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U–Pb dating of hydrothermal zircon from the Dongping gold deposit in North China: Constraints on the mineralization processes

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ABSTRACT

The Dongping gold deposit is a large deposit with total gold reserves of >100 tons. It is located at the northern margin of the North China Craton, northwestern Hebei province, China. The ore-bodies are hosted by the Devonian Shuiquangou syenite complex and consist mainly of auriferous quartz veins and disseminated ore in the altered and silicified syenite. U–Pb dating of zircon from hornblende syenite on the western margin of the complex yields a crystallization age of 400 ± 3.5 Ma (MSWD = 0.018). Morphology, cathodoluminescence imaging and geochemical classifications of zircon from the first stage of disseminated ore and gray auriferous quartz veins, and from later stage, low grade quartz veins point to their newly crystallized hydrothermal origin. The hydrothermal zircon from the disseminated ore and auriferous gray quartz vein are dated at 389 ± 1.0 Ma and 385 ± 5.7 Ma, respectively, which are detectably younger than but close to the crystallization age of the syenite complex and might have been formed by post-magmatic hydrothermal processes. Both types of ore are dominant in the ore deposit, and we propose that the pervasive, post-magmatic hydrothermal alteration is the main ore forming stage. Hydrothermal zircon from a low grade auriferous quartz vein yields a U–Pb age of ~140 Ma, interpreted as forming during a younger period of superimposed Yanshanian hydrothermal mineralization. Thus, the ore of the Dongping gold mine represents a post-magmatic Devonian hydrothermal ore deposit with Jurassic–Cretaceous hydrothermal overprinting.

1. Introduction

The Dongping gold deposit, which is located in northwestern Hebei province, China, is a large deposit with proven gold reserves of >100 tons. The deposit is hosted in the Devonian Shuiquangou syenite complex. Ore types consist mainly of auriferous quartz veins and disseminated ores (K-feldspar altered and silicified syenite), both of which are characterized by low sulfide and As contents, and a Te-enrichment. The geological and geochemical features of the Dongping gold deposit have been extensively investigated and debated during the past two decades (Bao and Zhao, 2006; Bao et al., 2003; Cook et al., 2009; Fan et al., 2001; Lu et al., 1993, 1997; Mao and Li, 2001; Mao et al., 2003; Mo, 1996; Nie, 1998; Song and Zhao, 1996; Zhang, 1996). Based on ^{40}Ar–^{39}Ar ages of the hornblende from the syenite (327 ± 9 Ma) and hydrothermal K-feldspar from ores (157–177 Ma), Song and Zhao (1996) proposed a model suggesting that the ore metals were leached from the syenite by hydrothermal fluids during Yanshanian (Jurassic–Cretaceous) tectonism. Similarly, based on the ore metal association, close spatial relation with the syenite complex, and S, Si, and Pb isotope compositions of the ore-related minerals, some researchers suggested that the ore deposit is genetically directly related to the syenite complex (Nie, 1998; Nie et al., 2004; Zhang et al., 2005). However, this hypothesis is inconsistent with the more than 200 m.y. gap between the available ages of the syenite complex and ore formation. Moreover, some other workers argued that the low salinity, CO_2-rich ore fluids reflect a metamorphic hydrothermal origin (Hart et al., 2002; Mao et al., 2003), which is typical of most orogenic gold deposits (e.g., Goldfarb et al., 2001). Orogenic gold deposits are usually associated with greenschist phase metamorphic rocks (e.g., Goldfarb et al., 2001), which is likely due to the pyrite to pyrrhotite transition during prograde metamorphism from greenschist to amphibolite phases (e.g., Sun et al., 2013). The Dongping gold deposit, however, is located in the central part of the Shuiquangou syenite, which is not the usual geologic setting for orogenic gold deposits. More importantly the reported argon ages of ore formation are inconsistent with those of the regional tectonic and magmatic events (Hu and Song, 2002, 2003; Li and Bao, 2012; Miao et al., 2002). The suspect ^{40}Ar–^{39}Ar ages for the magmatic hornblende and hydrothermal K-feldspar might be the result of partial resetting by later thermal events or excess ^{40}Ar inherited from the feldspars during K-feldspathization. The mixing of two generations of K-feldspar has also been proposed as a possible explanation of the spurious ages (Berger, 1975; Kuiper, 2002). Obviously, the geochemical and metallogenetic understanding of the Dongping gold deposit is hindered by a lack of precise dating of the ore forming process.

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Studies have demonstrated that precise U–Pb dating of hydrothermal zircon from altered rocks and quartz veins of ore deposits is a good tool for dating hydrothermal ore formation (Claoué Long et al., 1990; Kerrich and King, 1993; Pelleter et al., 2007; Toscano et al., 2014; Zartman and Smith, 2009). However, presumed hydrothermal zircon in altered rocks and ores might alternately be hydrothermally altered wall rock zircon, or zircon mechanically entrapped from the wall rocks. Therefore, U–Pb dating of zircon must be accompanied by detailed mineralogical and chemical study to indentify its source. Hydrothermal zircon, either directly precipitated from fluid solution or formed from hydrothermal alteration of country rock, often shows cathodoluminescence images and rare earth element compositions different from that of magmatic zircon (Hoskin, 2005; Pelleter et al., 2007; Yang et al., 2013).

In order to precisely date the ore-forming processes, LA–ICPMS and SIMS zircon U–Pb dating, CL imaging, and LA–ICPMS trace element analysis were carried out on hydrothermal zircon from auriferous quartz veins and K-feldspar altered disseminated ores obtained from the Dongping gold deposit, and magmatic zircon from hornblende syenite of the Shuiquangou syenite complex. A metallogenetic model for the Dongping gold deposit is proposed based mainly on the new dating results.

2. Geological background

The Dongping gold deposit is situated in Chongli county, Hebei province. Tectonically, it is located on the western end of the Yanshan orogen at the northern margin of the North China Craton, about 10 km to the south of the Shangyi–Chongli–Chicheng fault (Fig. 1). The Shangyi–Chongli–Chicheng fault belt, a deep-rooted fault that extends along the southern boundary of the Inner Mongolia axis on the edge of the craton, was formed in the Mesoproterozoic, and was subsequently reactivated in the Neoproterozoic, Paleozoic, and Mesozoic (Hu et al., 2003; Zhang et al., 2007). The fault system is a ductile to brittle, multi-stage thrust fault, and it is still an important seismically active zone (Ma and Zhao, 1999).

Archean and Paleoproterozoic metamorphic rocks are widespread in the region. The Sanggan metamorphic complex, consisting of Archean amphibolite and granulite generated from a series of mafic to felsic volcanic rocks and clastic sediments, is widespread to the south of the Shangyi–Chongli–Chicheng fault. The Paleoproterozoic Hongqiyingzi Group, consisting of marble, quartzite, amphibolites, and gneiss generated from a series of marine volcanic and sedimentary rocks, occurs to the north of the fault. Mesoproterozoic marine sedimentary rocks occur sparsely in the southeastern corner of the deposit area. Early Cretaceous Zhangjiakou Group continental volcanic–sedimentary rocks occur in the southern and southeastern part of the mining area.

The Devonian Shuiquangou syenite complex intruded Archaean metamorphic rocks and are locally unconformably overlain by Early Cretaceous volcanic rocks. The syenite complex is NW-trending and dips to the south, with an outcropping area of about 350 km^2. The syenite complex is composed of augite–hornblende–alkali feldspar syenite, alkali feldspar syenite, quartz–alkali feldspar syenite, and quartz syenite. It is noteworthy that the lithology of the complex changes

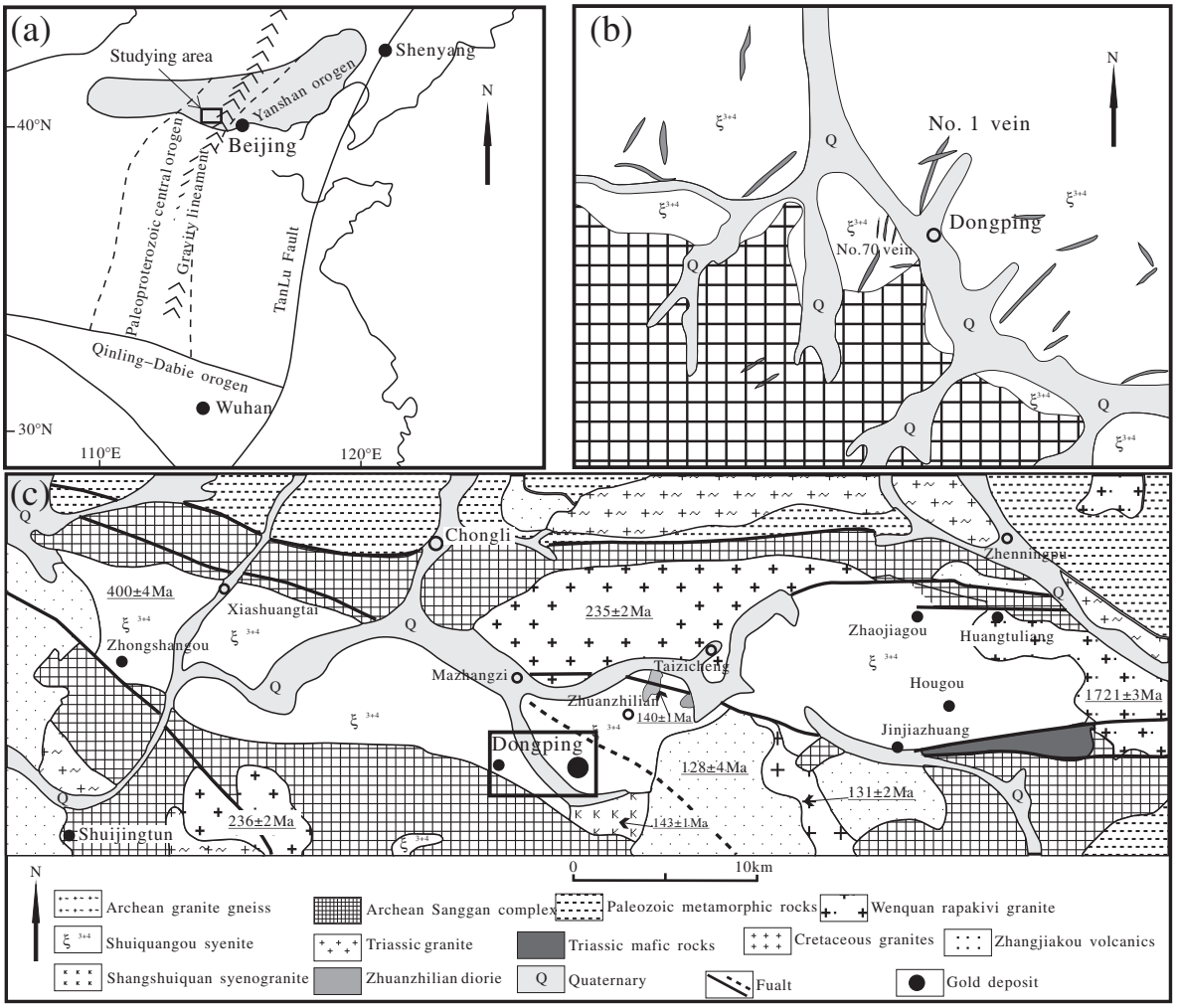

Fig. 1. Geological sketch map of the Shuiquangou syenite complex and distribution of the related gold deposits in Northwest Hebei province.