1 Gold deposits in the Jiaodong Peninsula

The Jiaodong Peninsula is currently the most important gold province in China, with a total gold ore reserve of >1300 tons (Li et al. 2007). Seven world-class gold deposits (> 100 t gold), eight large gold deposits (20 to 100 t gold) and more than one hundred middle to small gold deposits (< 20 t gold) have been discovered in the peninsula (Fig. 1) during the past three decades, accounting for about 25% of China’s gold reserves (Fan et al. 2003). It is located along the southeastern margin of the North China Craton, which is the largest and oldest (3.8–2.5 Ga) craton in China. Mesozoic granitoids, occupying >50 percent of the northwestern part of the Jiaodong Peninsula, intrude Precambrian basement rocks that have undergone amphibolite to granulite facies metamorphism. The majority of gold resources (>95%) are hosted by these granitoids, making the Jiaodong gold province one of the largest granitoid-hosted gold provinces recognized in the world.

The Jiaodong Peninsula occupies the easternmost edge of the Eastern Block of the North China Craton (Zhai and Santosh) and is geologically divided into the southeastern Ludong terrane and the northwestern Jiaobei terrane by the Mishan fault. The Ludong terrane petrotextonically belongs to the northern margin of the South China Block, which records a subduction history associated with a Triassic collisional event.

The Jiaobei terrane petrotextonically belongs to the North China Craton. Almost all gold deposits are hosted in the Jiaobei terrane, and more than 80% of the gold reserves are concentrated in the Zhaoyuan-Laizhou gold belt (Fig. 1). The Precambrian basement in the Jiaobei terrane is principally defined by the Archean Jiaodong Group and the Paleoproterozoic Fenzishan and Jingshan Groups. Mesozoic magmatic rocks are widely exposed in the Jiaobei terrane and two main periods of magmatism are recognized, Jurassic and Early Cretaceous. The Jurassic magmatic activity is represented by the crustally-derived Linglong, Luanjihae, and Kunyushan granitoids, emplaced at 160–150 Ma (Yang et al. 2012). In the Early Cretaceous, extensive magmatism took place through strong crust-mantle interaction, including formation of widespread granitoids (130–126Ma, and 113–110 Ma), mafic to felsic volcanic rocks in the Jiaolai Basin (130–110 Ma), and numerous mafic dikes (124–122 Ma) with less commonly at 110 to 102 Ma (Yang et al. 2012; Cai et al., 2013). The Mesozoic granitoids are hosts for most gold deposits.

Gold deposits in the peninsula can be divided into three mineralized belts from west to east, which include Zhaoyuan-Laizhou, Penglai-Qixia, and Muping-Rushan (Fig. 1). Each belt is separated by Jurassic to Cretaceous volcanic-sedimentary basin. Gold deposits have been classified as the Linglong-type and the Jiaojia-type, both of which are essentially fault controlled. The Linglong-type mineralization is characterized by massive auriferous quartz veins hosted in subsidiary second- or third-order faults cutting Mesozoic granitoids, whereas the Jiaojia-type mineralization consists of disseminated- and stockwork-style ores located in regional faults, which are enveloped by broad alteration halos.

2 Ore-Forming Fluids

Samples for the fluid inclusion study were collected from representative gold deposits in the Peninsula (Fig. 1). From west to east, they are Sanshandao, Jiaojia, Xincheng, Dongfeng, Linglong, Denggezhuan and Jinqingding deposits. Among them, Sanshandao Jiaojia, Xincheng and Dongfeng are representative of the Jiaojia style, Linglong, Denggezhuan and Jinqingding are examples of the Linglong style. Microthermometric and Raman
measurements of fluid inclusions were carried out at the Key Laboratory of Mineral Resources, Institute of Geology and Geophysics, Chinese Academy of Sciences.

Three types of fluid inclusions occur in quartz from Linglong and Jiaojia style deposits: (A) H2O-CO2 inclusions, (B) CO2-H2O±CH4 inclusions, and (C) aqueous H2O inclusions.

Fluid inclusion measurements and laser Raman spectroscopy suggest that the ore-forming fluid in the two style gold deposits in the whole peninsula have similar chemical and physical properties. The early-stage quartz contains the type A and type B inclusions, whereas the late-stage quartz contains only the type C inclusions. In the early stage, ore-forming fluid belongs to H2O-CO2-NaCl system, which is characterized by medium-high temperature, enrichment of CO2, and medium-low salinity, in contrast to typical high temperature and high salinity magmatic fluids. These features, combined with the analytical results of hydrogen and oxygen isotopes, indicate that the hyperthermal, volatiles-abundant and Au-rich primary ore-forming fluid probably mixed with meteoric water infiltrating downward along fractures, when it moved upward through the fractures, altering the primary characteristics of the ore-forming fluid. The fluid evolved into H2O-CO2-NaCl system with medium-low temperature, less CO2, and variable salinity in the middle stage. During the mineralization, more meteoric water was involved. Finally, the ore-forming fluid, in the late stage, turned into H2O-NaCl system with low temperature, low salinity and no CO2.

Fluid inclusions studies in the gold ores and altered wallrocks from the different depths of at Sanshandao deposit show that the nature of the ore-forming fluids is nearly same across the whole 3000 m vertical depth. There is no systematic variation in the homogenization temperatures, salinity and fluid types with depth in the deposit. Independently, it has been found that gold mineralization at Sanshdao extends over the depth range investigated, and even deeper. Recent exploration works have found >30 meter thick rich gold ores with average Au 2.5 ppm in a drill core at the vertical depth of 2700 m (Hu et al., 2013).

3 Suggested Ore Genesis

The gold deposits in the Jiaodong province are mostly hosted in the Mesozoic granitoids and are structurally controlled by faults and shear zones that cut the Mesozoic granitoids. Previous studies have shown that the ages of the gold deposits in the Jiaodong gold province cluster between 123 and 114 Ma as determined by sericite/muscovite 40Ar/39Ar and single grain pyrite Rb–Sr dating (Yang and Zhou, 2001; Li et al., 2008; Hu et al., 2013). The formation ages of the Mesozoic granitoids are 160–156 Ma, 130–126 Ma and ~113–110, respectively, as obtained by zircon U–Pb dating (Goss et al., 2010; Yang et al., 2012). The timing of gold mineralization is significantly younger than the ages of the regional granitoid magmatism in the Jiaobei terrain, and slightly older than Early Cretaceous magmatism in the Ludong.
terrain, indicating that the gold mineralization has no
direct relationship to the granitoid magmatism. Instead,
most gold deposits show temporal and spatial association
with abundant mafic to intermediate dikes that are
widespread in the Jiaodong gold province, and which have
been dated at ca.122 to 119 Ma.

The first-order faults in this area underwent multi-stage
reactivation, and the stress types were diverse at different
periods. Repeated stress and tectonic movements caused
the rocks around faults to become highly cataclastic. Large
and small fissures and cavities were developed within the
cataclastic rocks, which provided the pathways for ore-
forming fluids against the wall rocks, creating favorable
conditions for fluid permeation and hydrothermal
alteration. The first-order faults are the main migration
pathway of the ore-forming fluids. High temperature and
strong water-rock interaction occurred along the first-order
faults, resulting in the formation of “Jiaojia-type”
disseminated and stockwork gold mineralization. In
contrast, the secondary faults were less activated and the
rocks around these show less degree of fracture. They
were thus unfavorable water-rock interaction but served as
open conduits for the migration of ore fluids. During the
process of ore fluid migration from the first-order faults to
the secondary faults, the temperature gradually decreased.
Opening of the faults led to sudden decompression and
fluid phase separation (boiling). A sharp fall in
temperature and large-scale exsolution of volatiles also
occurred at the same time. This process brought about the
precipitation of the “Linglong-type” lode gold
mineralization.

Gold deposition in the Jiaodong province happened
during a short period, and formed in the same tectonic-
geological setting and from the same type of ore fluid.
Although different mineralization and alteration stages can
be defined, these stages are the results of the same broad
metallogenic event.

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