit. The upper crust of this area was split in the Jixianian Period (the second opening-closing cycle in this area). At the end of the Neoproterozoic or the Caledonian stage, the Qilian Ocean was subducted toward the North China plate, forming the Andean active continental margin, and afterwards a continental-margin arc was formed. During the separation of the continental-margin arc from the continent, an island arc rift came into being, which was the environment where the Baiyin copper- polymetallic metallogenic system was formed. As the continental-margin arc was pulled apart from the continent, the North Qilian Ocean took shape, resulting in an intraoceanic arc—the oceanic crust arc. Volcanic rocks of the oceanic crust arc are the source of ore-forming materials of the Hanshan gold deposit. Back-arc spreading of the oceanic crust arc resulted in the formation of ophiolites represented by the Jiugequan ophiolite and the associated copper deposits. At the late Caledonian stage, the Qaidam-Central Qilian plate collided with the North China plate, and then the Tianlu copper deposit was formed. At the end of the Caledonian Movement, the collision led to orogeny, and then an intraplate movement began. The Himalayan orogeny resulted in elevation and orogeny of this area, forming the V-pattern structure. The related Altun faulting is the primary dynamic force for driving the fluids to form the Hanshan gold deposit.

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