Ore Geology Reviews 57 (2014) 406–424

Contents lists available at ScienceDirect

Ore Geology Reviews

journal homepage: www.elsevier.com/locate/oregeorev

Geology, geochemistry, and geochronology of the Zhibo iron deposit in the Western Tianshan, NW China: Constraints on metallogenesis and tectonic setting

Zongsheng Jiang [a,*], Zuoheng Zhang [a], Zhihua Wang [b], Shigang Duan [a], Fengming Li [c], Jingquan Tian [d]

[a] MLR Key Laboratory of Metallogeny and Mineral Assessment, Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing 100037, China
[b] School of the Earth Sciences and Resources, China University of Geosciences, Beijing 100083, China
[c] Xinjiang Bureau of Geology and Mineral Resources, Urumqi 83000, China
[d] The Third Geological Team of Xinjiang Bureau of Geology and Mineral Resources, Kuerle 841000, China

ARTICLE INFO

Article history:
Received 1 May 2013
Received in revised form 22 August 2013
Accepted 10 September 2013
Available online 4 October 2013

Keywords:
Volcanic rocks
Metallogenesis
Tectonic setting
U–Pb zircon ages
Zhibo iron deposit
Western Tianshan

ABSTRACT

The Zhibo iron deposit (337 million metric tons with 26%–68% Fe) is one of several recently discovered iron deposits in the Awulale iron metallogenetic belt, in the eastern part of the Western Tianshan (NW China). The deposit is hosted by volcanic and volcaniclastic rocks of the Carboniferous Dahalajunshan Formation. Orebodies are tabular-lenticular in shape and consist of four ore types, including massive, banded, brecciated, and disseminated ores. Iron-oxides are predominantly low-Ti magnetite, with minor hematite. Dendritic and platy magnetite is characteristic features at Zhibo. Pyrite is the most common sulfides. Associated alteration assemblages mainly include pyroxene, albite, K-feldspar, actinolite and epidote. Four paragenetic stages of alteration and mineralization are recognized: stage I, characterized by albite–diopside alteration; stage II, represented by widespread actinolite–K-feldspar alteration; stage III, dominated by epidote–pyrite veins; and stage IV, occurring chiefly as hematite–calcite–quartz veins.

Geochemical analyses indicate that the volcanic host rocks are calc-alkaline, enriched in LILEs (e.g., Rb, K) and LREEs, and depleted in HFSEs (e.g., Nb, Ta, Ti), supporting a subduction origin for the volcanic rocks and the ore-related magma. LA-ICP-MS U–Pb dating of igneous zircon from an andesite (12ZB56) and a disseminated ore (12ZB06) yielded identical ages (within error) of 328.7 ± 2.1 Ma and 329.9 ± 1.5 Ma, considered to represent the crystallization ages of the host rocks. It has been suggested that iron mineralization at both Zhibo and Chagangnuoer was broadly coeval. The timing of mineralization at Zhibo was bracketed widely between ca. 316 Ma (the age of mineralization at Chagangnuoer) and ca. 330 Ma.

This study indicates that the Zhibo ore is typical of volcanic-hosted magnetite deposit formed in a subduction setting. Mineralogical and geochemical characteristics suggest a magmatic origin for the Zhibo deposit, and the most likely origin of the ore-related magma is partial melting of a mantle wedge that had been fertilized by fluids released from subducted slabs. Fe-rich melts (or fluids), derived from the mafic magma, were channeled along major faults and fractures within a volcano, forming the Zhibo deposit.

1. Introduction

Magnetite deposits associated with volcanic and subvolcanic rocks in volcano-plutonic terranes occur worldwide, and they range in age from Proterozoic to Cenozoic. Well-documented examples include magnetite deposits (e.g., El Romeral; Bookstrom, 1977), magnetite–apatite (Kiruna-type) deposits (e.g., El Laco; Nyström and Henríquez, 1994), and magnetite deposits with economic Cu and Au mineralization (the IOCG sensu stricto deposits, described by Williams et al., 2005; e.g., Marcona-Mina Justa; Chen et al., 2010a,b) in the Chilean iron belt. The majority of these deposits are genetically related to intermediate calc-alkaline magmas in a volcano-plutonic arc. The origin of these deposits has been the subject of numerous studies, but debate continues, with both magmatic models that invoke immiscible iron oxide-rich melts (e.g., Frietsch, 1978; Nyström and Henríquez, 1994; Travisany et al., 1995) and hydrothermal models (e.g., Barton and Johnson, 1996; Bookstrom, 1977; Marschik and Fontboté, 2001; Ménard, 1995; Sillitoe, 2003) being proposed.

Western Tianshan (Xinjiang, NW China) has long been known as an important metallogenic province in the Central Asia Orogenic Belt (or Altaids). Metallic mineralization in Western Tianshan is related to the tectonomagmatic evolution of the region during multiple accretionary orogeny (e.g., Rui et al., 2002; Xiao and Kusky, 2009 and references therein). The most economically significant mineralization styles are porphyry Cu–(Mo) deposits, epithermal Au deposits (Pirajno et al., 2011; Qin et al., 2002; Yang et al., 2009), and recently discovered volcanic-hosted iron deposits (Dong et al.,

---

* Corresponding author at: MLR Key Laboratory of Metallogeny and Mineral Assessment, Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing 100037, China.

E-mail address: jzongsheng@126.com (Z. Jiang).

0169-1368/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.oregeorev.2013.09.016

2012; Zhang et al., 2012a; Zhang et al., 2012b and references therein). These iron deposits collectively form the Awulale iron metallogenetic belt (AIMB) (Fig. 1a), with total indicated resources of Fe up to 1000 million metric tons (Mt) (Dong et al., 2012). Most iron deposits in the AIMB are hosted by calc-alkaline volcanic rocks, containing large volumes of high-grade massive ores. As such, the AIMB provides an ideal site to study the connection between the iron mineralization and the volcano-plutonic activity in a subduction setting.

The Zhibo (also called Nuoerhu) deposit represents one of the largest of the volcanic-hosted magnetite deposits in the AIMB. It is of particular interest in terms of its large size and high grade, as well as its characteristic mineral features such as platy magnetite. The iron mineralization at Zhibo has been considered to be either of volcanic hydrothermal origin (Tian et al., 2009) or of magmatic origin with subordinate hydrothermal overprinting (Feng et al., 2010). Previous studies of Zhibo have focused largely on the geochemistry and geochronology of the volcanic host rocks and associated intrusions (Jiang et al., 2012; Zhang et al., 2012a). However, the nature and tectonic affinity of the volcanic host rock is still controversial and proposed models include a rift-related origin (Che et al., 1996; Xia et al., 2004, 2008) and a subduction-related origin (Long et al., 2008; Wang et al., 2007; Zhu et al., 2009) for the volcanic rocks. Furthermore, detailed descriptions of the geology and mineralogy of the deposit are still lacking.

In this paper, the geology, paragenetic sequence, mineralization styles, and mineral chemistry of the Zhibo deposit are described in detail. Whole-rock geochemical analyses of volcanic host rocks were carried out to reveal the metallogenic setting. Zircon grains from an andesite and a disseminated ore sample were dated by LA-ICP-MS to constrain the timing of volcanism and iron mineralization. All these data are combined to provide preliminary constraints on the genesis of the Zhibo deposit.

2. Geological setting

2.1. Regional geology

The Tianshan belt (NW China) is located along the southwestern margin of the Central Asia Orogenic Belt (CAOB), a typical accretionary orogenic belt formed by multistage accretion of various micro-continents, continental fragments, and arc complexes from Precambrian to Mesozoic (e.g., Jahn, 2004; Sengör et al., 1993; Windley et al., 1990, 2007; Xiao et al., 2004, 2008).

The Western Tianshan (Fig. 1a), the western part of the Tianshan belt (west of Meridian 88°E), is situated between the Junggar block to the north and the Tarim block to the south. It has traditionally been subdivided into the northern, middle, and southern Tianshan units, separated by major suture zones and regional-scale strike-slip faults (Allen et al., 1992; Gao et al., 1998; Han et al., 2010; Windley et al., 1990). Recently, four major tectonic units were recognized in Western Tianshan (Fig. 1a), which are, from north to south, the north Tianshan arc accretionary complex (NTAC), the Yili block (YB), the central Tianshan arc terrane (CTT), and the northern margin of the Tarim block (NMT) (Gao et al., 2009; Qian et al., 2009). The regional geological and tectonic setting of Western Tianshan within the evolution of the CAOB has been described extensively (e.g., Charvet et al., 2011; Gao et al., 2009), and it has been regarded as an accretionary orogenic belt whose final structural architecture resulted from the closure of three Paleozoic oceans (the Terskey, North Tianshan, and South Tianshan oceans) and the related amalgamations of micro-continents during Late Paleozoic to Early Mesozoic (e.g., Charvet et al., 2011; Gao et al., 2009; Wang et al., 2007; Windley et al., 2007).

The Yili block is a roughly triangular-shaped terrain comprising Precambrian basement overlain variously by Mesoproterozoic to Phanerozoic volcanic-sedimentary cover and intruded by numerous granitic intrusions, which range in age from Neoproterozoic to Permian (Gao et al., 2009). The Precambrian basement comprises granitic gneisses, quartz schist, migmatite, and marble, with isotope ages ranging from 919 to 798 Ma (Chen et al., 1999). During the subduction of the North Tianshan and South Tianshan oceans, Late Devonian to Carboniferous arc magmatism produced a number of volcanic and intrusive complexes in the Yili block (e.g., Long et al., 2011; Wang et al., 2007; Zhu et al., 2005, 2009, 2011), including the Dahalajunshan Formation, which is composed predominantly of basalt, trachyte, trachyandesite, andesite, rhyolite, and tuffaceous rocks with volcaniclastic sedimentary rocks, and sandstone and limestone (Qian et al., 2006; Zhu et al., 2009). The Dahalajunshan Formation is widespread throughout Western Tianshan, ranging in age from Late Devonian (363 Ma) to Late Carboniferous (313 Ma) (Zhai et al., 2006; Zhu et al., 2009). It is the main host to numerous styles of mineralization in Western Tianshan, including porphyry Cu–(Mo) deposits (e.g., Lailisigao'er, Lamasu, Dabate; Tang et al., 2010; Zhang et al., 2010), epithermal Au deposits (e.g., Axi, Jingxi-Yiermande, Tawuerbieke; Qin et al., 2002; Yang et al., 2009; Zhai et al., 2009), and volcanic-hosted iron deposits in the AIMB (Dong et al., 2012; Zhang et al., 2012a; Zhang et al., 2012b).

2.2. The Awulale iron metallogenetic belt

Several volcanic-hosted iron deposits (e.g., Zhibo, Chagangnuoer, Beizhan, Dunde, Songhu, and Shikebutai) have been discovered in the past decade by the Xinjiang Bureau of Geology and Mineral Resources (XBGMR) during geological and geophysical surveys in the eastern part of the Western Tianshan. These iron deposits collectively form a 250-km-long and 10–20 km-wide iron belt, termed the Awulale iron metallogenetic belt (AIMB) (Fig. 1a). Most iron deposits are hosted by calc-alkaline volcanic rocks, and it has been suggested that they are genetically linked (Dong et al., 2012). The iron mineralization is characterized by high-grade magnetite ores that is accompanied by extensive alteration mainly involving Ca, Na, and K metasomatism. Individual deposits have been classified as skarn, volcanic-hydrothermal, and exhalative-sedimentary in origin (Shan et al., 2009; Wang et al., 2011; Zhang et al., 2012b). The variations in styles of mineralization may imply local control (e.g., host rock) on the alteration mineralogy.

In the eastern part of the AIMB (Fig. 1b), there are four magnetite deposits (Zhibo, Chagangnuoer, Beizhan, and Dunde) that have similarities in ore style, paragenesis, and alteration. The region is underlain by a Precambrian metamorphic basement, comprising migmatite, gneiss, marble and quartzite. The Precambrian basement is unconformably overlain by the Dahalajunshan Formation, which hosts the majority of the magnetite orebodies in this region. Locally, Permian to Triassic continental sedimentary rocks, consisting of conglomerate, sandstone, mudstone, and shale, unconformably overlie the Carboniferous volcanic and volcaniclastic strata. Abundant Permian dikes (porphyritic diorite, diabase, porphyritic diabase, and lamprophyre) occur in the region, some of which crosscut the volcanic strata, the alteration zones, and the iron orebodies.

Multiple tectonic episodes resulted in numerous E–W-striking, north-dipping high-angle faults, associated fractures zones, and a synclinal structure that defines the structural architecture of the eastern part of the AIMB. Notably, an inferred caldera and associated ring fracture zones have been identified from remote sensing image data (Feng et al., 2010). The caldera has a diameter of approximately 20 km, and is marked by at least four episodes of collapse and pyroclastic activity. A package of tuffaceous rocks, volcaniclastic conglomerates and breccias, and agglomerates (Bangyao Wang, pers. comm.) crops out around Zhibo, and further characterizes the caldera. The Zhibo iron deposit is centered on the caldera structure, while the Chagangnuoer deposit is situated on the northwestern margin of the caldera structure (Fig. 1b).