Characteristics and Genesis of Fine-Clastic Rock-Type Au Deposits in the Liaodong Rift

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Abstract Gold deposits occurring in the Liaodong rift are located in interlayered carbonate rocks and fine-clastic rocks, belonging to the middle and upper parts of the lower Proterozoic. Compared with the Carlin-type Au deposits abroad and gold deposits in Yunnan-Guizhou-Guangxi, Qinling and western Sichuan Province, they are similar in many respects. This paper discusses the geological features of ore-bearing formations and ore-filling structures and metallogenetic characteristics. Through the discussion on the sources of ores, heat and water, it points out that the Au deposits belong to vadose reworked hydrothermal deposits. This conforms to the principle of "mineralization in the neighbouring areas", i.e., the deposits are formed in nearby ore-bearing layers, and the latest hydrothermal event was the main factor in forming the Au deposits.

Key words: Liaodong, fine-clastic rock-type Au deposit, vadose reworked hydrothermal deposit

1 Introduction

There are abundant metallic and nonmetallic minerals in the Liaodong rift. With the development of theories of metallogeny, accumulation of prospecting experiences and improvement of micro-gold analyzing techniques, great breakthrough has been obtained in finding gold from the interlayered carbonate rocks and fine-clastic rocks of the mid-upper parts in the Liaodong rift since the 1980s. So far, Au deposits have been discovered in Xiaotongjiapuzi (Liu Guoping et al., 1999), Taoyuan, Baiyun, Sidaogou, Maoling and Weizi. Compared with the Carlin-type Au deposits abroad and Au deposits in Yunnan-Guizhou-Guangxi, Qinling, western Sichuan and Hebei Province of China (Liu Dongcheng et al., 1994; Wu and Hu, 1992; Qiu et al., 1997; Xie et al., 1999), those occurring in the Liaodong rift are similar in Metallogenetic environments (all being rifts or back-arc basins), ore-control factors as well as geological features of the deposits, except that the ore-bearing strata of the latter were older. This type of Au deposit is sometimes called the Carlin-type, or fine disseminated type, C-Si-mudstone type, carbonate rock type, turbidite type or fine-clastic rock type. As the Au deposits in the Liaodong rift mainly occur in fine-clastic rocks and carbonate rocks, they are called "fine-clastic rock type" Au deposits. A comparison of Au deposits in the Liaodong rift with typical gold deposits in China and abroad is given in Table 1.

2 Geological Setting

The Liaodong rift was formed by extension and fracturing of the crust in the early Proterozoic. During the process of extension-subsidence-inversion, three major series, the volcano-sedimentary clastic formation, carbonate formation and clay clastic formation were formed from bottom to top. Differences in the ore-bearing features of the rock formations have resulted in different ore-bearing formations of Cu, Co, Pb-Zn and Au in the region. The compression, contraction, folding and metamorphism as well as subsequent geothermal events completely reformed the ore formations and created favourable conditions for enrichment and re-enrichment of metallic elements. In particular, tectonomagmatic activities during Indosinian and Yanshanian epochs reformed the crust most strongly and played an important role in the formation of minerals in the region.

Table 1 A comparison of Au deposits in the Liaodong rift with typical gold deposits in China and abroad

Main geological features	Au deposits in the Liaodong rift	Typical deposits in China	Carlin-type Au deposits in USA
Tectonic setting	Rift area of the early Proterozoic	Transitional zone of eugeosyncline-miogeosyncline of the Palaeozoic	Rift area at the margin of Palaeozoic old land
Ore-bearing stratum	Carbonate and argillaceous fine-clastic formations in mid-upper parts of Pt_1	Carbonate and fine-clastic formations in Devonian-Triassic	Carbonate and fine-clastic formations in Silurian-Devonian
Host rock	Interlayered carbonate rock and fine-clastic rock, fine-clastic rock	Fine-clastic rock, C-Si-mudstone, breccia	Impure carbonate rock, fine-clastic rock, breccia
Metamorphic grade of wall rock	Greenschist	Slate-phyllite	Slate-phyllite
Ore-control structure	Contemporaneous fault, secondary fault, fold of anticline, interlayer fault	Secondary fault, breccia zone, interlayer fracture zone, plane of unconformity	Reversed fault, tectonic window, high-angle normal fault, interlayer fracture zone
Volcanic-intrusive rock	Veins well developed in the deposits or near the Indosinian-Yanshanian intrusive rocks	Veins well developed in the deposits, partly with intrusive rocks	Cretaceous-Triassic volcanic-intrusive rocks well developed in the deposits and ore belts
Metallogenetic epoch	Indosinian-Yanshanian	Indosinian-Yanshanian	Late Cretaceous-Tertiary
Morphology of ore-body	Bedded, lenticular, veined	Bedded, lenticular, veined	Bedded, lenticular, veined
Wall rock alteration	Silicification, sericitization pyritization, arsenophyritization, K-feldspathization, carbonization	Silicification argillation, pyritization, ankeritization, albitization carbonization	Jasperoidization, silicification, argillation, pyritization, carbonization, dolomitization
Ore structure	Massive, disseminated, net-veined, brecciated, banded	Disseminated, net-veined, brecciated	Disseminated, net-veined, brecciated
Granularity of Au	Mainly micro- to submicro-sized, occasionally visible	Mainly micro- to submicro-sized, gold grains occasionally visible	Mainly micro- to submicro-sized
Ore mineral assemblage	Native gold, electrum, pyrite, arsenopyrite, pyrrhotite, marcasite, stibnite; quartz, sericite, carbonate	Native gold, pyrite, realgar, orpiment, cinnabar, stibnite, arsenopyrite, pyrrhotite; quartz, clay minerals, carbonate, barite, organic carbon	Native gold, pyrite, realgar, orpiment, cinnabar, stibnite, arsenopyrite (lorandite); quartz, clay minerals, carbonate, barite, organic carbon

3 Geological Features of Au Deposits

The fine-clastic-type Au deposits in this region mainly include Xiaotongjiapuzi (Zhao and Shun, 1997), Sidaogou, Maoling (Wang and Guo, 1992), Baiyun, Taoyuan and Weizi (Peng and Yang, 1996) (see Fig. 1). The main features for the first three deposits are shown in Table 2.

3.1 Ore-bearing strata

The 4th and 5th layers of the 3rd member of Dashiqiao Formation and Gaixian Formation of the Liaohe Group are the main ore-bearing layers.

The Gaixian Formation mainly consists of sillimanite biotite schist interlayered with biotite schist, biotite granulite, leucogranulitite, tremolite granulite and thin-bedded marble. The protoliths are dominated by terrigenous argillaceous clastic rocks consisting of pelite, quartzose sandstone and siltstone. This formation is the main ore-bearing strata, where Au deposits such as Baiyun, Taoyuan, Sidaogou, Maoling, Weizi and Linjiasandaogou are located.

The interbeds of carbonate rocks and argillaceous clastics of the 4th and 5th layers of the Dashiqiao Formation are characterized by the Xiaotongjiapuzi Au deposit. The 5th layer mainly consists of banded Mg-rich dolomite-marble, interlayered with 1 or 2 layers of sillimanite mica schist, 0.5–2 m thick. Between the upper part of Dashiqiao Formation and the lower part of Gaixian Formation, there is a layer of tremolite granulite, 5–10 m thick. Lenticular siliceous rocks occur near the boundary between sillimanite and dolomite-marble. The interlayer fracture zones between siliceous rocks, tremolite granulite and dolomite-marble are favourable ore-bearing strata, where the No. I and No. I-1 orebodies are located. The tremolite granulite is associated with siliceous rocks, and both are formed by syngenetic-exhalative sedimentation. The 4th layer of the formation consists of garnet schist intercalated with plagioclase leu-

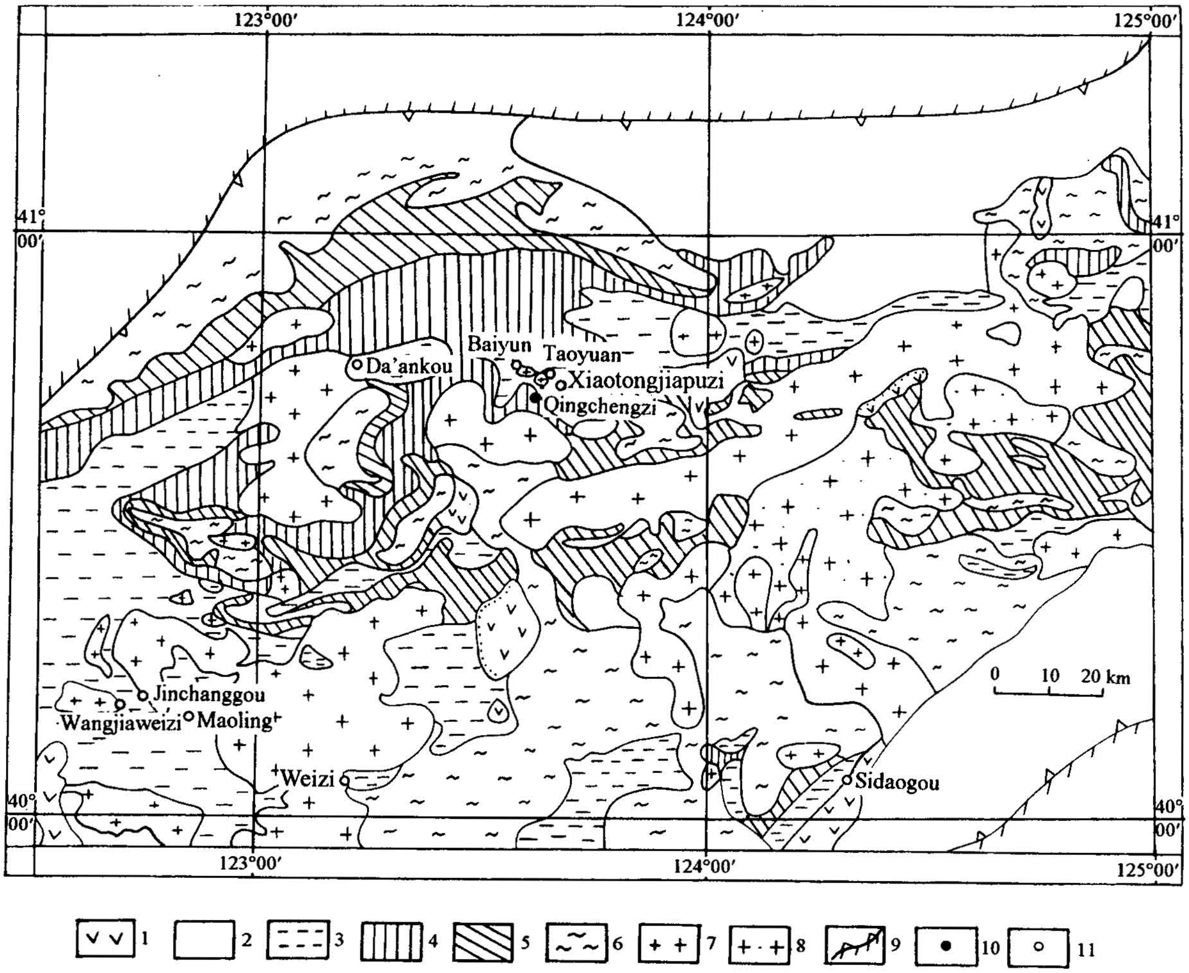

Fig. 1. Distribution of fine-clastic rock-type Au deposits in the Liaodong rift.

1. Volcanic rock and volcano-sedimentary rock (Mz); 2. sedimentary rock ($Pt_{2\text{-}3}$-Pz); 3. fine-clastic formation (Pt_1); 4. carbonate formation (Pt_1); 5. volcano-sedimentary clastic formation (Pt_1); 6. migmatite and migmatitic granite; 7. granite (Mz); 8. granite (Pt); 9. boundary of rift; 10. Pb-Zn deposit; 11. Au deposit.

cogranulite in the lower part, banded calcite marble in the middle part and sillimanite mica schist and biotite granulite in the upper part. In the interlayer fracture zones in the middle and upper parts and the contact zones between the 4th and 5th layers, there occurs the No. II ore body.

3.2 Host structure

The axis or pitching end of a brachyanticline, especially the compound part of a fault, is the most favourable host structure. There are two types of ore-bearing faults. The first is the interlayer faults. Most of orebodies in the region are controlled by interlayer faults, especially décollement faults at the axis or pitching end of folds. For example, the No. I, I-1 and II orebodies in Xiaotongjiapuzi are controlled by the interlayer faults at the limbs of the Zhenzigou anticline; the Sidaogou orebodies are mainly controlled by décollement structures and interlayer fracture zones resulting from NE-trending faults; part of the Taoyuan orebodies are controlled by interlayer fracture zones of the Gaixian Formation and the 5th layer of the 3rd member of Dashiqiao Formation; the Linjiasandaogou orebodies (Nos. 4–6) under prospecting are controlled by interlayer fracture zones of Gaixian Formation schists. The second type is bed-dissected faults. They have the following characteristics: (1) Only faults at certain horizons are host structures, i.e., the Au ore-

Table 2 Geological features of some gold deposits in the Liaodong rift

Name of deposit	Xiaotongjiapuzi	Sidaogou	Maoling
Ore-bearing stratum	The 4th and 5th layers of Member 3 of Dashiqiao Fm. and its contact with bandded marble, tremolite granulite and	Gaixian Fm.; mica schist, tuffaceous phyllite and metasandstone	Gaixian Fm.; sericite-schist, and meta-quartzose sandstone
Host structure	Interlayer fracture zone at limbs of anticlines	Décollement and interlayer fracture zone at axial parts of anticlines	High-angle compressive fracture zone at axial parts of inverted anticlines
Magmatic rocks in the mining district	Veins well developed, occupied by rock bodies at depth of 1500 m (by frequency sounding) within 3000 m from the Indosinian Xinling granite	Yanshanian Sanguliu granite	Indosinian Maoling granite
Metallogenic type	Silicified fractured marble type, Silicified fractured mica schist or granulite type	Altered fracture zone type	Quartz veinlet type and altered fractured phyllite or schist type
Ore composition	Pyrite, arsenopyrite, marcasite, electrum, quartz and dolomite	Pyrite, electrum, pyrrhotite, native gold,	Arsenopyrite, pyrrhotite, pyrite, native gold, quartz, sericite and electrum
Ore structure	Disseminated, veined, banded and brecciated,	Disseminated, massive and brecciated	Veinlet and disseminated
Wall rock alteration	Silicification, sericitization and arsenophyritization	Silicification, sericitization and pyritization	Sericitization, arsenophyritization, chloritization, pyritization and silicification
Occurrence mode of gold	Dominated by electrum, grain size 0.01–0.001 mm	Dominated by electrum and native gold, Au grain size 0.7–0.003 mm	Dominated by native gold and electrum, Au grain size 0.01–0.008 mm
Metallogenetic age	206–348 Ma	134 Ma	246 Ma

bodies mainly occur in the Gaixian Formation or the 4th and 5th layers of the 3rd member of Dashiqiao Formation, whereas those at other horizons have no ore occurrences or only some mineralization shows. That is to say, deposits of this type are obviously stratabound. (2) Mineralization is not decided by the rock type. When the layer-dissected faults cut through ore-bearing layers, orebodies may occur in various types of rocks such as marble, schist, tremolite granulite, lamprophyre and granitophyre. However, the thickness of orebodies may vary in different rocks. For example, the orebodies are thicker when layer-dissected faults cut through interlayers of biotite schist and biotite granulite.

3.3 Mineralization characteristics

Mineralization types There are many types of mineralization in the region, and there may also be several types of mineralization in one deposit. However, in a deposit only 1 or 2 form commercial orebodies, the others are just mineralized bodies. There are three representative mineralization types: (1) The silicification (or alteration) fracture zone type. It is the main type, which can be divided into the silicified fracture marble type and the silicified fracture schist (or granulite) type according to the wall rocks. The No. I, I-1 and II orebodies in Xiaotongjiapuzi and No. III orebody in Taoyuan and Weizi stand for the former type, whereas those in Sidaogou, Weizi, Maoling and Linjiasandaogou belong to the later type. (2) The Si-K alteration zone type. The typical deposit of this type is the Baiyun Au deposit, which is characterized by the K-feldspathization of wall rock alteration. (3) The altered lamprophyre type, e.g. the Taoyuan and Xinling Au deposits. The altered lamprophyre mainly occurs in interlayer faults or layer-dissected faults.

Distributive features of orebodies and mineralization intensity The spatial spreading of orebodies is strictly controlled by the mineralized alteration zone. There are no obvious boundaries between orebodies, the alteration zone and wall rocks, showing a gradual transition. Most of orebodies appear bedded, lenticular or pod-like. The occurrence of orebodies is accordant with that of the strata or at low angles. The orebodies vary in size, raging from several tens of metres to a thousand metres long, several metres to tens of metres thick, and hundreds of metres deep. The length and depth are nearly equal. The mineralization is of weak intensity. The grade of gold is relatively low, less than 10 g/t, and only occasionally reaching several dozens or even hundreds of grams per ton.

3.4 Composition and fabrics of ores

The composition of ores in this type of Au deposits is rather simple. Besides native gold and electrum, the major metallic minerals include pyrite, arsenopyrite and pyrrhotite, also marcasite, sphalerite, galena, chalcopyrite, etc. Generally, only 1–3 minerals are dominant in a deposit, the others are minor or trace.

Except for the Baiyun and Sidaogou deposits, the others in the region all contain a relatively high content of arsenopyrite, which is coincident with similar deposits in China and abroad. This may be attributed to the high As content in the ore-bearing formations of this region. The element As may be taken as a geochemical indicator for searching gold in the Liaodong rift area.

The main vein minerals include quartz, carbonate, albite, K-feldspar, sericite and barite. The ore structures are mainly dense massive, disseminated, net-veined, brecciated and banded.

3.5 Occurrence mode of gold

An obvious feature of Au deposits in the Liaodong rift is that the native gold or gold mineral is very fine-grained, mostly belonging to micro-gold or submicro-gold. This is accordant with the Carlin-type Au deposit, For example, the granularity is generally 0.01–0.001 mm for the gold in Xiaotongjiapuzi, 0.01–0.001 mm (mostly $<$ 0.003 mm) for Taoyuan, 0.001–0.0005 mm for Xinling, 0.7–0.003 mm for Sidaogou, 0.01–0.008 mm in Maoling and 0.05–0.001 for Baiyun.

The gold minerals are dominated by electrum and native gold, occasionally with küstelite.

3.6 Alteration of wall rocks

The main alteration types include silicification, pyritization, arsenophyritization, sericitization and carbonatization. Gold mineralization is closely related to silicification, pyrization and arsenophyritization.

4 Discussion on Genesis of the Deposits

There are different opinions on the metallogenetic types because of the complexity of the regional geological settings and evolutionary processes.

In this paper, the author considers the fine-clastic Au deposit in the Liaodong rift a vadose reworked hydrothermal deposit. The ore source is the wall rocks, the water source is the formation water or meteorological water, and the heat source is the magma. The formation of deposits conforms to the principle "mineralization in the neighbouring areas", which includes two meanings: (1) the ores come from the nearby wall rocks, i.e., the migration distance of minerals is not long, and the ore-bearing layers are sometimes just the source beds; (2) the leading factor for the mineralization is the tectonomagmatic activity in the Mesozoic, which was the latest geothermal event related to the mineralization.

4.1 Ore source

Most researchers think that the ore-forming elements came from the strata. Then comes the question: are the source beds the ore-bearing layers or deeper strata? The author believes that the source bed is the ore-bearing bed. This is because the layers with relatively high gold abundances, especially some exhalative rocks, are the deposits or ore-bearing strata. (1) The background value of gold in the Liaodong rift is 2.54×10^{-9}; that of the Gaixian Formation is the highest, 4.1×10^{-9}; therefore most of the gold deposits occur in that formation. (2) In the contact part between the Dashiqiao and Gaixian formations, which is near the Jianshanzi contemporaneous fault in the Qingchengzi ore field, the rocks are mainly interlayered banded marble, schist and granulite, and associated with siliceous rocks (exhalative rocks). The layers are 50–165 m thick; the abundance value of gold is averaged at 29.9×10^{-9}, reaching 70.8×10^{-9} for the marble with high Si content. The Xiaotongjiapuzi and Taoyuan deposits as well as a large number of gold occurrences are located in this horizon. (3) In the Baiyun mining area, the horizon with sillimanite biotite schist interlayered with biotite granulite, biotite leucogranulite and tremolite diopsidite as well as thin-bedded marble has a total thickness of about 500 m, where the gold content ranges from 2×10^{-9} to 203×10^{-9}, averaging 20.1×10^{-9}. This layer extends several tens of kilometers westwards. (4) When a fault cuts through layers with high gold abundances orebodies will form, but for layers with lower gold abundances only mineralization can be found or none at all. For example, in the Sidaogou deposit, the fault cut through schist and metamorphic sandstone, which had relatively high gold abundances, and orebodies formed; when it went through other layers such as the lower Dashqiao Formation, the upper Sinian and Jurassic systems, which had lower gold abundances, only weak mineralization was formed. This reflects the limitation of mineral migration.

4.2 Reconstruction of geothermal events

The Liaodong rift has experienced geothermal events of the Liaohe, Indosinian and Yanshanian epochs after sedimentary ore-bearing formations were generated. During the Liaohe epoch, the Liaodong rift folded and inversed, metamorphosed regionally and invaded by magmas, all of which influenced the migration and repartitioning of the gold element. Regenerated source beds or belts might be formed in some parts. However, the reworking activity of this period could hardly result in Au deposits. The decisive factor is the Indosinian and Yanshanian tectonomagmatism. (1) Indosinian and Yanshanian intrusive rocks are well developed around the Au deposits in the region and the periphery areas within 3 km. For example, the Sanguliu granite rock body in the Sidaogou Au deposit, biotite granite rock body in the Baiyun deposit, both of the Yanshanian epoch. In the Maoling Au deposit there developed Maoling granite rock body of the Indosinian epoch. Furthermore, a large number of vein rocks developed in the mining areas. All of these indicate that there are plentiful sources of heat. (2) The measured isotopic ages all fall in the Mesozoic, The model ages for the Sidaogou, Baiyun, Maoling and Xiaotongjiapuzi deposits are 134 Ma, 192 Ma, 245.9 Ma and 206–348 Ma respectively. (3) In some of the deposits, vein rocks form the orebodies. e.g., the altered lamprophyre and granitophyre in the Taoyuan and Xinling deposits are orebodies by themselves. (4) The host structure is not the deep ductile deformed structure of the Liaohe epoch, but the brittle interlayer or dissected structure formed by activation of the Mesozoic crust.

4.3 Water source

The analytical results of hydrogen and oxygen isotopes show that the fluids in the fine-clastic Au deposits in the Liaodong rift consist mainly of formation water and atmospheric water. For example, in the Xiaotongjiapuzi deposit, δD: −48‰ to −79.7‰, $\delta^{18}O_{quartz}$: 42‰ to10.7, $\delta^{18}O_{water}$: −2.82‰ to 8.63‰; in the Baiyun deposit, δD is −142‰; in the Maoling deposit, δD ranges from −94‰ to −168‰ for the main metallogenetic epochs; whereas in the strata, δD is −122‰ for quartz, so they are basically accordant.

From the above analyses the formation mechanism of the Au deposits may be explained in the following way: the invasion of magmas in the Mesozoic caused the formation water and atmospheric water to circulate and flow, thereby extracting the gold element from the source beds to form ore-bearing fluids. With the changes of physical and chemical conditions, the ore-bearing fluids were then deposited in the favourable places (mainly in brittle faults). This conforms to the principle “mineralization in the neighbouring areas”.

5 Conclusions

(1) Fine-clastic rock-type Au deposits in the Liaodong rift are identical with similar deposits in China and abroad with regard to the metallogenetic environment and geological features except that the ore-bearing strata of the former are older.

(2) The deposits mainly occur in interlayer zones of carbonate and fine-clastic rocks and the latter.

(3) The deposits are strictly controlled by interlayer fracture zones (some are bed-dissected faults), especially by décollement structures at the axes of brachyanticlines and interlayer faults at the pitching ends.

(4) The boundaries between orebodies and wall rocks are not very clear, so delineation is based on the grade of gold. The grade of gold is relatively low, generally less than 10 g/t. Gold is very fine-grained, mainly micro- or submicro-sized.

(5) The formation of Au deposits conforms to the

principle "mineralization in the neighbouring areas", i.e., the source bed is also the ore-bearing layer. The leading factor for mineralization is tectonomagmatic activity during the Indosinian and Yanshanian epochs.

(6) The Au deposits belong to vadose reworked hydrothermal deposits.

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References

Liu Dongcheng et al., 1994. *The Carlin-type (Fine-Disseminated Type) Gold Deposit in China.* Nanjing: Nanjing University Press, 414 p. (in Chinese).

Liu Guoping, Ai Yongfu, Feng Kezhu and Zhang Zhimin, 1999. Metamorphic rock-hosted disseminated gold deposits—a case study of the Xiaotongjiapuzi gold deposit of eastern Liaoning. *Acta Geologica Sinica* (English Edition), 73(4): 429–437.

Peng Shenglin and Yang Dejiang, 1996. The characteristics and genesis of the Weizi gold deposit. *Geological Exploration for Non-ferrous Metals*, 5(3): 146–153 (in Chinese).

Qiu Xiaoping, Hu Shixing, Wang Jun and Wang Sen, 1997. Gold mineralization of Xiaoyingpan quartz-carbonate gold deposit, Hebei Province. *Acta Geologica Sinica*, 71(4): 350–359 (in Chinese with English abstract).

Wang Hong and Guo Jiahui, 1992. On geological characteristics and genesis of the Maoling gold deposit. *Journal of Precious Metallic Geology*, 1(1): 48–57 (in Chinese).

Wu Ruzhuo and Hu Lunji, 1992. Gold deposits of lower Proterozoic turbidites in the Qinglong River area, Hebei. *Geological Review*, 38(3): 279–288 (in Chinese with English abstract).

Xie Qinglin, Lin Jingfu, Chen Yudao et al., 1999. A preliminary study on the water sources of ore-forming solutions of Carlin type of gold deposits in western Guangxi and adjacent regions. *Geological Review*, 45(sup.): 839–843 (in Chinese with English abstract).

Zhao Guangfan and Shun Limei, 1997. Geology and ore-forming mechanism of the Xiaotongjiapuzi gold deposit. *Geological Exploration for Non-ferrous Metals*, 6(4): 212–217 (in Chinese).

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