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Geochronology and geochemistry of the major host rock of the Dong'an gold deposit, Lesser Khingan Range: Implications for petrogenesis and metallogenic setting during the Early–Middle Jurassic in northeast China

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ABSTRACT

The Dong'an gold deposit is a large-sized epithermal gold deposit recently discovered in the Lesser Khingan Range, NE China. Here, we present a detailed study of the petrogenesis, magma source, and tectonic setting of a medium–coarse grained alkali-feldspar granite, the major host rock of the Dong'an gold deposit. The LA–ICP–MS zircon U–Pb dating of the medium–coarse grained alkali-feldspar granite yields an early Jurassic age of 176.3 ± 1.1 Ma (MSWD = 0.62). The whole-rock geochemical data indicate that the samples are felsic, ferroan, alkali-calcic and peraluminous with relatively high alkali ($K_2O + Na_2O$) content. They are enriched in LREEs and LILEs (e.g., Rb, Ba, K), but are depleted in HFSEs (e.g., Nb, Ta, P, Ti), especially in P and Ti, showing characteristics of volcanic arc magmas and similarities with the Early–Middle Jurassic granitic rocks in Xing'an Mongolian orogenic belt. Meanwhile, the negative Eu, Nb, Ta, Ti, and P anomalies are consistent with fractional crystallization of plagioclase, Ti-bearing phases (rutile, ilmenite, titanite, etc.) and apatite during magma evolution. The samples have low Nb/Ta ratios (8.65–14.91) and low $Mg^{\#}$ values (18–36), which are indicative of crustal derived magmas and no interaction between source magmas and the mantle. In-situ Hf isotopic analyses of the zircons from the medium–coarse grained alkali-feldspar granite yield $\varepsilon Hf(t)$ values of +3.38–+5.68 and two-stage model ages (T_{DM2}) of 772–900 Ma, indicating the magmas formed this intrusion were generated by partial melting of Neoproterozoic basaltic materials in the young lower crust, and the magma source could be derived from a depleted mantle. The medium–coarse grained alkali-feldspar granite most likely formed in the late stage of Toarcian subduction of the Pacific plate, which can be identified on the tectonic setting discrimination diagrams, and the formation of this intrusion was associated with underplating of mantle-derived magmas, which provided heat for crustal partial melting. Similar to the medium–coarse grained alkali-feldspar granite, large amounts of granitic rocks and a series of nonferrous metal hydrothermal deposits (Mo, Cu, Au) formed in northeast China as results of magmatic activities triggered by subduction of the Pacific plate during the Early–Middle Jurassic.

1. Introduction

The Dong'an gold deposit is a large-scale epithermal gold deposit discovered in the Lesser Khingan Range, NE China, subsequent to the discovery of the Tuanjiegou gold deposit. As the deposit was discovered only recently, research on the deposit has been limited, with the exception of descriptions of the ore geology and some fluid inclusion research (Xue et al., 2002; Ao et al., 2004; Huo and Sun, 2010; Ma et al., 2012). Systematic research

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on the petrogeochemistry of the deposit has not yet been conducted, and the metallogenic tectonic setting and magma source that formed the igneous rocks and the emplaced gold deposit remain poorly known. In this study, we conducted detailed research on the medium–coarse grained alkali-feldspar granite, the major host rock of the Dong'an gold deposit, including U–Pb dating, geochemical analyses, and Hf isotopic compositional analyses. Our goal is to determine the geological age, magma source, petrogenesis, and tectonic setting of the medium–coarse grained alkali-feldspar granite, enhance research level of the Dong'an gold deposit. Meanwhile, our study will contribute to an understanding of magmatic evolution and the metallogenic tectonic setting in northeast China during the period when the medium–coarse grained alkali-feldspar granite formed.

2. Geological setting and sample description

The Dong'an gold deposit, located in the northern Lesser Khingan Range, is tectonically at the junction of the northeastern Xing'an Mongolian orogenic belt and the western Pacific tectonic belt (Fig. 1A). The area extends to the western boundary of the Xunke–Tieli–Shangzhi lithospheric fault (F1, Fig. 1B) and to the eastern boundary of the Mudanjiang lithospheric fault (F2, Fig. 1B; Ma et al., 2012). The geological history of the region is prolonged, and involved complex tectonic and magmatic activities: Prior to the Palaeozoic, the crust in the area experienced several episodes of supercontinent formation and breakup; During the early Palaeozoic, the area was in a state of relatively stable uplift, with only rare instances of magmatic activity; From the late Palaeozoic to the early Mesozoic, collision of the North China plate with the Siberian plate resulted in the reactivation and mobilization of metamorphic basement rocks, which led to large-scale emplacements of deep-seated magmas (Wen et al., 2013). During the Mesozoic, the region was affected by subduction of the Pacific plate, during which time the area was in an extensional tectonic setting along an active continental margin, and experienced strong tensional tectonics and taphrogeny. The middle Yanshanian movement, which occurred during the late Jurassic to Early Cretaceous, was especially strong, and was accompanied by large-scale fault activities (Ye, 2011). The F1 and F2 lithospheric faults were strongly mobilized during this time, resulting in the formation of a series of NE-, NW-, NNE-striking crustal faults and the Wudi River basin, associated with extrusions of intermediate to intermediate–acid volcanic rocks and the formation of volcanic edifices (Huo and Sun, 2010). The tectonic setting was especially favourable for various types of mineralization, including the hydrothermal mineralization of nonferrous metals (e.g., Mo, Cu, Au,). This period, which climaxed during the Early Jurassic to Early Cretaceous, yielded a variety of nonferrous metal hydrothermal deposits (Fig. 1A).

The major rock formations in the Dong'an gold deposit consist of intermediate–acid volcanic rocks (e.g., andesite, dacite, rhyolite, rhyolitic tuff) of the Lower Cretaceous Guanghua Formation, sandy conglomerate of the Miocene–Pliocene Sunwu Formation, and basalt of the lower Pleistocene Daxiongshan Formation. The major intrusions exposed in this deposit, which consist of medium–coarse grained alkali-feldspar granite, fine-grained alkali granite, and rhyolite porphyry, are broadly located in the centre of the ore district, close to ore bodies, constituting major host rocks of the Dong'an gold deposit. (Fig. 2). Faults and volcanic edifices are the major geological structures in the ore district. Three groups of NE-, near SN-, NNW-striking faults, which are secondary faults of the NNE-striking Kuerbin crustal fault, are the main structural and ore-conducting features that controlled the formation and emplacement of the fine-grained alkali granite, the subvolcanic rocks, and the volcanic edifices. Volcanic vents constituted major volcanic edifices, and cryptoexplosion breccias within the volcanic vents provided space favourable for mineralization.

The samples analysed in this study were collected from outcrops within the Dong'an gold deposit area. All samples are light fleshy red, medium–coarse grained, show a hypidiomorphic granular texture and a massive structure (Fig. 3A). Mineralogically, the samples consist of alkali-feldspar (55%–65 vol.%), plagioclase (4%–8 vol.%), quartz (25%–30 vol.%) and biotite (1%–5 vol.%) (Fig. 3B), with accessory apatite and zircon. Alkali-feldspar is present as 0.5–7 mm anhedral microcline and perthite crystals (Fig. 3C), with weak sericitization and argillization; plagioclase is generally present as 0.5–6 mm subhedral crystals, contains polysynthetic twins, and weakly sericitized; quartz is present as 0.5–7 mm anhedral crystals with undulatory extinction; biotite is present as 0.1–1.0 mm euhedral to subhedral crystals with weak chloritization. Characteristics of mineral assemblage show that the samples are alkali-feldspar granite, when plotted on an International Union of Geological Sciences (IUGS) classification diagram (Fig. 3D).

3. Analytical methods

3.1. *LA–ICP–MS zircon U–Pb dating*

Zircons were extracted from whole-rock samples using standard techniques of density and magnetic separation, and then by hand-picking under a binocular microscope, at the Langfang Regional Geological Survey, Hebei Province, China. The handpicked zircons were examined under transmitted and reflected light with an optical microscope. To reveal their internal structures, cathode luminescence (CL) images were obtained by using a scanning electron microscope housed at the Beijing GeoAnalysis Co., Ltd., China. Distinct domains within the zircons were selected for analysis, based on the CL images. LA–ICP–MS zircon U–Pb analyses were performed using an Agilent 7500a ICP–MS equipped with a 193 nm laser, housed at the State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences, Wuhan, China. Two zircons 91500 were used as external standard for age calibration, and the NIST SRM 610 silicate glass was applied for instrument optimization. The crater diameter was 32 μm during the analyses and Helium was applied as a carrier gas. For details on instrument settings and analytical procedures, see Yuan et al. (2004). The ICPMSDataCal (Ver. 8.3; Liu et al., 2008a, 2010) and Isoplot (Ver. 3.0; Ludwig, 2003) programs were used for data reduction. Errors on individual analyses by LA–ICP–MS were quoted at the 1σ level, while errors on pooled ages were quoted at the 95% (2σ) confidence level. The dating results are presented in Table 1.

3.2. *Major and trace element analyses*

The samples for whole-rock analyses were collected from outcrops in the Dong'an gold deposit. All samples were crushed in a corundum jaw crusher (to 60 mesh) after the removal of weathered surfaces, then they were powdered in an agate ring mill to less than 200 mesh. X-ray fluorescence (XRF) and ICP–MS (Agilent 7500a) were used to measure the major and trace elements compositions, respectively, at the Experimental Center of Testing Science, Jinlin University, Changchun, China. By pressing the powder into disks directly, a method for X-ray fluorescence analysis of major elements was established, with analytical errors in a range of 2%–5%. Before trace element analyses, about 60 g samples powder were digested by $HF + HNO_3$ in Teflon bombs, then they were analysed in an Agilent 7500a ICP-MS. The detailed sample-digesting procedure for ICP-MS analyses and analytical precision and accuracy for trace elements are the same as description by Liu et al. (2008b). The results of analyses are listed in Table 2.