

# **ECONOMIC GEOLOGY RESEARCH INSTITUTE HUGH ALLSOPP LABORATORY**

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**MESOZOIC GOLD DEPOSITS IN THE EASTERN  
SHANDONG PENINSULA, P. R. CHINA:  
PRELIMINARY GEOLOGY, GEOCHEMISTRY AND  
FLUID INCLUSION CHARACTERISTICS**

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CHINA – PRELIMINARY GEOLOGY, GEOCHEMISTRY AND FLUID INCLUSION  
CHARACTERISTICS**

by

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# MESOZOIC GOLD DEPOSITS IN THE EASTERN SHANDONG PENINSULA, P. R. CHINA – PRELIMINARY GEOLOGY, GEOCHEMISTRY AND FLUID INCLUSION CHARACTERISTICS

## ABSTRACT

The Jiaodong Peninsula of eastern Shandong Province is located in the southeast portion of the North China craton and is the largest area of gold mining and production in China. The Peninsula possesses more than 25% of China's total national exploited gold reserves and currently provides over one fourth of China's total gold production per annum. The basement of the Jiaodong Peninsula consists of Archaean-Proterozoic metamorphosed rocks, including mainly amphibolite, granulite, gneiss, schist, marble, quartzite and sandstone. The rocks have been subjected to multiple stages of granulite- to greenschist-facies metamorphism during the timespan 2945-1674 Ma. The basement has been reactivated by the Mesozoic Yanshanian orogeny (Jurassic to Cretaceous), which was an important tectono-magmatic-mineralization event in the area. The Early Yanshanian (130 to 160 Ma) granitoids were formed by anatexis of the basement rocks. More than 80% of the lode gold deposits in the Peninsula are hosted within the granitoids and/or the contact zones between the granitic and basement rocks, and together constitute the largest granitoid-related gold province in the world.

Two types of gold deposits are recognized: (1) lode gold-quartz-sulphide veins (i.e., the Linglong type); and (2) shear-zone hosted disseminated sulphides (i.e., the Jiaojia type). Both types of gold deposits are similar in their geology and geochemistry. Ore mineral assemblages are dominated by pyrite, followed by galena, sphalerite, chalcopyrite, pyrrhotite and arsenopyrite. Gold-silver-bearing minerals are mainly composed of native gold and electrum. Four stages of mineralization include: (1) pyrite-quartz; (2) gold-bearing pyrite-quartz; (3) gold-bearing multiple metallic sulphides and quartz; and (4) quartz-carbonate. The gold is concentrated in stages 2-3. Alteration minerals consist of sericite, muscovite, sulphides (mainly pyrite, pyrrhotite and arsenopyrite), carbonates, K-feldspar, chlorite, and kaolinite. Radiogenic ages of mineralization, dated by Rb-Sr and K-Ar methods on hydrothermal and ore minerals and inclusion fluids, are mostly between  $100 \pm 4$  to  $135 \pm 5$  Ma for eight major gold deposits. These ages are 5 to 20 million years younger than those of corresponding granitic intrusions in the Zhao-Ye belt.

Mineralizing fluids are  $\text{H}_2\text{O}-\text{CO}_2-\text{NaCl}$  solutions (salinity:  $<12$  wt.% NaCl equiv.) at minimum  $T-P$  of 250-350 °C and 0.3-1 kbar. Isotopic compositions of ore minerals or inclusion fluids are:  $\delta^{13}\text{C}$  (0 to -5‰),  $\delta^{34}\text{S}$  (+4 to +12 ‰),  $\delta\text{D}$  and  $\delta^{18}\text{O}$  (-20 to -110‰; -10 to +8‰). Taking into account the geological, geochemical and isotopic data, it is suggested that the gold mineralization in the Jiaodong Peninsula post-dated the granitic emplacement and was formed mainly by evolved meteoric waters in the waning stages of the Mesozoic Yanshanian orogeny at *c.* 100 to 130 Ma.

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# MESOZOIC GOLD DEPOSITS IN THE EASTERN SHANDONG PENINSULA, P. R. CHINA

## INTRODUCTION

The Jiaodong Peninsula in the eastern Shandong Province of People's Republic of China (Fig. 1) is located in the southeast portion of the Precambrian North China Craton and constitutes the western continental margin of the Mesozoic-Cenozoic Circum-Pacific mobile belt. Numerous gold deposits are hosted mainly by Mesozoic granitoid rocks (>80%) and subordinately by Archaean-Proterozoic basement metamorphic rocks of granulite-amphibolite facies. Several Mesozoic granitic intrusions host numerous (>100) gold deposits, the total reserves of which are some 1600 tons, making the Jiaodong Peninsula the largest granitoid-related gold province in the world. The regional gold deposits possess more than 25% of China's exploited gold reserves and annually provide over one fourth of China's total present gold production (Chen et al., 1997; Zhou and Lü, 2000; Zhai et al., 2001).

The geology and gold deposits in the area have been intensively investigated over the past fifty years since 1949 (Yang et al., 1998) and highlight the evolutionary history of the regional geology, geotectonics and mineralization (Zhou and Lü, 2000; Qiu et al., 2002).

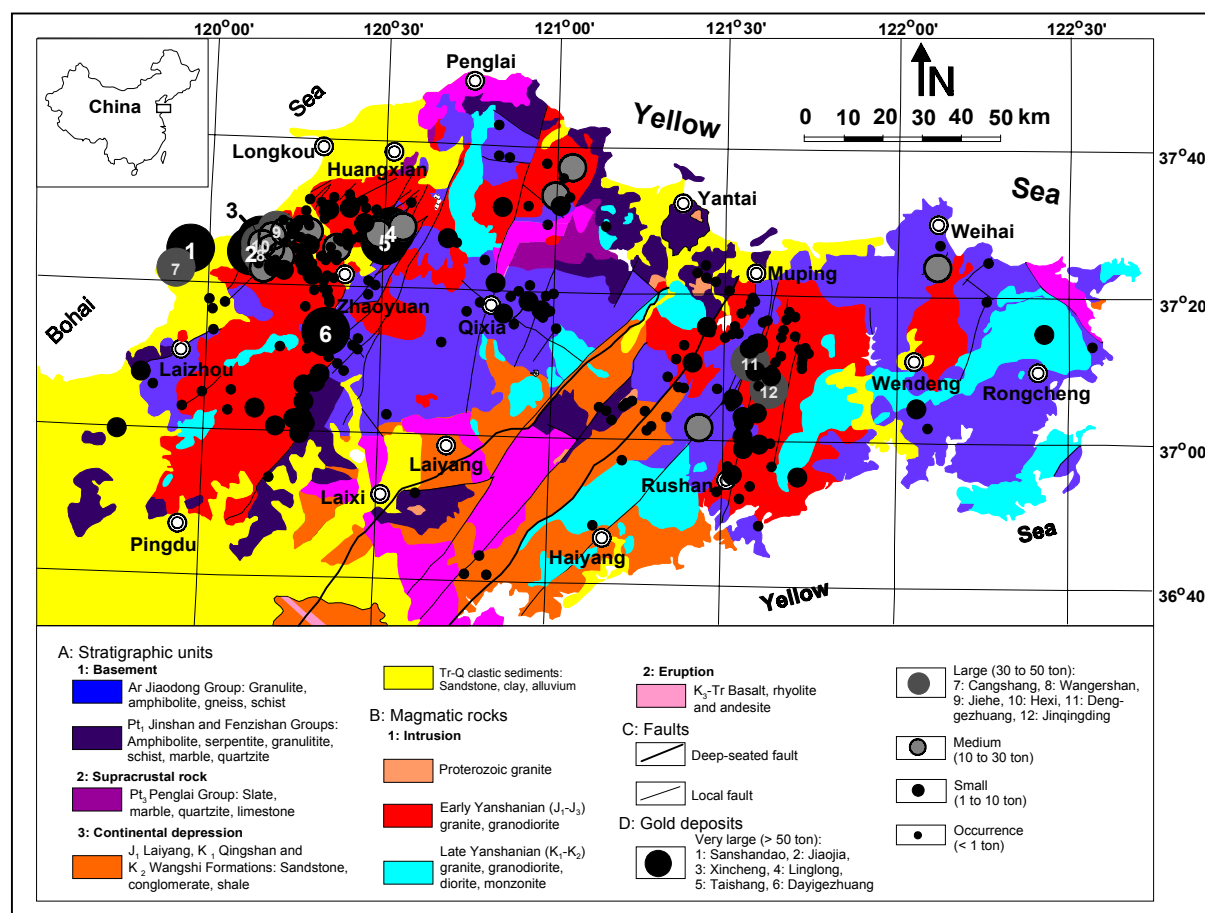


Figure 1. Geology and gold deposits of the Jiaodong Peninsula in the eastern Shandong Province, China (after Cun et al., 1992).

According to Li and Yang (1993) and Yang et al. (1998), the basement of the Jiaodong Peninsula consists of Precambrian metamorphic sequences, which include the Archaean Jiaodong Group (AJG: 4.3 km thick, U-Pb zircon age: c. 2858-2415 Ma), the Lower Proterozoic Jinshan (LPJ: 1.7 km thick, U-Pb zircon age: c. 2484-1847 Ma) and Fenzishan (LPF: 2.83 km thick, U-Pb zircon age: c. 2381-1674 Ma) Groups and the upper Proterozoic Penglai Group (UPP: 5.18 km thick). The AJG comprises granulite, gneiss, amphibolite and schist and its protolith consist of basaltic volcanic and sedimentary rocks, which have been subjected to granulite-amphibolite facies metamorphism. The LPJ and LPF are composed of serpentinite, peridotite, amphibolite, schist, marble and quartzite, which were originally derived from basic volcanic rocks, carbonates and sedimentary rocks subjected to amphibolite-facies metamorphism (Li and Yang, 1993; Luo et al., 1996). The UPP unconformably overlies the Archaean-lower Proterozoic strata and comprises slate, marble, quartzite, carbonates and shale, which have undergone low-greenschist facies metamorphism (Luo et al., 1996). Mafic and felsic igneous plutons intruded the basement during the Fuping (c. 2500 Ma), Jiaodong (c. 200 Ma) and Fenzishan (c. 1600 Ma) and Penglai (c. 600-700 Ma) orogenies (Li and Yang, 1993; Yang et al., 1998). Palaeozoic to lower Mesozoic strata were not developed in the region. The Upper Jurassic ( $J_2$ ) Laiyang Formation (445-2674 m thick) and Cretaceous Qingshan ( $K_1$ , 690-980 m thick) and Wangshi (1100 m thick) Formations were locally deposited in a basin. The three formations consist of sandstone, sandy gravel and shale; basic to felsic volcanic rocks; and sandy gravel and siltstone, respectively (Li and Yang, 1993). Cenozoic sediments, comprising conglomerate, sandstone and shale, are 500-1700 m thick, and are mainly found in the northern and western parts of the Jiaodong Peninsula (Fig. 1).

The metamorphosed rocks are strongly folded, and the folded axes strike E-W, NE-NNE directions. The Precambrian basement shows E-W and ENE-striking faults and fractures, which developed late in the geotectonic evolution of the region. The basement was strongly reactivated by the Jurassic-Cretaceous tectono-magmatic event (i.e. the Yanshanian orogeny), which resulted from the subduction of the Pacific-Izanagi plate beneath the eastern margin of the China sector of the Asian continent (Li and Yang, 1993; Yang et al., 1998; Zhou and Lü, 2000). Regional deep-seated and large-scale NE- and NNE-striking faults and second-order faults and fractures formed during this orogenic episode. The late structures also controlled the distribution of the Mesozoic granitic intrusions and gold deposits in the area (Fig. 1).

This paper resulted from a co-operative project between the University of the Witwatersrand, Johannesburg and the Institute for Geology and Geophysics of the Chinese Academy of Sciences, Beijing, and briefly reviews the gold deposits of the Jiaodong area on the basis of data mostly available from Chinese publications. The study aims to present the regional geological, geochemical and geochronological characteristics of the Jiaodong Peninsula gold deposits and to discuss the genesis of the gold mineralization in the region.

## **YANSHANIAN GRANITOIDS**

Mesozoic Yanshanian granitoids are widespread throughout the Jiaodong Peninsula (Fig. 1) and collectively occupy an area of 5551 km<sup>2</sup>, which accounts for about 43% of the total area of the region (Li and Yang, 1993). The granitoids have been classified into an early (Jurassic) and a late (Cretaceous) Yanshanian series on the basis of their host rocks and the crosscutting relationships of the intrusions (Cun et al., 1992, Fig. 1). The early granitoids occur in the eastern and western portions of the Jiaodong Peninsula, whereas the late plutons are found in the eastern and central parts of the area (Fig. 1). The granitoids are spatially and temporally associated with regional gold mineralization and have been intensively studied

over the past decade (e.g., Xu et al., 1989; BGMRSF, 1991; Li and Yang, 1993; Sun et al., 1995; Luo et al., 1996; Yang et al., 1998; Zhou and Lü, 2000; Qiu et al., 2002). The early Yanshanian granitoids are major hosts to gold deposits and are described in some details.

Most of the mineralized intrusions occur in the Zhao-Ye area and are grouped into three types (Fig. 2). These include: (1) the Linglong (biotite granite with gneissic structure); (2) the Guojialing (biotite-hornblende granodiorite); and (3) the Luanjiahe (medium to coarse-grained massive granite). The intrusions occur as multi-phase batholiths and contain numerous xenoliths of the basement country rocks of the Jiaodong Group. The granitoids are typically calc-alkaline in character and are granodiorite to granitic in composition (Fig. 3). The aluminum-saturation index ( $ASI = Al_2O_3 / (Al_2O_3 + Na_2O + K_2O)$ ) is  $>1$  for the Linglong and Luanjiahe granitoids and  $<1$  for the Guojialing granodiorite (Fig. 4).  $\delta^{18}O_{SMOW}$  values of the granites fall in a range from +6 to +11‰ and are similar to those of the basement rocks (Luo et al., 1996). U-Pb zircon ages are mostly between 150 and 160 Ma for the Linglong and

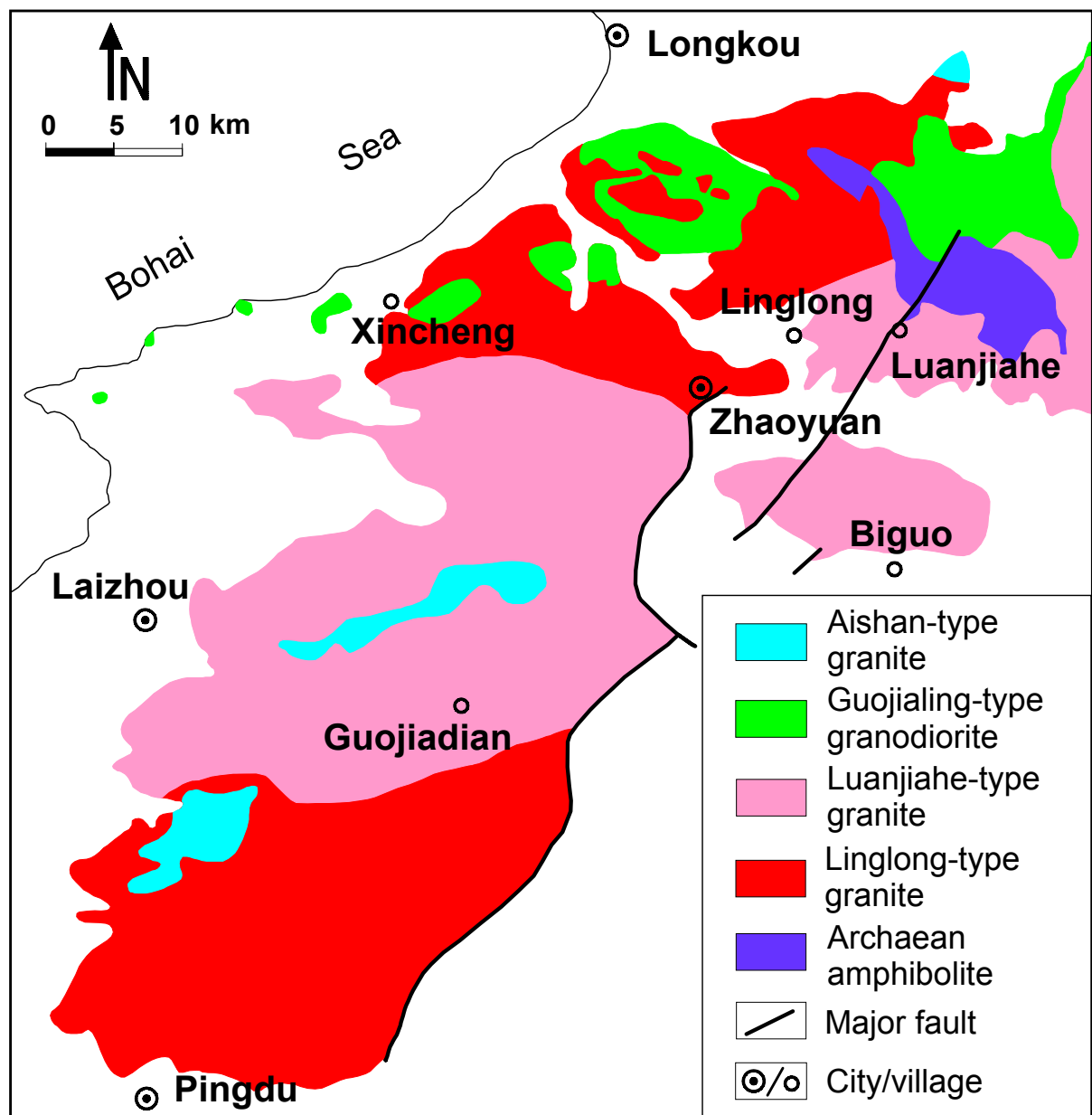


Figure 2. Granitoid types in the Zhao-Ye mineralization belt (after Luo et al., 1996).

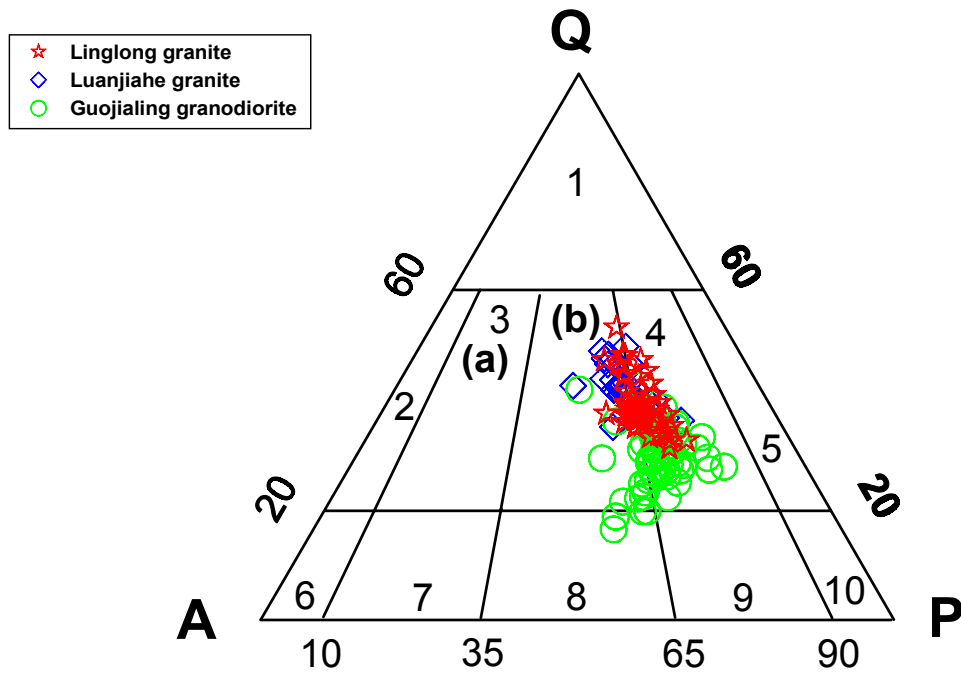


Figure 3. QAP normative mineral compositions of the Linglong, Luanjiahe and Guojialing granitoids. Q=quartz, A=alkali feldspar, P=plagioclase. 1=quartz-rich granite, 2= alkali-granite, 3=granite, 3(a)=syenogranite, 3(b)=monzogranite, 4=granodiorite, 5=tonalite/trondhjemite, 6=alkali syenite, 7=syenite, 8=monzonite, 9=monzogranite/monzogabbro, 10=diorite/gabbro /anorthosite.

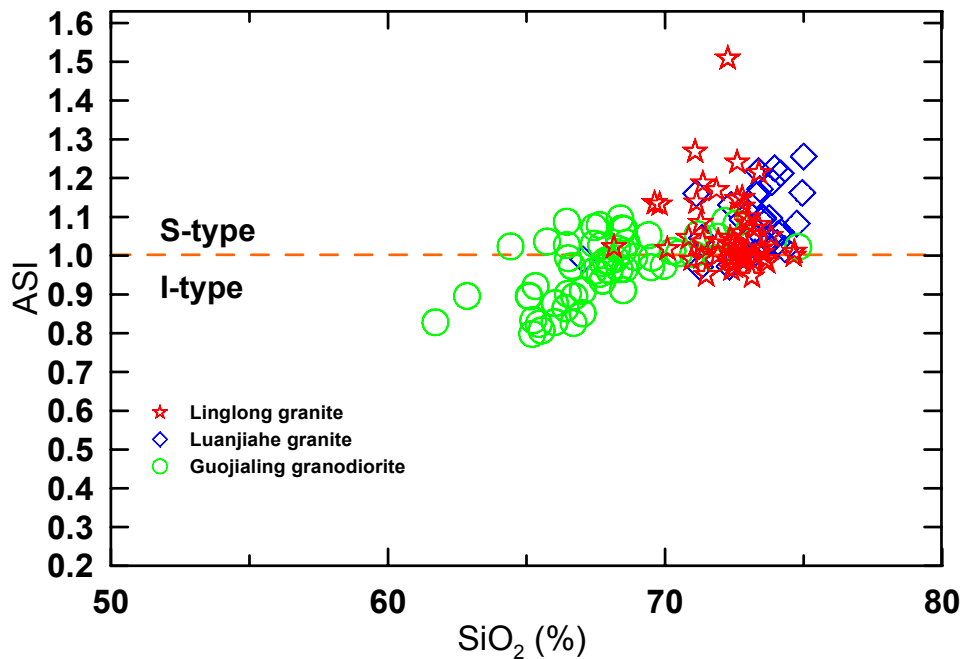


Figure 4. Granitoids types in the Zhao-Ye mineralization belt (after Luo et al., 1996).



Luanjiahe granitoids and between 126 and 130 Ma for the Guojialing granodiorite. Inherited zircons show a wide range of ages from 200 to 3400 Ma (Wang et al., 1998), implying the influence of multiple tectonic events and magmatism in the area. Based on petrographic, geochemical and geochronological characteristics, it is suggested that the various granitoids were formed by anatexis of basement metavolcanic and metasedimentary rocks during the Yanshanian orogeny (Li and Yang, 1993; Luo et al., 1996; Wang et al., 1998).

## GOLD DEPOSITS

Over 100 gold deposits, as well as some 200 gold occurrences, have been found in the Jiaodong Peninsula (Fig. 1). Most of the gold deposits (>80%) are hosted within the

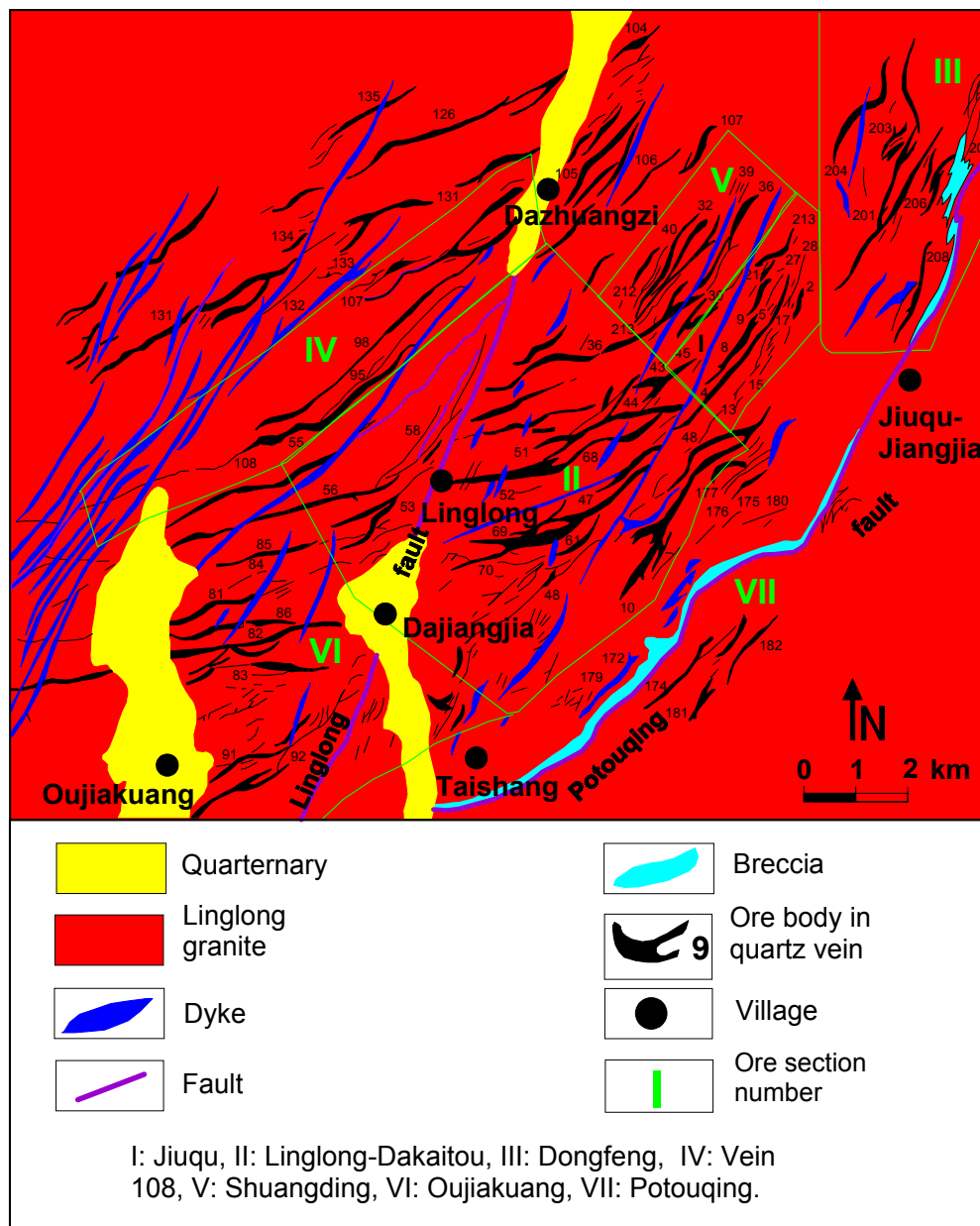


Figure 5. Simplified geology of the Linglong gold deposit (modified from Luo et al., 1996 and Zhou and Lü, 2000). The gold-quartz veins are numbered.

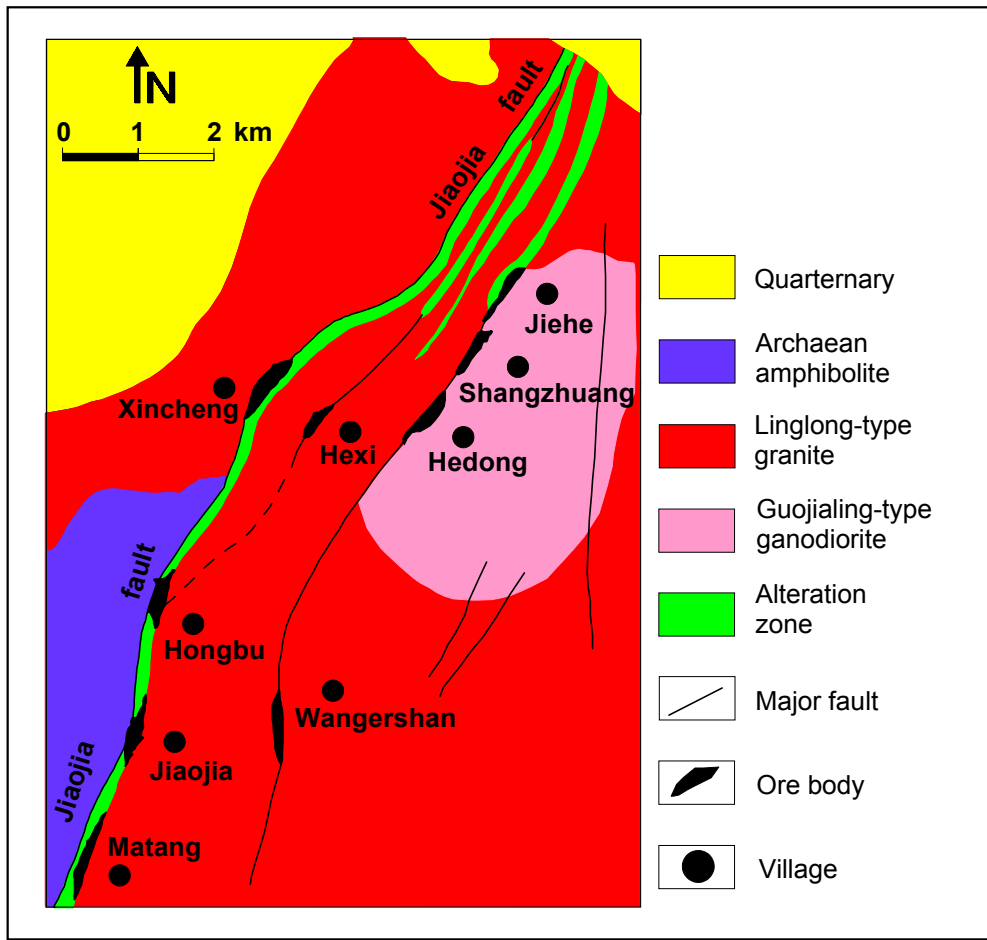


Figure 6. Simplified geology of the Jiaojia Gold Field (after Luo et al., 1996).

Yanshanian granitoids. The gold deposits are divided into two types: (1) gold-quartz-sulphide veins (i.e., the Linglong type, Fig. 5); and (2) shear-zone hosted dissemination (i.e., the Jiaojia type, Fig. 6). The gold deposits are controlled by regional NE-NNE-striking faults and fracture zones (Fig. 1). Detailed descriptions of the Linglong and Jiaojia gold fields are provided by Zhou and Lü (2000).

According to Li and Yang (1993), Luo et al. (1996) and Yang (1998), the ore minerals of individual gold deposits are dominated by pyrite, followed by pyrrhotite, arsenopyrite, chalcopyrite, galena and sphalerite. Gold-bearing minerals are mainly composed of native gold and electrum, which are associated with sulphides (mainly pyrite). Four mineralization stages are recognized: (1) pyrite-quartz; (2) gold-bearing pyrite-quartz; (3) gold-bearing multiple metallic sulphides and quartz; and (4) quartz-carbonate. The gold is mainly concentrated in stages 2-3. Wall rock alteration is marked by K-feldspathization, silicification, sericitization, chloritization, pyritization and carbonatisation, indicating that the alteration was formed under a mesothermal P-T conditions. Radiogenic ages of mineralization (Rb-Sr and K-Ar on hydrothermal sericite, muscovite and K-feldspar) are mostly between 100 and 130 Ma. The mineralization ages of individual gold deposits in the Zhao-Ye belt are 5 to 20 million years younger than those of corresponding granitoid intrusions (Luo et al., 1996), indicating that the gold mineralization in the region is related to the waning stages of the Yanshanian orogeny. Recently, Yang and Zhou (2001) dated pyrites from the Linglong goldfield using Rb-Sr, Sm-Nd and Pb-isotope methods. The Rb-Sr pyrite isochron ages are between 122 and 123 Ma, with initial  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios of 0.7114-0.7101. In combination with

the Sm-Nd and Pb-isotope signatures of the pyrites, Yang and Zhou (2001) concluded that the mineralizing fluids are a mixture of magmatic and meteoric waters, which have interacted with the wall rocks.

## FLUID INCLUSIONS

Fluid inclusions in quartz from the gold deposits in the Jiaodong Peninsula are similar and are dominated by H<sub>2</sub>O-CO<sub>2</sub>-NaCl and H<sub>2</sub>O-NaCl types with minor CO<sub>2</sub>-rich gaseous and sporadic H<sub>2</sub>O-NaCl-daughter types (i.e., the Linglong and Taishang gold deposits). The inclusions are generally <15 µm in size and the salinity of the inclusion fluids is commonly less than 12 wt.% NaCl equivalent. Homogenization temperatures of primary fluid inclusions from individual gold deposits fall in a wide range from 130 to 450 °C (Fig. 7), with a main group between 200 and 350 °C. These temperatures represent a minimum temperature range of mineralization, from which minimum pressures of mineralization were estimated to be between 0.3 and 1 kbar, on the basis of isochores and compositions of fluid inclusions (Li and Yang, 1993).

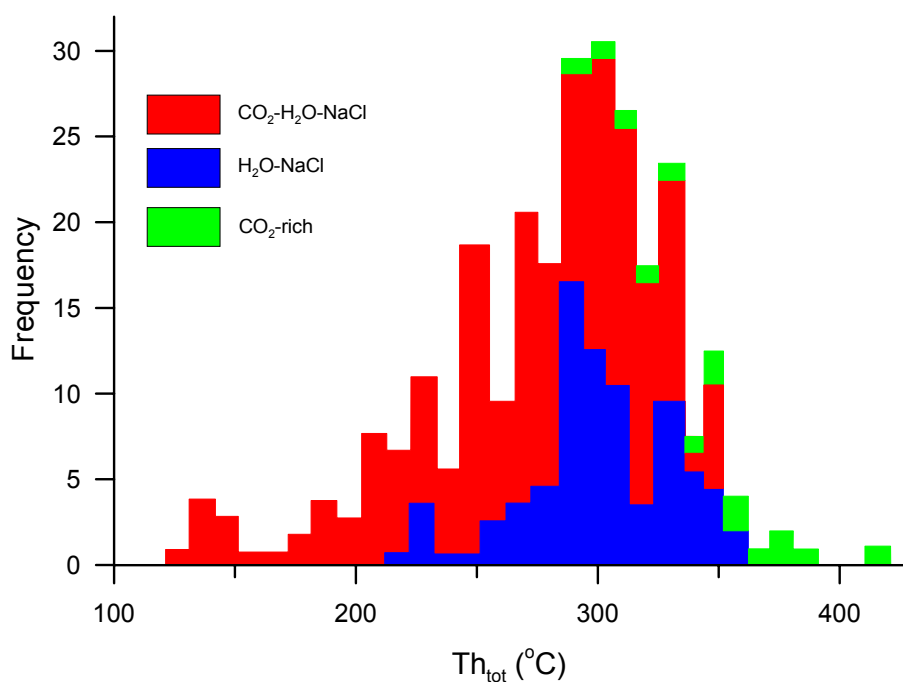


Figure 7. Total homogenization temperature of fluid inclusions from the Linglong gold deposit (after Li and Yang, 1993).

## STABLE ISOTOPES

More than 500 sulphur isotopic analyses of sulphides (mainly pyrite) from the regional gold deposits, the Jiaodong Group, the Yanshanian granitoids and the mafic-felsic dykes, have been carried out over the last ten years. Most of the gold deposits show  $\delta^{34}\text{S}_{\text{CDT}}$  values in a range from +4 to +12‰, which are comparable with those of pyrites from the Jiaodong Group, as well as the granitoids and the dykes, suggesting that the sulphur is derived from the basement rocks and/or from a magmatic source (Wang, 1989; Li and Yang 1993; Luo 1996).

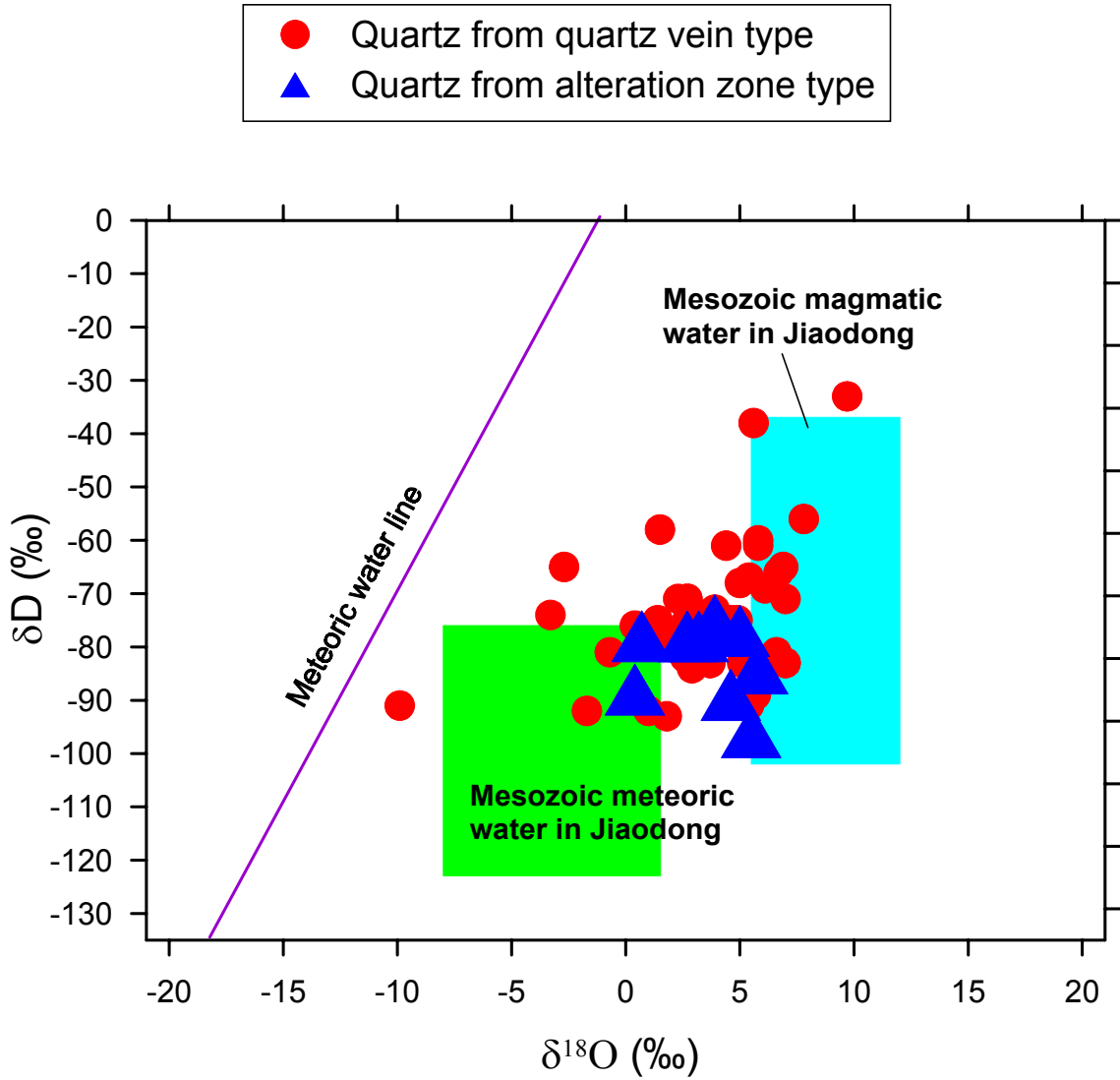


Figure 8. Hydrogen and oxygen isotopic compositions of ore-forming fluids from the gold deposits in the Jiaodong Peninsula (Luo et al., 1996).

Carbon and oxygen isotopic compositions of carbonates and fluid inclusion  $\text{CO}_2$  from the gold deposits, granitoids and marble were summarized by Li and Yang (1993) and Luo et al. (1996).  $\delta^{13}\text{C}_{\text{PDB}}$  values of  $\text{CO}_2$  from fluid inclusions in quartz and of carbonates from the gold deposits fall in a narrow range of -7 to 0‰ (mean = +5.0‰,  $n=9$ ). These values are similar to those of inclusion  $\text{CO}_2$  released in quartz from the granitoids. Oxygen isotopic compositions of marble, carbonates and fluid inclusion  $\text{CO}_2$  fall in a wide range from -4 to +24‰. The shift of oxygen isotopic compositions of carbonates and inclusion  $\text{CO}_2$  are likely to be related to physico-chemical conditions of mineralization. It is suggested that the carbon was derived from the basement rocks, together with a possible mixture of deep-seated (magmatic) carbon sources (Luo et al., 1996).

$\delta\text{D}_{\text{SMOW}}$  and  $\delta^{18}\text{O}_{\text{SMOW}}$  values of ore-forming fluids range from -100 to -30‰ and from -10 to +10‰, respectively (Fig. 8). The fluids of Mesozoic granitoids have  $\delta\text{D}$  and  $\delta^{18}\text{O}$  values of -37 to -102‰ and +5.5 to +12‰, respectively. The Mesozoic meteoric waters, by contrast, show  $\delta\text{D}$  and  $\delta^{18}\text{O}$  values of -123 to -76‰ and -8.0 to +1.5‰, respectively. At mineralization temperatures of 250 to 350 °C, oxygen isotopic values of water from quartz-

water isotopic equilibria are between 0 and +6‰ for shear-zone hosted gold deposits and between -3 and +9‰ for quartz-vein gold deposits. The oxygen isotopic compositions of mineralizing fluids show a shift from those of granitoids towards those of Mesozoic meteoric waters. It is suggested that the oxygen and hydrogen isotopic compositions of mineralizing fluids from most of the gold deposits represent sources of the fluids that were derived from the Mesozoic meteoric waters in equilibrium with regional granitoids and/or basement metamorphic rocks at relatively low water/rock values of 0.005 to 0.01 at 250 to 350 °C, with significant addition of magmatic fluids (Luo et al., 1996).

## DISCUSSION

The North China Craton has undergone two major geotectonic events, namely, the Precambrian basement formation and the late Mesozoic reactivation. Multiple orogenies (Jiandong: c. 2500 Ma; Jinshan: c. 1800 Ma; Penglai: c. 600-700 Ma; Luo et al., 1996) in the Precambrian resulted in the production of the regional granulite-amphibolite-greenschist facies basement and established E-W and NE-ESE-striking faults and fractures, which established the basic structural framework and which was formed by late-stage geotectonic movement of the craton. The Mesozoic Yanshanian orogeny (c. 170-70 Ma, Luo et al., 1996) resulted from the subduction of the Pacific-Izanagi plate beneath the eastern margin of continental China, producing extensive tectono-magmatic-mineralization belts on the margins of the North China craton (Trumbull et al., 1992; Miller et al., 1998). In the Jiaodong Peninsula, early (Jurassic) and late (Cretaceous) Yanshanian granitoids are widespread, and correspond to the Middle (c. 160-130 Ma) and Late (c. 117-85 Ma) Yanshanian granitoids of Zhou and Lü (2000). The authors suggested that the former is the result of collision and suturing of the North and South China cratons and that the late Yanshanian granitoids formed from the distal (inland) influence of subduction of the Pacific-Izanagi plate beneath the Eurasian continent during the Cretaceous. In terms of plate tectonics, the regional granitoids are believed to be derived from the anatexis of crustal materials (i.e., basement rocks) due to the tectonic-thermal event (Li and Yang, 1993; Luo et al., 1996; Zhou and Lü, 2000). The mineralised granitoids are granitic to granodioritic in composition and are controlled by regional NE-NNE faults and fractures, which were reactivated by the Yanshanian orogeny. The faults and fractures are ductile-brittle shear zones and brittle zones, which acted as weak zones for granitic intrusion and fluid upwelling. The first-order NE-NNE structures controlled the distribution of regional granitic intrusions and gold mineralization belts, whereas the gold deposits are mainly controlled by subordinate NE-NNE-striking faults and fractures on local scale. Ore bodies occupied the brittle segments of structures as well as ductile-brittle structures.

The major gold deposits in the Jiaodong Peninsula are hosted in the early Yanshanian granitoids. The similarity of the geological settings, geochemical features and geochronological ages of the ores implies that the gold mineralization is related to similar processes. Li and Yang (1993) proposed a four-stage model for the regional gold mineralization, including: (1) source rocks of the basement Jiaodong Group; (2) remobilisation, migration and precipitation of gold from the source rocks during the Proterozoic; (3) the Yanshanian magmatism and its related fluids leaching ore components from the basement; and (4) wall-rock alteration, mixing of meteoric fluids and gold mineralization. Luo et al. (1996) suggested that the mineralization was caused by mixed magmatic and meteoric fluids leaching the source rocks of the Jiaodong Group at c. 126-120 Ma. Recently, Zhou and Lü (2000) held the view that the major gold deposits in the region were formed during the subsequent exhumation stage after the collision of the North and South China cratons. Zhai et al. (2001) offered the alternative suggesting that the metallogenic

process of mineralization in the Jiaodong area is geodynamically controlled by the tectonic evolution of the eastern North China craton, involving interaction of mantle and crust during the late Mesozoic, and that the ore-forming components were derived from multiple sources. The geological, geochemical and geochronological data available suggest that the gold mineralization in the Jiaodong Peninsula may reasonably be considered to be “orogenic” in origin, which is temporally related to Pacific Plate subduction at c. 130-120 Ma (Qiu et al., 2002). Such a proposal for the gold mineralization along the northern margin of the North China craton was proposed by Miller et al. (1998). As noted by the authors, the back-arc environment for the gold deposits in the North China craton is different to the typical orogenic gold deposits of Groves et al. (1998). The descriptive model proposed for the orogenic gold deposits in the Jiaodong Peninsula requires a better understanding of the regional geodynamic processes during the Mesozoic Yanshanian orogeny.

## CONCLUSIONS

The early Yanshanian granitoids were formed by anatexis of the basement rocks. Regional gold deposits comprise quartz-vein and alteration-disseminated types and are controlled by Mesozoic NE-NNE striking faults and fractures. Ore minerals are polymetallic sulphides. Alteration minerals are dominated by K-feldspar, quartz, sericite, chlorite, pyrite and carbonates. Mineralizing fluids are H<sub>2</sub>O-CO<sub>2</sub>-NaCl solutions with salinities of commonly <12 wt.% NaCl equiv. Minimum *T-P* of mineralization are at 250 to 350 °C and 0.3 to 1 kbar. Ore-forming fluids were mainly derived from evolved meteoric waters mixed with magmatic fluids. In combination with the regional geological settings, geochronological ages and stable isotope signatures of the ores, it is suggested that the gold in the Jiaodong Peninsula is a product of the waning stages of the Mesozoic Yanshanian orogeny.

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