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Implications of pyrite geochemistry for gold mineralisation and remobilisation in the Jiaodong gold district, northeast China

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ABSTRACT

The Jiaodong gold district of eastern China, the largest gold producing district in China, is located on the eastern margin of the North China Craton. It consists of three mineralisation belts: the western Zhao-Ye belt, the middle Qixia belt, and the eastern Muping–Rushan (Muru) belt. Over 85% of mineralisation is hosted in the Zhao-Ye belt, which is bordered by the mantle-tapping Tan Lu fault zone. Pyrite crystals from three deposits in the Zhao-Ye belt and three deposits in the Muru belt were studied using a combination of optical petrography, bulk pyrite geochemistry, and in-situ laser ablation ICP-MS. Results show that although mineralisation is broadly similar between the two belts, there are significant differences in ore and gangue mineral textures, pyrite geochemistry, and style of gold mineralisation.

Texturally, pyrite grains from the Zhao-Ye belt are generally cubic and do not exhibit zoning. In contrast, Muru pyrite grains are more often pyritohedral, commonly exhibit well-defined concentric zoning, and display textures in ore and gangue minerals indicative of open space growth. Bulk pyrite geochemistry suggests a distinct enrichment in Pb, Bi, Au, Ag and Te in the Zhao-Ye belt, whereas the Muru belt pyrite is significantly enriched in As, Cu and Co. In situ pyrite geochemistry indicates that Au and As are variably correlated in the Zhao-Ye belt, typically only exhibiting correlation at low Au concentrations. Most gold occurs as visible electrum along pyrite fractures and grain boundaries, with a minor generation of invisible gold formed through As-facilitated uptake into pyrite. In the Muru belt, Au and As have a strong correlation and there is limited occurrence of gold particles, indicating that most gold in the Muru belt is invisible gold contained in the crystal structure of As-rich pyrite.

The differences in style of gold mineralisation between the belts indicates an inherent difference in timing of gold introduction: in the Zhao-Ye belt, the visible electrum accounting for most of the gold endowment is formed post-pyrite, whereas the invisible gold in the Zhao-Ye and Muru belts is formed syn-pyrite. The heterogeneity in gold distribution in the Jiaodong district is attributed to melting of metallogenically fertile Archean crust at the base of the well-endowed Zhao-Ye belt, and the lack of a similarly fertile source region beneath the Muru belt.

1. Introduction

The Jiaodong gold district is located on the Shandong Peninsula in eastern China, on the eastern margin of the North China Craton (Fig. 1). It is a world-class gold district and the most important gold producing region in China, yielding over a quarter of annual gold production (Yang et al., 2009). It contains more than 30% of the national gold reserves in China and contains seven deposits containing >100 t of gold and eight with 20–100 t of gold (Fan et al., 2007). Gold deposits in the Jiaodong district are divided into three belts, known as the Zhao-Ye (western-most), the Qixia (central), and the Muping–Rushan, or Muru (eastern-most) gold belts (Qiu et al., 2002; Fan et al., 2007). Over 85% of mineralisation is hosted in the westernmost Zhao-Ye belt, and over 95% of all mineralisation in the district is hosted in Mesozoic granitoids which intrude the Precambrian basement of the North China Craton (Qiu et al., 2002).

The North China Craton experienced significant and diverse regional tectonomagmatic events during the Phanerozoic (Fig. 2). These events include Palaeozoic to Triassic accretionary collision on the northern margin (Xiao et al., 2003; Windley et al., 2007; Zhou and Wilde, 2013); mid-Triassic continental collision on the southern margin (Hacker et al., 2004; Faure et al., 2008; Chang and Zhao, 2012); Cretaceous loss of over 80 km of sub-continental lithospheric mantle beneath the eastern craton (Griffin et al., 1998; Kusky et al., 2007; Xiao et al., 2010); Cretaceous faulting along the Tan Lu fault in eastern the North China Craton (Y.Q. Zhang et al., 2003b; Zhu et al., 2005, 2010); Cretaceous subduction of the Pacific Plate beneath East Asia (Sun et al., 2007; Zhu et al., 2012; Wei et al., 2012); and widespread Cretaceous magmatism

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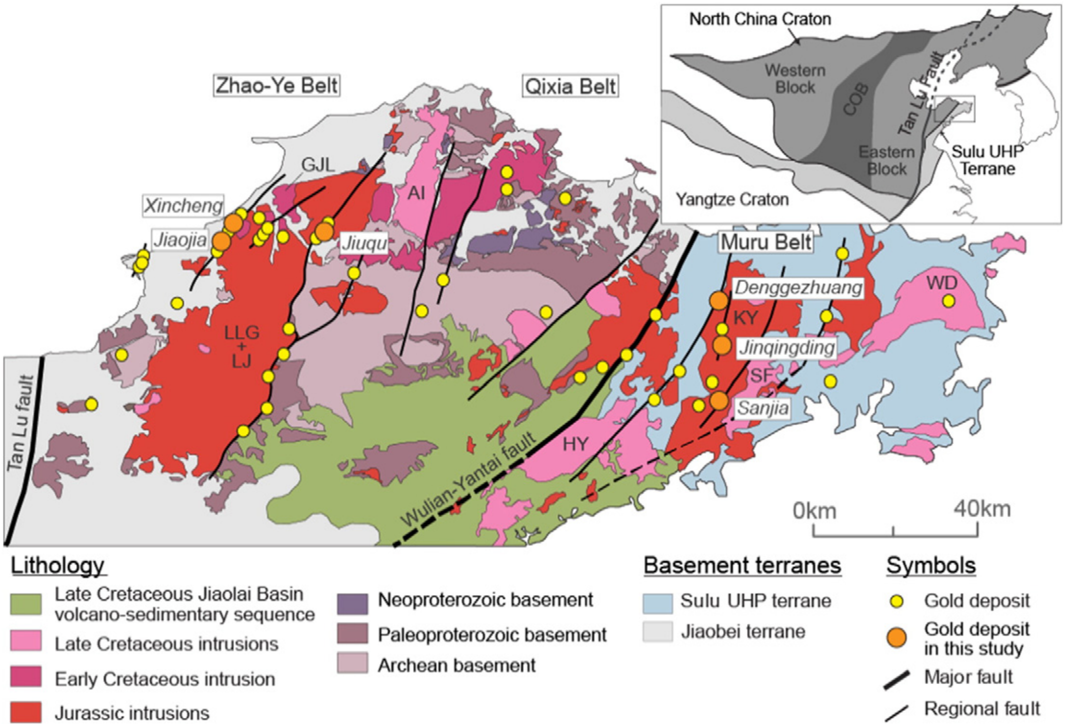

Fig. 1. Regional map of the North China Craton, and geologic map of the Jiaodong gold district. Major gold mineralisation belts and the deposits sampled for this study are indicated (after Fan et al., 2003; Hacker et al., 2006; Goss et al., 2010; Zhang et al., 2010; Yang et al., 2012; Li et al., 2012a,b; Liu et al., 2013). LLG = Linglong granite, LJ = Luanjiahe granite, GJL = Guojialing granodiorite, AI = Aishan granite, HY = Haiyang granite, KY = Kunyushan granite, SF = Sanfoshan granite, WD = Weideshan granite.

and extension in the eastern North China Craton, especially in the area around the Jiaodong district (Wu et al., 2005; Goss et al., 2010; Charles et al., 2011).

Previous studies based on geochronology, isotope, or fluid inclusion analyses variably suggest that mid-Triassic continental collision, Tan Lu faulting, loss of lithospheric mantle, Pacific Plate subduction, or a combination of these events influenced mineralisation in Jiaodong (Wang et al., 1998; Zhou et al., 2003; Y.Q. Zhang et al., 2003b; Fan et al., 2003; Li et al., 2003, 2006, 2012a; Chen et al., 2005; Mao et al., 2008; Tan et al., 2012; Sun et al., 2013). As yet, there has been little attention given to mineral chemistry of the ore-bearing phases. In the Jiaodong district, pyrite is by far the most abundant and the most important sulphide mineral because gold, where visible, is hosted in pyrite (Mills, 2013). Investigation of pyrite geochemistry is useful because the trace element composition reflects aspects of ore-forming fluids and, by association, of ore-forming processes. It also presents an opportunity to directly compare aspects of mineralisation in different parts of the district, since pyrite is the main sulphide phase in almost all deposits.

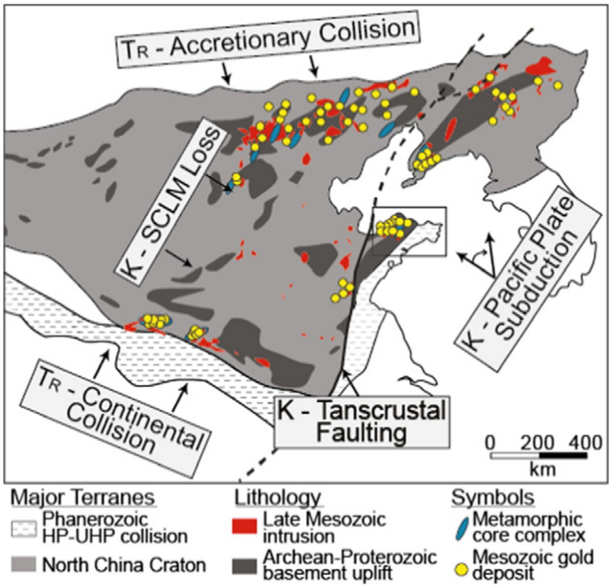

Fig. 2. Regional map of the North China Craton illustrating the relationship between basement uplift, Mesozoic magmatism, Mesozoic gold deposits, and Mesozoic metamorphic core complexes, as well as the regional events that affected the North China Craton during the Mesozoic.
(After Li et al., 2012a,b; Goldfarb et al., 2014).

In this study we present new pyrite geochemistry from three of the most significant deposits in each the Zhao-Ye and the Muru gold belts. Our bulk and in situ trace element geochemistry from the Jiaojia, Xincheng, and Jiuqu deposits in the Zhao-Ye belt and the Denggezhuang, Jinqingding, and Sanjia deposits in the Muru belt highlights differences between mineralisation in the Zhao-Ye and the Muru belts and identifies significant variations in the timing and style of gold mineralisation. These results are also evaluated in terms of their relationship to the varying regional tectonomagmatic processes affecting the Jiaodong district during mineralisation.

2. Geologic background

The Jiaodong gold district (Fig. 1) is bounded to the west by the Tan Lu fault, which extends across the entire eastern North China Craton and was active during the Cretaceous (Zhu et al., 2010). To the south and the east the district overlaps with and is bounded by the Sulu ultrahigh pressure (UHP) terrane, which resulted from mid-Triassic continental collision between the North China Craton and the Yangtze Craton (Qiu et al., 2002; Hacker et al., 2006; Fan et al., 2007). Widespread Mesozoic magmatism, which characterises the eastern North China Craton, occurred in three pulses in the Jiaodong district: 1) 160–150 Ma, which includes the Linglong and Luanjiahe granites in the Zhao-Ye belt and the Kunyushan granite in the Muru belt, 2) ca. 125 Ma, including the