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Research paper

Mineral chemistry and isotope geochemistry of pyrite from the Heilangou gold deposit, Jiaodong Peninsula, Eastern China

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ABSTRACT

The Heilangou gold deposit is located in the northern Qixia–Penglai gold belt, which is one amongst the three large gold belts in the eastern Shandong Province (Jiaodong Peninsula). The ore body has formed within the Guojialing granite. In this study, we report the mineral chemistry of pyrite, as well as the S, Pb, and H–O isotope data of the Heilangou gold deposit. The chemical composition of pyrite in the Heilangou gold deposit indicates that the associated gold deposit is a typical magmatic hydrothermal one. The geochemical signatures and crystal structure of pyrite show that the ore-forming materials have been derived from the crust. The S isotope data of the pyrites from Heilangou show an overall range from 5.5 to 7.8‰ and an average of 6.7‰. The S isotope data in this deposit are similar to those from the deposits in the Jiaodong gold belt. The Pb and S isotope variations are small in the Heilangou gold deposit. The $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratios are 17.4653–17.5958, 15.5105–15.5746 and 38.0749–38.4361, respectively. These data plot between the lower crust and the orogenic belt. The Pb isotope data in the Heilangou gold deposit are similar to those in the Linglong gold deposit. From the Qixia gold area (the Liukou and Majiayao gold deposits) to the Muping–Rushan gold belt (Rushan gold deposit) to the Zhao–Ye gold belt (the Linglong, Sanshandao and Jiaojia gold deposits), the $^{206}Pb/^{204}Pb$ ratios progressively increase. The D–O isotope data obtained from quartz separates suggest that the ore-forming fluid was similar to a mixture of magmatic and meteoric waters. These results suggest that the ore-forming elements were primarily from source fluids derived from the lower crust.

1. Introduction

The Jiaodong Peninsula in the eastern part of the North China Craton is the largest gold province in the country, and belongs to the Mesozoic metallogenic event in the region (Guo et al., 2013; Li and Santosh, 2013; Li et al., 2013; Zhai and Santosh, 2013). The Heilangou gold deposit is located in the Qixia–Penglai gold belt, which is one amongst the three large gold belts in the eastern Shandong Province (Jiaodong Peninsula). Recent exploration has targeted gold deposits in the Qixia–Penglai gold belt that are associated with the Guojialing granitoids, and many gold deposits, such as Heilangou, Daliuxing, Yujiakuang and Hexi have been identified (Zhou et al., 2002; Chen et al., 2005). Previous studies of gold deposits have focused on the Zhaoyuan–Laizhou gold belt and the Rushan–Muping gold belt (Hu et al., 2006; Li et al., 2008; Deng et al., 2009). However, the gold deposits in the Qixia–Penglai gold belt are still poorly studied (Hou et al., 2006, 2007). The aforementioned studies did not consider the geochemistry of pyrite and lacked new isotopic data.

Pyrite is the most common and important gold-bearing mineral in gold deposits (Boyle, 1979; Murowchick and Barnes, 1987; Chen et al., 1989; Maddox et al., 1998; Abraitis et al., 2004; Deditius et al., 2008; Prolledesma et al., 2010), and it accounts for 85% of the major gold-bearing minerals in gold deposits (Gao et al., 2000). The properties of pyrite, such as morphology (Donnay and Harker, 1937; Evzikova, 1984; Chen et al., 1989), chemical composition (Chen et al., 1989; Ressel et al., 2000; Abraitis et al., 2004; Cook et al.,

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2009), crystal structure (Chen et al., 1989; Abraitis et al., 2004) and thermoelectricity (Chen et al., 1989; Abraitis et al., 2004), have been studied previously. However, the geological relevance of pyrite geochemistry is still unclear. Many factors, such as ore genesis, the sources of metals and fluids, the relationships among the ambient environmental factors and the various characteristics of pyrite need to be studied. In this paper, we present the pyrite geochemistry data that are related to its chemical composition and S and H–O isotopes in the Heilangou gold deposit. We also use new systems, such as δFe/δS–As, (Fe + S)–As and Co–Ni–As, for the chemical composition of pyrite. This work will provide a valuable tool for the exploration of similar deposits in the region. An attempt is also made to determine the source of ore-forming fluids in the Heilangou gold deposit.

One method to constrain the nature of ore-forming fluids is to study stable isotopes, such as those of hydrogen, oxygen, carbon, sulfur, and nitrogen, and noble gases of the ore-forming fluids and related minerals. Although some studies on stable isotopes exist for the Jiaodong gold deposits (e.g., Li, 1988; Zhang et al., 1994; Zhai et al., 1996; Sun et al., 2001; Mao et al., 2002; Zhang et al., 2002; Liu et al., 2003a,b; Mao et al., 2008), to date none exist for the Heilangou gold deposit. Furthermore, data from the existing studies give conflicting views regarding the sources of ore-forming fluids in the Jiaodong gold province. The fact that most of the gold ore bodies are hosted in 160–150 Ma Linglong-type biotite granite or 130–126 Ma Guojialing-type granodiorite has prompted researchers to suggest that the ore-forming fluids were dominantly derived from granitic magma, which increasingly mixed with meteoric water during the late stages of hydrothermal activity (Qiu et al., 1988; Sun et al., 2001; Wang and Yan, 2002; Mao et al., 2008). Others, on the basis of stable isotope systematics and initial ratios of Sr isotopes, suggested that the major component of the ore-forming fluids was meteoric water, or that the meteoric water mixed with small amounts of magmatic fluid (e.g., Zhai et al., 1996; Lu et al., 1999; Shen et al., 2004). Owing to the close spatial relationship between the ore bodies and Cretaceous lamprophyre dykes, together with some evidence of mantle-derived components, others argued that deep fluids or mantle-derived fluids were responsible for the gold deposits in the Jiaodong Peninsula (Deng et al., 2000; Fan et al., 2003; Liu et al., 2003a,b; Zhou et al., 2003).

2. Regional geological setting

The Heilangou gold mine is situated in the middle portion of the Jiaodong Peninsula in eastern Shandong Province (Fig. 1). Based on historical production rates, this area is the largest repository of gold (>35 Moz Au) in China. Most of the gold deposits are distributed between the Tanlu Fault zone and the Wulian–Qingdao–Yantai Fault. The latter is considered to be the boundary between the North China Craton and the Sulu ultrahigh-pressure (UHP) orogenic belt (Zhai et al., 2000). The northwestern Jiaodong Peninsula is composed primarily of Precambrian metamorphic sequences, Mesozoic volcanic rocks and granitoids, and minor Mesozoic sedimentary cover rocks (Wang et al., 1998). The Precambrian sequences primarily comprise the late Archean amphibolite- to granulite-facies of the Jiaodong Group, and the Proterozoic Fenzishan and Penglai groups are composed of low-grade metasedimentary rocks. The Jiaodong Group, which was dated at 2665 Ma using the U–Pb zircon method, consists primarily of mafic to felsic volcanic and sedimentary rocks and has been identified as an Archean greenstone belt (Shimazaki et al., 1994). The Mesozoic granitoids that intrude the high-grade Jiaodong Group can be subdivided into the following three groups according to their compositional and textural characteristics and their field relationships (Qiu et al., 2002): (1) a granite-granodiorite group that is primarily composed of biotite granites, granodiorites and monzonites; (2) a porphyritic granodiorite group that consists of porphyritic, hornblende-bearing granodiorites, monzogranites and granites; and (3) a peralkaline granitoid group that consists primarily of monzonites and syenites. Most of the large gold mines in the Jiaodong Peninsula are hosted in the widely distributed metaluminous to slightly peraluminous granitoids of the first two groups. These include the Linglong and Jiaojia gold deposits that are hosted in the 160–156 Ma old Linglong medium-grained biotite granite and the 130–126 Ma old Guojialing porphyritic granodiorite (Miao et al., 1997).

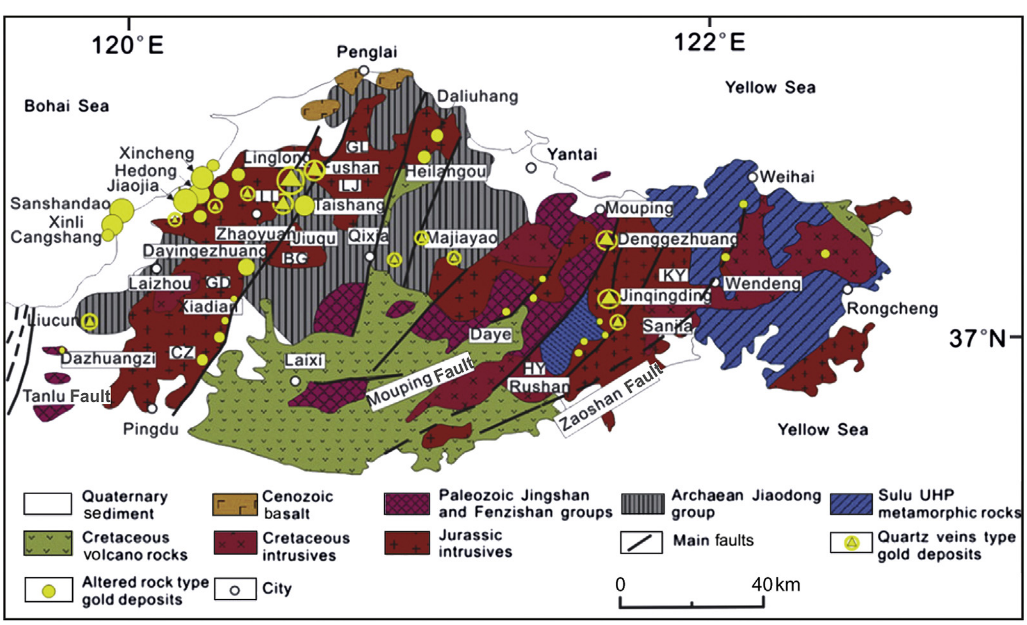

Figure 1. Simplified geological map of the Jiaodong Peninsula, eastern China (modified after Li et al., 2013). CZ: Cuizhao rock, HY: Haiyang rock, KY: Kunyushan rock, GD: Guojiadian rock, GL: Guojialing rock, LL: Linglong rock, BG: Biguo rock, LJ: Luanjiahe rock.