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The relationship of mantle-derived fluids to gold metallogenesis in the Jiaodong Peninsula: Evidence from D–O–C–S isotope systematics

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Abstract

The largest gold district in China is the Jiaodong Peninsula, where three types of gold deposits are recognized: quartz vein, fracture-altered and breccia types. The first two developed along a group of NE-trending faults and are hosted by granitic intrusions, dated at 160 to 150 Ma (biotite granite) and 130 to 126 Ma (granodiorite), and by metamorphic rocks of the Precambrian crystalline basement. The breccia-type gold system is mainly located around the northern margin of the Jiaolai Cretaceous basin, where mineralisation is controlled by both detachment fractures and NE-trending faults. This study is based on stable isotope determinations from ten gold deposits, including Linglong, Jiaojia, Sanshandao, Cangshang, Wang'ershan, Dayigezhuang, Denggezhuang, Pengjiakuang, Fayunkuang and Dazhuangzi, as well as the Linglong Jurassic biotite granite, Guojialing Cretaceous granodiorite and Archean gneiss. The stable isotope systematics reflect the style of the three types of gold deposits, but also show that they belong to the same metallogenic system, in which the hydrothermal fluids were derived from a mantle fluid reservoir and mixed with crustal fluids. The ore-forming age is later than both the Jurassic biotite granite and Cretaceous granodiotite, but overlaps with the 121 to 114 Ma ages of lamprophyre and diabase dykes. The hydrothermal fluids that were responsible for both gold mineralisation and the retrograde alteration of the diabase and lamprophyre dykes are similar, and represent a CO_2 and potassium-rich system. This fluid system is interpreted to be the consequence of Cretaceous lithospheric thinning, asthenospheric upwelling and mantle degassing in Eastern China.

Keywords: D–O–C–S isotopic systematics; Mantle fluids; Meteoric water; Gold deposits; Jiaodong Peninsula; China

1. Introduction

The Jiaodong Peninsula is the premier gold district in China, with total measured gold reserves exceeding 1000 t, and current annual production of over 30 tonnes. An important gold mineralising event affected this relatively small area, which has been the object of intensive studies by several researchers in the past two decades. Lü and Kong (1993), Yang and Lü (1996), Yang (1998), Zhaoyuan Gold Mining Group Corporation (2002), Qiu et al. (2002) and Lü et al. (2002) have

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discussed, in varying detail, the geological setting, metallogenic features and mineralisation systematics of this important gold district.

There are conflicting views regarding the sources of ore-forming fluids in the Jiaodong gold province. The fact that most of the gold orebodies are hosted in 160 to 150 Ma Linglong-type biotite granite or 130 to 126 Ma Guojialing-type granodiorite has prompted a group of 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; Chen et al., 1989; Li, 1992; Lin and Yin, 1998; Yang, 1998; Yang et al., 2000; Sun et al., 2001; Wang and Yan, 2002). 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 orebodies and Cretaceous lamprophyre dykes, together with some evidence of mantle-derived components, other researchers argued that deep fluids or mantle-derived fluids were responsible for the gold deposits in the Jiaodong Peninsula (Sun et al., 1995; Sun and Shi, 1995; Deng et al., 2000, 2001; Mao et al., 2002b; Zhou et al., 2003; Liu et al., 2003a,b; Xing et al., 2003; Fan et al., 2003).

One method to constrain the nature of ore-forming fluids is to study fluid inclusions trapped in transparent ore-related minerals, in order to define the physical and chemical conditions of deposition and compositions of ore-forming fluids. Another method 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 of stable isotopes have been carried out for some of the Jiaodong gold deposits (e.g., Li, 1988; Zhang et al., 1994; Zhai et al., 1996; Sun et al., 2001; Mao et al., 2002a; Zhang et al., 2002c; Liu et al., 2003a,b), the data obtained are dispersed and published only in Chinese. Zhang et al. (2002b) measured noble gas isotopes in four samples of breccia-type gold deposits, and these provide some evidence of mantle-derived fluids involved in mineralisation.

In the present work, we present hydrogen, oxygen, carbon and sulfur isotopic data obtained from ten gold deposits (Linglong, Jiaojia, Sanshandao, Cangshang, Wang'ershan, Dayigezhuang, Denggezhuang, Pengjiakuang, Fayunkuang, and Dazhuangzi), as well as from granite intrusive and metamorphic basement rocks. Based on the results of this study, an attempt is made to determine the source of ore-forming fluids, discuss the geodynamic setting of the mineralising event, and propose a metallogenic model for the Jiaodong gold district.

2. Regional geological setting and gold deposits

The Jiaodong Peninsula is located along the southeastern margin of the North China craton and at the western margin of the Pacific Plate. It is bounded to the west by the NNE-trending Tanlu Fault zone that extends for thousands of km from the Yangtze River north to Far East Russia (Xu et al., 1987; Fitches et al., 1991; Qiu et al., 2002). The peninsula is divided into two-Jurassic tectonic units: the Jiaobei Terrane in the north and Sulu Terrane in the south. These terranes are separated by the Wulian–Yantai suture (Fig. 1). The Sulu Terrane is at the eastern end of the Qinling–Dabie–Sulu diamond- and coesite-bearing ultra-high pressure metamorphic belt, dated at 240 to 220 Ma (Ames et al., 1996; Hacker et al., 1996). The Jiaobei Terrane consists of the Jiaobei uplift in the north and the Jiaolai basin in the south.

The basement of the Jiaobei uplift comprises the Archaean Jiaodong Group, the Palaeoproterozoic Jingshan Group and Fenzishan Group, and the Neoproterozoic Penglai Group. The Jiaodong Group consists mainly of biotite–plagioclase gneiss and plagioclase–amphibole gneiss, dated by the SHRIMP U–Pb method at 2858 to 2665 Ma (Zhaoyuan Gold Mining Group Corp., 2002). It is discordantly overlain by the Palaeoproterozoic Jingshan Group, which mainly consists of marble, biotite–plagioclase gneiss, and amphibolite. Yang and Lü (1996) obtained ages of 2313 to 2033 Ma from biotite–plagioclase gneiss, using the single crystal ID TIMS method. The No. 4 Geological Team of Shandong Province dated the biotite gneiss at the top of the Jingshan Group by the single crystal ID TIMS method at 1998 to 1830 Ma (Zhaoyuan Gold Mining Group Corp., 2002). The Palaeoproterozoic strata comprise the Jingshan and Fenzishan Groups, which are separated by a discordant boundary. The Fenzishan Group mainly consists of marble, schist, gneiss, and amphibolite, with ages of 2381 to 1674 Ma (Zhaoyuan Gold Mining Group Corp., 2002). The ages of the Jingshan and Feizishan Groups are similar, but their relationship is poorly understood. The Neoproterozoic Penglai Group discordantly overlies both the Jingshan and Fenzishan Groups, and consists mainly of limestone, shale, marble, and chert.

The Jiaolai basin contains the Cretaceous Laiyang Formation (fluvial-facies clastic rocks), the Qingshan Formation (mainly mafic, intermediate-felsic volcanic rocks), the Wangshi Formation (dominantly clastic rocks