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Early Cretaceous magma flare-up and its implications on gold mineralization in the Jiaodong Peninsula, China

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ABSTRACT

The gold deposits of the Jiaodong Peninsula in the eastern part of the North China Craton constitute one of the richest gold reserves in the world and also define a unique class of gold mineralization. Previous studies correlated the gold mineralization in Jiaodong to Mesozoic magmatic intrusives, particularly granitoids derived from mixed sources of reworked Paleoproterozoic basement rocks, or Early Cretaceous dykes. Here we evaluate the geochemical characteristics of the major magmatic suites in the region as well as the timings of the magma pulses with respect to that of gold metallogeny. It is revealed that the peak of gold mineralization at ca. 120–125 Ma coincides with the major volcanic activity in Jiaodong as represented by the extrusion of basaltic trachyandesites. The magma flare-up was accompanied by a transient fluid influx through an enriched and metasomatised mantle with gold and sulfur predominantly scavenged from subducted sediments over the downgoing paleo-Pacific Plate. The remarkable structural control of the gold-bearing quartz veins and the proximity of the larger gold deposits in Jiaodong to the major Tan–Lu Fault clearly indicate that fluids channeled along structural pathways were the major contributor to the gold mineralization in the area. The asthenospheric upwelling and decompression melting triggered extensive magmatism and crustal recycling aided by the development of deep extensional fractures possibly associated with major stress field changes during plate re-orientation in the Early Cretaceous.

1. Introduction

As the current largest gold producer in the world, Chinese gold reserves are distributed widely along the margins of the craton, at the junctions of the microblocks that built the cratonic architecture, and within some of the reactivated paleo-suture zones (Li and Santosh, 2014; Zhai and Santosh, 2013) (Fig. 1). The gold deposits range in size from small (<5 t Au), medium (5 to 20 t Au) large (>20 t Au) and to super-large (exceeding 100 t Au) (Goldfarb and Santosh, 2013, and references therein). Among these, the gold mineralization in the North China Craton are spatially, and in some cases temporally, associated with the voluminous Late Jurassic–Early Cretaceous magmatism that destroyed the fundamental cratonic architecture of the NCC and caused extensive and differential lithospheric erosion and thinning (Li et al., 2013; Yang et al., 2013a; Zhang et al., 2013). Recent evaluations reveal that the peak of gold metallogeny is restricted to a relatively short period at around 120–125 Ma (Goldfarb and Santosh, 2013). Despite the scenario that the gold mineralization is hosted by Jurassic–Cretaceous magmatic intrusions generated by both recycling of older crustal basement and through input from juvenile mantle components (Yang et al., 2013a), the ore source and genesis appear to be unrelated to either the basements rocks that are at least 2 billion years older (e.g., Yang et al., 2013a) than the gold mineralization, or with the Mesozoic magmatic intrusions (Goldfarb and Santosh, 2013).

The ca. 125 to 120 Ma Au deposits in Jiaodong Peninsula in eastern NCC are one of the major ore fields for gold in East Asia (Goldfarb et al., 2014), and constitute the largest gold province in China with an overall endowment estimated as >3000 t Au (Goldfarb and Santosh, 2013; Guo et al., 2013). This accounts for more than 25% of China's gold reserves. The gold mineralization in this region has been broadly classified into two types: (1) Linglong-type that occurs as extensional massive gold–quartz–pyrite veins, and (2) Jiaojia-type that occurs as disseminated veinlets and wallrock disseminations (Goldfarb and Santosh, 2013; Li and Santosh, 2014; Qiu et al., 2002a,b). Among these, the Zhao–Ye belt in the western part of the Jiaodong gold province carries more than 95% of the gold resource (Qiu et al., 2002a,b; Wang et al., 1998; Zhou and Lv, 2000). The Linglong and Jiaojia types of vein and disseminated ores are principally hosted by NE- to NNE-trending brittle normal faults that parallel the margins of the Jurassic and Cretaceous granitoids, with the larger orebodies associated with dilational jogs (Goldfarb and Santosh, 2013). The tectonic setting and ore genesis of the Jiaodong gold deposits have remained equivocal with debates surrounding their classification into traditional models of orogenic gold (Goldfarb et al., 2014) versus a unique class of "Jiaodong-type" gold deposits associated with intraplate processes (Li and Santosh, 2014; Zhai and Santosh, 2013; Zhai et al., 2004a,b,c).

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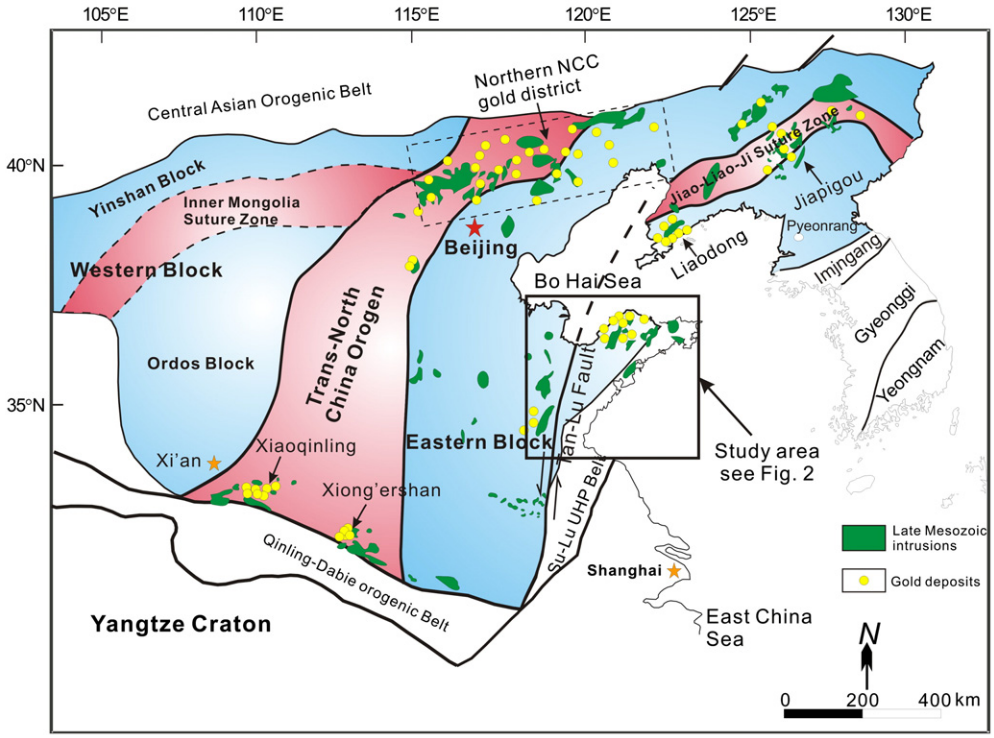

Fig. 1. Generalized tectonic framework of the North China Craton showing the major crustal blocks and intervening sutures. The present study area in Jiaodong Peninsula illustrated in Fig. 2 is marked by box.
After Zhao et al. (2005), Santosh (2010) and Zhang et al. (2013).

In this paper, we present an overview of the age and geodynamics of magmatism and gold mineralization in Jiaodong. We evaluate the Mesozoic magmatic pulses in the Jiaodong Peninsula and investigate the possible relationship between magma flare-up, transient fluid flux and gold metallogeny. We also address the possible tectonic milieu associated with the Early Cretaceous magmatism and its implications.

2. Geological background

2.1. Geological setting

The NCC preserves the rock records of a prolonged history of crust building and recycling events during the early Precambrian, with the final cratonization during late Paleoproterozoic through double-sided subduction and amalgamation of the two major crustal blocks — the unified Western Block comprising the Yinshan and Ordos Blocks, and the Eastern Block (Santosh, 2010; Geng et al., 2012; Zhai and Santosh, 2011, 2013; Zhao and Zhai, 2013, among others) (Fig. 1). The major tectonic events associated with the evolution of the NCC have been summarized in previous studies as follows (Zhai and Santosh, 2011; Zhang et al., 2012). (1) Crustal growth and stabilization during Neoarchean; (2) rifting–subduction–accretion–collision from early to late Paleoproterozoic; (3) multistage rifting during Late Paleoproterozoic–Neoproterozoic; (4) craton margin orogenesis during Paleozoic and (5) Mesozoic extensional tectonics associated with lithosphere thinning and decratonization. The secular changes in tectonic regimes were also accompanied by the formation of at least five major metallogenic systems: Archean Banded Iron Formation (BIF), Paleoproterozoic Cu–Pb–Zn and Mg–B, Mesoproterozoic REE–Fe–Pb–Zn, Paleozoic orogenic Cu–Mo, and Mesozoic intracontinental Au and Ag–Pb–Zn and Mo (Zhai and Santosh, 2013). Among these, the large-scale Mesozoic magmatism and the associated gold mineralization provide important insights into mantle dynamics and crust–mantle interaction during lithospheric thinning and craton destruction.

In a recent study, Zhang et al. (2013) evaluated the U–Pb geochronology and Hf isotope data on zircons from granulite/pyroxenite xenoliths occurring within Phanerozoic magmatic rocks and inherited xenocrysts from the associated lower crust rocks in various domains of the NCC. Their study emphasized that the late Mesozoic (ca. 120 Ma) marks a major event of widespread magmatism throughout the NCC which they correlated with the 'giant south Pacific mantle plume'. The widespread and episodic magmatism and rejuvenation of the ancient lower crust beneath the NCC witnessed addition of juvenile materials from mantle to lower crust, and mixing of the old crust with these melts. The process is also considered to have resulted in the transformation of the refractory lithospheric mantle to a fertile one.

The Jiaodong Peninsula in eastern Shandong Province along the eastern margin of the NCC is bordered by the Tan–Lu Fault to the west and the Su–Lu ultrahigh-pressure metamorphic belt to the east (Fig. 2). The Precambrian basement in this region is dominantly composed of Neoarchean–Paleoproterozoic TTG (tonalite–trondhjemite–granodiorite) gneisses, felsic and mafic volcanics and volcano-sedimentary successions, all metamorphosed under upper amphibolite to granulite facies conditions and variously reworked during the Mesozoic orogeny (Qiu, 1989; Wang et al., 1998; Yang et al., 2003, 2013a). The Mesozoic intrusions have been classified into three suites: the Linglong, Kunyushan and Guojialing. The Linglong and Kunyushan suites are represented by medium grained metaluminous to slightly peraluminous biotite granite with ages of 160 to 156 Ma. The Guojialing suite is composed of porphyritic hornblende–biotite granodiorite ranging in age from 130 to 126 Ma (Guan et al., 1998; Wang et al., 1998; Zhang et al., 2003a,b). Numerous Cretaceous mafic-intermediate dikes are widespread in Jiaodong Peninsula. In the western Shandong domain, to the west of the Tan–Lu Fault, the corresponding magmatism is represented by gabbro, diorite, granodiorite, monzonite and syenite, intruding into the basement and Paleozoic strata (e.g., Chen, 2001; Yang et al., 2003). The available geologic and geochronologic data clearly indicate that a major magmatic