



Cryptic sediment-hosted critical element mineralization from eastern Yunnan Province, southwestern China: Mineralogy, geochemistry, relationship to Emeishan alkaline magmatism and possible origin

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ARTICLE INFO

Article history:

Received 18 September 2015

Received in revised form 15 June 2016

Accepted 19 June 2016

Available online 26 June 2016

Keywords:

Nb(Ta)-Zr(Hf)-REE-Ga mineralization

Emeishan

Alkaline volcanism

Hydrothermal fluids

ABSTRACT

A previous study briefly described the occurrence of a new type of Nb(Ta)-Zr(Hf)-REE-Ga (REY: rare earth elements and yttrium) polymetallic mineralization in eastern Yunnan, southwest China. In this paper, the mineralogical and geochemical features have been further advanced through a study of two regionally extensive and relatively flat-lying mineralized layers from No. XW drill core. The layers are clay-altered volcanic ash and tuffaceous clay, and are dominated by clay minerals (mixed layer illite/smectite, kaolinite, berthierine, and chamosite); with lesser amounts of quartz and variable amounts of anatase, siderite and calcite; along with trace pyrite, barite, zircon, ilmenite, galena, chalcopyrite, and REE-bearing minerals. The mineralized samples have higher $\text{Al}_2\text{O}_3/\text{TiO}_2$ values (13.7–41.4) and abundant rare metal elements (Nb, Ta, Zr, Hf, REE, Ga, Th, and U) whereas less mineralized samples are rich in V, Cr, Co, and Ni and have lower $\text{Al}_2\text{O}_3/\text{TiO}_2$ values (2.32–7.67). The mineralized samples also have strong negative δEu in chondrite-normalized REE patterns. Two processes are most likely responsible for the geochemical and mineralogical anomalies of the mineralized samples: airborne volcanic ash and multi-stage injection of low-temperature hydrothermal fluids. Based on paragenetic analysis, this polymetallic mineralization is derived from the interaction between alkaline volcanic ashes and subsequent percolation of low-temperature fluids. The intense and extensive alkaline volcanism of the early Late Permian inferred from this study possibly originated from the coeval Emeishan large igneous province (ELIP). This unique Nb(Ta)-Zr(Hf)-REE-Ga mineralization style has significant economic and geological potential for the study of mineralization of the lowest Xuanwei Formation.

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1. Introduction

A Nb(Ta)-Zr(Hf)-REE-Ga (REY: rare earth elements and yttrium) polymetallic mineralization within the Late Permian strata of eastern Yunnan Province, southwestern China, was briefly described in a previous study by Dai et al. (2010). This polymetallic mineralization occurs as thick layers (1–10 m, but mostly 2–5 m) in the lower Xuanwei Formation of Wuchiapingian, Late Permian age, and is characterized by an abnormal significant anomaly in the natural gamma logging curve and high concentrations of rare metal elements (such as Nb, Ta, Zr, Hf, REY, and Ga). According to the China industrial standards, the

concentrations of oxides of these critical elements, for example, (Nb, Ta)₂O₅ (302–627 ppm), (Zr, Hf)O₂ (3805–8468 ppm), REO (oxides of REY; 1216–1358 ppm), and Ga (52.4–81.3 ppm) have reached the corresponding marginal to industrial grades, especially the content of (Nb, Ta)₂O₅, which is far beyond the required industrial grade of a weathered crust Nb(Ta) ore deposit (160–200 ppm; Dai et al., 2010). Although macroscopically very similar to the surrounding unmineralized host sedimentary rocks, the Nb-Zr-REE-Ga-mineralized beds are believed to have been initially derived from pyroclasts, this hypothesis being mainly due to the presence of high-temperature mineral phases such as beta-quartz with sharp edges and high-temperature embayments (Dai et al., 2010). Based on the particle size and degree of alteration, four main rock types within this mineralization including clay-altered volcanic ash, tuffaceous clay, tuff and volcanic breccia were identified (Dai et al., 2010). The remarkable similarity in mineralogy, geochemistry, and natural gamma anomalies to the alkali tonsteins from

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southwest China additionally indicate that this polymetallic mineralization was probably initially derived from alkali pyroclasts (Dai et al., 2010).

However, enrichment of critical elements in such a sediment-hosted pyroclastic depositional setting seems abnormal because, in general, the polymetallic deposits (or mineralization) of Nb, Ta, Zr, Hf, REY, and Ga are commonly associated with alkaline igneous intrusives (e.g. Kovalenko et al., 1995; Horbe and da Costa, 1999; Seidler et al., 2005; Sheard et al., 2012; Sun et al., 2013; Wang et al., 2013; Kempe et al., 2015). Additionally, there are generally two main types for Nb deposits: magmatic Nb-Ta-Sc and sedimentary Nb-Ta (Dill, 2010). The former Nb ore type includes calc-alkaline/alkaline granites or pegmatites, alkaline complexes, and carbonatites while the latter contains Nb-P-Ti laterites/bauxites and Sn-Ta-Nb placer deposits (cf. Dill, 2010; Wang et al., 2012; Mackay and Simandl, 2014). Notably, the sedimentary Nb ores are mainly derived from weathering of the magmatic Nb ore type. Therefore, from a genetic viewpoint, such a pyroclastic origin for Nb-dominant polymetallic mineralization as reported by Dai et al. (2010) does not seem to belong to any Nb-ore types previously reported.

The preliminary study of this new type of Nb(Ta)-Zr(Hf)-REY-Ga polymetallic mineralization established the recognition of this mineralization style and presented preliminary data on the critical metals and minerals therein; however, the mineral occurrence and enrichment mechanism of the rare metals still require further study (Dai et al., 2010). In this paper, we describe the morphological and quantitative analyses of the mineral phases and detailed wholerock geochemistry (major and trace elements) of the Nb(Ta)-Zr(Hf)-REY-Ga polymetallic mineralization through a case study of No. XW drill core from Xuanwei City, eastern Yunnan Province, southwestern China. Based on this work, we attempt to discuss the possible origin of the polymetallic mineralization and to reveal the genetic linkage between the mineralization and igneous activity within the Emeishan large igneous province (ELIP).

2. Geological setting

2.1. Regional geology

Present-day China mainly consists of three major tectonic blocks which comprise the North China Block in the north, Tarim Block in the west, and South China Block in the south (cf. Pirajno, 2012; Shellnutt, 2014; Fig. 1A). The South China Block comprises the Yangtze craton and the Cathaysian Block while, at the western margin of the Yangtze craton, emplacement of the Emeishan large igneous province probably was the most important geological event during the Middle-Late Permian (Shellnutt, 2014).

In the late Middle Permian, the Maokou Formation (primarily composed of carbonates) covered the whole of southwestern China (Feng et al., 1997) while in the late Maokou stage, the “Dongwu Movement”, recently interpreted as the result of uplift of the ELIP, triggered regression and seawater withdrawal from southern China (He et al., 2003; Xu et al., 2007). The ~260 Ma ELIP flood basalts were disrupted after eruption by later tectonic movements, resulting in a rhombic-shaped distribution pattern (Xu et al., 2013a). An example of this is faulting related to the formation of the Songpan-Ganzi terrane and the India-Eurasia collision during the Mesozoic and Cenozoic (Chung and Jahn, 1995; Chung et al., 1997).

The ELIP is bounded by the Longmenshan Fault to the northwest and the Ailaoshan-Red River Fault to the west-southwest (Xu et al., 2013a; Fig. 1A). Based on the extent of erosion of the pre-eruption Maokou Formation, the Emeishan LIP is subdivided into three zones, namely inner, intermediate, and outer zones in which the crustal thickness progressively thins inwards (He et al., 2003; Shellnutt, 2014; Fig. 1A). The raised central ELIP (inner zone of ELIP) within the Panzhihua-Xichang area of southwest China is also called the “Kangdian Upland”. During the Late Permian, the Xuanwei and Longtan formations of terrestrial and

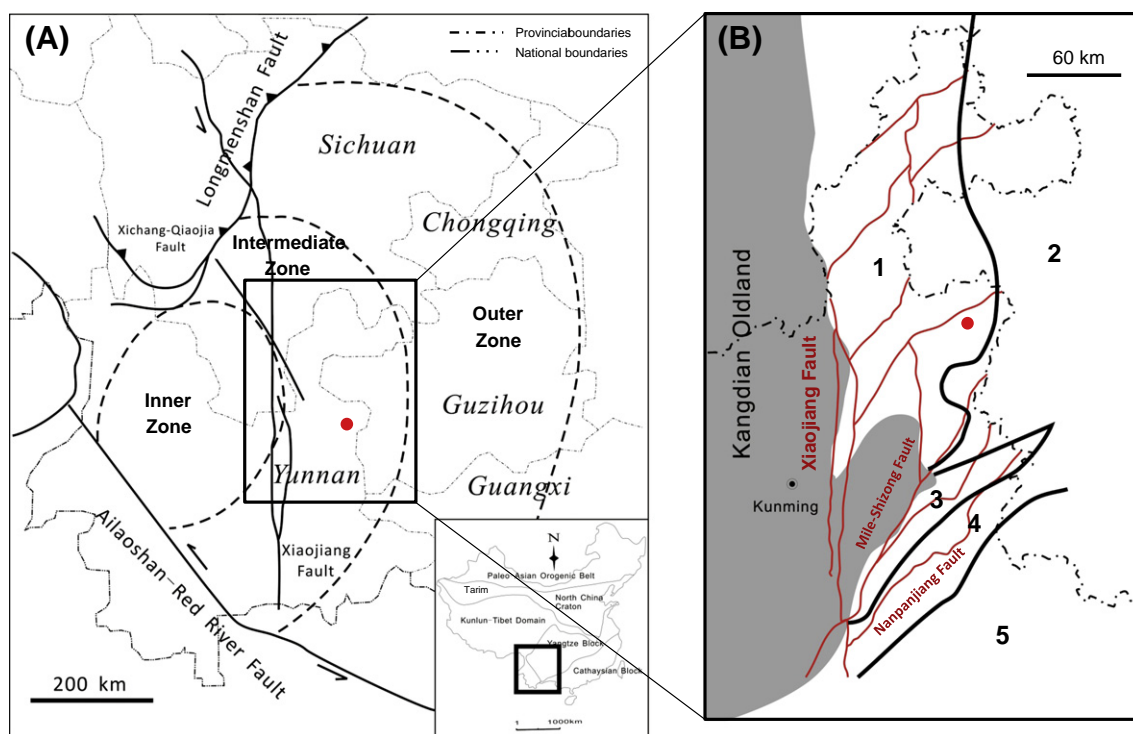


Fig. 1. A: Schematic map showing the extent of the ~260 Ma Emeishan large igneous province (ELIP; after He et al., 2003); in italics are the names of the provinces in southwest China; the bold dashed lines are the boundaries for the three zones of the ELIP; the inset shows the major tectonic blocks of China (after Shellnutt, 2014). B: Paleogeography during the late Permian in eastern Yunnan, southwest China (enlargement of specific area in A; modified from Dai et al., 2010). 1, Terrestrial Xuanwei Formation; 2, transitional Longtan Formation; 3, epicontinental littoral clinoform; 4, Luxi-Luoping submarine trench; 5, limited carbonate platform. The red spots indicate the location of the studied drill core. Red lines indicate major faults while bold black lines indicate contacts between the major geological terranes (numbered 1–5).

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