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Geology, Genetic Types and Metallogeny of Gold Deposits in the Eastern Tianshan, Xinjiang

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Abstract As a typical Palaeozoic island arc system, the eastern Tianshan area, Xinjiang, is different from eastern China but similar to the Meso-Cenozoic island arc metallogenic provinces along the coast of the Pacific Ocean in metallogenic environment, geology and geochemistry. Three types of gold deposits, ductile shear zone-hosted gold deposits (Kanggur `), magmatic hydrothermal gold deposits (Jinwozi) and volcanic- or subvolcanic-hosted gold deposits (Xitan and Mazhuangshan), have been identified in this area. Regionally, gold deposits are structurally controlled by the Kanggur Tag ductile shear zone, Shaquanzi fault, Hongliuhe fault and Yamansu fault. Generally, gold mineralization occurs in the transition zones from volcanic rocks to sedimentary rocks. The horizon bearing well-developed jasper is an important indicator for gold mineralization. Each of the three types of gold deposits has its distinctive metallogenic background and geological-geochemical characteristics.

Key words: eastern Tianshan, gold, metallogeny, genetic type, geology, geochemistry

1 Metallogenic Background of the Eastern Tianshan

The eastern Tianshan area is a typical Palaeozoic island arc-trench system adjoining the Junggar plate on the north and the Tarim plate on the south, composed of the Bogda island arc, Qoltag island arc, Xingxingxia island arc and Liushugou island arc (Li et al., 1999; Guo, 2000). A series of E-W- to ENE-trending deep faults are well developed, including the Kanggur fault, Yamansu fault, Shaquanzi fault, Kushui fault and Hongliuhe fault (Fig. 1) (Ji and Tao, 1994) (Gao, 1959; Ji et al., 1997; Zhang and Ji., 1999)

The strata in the area consists dominantly of the Carboniferous and subordinately of the Devonian and Permian. The Devonian, exposed north of the Kanggur Tag fault and south of the Shaquanzi fault is composed of neritic intermediate-basic and intermediate-acid volcanic rocks and clastic sedimentary rocks with carbonates. The Carboniferous is extensively distributed, consisting dominantly of intermediate-basic volcanic rocks and clastic sedimentary rocks with a small amount of limestone. Controlled by the Kanggur fault and Shaquanzi fault, the Permian is mainly distributed in the Kanggur Tag island arc and Beishan island arc, and is composed of clastic rocks with carbonates and basic to acid volcanic rocks. Intrusive and subvolcanic rocks are well developed, including mainly granite, quartz porphyry, quartz moyite, rhyolite, dacite porphyry, orthophyre and albitophyre.

2 Metallogeny and Ore-controlling Factors

Different from the circum-Pacific metallogenic domain in eastern China and Tethyan-Himalayan metallogenic domain in southwestern China, the eastern Tianshan is a typical island arc system. It has many similarities to the island arc environment in the inner zone of the western Pacific in respect to the gold metallogenic setting, types of ore deposits and volcanic formation types (Feng, 1999). In Papua New Guinea, New Zealand, Fuji, Japan, Taiwan and the Philippines and other typical island arc areas in the western Pacific, many large and superlarge gold deposits have been discovered. The Axi superlarge epithermal gold deposit has been discovered in the western Tianshan. The eastern Tianshan has great gold prospects, where a lot of gold deposits have been discovered.

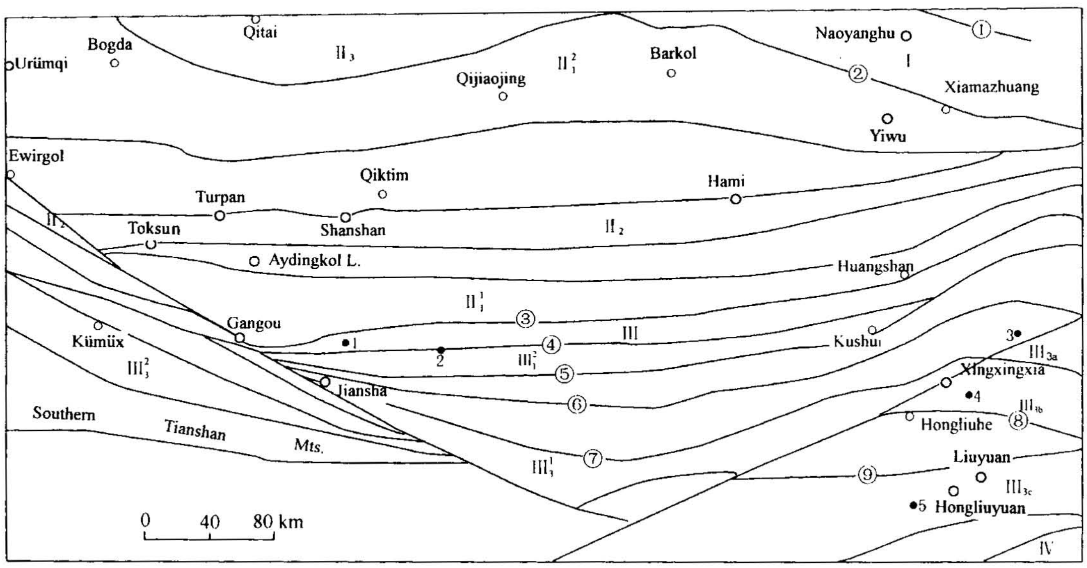

Fig. 1. Map showing the tectonic units in eastern Tianshan (modified from Ji Jinsheng, 1995).

I–Siberian plate; II–Junggar–Kazakhstan plate; II_1–Kanggur Tag–Karlik island arc system; II_1^1–Kanggur Tag—Karlik island arc; II_1^2–Bogda back-arc basin; II_2–Turpan-Hami basin; III–Tarim plate; III_1–Yamansu-Aqishan island arc system; III_2–Eren Habirga island arc system; III_3–early Palaeozoic central Tianshan island arc; III_1^3– Caledonian central Tianshan island arc; III_2^3–southern Tianshan back-arc basin; III_4–Kuruktag on the margin of the Tarim plate; III_5–Beishan rift; IV–North China plate. Ore-controlling deep faults: ① Armantai fault; ② Kelamaili fault; ③ Kanggur Tag-Huangshan suture; ④ Huangshan fault; ⑤ Yamansu fault; ⑥ Shaquanzi fault; ⑦ Jianshanzi fault; ⑧ Hongliuhe fault; ⑨ Liuyuan fault. Gold deposits: 1. Xitan; 2. Kanggur Tag; 3. Mazhuangshan; 4. Jinwozi; 5. Laojinchang gold deposit.

Three types of gold deposits have been found; they are: ductile shear zone-hosted gold deposits (Kanggur Tag), magmatic hydrothermal gold deposits (Jinwozi) and volcanic or subvolcanic-hosted gold deposits (Xitan and Mazhuangshan). Their distribution and mineralization are controlled by ductile shear zones, deep faults, strata and volcanism-subvolcanism.

2.1 Control of ductile shear zones on gold deposits

The Kanggur Tag fault is not only a Palaeozoic suture but also a ductile shear zone, which separates the Turpan-Hami basin from the Qoltag island arc and controls the distribution of gold deposits such as the Kanggur Tag gold deposit. The northern Tianshan ocean was subducted beneath the Tarim plate along the Kanggur Tag fault. In the process of subduction, ore-forming elements were remobilized from the subducting plate to the overlying plate where the temperature and pressure decreased and were precipitated there under appropriate conditions. In the ductile shear zone in the east, the Kanggur Tag gold deposit was formed; in the west, the Xitan gold deposit was formed in volcanic rocks; in the centre, the Yuanbaoshan and Dadonggou gold deposits and a series of ore occurrences have been discovered, which are distributed between the ductile shear zone and Kushui fault and nearby. Gold deposits related to the ductile shear zone are located in the Kushui Formation in the east. Gold deposits related to volcanism were formed in the Aqishan Formation volcanic rocks in the west. The Kelamaili fault in its north, featuring ductile shearing also, controls the location of the Jinshan and Shuangfengshan gold deposits in its northeast segment. In the Middle Carboniferous, as the Turpan ocean basin was again subducted southwards along the Kanggur fault, the Kushui Formation greywacke in the Huangshan-Qiugemingtashi trench and the strata on the northern margin of the adjacent Aqishan island arc were intensely deformed and mylonitized to form ductile shear zones. The ductile shear zones provided conduits for transport of gold-bearing fluids and structural sites for deposition of gold. The strata with intense ductile shearing have high contents of gold. Especially, the structural sites superimposed by late-stage brittle faults are favourable loci for the formation of gold deposits.

2.2 Relations of the distribution and types of gold deposits to deep faults

The Kanggur Tag fault, Yamansu fault, Shaquanzi fault and Hongliuhe fault are the main transcrustal deep faults controlling the distribution of different types of gold deposits. Volcanic- or subvolcanic-hosted gold deposits and magmatic hydrothermal gold deposits are mainly distributed from the Shaquanzi fault to Beishan area. In intermediate-basic to acid volcanic rocks of the Carboniferous Yamansu Formation and Nanmingshui Formation distributed from the Kushui fault in the north to Hongliuhe fault in the south, there occur the Mazhuangshan, Nanjinshan, No. 460, Langwashan and Shuangjianshan gold deposits. Magmatic hydrothermal gold deposits are mainly distributed south of the Hongliuhe fault, including the Jinwozi, No. 210, Nanjinshan, Shijinpo, Huaniushan, Laojinchang and Jinchanggou gold deposits (occurrences). These transcrustal deep faults are important conduits for emplacement of intrusions and orebodies, along which intrusions and ore deposits are distributed in zones. For example, in the Beishan area, the Jintanzi, Jingoujing, Shijinpo, Huaniushan and Jinchanggou gold deposits (occurrences) are distributed in an E-W direction along the Liuyuan-Aqishan fault.

2.3 Control of strata and lithology on gold mineralization

The strata hosting gold deposits are complex in lithology. They are polymictic complexes composed of bimodal volcanic rocks and sedimentary clastic rocks. For example, the Huaniushan Formation is composed of the overlying sedimentary clastic rocks with acid volcanic rocks and the underlying basic volcanic rocks with sandstone. The Baishan Formation is sedimentary clastic rocks with intermediate-acid volcanic rocks. The Fangshankou Formation and Hongliuhe Formation are paralic clastic rocks and continental volcanic rocks. The mineralized Shaquanzi Formation consists lithologically of tuff, acid-interintermediate lava, basalt and siltstone. Several gold deposits and occurrences have been discovered in basalt, andesite, tuff, dacite and sedimentary clastic rocks of the Yamansu Formation. The Xitan gold deposit is hosted in the Aqishan Formation intermediate-acid volcanic rocks. Geochemical surveys have revealed that volcanic rocks have higher content of gold, while clastic rocks have a lower content of gold. It indicates that volcanism provides a primary material basis for the formation of gold deposits. Iron-bearing jasper rock has a higher content of metals, which is an important ore marker. Au-bearing strata are usually intensely propylitized to show a dark green colour. When the rocks are bleached, the gold content therein increases somewhat. The bleaching of the dark altered rocks indicates remobilization and gold mineralization and enrichment metals.

2.4 Control of intrusions and subvolcanic bodies on gold mineralization

Gold mineralization from the eastern Tianshan to the Beishan area is unexceptionally related to intrusive rocks and subvolcanic porphyries. Mineralization occurs within intrusions, in contact zones or in wall rocks nearby. Intrusive and subvolcanic bodies offer heat and ore sources for mineralization. Especially, the combination of intermediate-basic volcanic rocks with intermediate-acid intrusions favours mineralization. The Xitan gold deposit is intimately associated with granite-rhyolite porphyry. The orebodies are distributed on the northwestern margin of the caldera. The No. 6 orebody in the Kanggur Tag gold deposit and the Matutan gold deposit are only about 6 km south of tonalite. Large amounts of small granodiorite porphyry and granite porphyry stocks occur near the Xifengshan and Huangshigang gold deposits. The Mazhuangshan gold deposit is just hosted within a subvolcanic body. Intrusions and orebodies are temporally and spatially associated. They are formed by the same geological processes, i.e. magmatic differentiation crystallization and late hydrothermal fluid filling and replacement.

3 Geology and Geochemistry of Ductile Shear Zone-hosted Gold Deposits

Along the Kanggur Tag-Huangshan ductile shear zone and in its vicinity large Kanggur Tag gold deposit and a number of gold occurrences have been discovered (Ji et al., 1997). The contents of Au, As, Sb and Pb in the primary halos of the inner zone are obviously higher than those in the outer zone, but the contents of Ti, Cr and Ni in the inner zone are lower than those in the outer zone. So, gold deposits are located in or near the ductile shear zone, while Cu-Ni deposits generally occur in the outer zone of the shear zone. Gold deposits are formed in the strongly sheared zone, featuring distinct fine-granulation and dynamic differentiation. For example, in the Kanggur Tag gold deposit, quartz and pyrite are finely granulated; banded-streaky structures are formed in phyllonite and mylonite. The superimposition of brittle deformation on the ductile shear zone favours mineralization. For example, a large amount of tectonic breccia is present in the No. 6 orebody of the Kanggur Tag gold deposit. The angular fragments of wall rocks are cemented by sulphides to form brecciated ores. Sulphides are obviously enriched in the brittle fracture portions of the phyllonite and mylonite zones. With the uplift of the deep ductile shear zone, the temperatures, pressures and thermal values decrease, and the water content and brittleness of rocks increase, thus creating conditions for brittle fracturing. The microfracture surfaces in the phyllonite and mylonite zones become zones of weakness in rocks and are succeeded by late-stage structural activity. The brittle fracture zone offers appropriate conduits for transport of ore-forming fluids and structural sites for deposition of metals.

Gold deposits are generally far away from the large rock bodies and veins and dykes are common. This type of gold deposit is large in size with persistent extension. Orebodies commonly occur as lenses and pockets, and seldom as stockworks and veins.

Pyrite and chalcopyrite are dominant in sulphides. Compared with volcanic-hosted deposits, this type of deposit contains considerable amount of sulphides, especially chalcopyrite.

The ore-forming fluids are characterized by high contents of Cl^-, SO_4^{2-}, Na^+, Ca^{2+} and CO_2. In some deposits, the fluid contains higher F^- (e.g. F^- is as high as 122 g/l in quartz inclusions of one sample in the Kanggur Tag gold deposit and 132 g/l in the Jinshan gold deposit and Na^+, Ca^{2+}, CO_2, SO_4^{2-} and CO_2 are dominant in the fluid, while CH_4 is very low). It is different from the other two types of gold deposits in chemical composition, but they all feature Na>K. The fluid inclusions have a low salinity, generally 15–20 wt% NaCl equiv. They are mainly gas and liquid ones, and NaCl daughter minerals and immiscibility are rare. This indicates that no boiling took place. The deposition of metals was caused by slow lowering of temperature.

4 Geology and Geochemistry of Magmatic Hydrothermal Gold Deposits

This type of gold deposit is hosted within intermediate-acid granitoids or at their endo- and exocontacts. The metallogenesis is related to the evolution and differentiation of granitic magma. Controlled by the Shaquanzi fault, Hongliuhe fault and Yamansu fault, this type of gold deposits is mainly distributed in an E-W-trending belt in the central and southern Tianshan.

Gold mineralization is related to the types, shapes and chemical compositions of intrusions. Large batholiths are not good for mineralization. The ore-bearing intrusions are generally small intermediate-basic diorite, granodiorite, tonalite, monzonite and plagiogranite intrusions, and contain appreciable amounts of amphiboles (Chen et al., 1999). Granitoids commonly have the following characteristics of chemical composition, SiO_2 generally constitutes 56 to <70% and mostly 60–70%; K_2O is equivalent to Na_2O or K_2O is slightly higher than Na_2O and in some cases $Na_2O>K_2O$; alumina-oversaturated; calc-alkaline rocks predominate.

As for the large gold deposits, gold orebodies are located not only in intrusions but also in contact zones and even wall rocks. From the intrusion→contact zone→wall rocks, mineralization tends to change from disseminations and stockworks→veinlets→large veins. The combination of sandstone, tuff and volcanic breccia and the high content of carbon in wall rocks favour mineralization. For example, the No. 210 gold deposit is hosted in Permian siltstone, carbonaceous schist and carbon-bearing siltstone. Graphite schist is formed in compressive zones. Pyrite is common in compressive zones and graphite schist. Quartz occurs as stockworks, veinlets, lenses and boudins, injecting along schistosity.

The main ore type is the fracture zone-hosted alteration type with subordinate quartz vein type. For example, in the Jinwozi ore field, the No. 210 gold deposit in the south is of alteration type, hosted in wall rocks of an altered fracture zone, and the Jinwozi gold deposit in the north is of quartz vein type, hosted in granodiorite. Ores are composed mineralogically of polymetallic sulphides. Compared with the other two types of gold deposit, the ore contains large amounts of sulphides featuring coarse grain size and massive or vein-like structure. The dominant metallic minerals are pyrite, chalcopyrite, pyrrhotite and galena. Orebodies, occurring as quartz veins and sulphide veins, have abrupt contacts with wall rocks. The dominant gangue minerals are quartz, plagioclase, sericite, calcite and chlorite. The mineralization-related alteration is mainly silicification, pyritization, potash alteration, sericitization, carbonitization and chloritization.

Gold shows a high fineness, generally > 850. The fineness has a tendency to decrease from the intrusion towards wall rocks. The gold in disseminated ores in intrusions shows a high fineness, generally > 900. The gold in vein ores in wall rocks shows a low fineness. This indicates that temperature is the main factor affecting the fineness.

5 Geology and Geochemistry of Volcanic- or Subvolcanic-hosted Gold Deposits

Volcanic- or subvolcanic-hosted gold deposits, such as the Xitan, Cuiling, Mazhuangshan and Shuangfengshan gold deposits (occurrences), are formed by interaction of ore-bearing fluids with wall rocks or intrusions in a circulation system of magmatic fluids and meteoric water in the late volcanism. Related to the deep faults, gold deposits are mainly controlled by the Shaquanzi fault and secondly by the Yamansu fault and Hongliuhe fault. This type of gold deposit is concentrated on the northern and southern sides of the Shaquanzi deep fault, e.g. the Mazhuangshan and Nanjinshan gold deposits in the east segment, the Xitan gold deposit in the west, and the Shuangfengshan gold deposit in the north.

The gold deposits are located in the central uplifts of volcanic basins or on margins of volcanic basins. The uplifts in the central volcanic basins are marked by volcanic domes or porphyry rises. For example. the Shuangfengshan gold deposit is hosted in a dome in andesite, tuff and rhyolite, and the Mazhuangshan gold deposit is hosted in a porphyry (Cui, 1996). The margins of volcanic basins are mostly the transition zones from volcanic rocks to sedimentary clastic rocks. The ore horizons are mainly Lower Carboniferous volcaniclastic rocks and Lower Permian volcanic-sedimentary rocks and subordinately Devonian equivalents. The orebodies are spatially, temporally and genetically related to subvolcanic rocks. There are two types of subvolcanic rocks. One occurs as dyke swarms, no large intrusions being connected with the deep magma chamber. The other type occurs as stocks, represented by intermediate-acid felsic porphyry, connected with the deep magma chamber. Correspondingly there are two types of gold deposit. The former type of subvolcanic rocks always host epithermal gold deposits, whose ore-forming fluids are mainly meteoric water, as exemplified by the Shuangfengshan and Xitan gold deposits. The latter type of subvolcanic rocks hosts porphyry gold deposits, which contain abundant sulphides formed during the circulatory convection of magmatic fluids and meteoric water, as exemplified by the Mazhuangshan gold deposit.

Gold deposits are spatially related to volocanic edifices, caldera and circular or radial fractures. In the Xitan gold deposit, tens of gold-bearing quartz veins are controlled by the circular fractures, ENE- and ESE-trending faults and interlayer fissures. In the Shuangfengshan gold deposit, NW-, NE- and, E-W-trending faults and arcuate faults are developed; orebodies occur in domes of caldera. Pyrite-bearing chert and hematite-bearing jasper are developed on the surface. Orebodies are auriferous silicified rocks.

The mineralization types are mainly of fracture zone alteration type and subordinately of quartz vein type. The wall-rock alterations mainly include silicification, adularization, kaolinization, montmorillonitization, sericitization, baritization, chloritization, chertification and carbonitization (as in the Xitan and Mazhuangshan gold deposits) which were caused mainly by acid leaching at medium to low temperatures. Silicic covers are developed in the ore districts.

The typical argillization zone, silicification zone, sinter, propylitization zone and hydrothermal breccia zone are developed on or near the surface. For example, in the Shuangfengshan gold deposit, from the inner zone outwards, the alteration shows clear zoning of potash alteration→sericitization→kaolinization→propylitization. The residues of geyserite and travertine are scarce, but the silicification zone below them, generally silicic stockworks, is well developed. The silicification was formed by acid leaching. SO_4^{2-} and CO_3^{2-} solutions and gases resulting from mixing of H_2S- and CO_2-rich hydrothermal fluids with meteoric water (or leaching of wall rocks by surface water) near the surface reacted with the wall rocks and leached them strongly; then fine- to very fine-grained quartz and aphanitic or amorphous flocculent quartz were deposited because of the low solubility of silica. As the products of the hydrothermal fluid filling and the boiling and explosion of hydrothermal fluids, the well-developed quartz stockworks and breccia resulting from eruption of hydrothermal fluids are important indicators for shallow-seated hydrothermal activity.

The gangue minerals are complex, including those formed in subvolcanism and in the supergene process. Ore minerals are simple, including pyrite, chalcopyrite, sphalerite, galena etc.

The gold deposits were formed at low temperature, generally less than 300°C. The fluids in the inclusions contain H_2O, F, Cl, CO_2, HCO_3^-, SO_4^{2-}, Na, K, Cu, Mg etc. The contents of Ca, Cl, HCO_3^-, SO_4^{2-} and CO_2 are relatively high and CH_4 is very low; generally $Cl^- > F^-$, and $Na^+ > K^+$. The fluid inclusions are characterized by rare daughter minerals and low salinity, less than 20 wt% NaCl equiv. The hydrogen and oxygen isotope features indicate that the ore-forming fluids are mainly meteoric water.

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