Thoughts on the Jiaodong Gold Province of China: Towards a Tectonic Model

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Abstract The Jiaodong gold province is situated in the eastern Sino-Korean Platform within the so-called Jiaoliao Uplift. The basement rocks are Archaean and Proterozoic metamorphic rocks. Mesozoic sedimentary and volcanic cover occur within extensional basins. Intrusive rocks are dominated by Mesozoic granitoid, with intermediate-acid and basic dyke swarms. The structures form an E-W-trending anticlinorium in the basement complex, and large-scale NE-SW- and NNE-SSW-trending fault zones of Mesozoic age. The gold mineralization is associated with the Mesozoic faults and related secondary fractures in the granites or granite-basement contacts. The mineralization types are quartz-vein type and wall-rock alteration type. Wall-rock alteration is very well developed around the ore zones. Alteration minerals include quartz, sericite (and fuchsite), pyrite, calcite, chlorite, hematite, rutile and graphite. The ore assemblage is uniform in all deposits, including pyrite, chalcopyrite, galena, sphalerite, arsenopyrite, pyrrhotite, gold, electrum, hessite, petzite, magnetite, molybdenite, tetrahedrite and wolframite. Mesozoic collision and subduction between the South China and North China continental blocks contributed to formation of the Mesozoic granitoid intrusions. The granitic magma is considered to be derived from partial melting of the crust through underplating processes. Gold was remobilised from basement rocks and deposited in fracture zones by the high-temperature fluids associated with these processes.

Key words: Jiaodong, gold, fluids, faults, granitoid, subduction, collision

1 Introduction

The Jiaodong gold province is one of the most important gold producing areas in China. As a result of an increase in exploration activity and research, a large amount of data on the Jiaodong gold province has been published in the Chinese literature. However, only limited information has been published in the international literature (e.g. Trumbull et al., 1992; Chen et al., 1996). We recently had the pleasure of a wonderful field trip in the Jiaodong gold province. As a result we have attempted to start to produce a model of the region. There is no doubt from our observation that there is still great potential for new resource development. There is very frequent gold mineralization in this region on many scales. It is comparable to the famous Otago gold fields of Otago, New Zealand and parts of the California Mother Lode gold region. In this paper we give a summary review of the large volume of information in the Chinese literature (e.g. Chen et al., 1989; Chen et al. 1993; Chen et al., 1996 and Li et al., 1996). We also give some new thoughts on the genesis of these gold deposits. A preliminary tectonic model is proposed for further research.

2 Geological Setting

The Jiaodong gold province is located in the Jiaoliao Uplift at the southeastern margin of the Sino-Korean

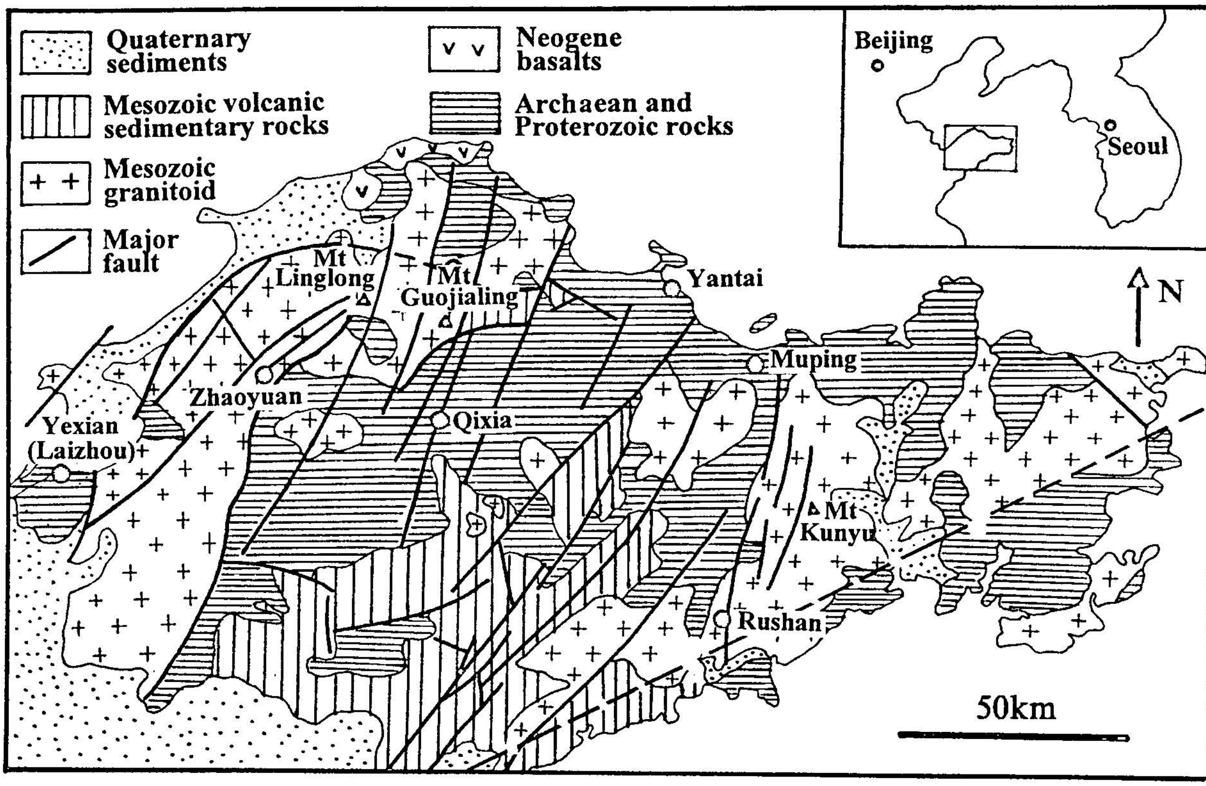

Fig. 1. Simplified geological map of the Jiaodong gold province (after Chen et., 1996). See text for description.

Platform. To the west the province is bounded by the NNE-SSW-trending Tanlu fault. Tectonically it is situated north of the suture between the North China and South China continental blocks, where the latter was subducted under the former before the Mesozoic collision (Li, 1994). Regional geology of the province is given in Fig. 1. The structures are an E-W-trending anticlinorium in the basement complex, and large-scale NE-SW- and NNE-SSW-trending fault zones of Mesozoic age. The major zones are cut by a number of NW-SE-trending post-mineralization faults. The basement rocks consist of Archaean and Proterozoic metamorphic rocks. The Archaean Jiaodong Group is mainly composed of various gneisses, (plagioclase) amphibolite and biotite schists with small amounts of ultramafic-mafic bodies. The lithology prior to the metamorphism is dominated by a sedimentary and volcanic sequence, including mafic-intermediate and intermediate-felsic volcanic rocks, and clastic sedimentary rocks (Chen et al., 1989; Li et al., 1996). The Proterozoic rocks include various schists, granulitites (leptites), marbles and iron formation. Also, a small amount of meta-volcanic rock occurs in the Proterozoic sequences. Jurassic, Cretaceous and Tertiary sedimentary and volcanic rocks occur within extensional basins. Intrusive rocks are dominated by Mesozoic granitoid intrusions. The most important host granites for gold deposits include the Linglong granite (170.6±2.3 Ma in age), the Guojialing granodiorite (148.4±2.3 Ma) and the Kunyushan granite (124.2±1.9 Ma), named after the mountains made up of these granitoids (Chen et al., 1996). Other intrusive rocks are the commonly occurring dykes in the Jiaodong region. They include felsic (pegmatite and aplite), intermediate (diorite and quartz diorite), and mafic (diabase, gabbro and lamprophyre) dykes.

3 Granitoid Intrusions

The Linglong granite is an important host rock for gold deposits in the west part of the province (it is also called the Zhaoyuan-Laizhou gold field). It is the largest of the intrusions in the west part, with an outcrop area of more than thousands of square kilometres. Contacts with Archaean and Proterozoic rocks are discordant and sharp, and in most cases contacts are faulted. It is a medium- to coarse-grained monzonitic granite. Mineralogically, the Linglong granite contains 20–30% quartz, 35–45% plagioclase (An=8–30), 25–30% microcline and 5–8% biotite. Accessory minerals include magnetite, epidote, allanite, apatite and titanite (Chen et al., 1989).

The Guojialing granodiorite occurs as small intrusions in the Linglong granite or Precambrian basement. An in-depth investigation of the granodiorite intrusions and associated gold mineralization is provided by Chen et al. (1993). The Guojialing granodiorite occurs not only in the west part of the province, but also in the east part. Gold deposits occur inside the intrusives or at the contacts, with the best mineralization occurring in the west part of the province. The outcrop area of an individual intrusive ranges from a few square kilometres to hundreds of square kilometres. Some occur in a NE-SW-trending zone. Geophysical survey suggests that these intrusives may form larger intrusions at depth. It is porphyritic with a fine- to medium-grained equigranular matrix. Phenocryst K-feldspar is generally a few centimetres in size (up to 25 cm) and up to 15% in concentration. In general the mineralogical composition is 47–53% plagioclase, 18–26% microcline, 10–22% quartz, 3–9% hornblende, and 3–8% biotite. Minor and accessory minerals include titanite, magnetite, allanite, apatite, zircon, garnet and pyrite.

The Kunyushan granite is the most important host rock for gold deposits in the east part of the province (it is also called the Muping-Rushan gold field). The outcrop area is up to 880 km^2. It is a medium- to coarse-grained monzonitic granite. The average mineral composition is 24% quartz, 39% plagioclase, 33% microcline and 4% biotite. Accessory minerals include magnetite, epidote, allanite, apatite, titanite, zircon, garnet, ilmenite and pyrite (Li et al., 1996).

4 Wall Rock Alteration

The alteration of granitic intrusions around the ore zones is mainly characterized by silicification, sericitization, carbonatization and chloritization. The alteration zones range from a few metres wide around quartz-sulphide veins to tens of metres wide in alteration shear zones. In most cases alteration can be divided into an outer zone and an inner zone on the basis of alteration mineral assemblages. The mineral most susceptible to alteration is biotite. Biotite is replaced completely by chlorite, epidote and leucoxene in the outer zone, and then replaced by white mica, quartz and rutile in the inner zone. Most plagioclase is replaced by sericite, quartz and carbonate. Microcline is selectively altered to sericite and quartz. Newly formed hematite and rutile clusters occur in feldspar crystals in the outer alteration zones, giving the rock a reddish colour. In the inner zones strong alterations result in a quartz-sericite-pyrite ultimate assemblage, which is particularly common in the wall-rock alteration type deposits. The rock is bleached, with a luster caused by fine-grained mica. Fuchsite or chrome-muscovite occurs in the alteration zones. Another characteristic feature is that graphite occurs in the strongly altered quartz-sericite-pyrite rocks, perhaps an indicator of hot, deep source fluids.

5 Gold Mineralization

The gold mineralization is mainly associated with NE-SW- and NNE-SSW-trending regional faults and related secondary fractures in the granitoid intrusions or at the contacts. An exception is the Qixia area, where quartz-vein type deposits occur in the Jiaodong Group. Mineralogical studies of the Qixia area suggested that there is a hidden granitic body occurring beneath those deposits (Chen et al., 1996). Also, the size of these deposits is limited. In general, the ores consist of veins (open space-filling) and altered wall rock (replacement or metasomatism). The former is called quartz-vein type and the latter wall-rock alteration type. They are also named after their primary deposits as the Linglong type and the Jiaojia type, respectively (Chen et al., 1996).

The quartz-vein type mineralization generally consists of coarse-grained quartz with lesser amounts of carbonates (siderite, dolomite and calcite), and sericite. Pyrite is invariably present and is the most abundant sulphide. Other opaque minerals include chalcopyrite, galena, sphalerite, etc. This type of deposits is generally related to steeply dipping brittle deformation zones. Typically, the thickness of a vein system is measured in metres. And the strike and dip dimensions can be measured in tens or hundreds of metres. The veins are typically layered, and the layering is usually ascribed to repeatedly opening and filling of the structure.

The wall-rock alteration deposits are generally related to gently dipping planar shear zones of ductile-brittle deformation. The shear zones are regional structures, and generally follow or are parallel to the granite intrusions contacts, up to tens of metres wide and may be well over 100 kilometres long. Mylonite is developed in the central part of most shear zones. The highest grade ore is confined to mylonitic rock enclosed in less strained rocks, the so-called fractured altered granite. Orebodies in the ductile deformation zones suggest that grain size reduction and the fracturing of grains associated with mylonitization may promote fluid flow in the rocks. The structures suggest frequent pulses of high-pressure fluids.

As discussed above, most gold ore in the province occurs as quartz sulphide veins or as disseminated sulphide mineralization in shear zones. The ore assemblage is quite uniform in all deposits. In order of decreasing abundance, minerals common to all deposits include pyrite, chalcopyrite, galena, sphalerite, arsenopyrite, pyrrhotite, gold, electrum and Ag-Au-tellurides (hessite and petzite), magnetite, molybdenite, tetrahedrite and wolframite. Gangue minerals, in order of decreasing abundance, include quartz, sericite and calcite. Pyrite is the most abundant ore mineral, both in quartz-vein type and wall-rock alteration type deposits.

6 Discussion and Conclusions

The gold deposits in the province are closely associated with granitoid intrusions that are intruded in the Archaean and Protozoic basement metamorphic rocks. The ages of magmatism and gold mineralization are Jurassic to Cretaceous. The Mesozoic granitoid-related gold deposits also occur in other areas in the Sino-Korean Platform, both in northern China and in Korea (Trumbull et al., 1996). The close relation between granitoid and gold deposits makes them different from gold deposits in many reworked shield areas.

For most Archean-hosted gold provinces, such as in Canada and Australia, the proposed sources for the hydrothermal fluids are metamorphic fluids (Kerrich, 1983), juvenile fluids formed by granulitization of the lower crust and/or degassing of the upper mantle (Colvine et al., 1984), magmatic hydrothermal fluids and recirculating seawater (Hutchinson and Burlington, 1984). The CO_2 of metamorphic fluids is either of the internal origins produced by decarbonation reactions, or it is derived from an external deep-seated source, the degassing of the mantle (Crawford, 1981; Fyfe, 1997).

Principally, because of the association of granitoid intrusions with gold deposits, a magmatic hydrothermal source for the ore-forming fluids is the most popular theory (Chen et al., 1989; Chen et al., 1993; Li et al., 1996). The granitic magma is derived from partial melting of the Precambrian basement, especially the Archaean Jiaodong Group. According to this model, gold is concentrated in the Jiaodong Group by volcanic-related processes. Gold, quartz and associated minerals are remobilised from the basement into vein structures by Mesozoic magmatic and hydrothermal processes. These processes are generally related to the Pacific-Eurasian plate boundary and subduction of the Pacific oceanic lithosphere beneath the Sino-Korean Platform (Chen et al., 1993; Chen et al., 1996). Also, a similar model has been proposed by Trumbull et al. (1992) to explain the Mesozoic granitoid-related gold mineralization far inland from the Jiaodong gold province on the Sino-Korean Platform.

The Mesozoic magmatic and hydrothermal processes are well supported by radiometric dating. The question is whether there was a subduction-collision process, and which continental blocks were involved? According to Li (1994), the Mesozoic tectonic events on the southern margin of the Sino-Korean Platform were the subduction and then collision between the South China and North China continental blocks. At the north margin of the Sino-Korean Platform, collision of the Siberian and North China plates occurred in the Jurassic and Early Cretaceous (Davis et al., 1998). This tectonic theory seems to explain very well the

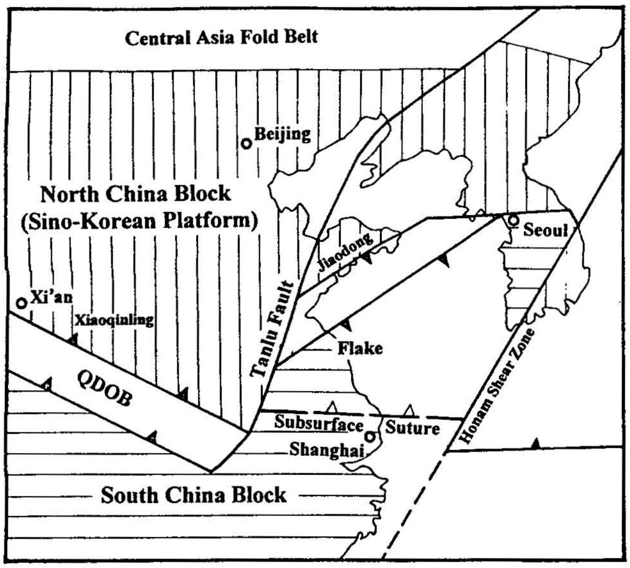

Fig. 2. A schematic diagram showing tectonic model for the Mesozoic collision between the North and South China continental blocks (after Li, 1994; Lin, 1995). Note that the flake of the South China block is underlain by the North China block just south of Jiaodong. Xiaoqinling is another important gold province. QDOB is the Qinling-Dabieshan Orogenic Belt.

east-west-trending structure belts and associated granitoid in the platform. It can explain the occurrences of gold deposits not only in the Jiaodong province but also the Xiaoqinling province (Fig. 2). These two gold provinces are currently top gold producers in China. The Xiaoqinling gold province is similar to the Jiaodong gold province in many aspects, such as the E-W-trending anticlinorium structure, the Archaean and Proterozoic metamorphic basement, and the close relationship between gold mineralization and the Mesozoic granitoid (Trumbull et al., 1992). According to this tectonic theory, the collision started from the Jiaodong region during the early to middle Mesozoic. The suture between the blocks in the region west of the Tanlu fault lies close to the northern margin of the Qinling-Dabieshan orogenic belt. Diverse opinions exist about the location of the suture east of the Tanlu fault. Biogeographical and lithological evidence and ultra-high-pressure metamorphic rocks suggest that the suture east of the Tanlu fault lies in the southern Jiaodong region. Latest interpretations of aeromagnetic anomalies and deep seismic profiles suggest that the suture in the lower crust of the blocks may be located about 400 km south of the Jiaodong gold province (Li 1994; Lin, 1995; Li, 1995). This phenomenon is well explained by flake tectonics.

Before the Mesozoic subduction-collision events, it appears that the Archaean and Proterozoic rocks were metamorphosed and reworked with local gold enrichment. In the early Mesozoic subduction of the South China block starts. Fluids from the descending slab trigger mantle melting to produce basaltic magmas (Fig. 3A). Then, massive mantle melting takes place. As basalt at high pressure is denser than continental crust, basic magmas underplate the crust and partially melt the crust, thus giving rise to granitic magma, and the crust starts to updome (Fig. 3B). Huge granite plutonic and high-grade metamorphic events commence (Fyfe, 1993). Plutons accumulate big drops. The crust is updomed. The granitic plutons rise to higher level (Fig. 3C). The entire crust undergoes prograde metamorphism. Hot fluids carrying gold penetrate all regions, from the Moho up to the surface. Because of updoming and deep high-pressure fluids, both near-vertical and low-angle thrust faults are developing (Fig. 3D). Thus, there can be vertical vein swarms and sub-horizontal or gently dipping alteration zones with mineralization. These deep source vein systems can cut the lower crust, metamorphic zones or even cut the plutons.

All gold enrichment processes involve fluid transport which is massive and pervasive. Typical fluids which transport gold include those rich in chloride, bisulphide (HS^-), and more recently we have shown that very hot (500–800°C) fluids with S, and carbon monoxide (CO) are very efficient in mobilizing gold (Fyfe, 1991). Cooling hot fluids with CO can produce graphite veins. Precipitation processes can involve a simple temperature drop (with silica and sulfide precipitation) or by mixing different fluids. For example, the vast discoveries of gold in the South Pacific are related to processes of mixing deep, hot, reduced (H_2) saline fluids with near-surface low-salinity, oxidized fluids.

Finally it seems clear that given the structures, and the magmatic types (mantle to crust), the mineralization processes will occur over a very large depth range. There is also hope that modern radar satellite fractur

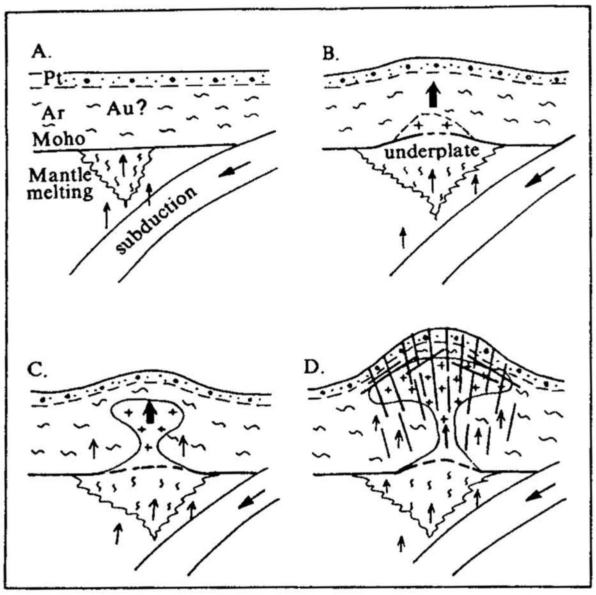

Fig. 3. Schematic diagrams showing the Mesozoic subduction, granitic magmatism and gold mineralization. A. During early Mesozoic subduction of the South China block fluids from the descending slab trigger mantle melting. B. Massive mantle melting produces basic magmas and causes underplating and partial melting and updoming of the crust. C. A huge granite pluton rises to the higher level. D. The crust undergoes prograde metamorphism, granitoid intruding, faulting and hydrothermal alteration and mineralization at many levels.

sensing could be of use for future prospecting in the region. We are in contact with the Canada Radarsat Group for assistance on this possibility. Further, in the field, we are impressed by the high frequency of small quartz vein systems which obviously carry some gold. The region must have vast alluvial potential as with the Otago region of New Zealand. The new technologies for environmentally friendly alluvial mining, which leave the terrain in better farming conditions than before mining, must have great potential in this region.

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References

Chen Guangyuan, Shao Wei, and Sun Daisheng, 1989. *Genetic Mineralogy of Gold Deposits in the Jiaodong Region with Emphasis on Gold Prospecting*. Chongqing: Chongqing Publishing House, 452 (in Chinese with English abstract).

Chen Guangyuan, Sun Daisheng, Zhou Xunruo, Shao Wei, Gong Runtan, and Shao Yue, 1993. *Genetic Mineralogy and Gold Mineralization of Guojialing Granodiorite in Jiaodong Region*. Beijing: China University Geosciences Press, 230 (in Chinese with English abstract).

Chen Guangyuan, Sun Daisheng, Shao Wei, and Li Shengrong, 1996. *Atlas of Mineralogical Mapping in Jiaodong Gold Province*. Beijing: Geological Publishing House, 128 (in Chinese).

Colvine, A.C., Andrews, A.J., Cherry, M.E., Durocher, M.E., Fyon, A J., Lavigne, M.J., Macdonlad, A.J., Marmont, S., Poulsen, K.H., Springer, J.S., and Troop, D.G., 1984. An integrated model for the origin of Archean lode gold deposits: Ontario Geological Survey. Open File Report 5524, 99.

Crawford, M.L., 1981. Fluid inclusions in metamorphic rocks—low and medium grade. In Hollister, L.S. and Crawford, M.L. (eds), *Fluid inclusions: applications to petrology: Mineralogical Association of Canada, Short Course Handbook*, 6: 117–132.

Davis, G.A., Wang Cong, Zheng Yadong, Zhang Jinjiang., Zhang Changhou, and Gehrels, G.E., 1998. The enigmatic Yinshan fold-and-thrust belt of northern China: new views on its intraplate contractional styles. *Geology*, 26 (1): 43–46.

Fyfe, W.S., 1991. Gold transport and deposition: rules of the game. In Ladeira, E. (ed.), Brazil Gold '91, Balkema. Rotterdam: Balkema, 7–9.

Fyfe, W.S., 1993. Hot spots, magma underplating, and modification of continental crust. *Canadian Journal of Earth Sciences*, 30: 908–912.

Fyfe, W.S., 1997. Deep fluids and volatile recycling: crust to mantle. *Tectonophysics*, 275: 243–251.

Hutchinson, R.W., and Burlington, J.L., 1984. Some broad characteristics of greenstone belt gold lodes. In: Foster, R. P. (ed.), Gold '82. Geological Society of Zimbabwe, Special

Publication no. 1, 339–372.

Kerrich, R., 1983. Geochemistry of gold deposits in the Abitibi greenstone belt. Canadian Institute of Mining and Metallurgy, Special volume 27, 75.

Li Shengrong, Chen Guangyuan, Shao Wei, and Sun Daisheng, 1996. *Genetic Mineralogy of Rushan Gold Field, Jiaodong, China*. Beijing: Geological Publishing House, 116p. (in Chinese with English abstract).

Li, Z-X., 1994. Collision between the North and South China blocks: a crustal-detachment model for suturing in the region east of the Tanlu fault. *Geology*, 22: 739–742.

Li, Z-X., 1995. Collision between the North and South China blocks: a crustal-detachment model for suturing in the region east of the Tanlu fault: reply. *Geology*, 23: 574–575.

Lin, S., 1995. Collision between the North and South China blocks: a crustal-detachment model for suturing in the region east of the Tanlu fault: Comment. *Geology*, 23: 575–576.

Trumbull, R.B., Morteani, G., Li Zhiliang, Bai Hongsheng, 1992. *Gold Metallogeny in the Sino-Korean Platform: Examples from Hebei Province, NE China*. Berlin: Springer-Verlag, 202.

Trumbull, R.B., Liu Hua, Lehrberger, G., Satir, M., Wimbauer, T., and Morteani, G., 1996. Granitoid-hosted gold deposits in the Anjiayingzi district of Inner Mongolia, People's Republic of China. *Economic Geology*, 91: 875–895.

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