Ore Geology Reviews 57 (2014) 498–517

Contents lists available at ScienceDirect

Ore Geology Reviews

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

Geology, tectonic settings and iron ore metallogenesis associated with submarine volcanism in China: An overview

Tong Hou [a], Zhaochong Zhang [a,*], Franco Pirajno [b], M. Santosh [a,c], John Encarnacion [d], Junlai Liu [a], Zhidan Zhao [a], Lijian Zhang [e]

[a] State Key Laboratory of Geological Process and Mineral Resources, China University of Geosciences, Beijing 100083, China
[b] Centre for Exploration Targeting, University of Western Australia, Crawley, WA 6009, Australia
[c] Division of Interdisciplinary Science, Kochi University, Kochi 780-8520, Japan
[d] Department of Earth and Atmospheric Sciences, Saint Louis University, 3642 Lindell Boulevard, St. Louis, MO 63108, USA
[e] No. 4 Geological Party of Hebei Bureau of Geology for Mineral Resources Exploration, Chengde 067000, China

ARTICLE INFO

Article history:
Received 21 April 2013
Received in revised form 1 August 2013
Accepted 8 August 2013
Available online 19 August 2013

Keywords:
Metallogenesis
Iron deposits
Submarine volcanic rocks
China

ABSTRACT

Submarine volcanogenic iron oxide (SVIO) deposits are one of the most important sources of high-grade iron ores in China. The spatial distribution of the deposits is controlled by the tectonic settings including arc, back-arc and rift environments, with the SVIO deposits mostly concentrated in the western part of China namely, the southwestern Yangtze Craton, Western and Eastern Tianshan, and Altay orogens and the Kaladawan iron ore district in the eastern part of the Altyn Tagh region. The Chinese SVIO deposits range in age from Paleoproterozoic to Mesozoic, and were formed during two main metallogenic epochs in the Proterozoic and Paleozoic. More than 70% of the SVIO deposits formed in the Paleozoic, with three important SVIO-metallogenic provinces recognized, in the Altay, Eastern and Western Tianshan orogens. These SVIO deposits are hosted in lithofacies that are related to submarine magmatism, such as lavas and associated pyroclastic and volcaniclastic-sedimentary rocks. The iron orebodies are hosted in different volcanic lithofacies with different features. Moreover, the different volcanic lithofacies in which the Fe ores are hosted also provide information as to their spatial relationship, ranging from distal to proximal to the eruption center or vent. Many of these deposits are characterized by well developed skarns, and could be interpreted either by a distal position of the ore system in question and/or exposed igneous rocks or active magma chamber, or a relationship to early metamorphism and continuous alteration at relatively high temperature followed by retrograde alteration as temperatures decline. Geological and geochemical evidence suggests that these deposits were formed as a result of submarine magmatic activity, including subaqueous volcanic eruptions, associated volcano-sedimentary lithofacies, and related post-magmatic hydrothermal activity. Iron oxide ore probably formed the hydrothermal fluids which generated the skarns could be a mixture of evolved magma-derived water and convecting sea water driven by the heat from the shallow active magma chamber, whereas volcano-sedimentary deposits could be formed by the fallout of the ore-bearing materials to the sea floor emanating from submarine eruption columns, or fractional precipitation of iron which had been introduced locally into the bottom water by volcanic-origin hydrothermal solutions and by leaching from the relatively iron-rich volcanic rocks. The formation of these various styles of Fe ore deposits is controlled by several key factors, such as magma differentiation, lithofacies of host rocks, temperature and chemical compositions of hydrothermal fluids, as well as the depth of sea water. In combination with their geological characteristics, geodynamic mechanisms and metallogenesis, we propose a genetic model in which the origin of these deposits can be related to the space–time evolution of the submarine volcanism, and their relationship to volcanic lithofacies variation, such as central, proximal and distal environments of ore formation.

1. Introduction

Three-quarters of the modern Earth's volcanic activity is submarine, located predominantly along the mid-ocean ridges, with the remainder along intra-oceanic volcanic arcs and hotspots, at sea floor depths varying from greater than 4000 m to near the sea level (e.g., Carey and Sigurdsson, 2007; Embley et al., 2007). Submarine volcanic eruption is difficult to observe directly, and their products are difficult to recover and study. Hence, evidence of submarine volcanism comes from sightings of explosive sea level manifestations (Kokelaar and Busby, 1992).

It is widely recognized that these volcanoes play a role in transferring mass and energy from the oceanic crust and mantle to the oceans,

* Corresponding author. Tel.: +86 10 82322195; fax: +86 10 82323419.
E-mail address: zczhang@cugb.edu.cn (Z. Zhang).

0169-1368/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.oregeorev.2013.08.007

which is a favorable environment to form metal-rich deposits (e.g. Tivey, 2007) as demonstrated by the abundant Fe and base metal deposits present on land formed during geologic history, such as Algoma-type BIF and VMS deposits (de Ronde et al., 2005; Mücke et al., 1996). The metallogenesis of these deposits, and the distribution and composition of submarine volcanic systems that create them had been relatively well studied. In contrast, many, and probably most, iron oxide deposits associated with submarine eruptions, especially those generated in the Phanerozoic have not been investigated in detail yet.

In China, the discovery of many iron oxide deposits associated with submarine volcanic rocks is considered as one of the last century's most exciting facets of geological research on iron oxide ore deposits (e.g. Jiang and Wang, 2005). Submarine volcanogenic iron oxide (SVIO) ore systems mainly include volcanic-associated and (volcano sedimentary)-hosted. The iron oxide ores typically occur as lenses, layers and veins that may form at or near the seafloor in submarine volcanic environments. They have been regarded to be formed by iron-enriched melts/fluids associated with seafloor volcanic eruptions, linked to submarine hydrothermal systems (Kelley et al., 2002; Hannington et al., 2005; see Pirajno, 2009 for an overview). SVIO deposits in China are possibly related to a wide range of geodynamic settings and depositional environments, such as island-arcs, rifts and mid-ocean ridges and oceanic islands. It is noteworthy that most of the SVIO of China are composed predominantly of high-grade iron oxide ores, thereby contributing a considerable amount of iron for the local industry (Jiang and Wang, 2005; see also Hu et al., 2011).

However, although these SVIO deposits have attracted a substantial number of petrologic and geochemical studies (e.g., Jiang and Wang, 2005), their metallogenesis and the genetic relationship with associated submarine volcanism are still poorly understood, with various genetic models proposed, including sea floor volcanic systems, skarn and exhalative-sedimentary (e.g., Feng et al., 2009; Hua, 1985; Shan et al., 2009; Zhang et al., 1987).

The previous studies of SVIO deposits of China have shown some similarities as well as differences from their subaerial counterparts (e.g. Jiang, 1983; Wang and Chen, 2001). For example, ores formed by eruption of iron oxide melt can be compared with the Kiruna style mineralization, such as the El Laco deposit in Chile (Henríquez et al., 2003). On the other hand, leaching of ore-bearing pyroclastics by deep sea water as one of the major sources of iron for the SVIO deposits is seldom seen in terrestrial environments. In this paper we present an overview of the geological characteristics, and geodynamic mechanisms of the Chinese SVIO deposits, comparing them with the actively forming iron deposits along modern subduction zones, mid-ocean ridges, and back-arc basin in order to refine our understanding of the metallogenesis of SVIO deposits. Furthermore we also provide a comprehensive overview based on published works on submarine volcanic processes and the related iron oxide deposits. At the end of the paper, we propose a genetic model which links the origin of these deposits to the space–time evolution of the submarine volcanoes, and integrated them on the basis of principal volcanic lithofacies variation according to their closeness to vent, i.e. central, proximal and distal facies.

It is worthwhile to point out that, in spite of the ancient Algoma-type BIFs being closely related to submarine volcanism (Mücke et al., 1996), in most cases they have been subjected to varying degrees of alteration, deformation, and metamorphism resulting in the destruction of the original textures and structures. The origin of the Algoma BIF deposits is therefore beyond the scope of this paper and will not be addressed.

2. Distribution of SVIO deposits and geological setting

The tectonic framework of China is dominated by three major Precambrian Cratons, the North China, South China (Yangtze + Cathysia) and Tarim Cratons (Fig. 1), surrounded by fold belts and accretionary orogens including accreted island arcs, back-arcs and oceanic lithosphere (Zhai and Santosh, 2011, 2013).

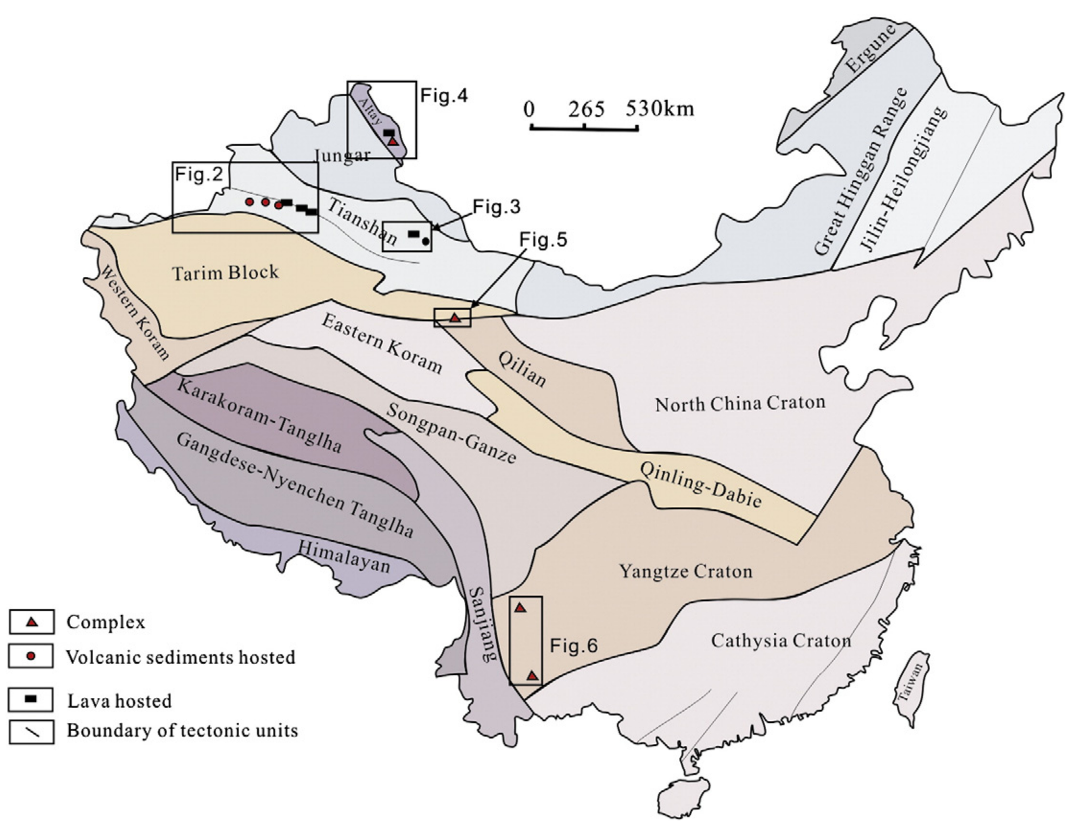

Fig. 1. Distribution of Chinese submarine volcanogenic iron oxide deposits.
Base map modified from Zhao et al. (2004).