

Review

Metallogeny of volcanogenic massive sulfide deposits of Iran

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ARTICLE INFO

Keywords:

Volcanogenic massive sulfide
VMS
Iran
Tectonic setting
Metallogeny

ABSTRACT

There are a lot of volcanogenic massive sulfide (VMS) deposits and numerous mineral occurrences of this type of mineralization in Iran. VMS deposits can be subdivided into different types, and Iranian VMS deposits represent all of the recognized types: mafic-, pelitic-mafic-, bimodal-mafic-, bimodal-felsic- and felsic-siliciclastic-type, and these are hosted in different tectonic settings. The major tectonic/structural zones of Iran that host VMS deposits are: (1) the Sanandaj-Sirjan Zone (SSZ; North: NSSZ; South: SSSZ), (2) the Urumieh-Dokhtar magmatic assemblage (UDMA), (3) the Central Iran (Sabzevar Zone/SZ and Kashmar-Kerman Zone/KKZ), and (4) the Mesozoic ophiolites (MO). The VMS deposits were formed during discrete time periods: (1) Late Neoproterozoic-Early Cambrian (Taknar bimodal-felsic-type Cu-Zn-Au-Ag-Pb and Nohkouhi felsic-siliciclastic-type Cu deposits in the KKZ), (2) Late Triassic-Early Jurassic (e.g., Sargaz bimodal-mafic-type Cu-Zn deposit in the SSSZ), (3) Early Jurassic (Bavanat pelitic-mafic-type Cu-Zn-Ag deposit in the SSSZ), (4) Middle Jurassic (e.g., Chahgaz felsic-siliciclastic-type Zn-Pb-Cu deposit in the SSSZ), (5) Cretaceous (e.g., Barika bimodal-felsic-type in the NSSZ, Nudeh and Garmab-e-Paein pelitic-mafic-type Cu-Ag in the SZ, Sheikh-Ali and Zurabad mafic-type Cu deposits which occur in the Upper Cretaceous ophiolites), and (6) Eocene-Oligocene (e.g., Dorreh and Varandan bimodal-felsic-type deposits in the UDMA).

Magmatic arcs (volcanic primitive arcs, arc/intra-arc rifts and back-arc basins) are the principal plate tectonic setting for the Iranian VMS deposits. All of the VMS deposits of the SSZ and UDMA formed within Mesozoic and Tertiary arcs, respectively, that developed during subduction of the Neo-Tethyan crust beneath the Iranian plate. Intra-oceanic or continental mature back-arc spreading settings are recognized in the Neo-Tethys domain in Iran (i.e., MO), and these host several Cu-rich VMS deposits. The host rock sequences for all deposits can be divided into three groups: (1) bimodal calc-alkaline; (2) bimodal tholeiitic; and (3) tholeiitic basaltic. The sulfur isotope compositions of the VMS deposits in the SSZ indicate that significant sources for sulfur in these deposits were inorganically reduced seawater sulfate and sulfur leached from the footwall volcanic rocks.

The main time period of the formation of VMS mineralization in Iran was from Jurassic to Cretaceous. The SSZ (particularly the SSSZ) is the most attractive metallogenic province in Iran for VMS exploration because it hosts different VMS deposit types, including the precious metal enriched Barika bimodal-felsic-type deposit in the NSSZ, and the Bavanat pelitic-mafic-type (mafic-siliciclastic-type), Chahgaz and Chahanjir felsic-siliciclastic-type, and Sargaz, Ghalerigi and Siahmadan bimodal-mafic-type deposits in the SSSZ.

1. Introduction

Volcanogenic massive sulfide (VMS) deposits are the third most important source of base (and precious) metals in Iran after porphyry-type Cu-Mo and sediment-hosted Zn-Pb deposits. Thirty-one significant VMS deposits and several tens of VMS mineral occurrences ranging in age from Late Neoproterozoic to Eocene-Oligocene have been identified to date (Fig. 1, Table 1), and many of these were mined in ancient times. Several of the deposits are enriched in gold and silver and the

majority of the deposits are actively being explored. The Bavanat, Chahgaz, Sargaz, Barika, Nudeh, Taknar, and Dorreh deposits are presently mined. Iranian VMS deposits in general have only been the subject of study by Iranian researchers over the past decade, and many of their findings are not available in the western literature (e.g., Razzaghmanesh, 1968; Nazari et al., 1994; Imamalipour and Masoudi, 1995; Rastad et al., 2002; Malekzadeh Shafaroudi, 2004; Karimpour and Malekzadeh Shafaroudi, 2005; Mazaheri et al., 2006; Aftabi et al., 2006; Mousivand et al., 2007, 2008a,b, 2010, 2011, 2012; Mousivand,

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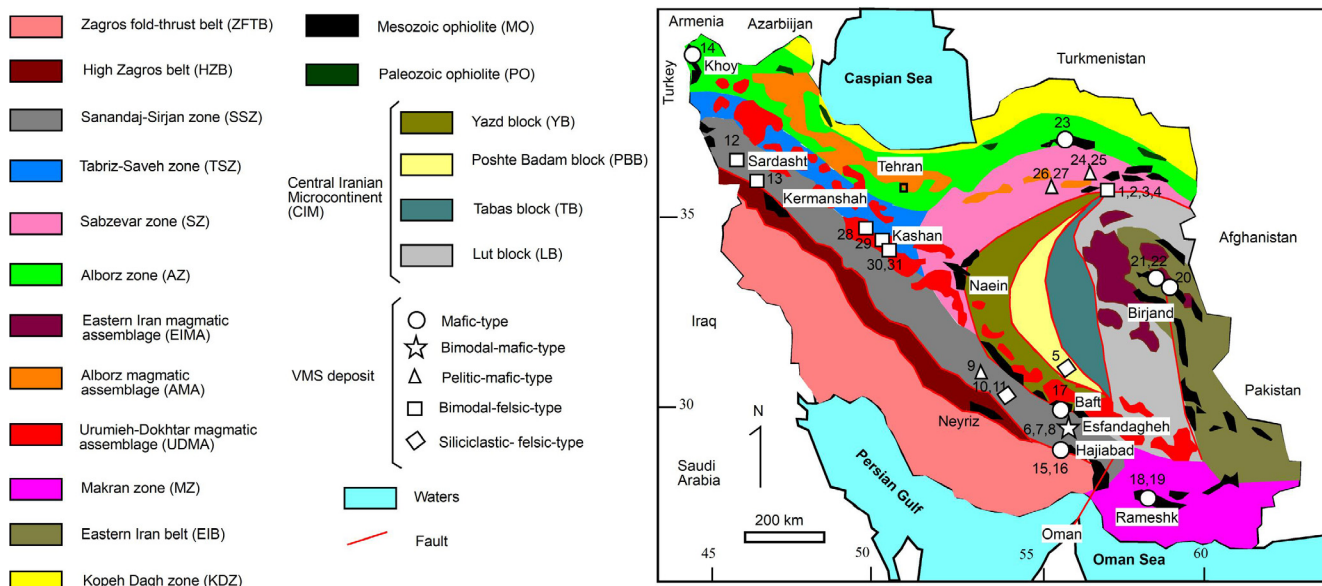


Fig. 1. Map of structural zones of Iran (modified from Alavi, 1991 and Aghanabati, 2003) showing locations of Iranian VMS deposits listed in Table 1.

2003, 2010; Yarmohammadi, 2006; Yarmohammadi et al., 2008a,b; Badrzadeh, 2009; Badrzadeh et al., 2010a,b, 2011; Maghfouri, 2012; Maghfouri et al., 2011a,b, 2012, 2016; Tajeddin et al., 2010).

Outside of Iran these deposits remain relatively poorly known. In an effort to ameliorate this situation, we provide herein an overview of Iranian VMS deposits, we present and synthesize their general features and styles, geological and tectonic settings, depositional environments, and classification, based on previous research and recent new data. Additionally, we relate the formation of these deposits to the geodynamic evolution of the Tethyan Orogen.

2. VMS deposit classification

Iranian VMS deposits can be subdivided into the following eight groups based on their metal contents (Table 1): 1) Cu (Nohkouhi, Zurabad, Sheikh-Ali, Ahmadabad, Sarsu, Tankashkan, Zagh Darreh, Gazic, Khalilan and Mesgaran deposits), 2) Cu-Zn (Sargaz, Ghalerigi and Siahmadan deposits), 3) Cu-Zn-Ag (Bavanat deposit), 4) Cu-Ag (Nudeh and Garmab-e-Paein deposits), 5) Cu-Zn-Au-Ag-Pb (Taknar deposits), 6) Zn-Pb-Cu (Chahgaz and Chahanjir deposits), 7) Ba-Zn-Pb-Cu-Ag-Au (Barika deposit), and 8) Ba-Pb-Zn-Cu (Dorreh and Tapeh Sorkh deposits). Most of these VMS deposits are rich in copper and poor in lead (Fig. 2).

Based on the host rock lithological classification of Franklin et al. (2005), Iranian VMS deposits are classified as: (1) mafic-type (ophiolite-associated or Cyprus-type Cu deposits in other classifications), (2) bimodal-mafic-type (Noranda-type or Ural-type deposits in other classifications), (3) pelitic-mafic-type (mafic-siliciclastic-type and Besshi-type Cu-Zn deposits in other classifications), (4) bimodal-felsic-type (Cu-Zn-Pb-Ba Kuroko-type in other classifications and some Archean Zn-rich deposits), and (5) felsic-siliciclastic-type (Iberian Pyrite Belt-type and Bathurst-type deposits in other classifications) (Table 1, Fig. 3a). These types of VMS deposits are discussed below:

1. Mafic-type: representative examples include the Sheikh-Ali, Ahmadabad, Zurabad, Sarsu, Tankashkan, Zagh Darreh, Gazic, Khalilan and Mesgaran deposits. These deposits occur within Late Mesozoic ophiolites (Table 1) and have previously been classified as Cyprus-type VMS deposits (e.g., Imamalipour and Masoudi, 1995; Rastad et al., 2002; Mousivand, 2006; Hellman, 2006). These deposits are similar to the ophiolite-hosted VMS deposits in Greece, Cyprus, Turkey and Oman.
2. Pelitic-mafic-type (mafic-siliciclastic): the most representative

example is the Bavanat deposit that is hosted by Early-Middle Mesozoic basalt and pelitic sedimentary rocks (Mousivand, 2010). Mousivand et al. (2007) previously classified this as a Besshi-type deposit. There are also some deposits (e.g., Nudeh and Garmab-e-Paein) and mineral occurrences in the Sabzevar Zone (SZ) which have Besshi-type characteristics (Maghfouri, 2012; Maghfouri et al., 2016; Tashi et al., 2014, 2017).

3. Bimodal-mafic-type: the Sargaz, Ghalerigi and Siahmadan deposits are of this type and are hosted by an Early-Middle Mesozoic bimodal volcanic suite (Dulatkhah and Mousivand, 2006; Badrzadeh et al., 2011). The volcanic rocks of this deposit type are dominated by basalt, andesite and rhyodacite flows and pyroclastics rocks. This VMS type only occurred in the Sanandaj-Sirjan Zone.
4. Bimodal-felsic-type: representative deposits are: (a) the Taknar deposits hosted by a Late Neoproterozoic bimodal volcanic suite, (b) the Barika deposit hosted by a Late Mesozoic bimodal volcanic suite, and (c) the Dorreh, Varandan, Tapeh Sorkh and Darreh Amroud deposits that are hosted by a Paleogene bimodal volcanic suite. These deposits have been classified as magnetite-rich, gold-rich Kuroko-type and barite-rich Kuroko-type VMS deposits, respectively (e.g., Nazari et al., 1994; Karimpour and Malekzadeh Shafaroudi, 2005; Yarmohammadi et al., 2008a,b; Hashemi et al., 2014).
5. Felsic-siliciclastic-type: is represented by the Chahgaz and Chahanjir deposits that are hosted by a Middle Mesozoic bimodal volcanic sequence (Mousivand et al., 2011). Recently, Hajsadeghi et al. (2016) classified the Nohkouhi Cu deposit, which is hosted by an Early Cambrian volcano-sedimentary sequence, as a Felsic-siliciclastic-type.

3. VMS deposit metallogeny, age and tectonic distribution

The main time period of VMS mineralization in Iran is the Mesozoic, specifically Jurassic to Cretaceous (Fig. 3b). The VMS deposits occur in five discrete terranes (Fig. 3c): 1. Sanandaj-Sirjan Zone (SSZ; North: NSSZ; South: SSSZ): Bavanat, Sargaz, Ghalerigi, Siahmadan, Barika, Chahgaz and Chahanjir deposits. The SSZ hosts different VMS deposit types, including the Barika bimodal-felsic-type deposit in the NSSZ, and the Bavanat pelitic-mafic-type, Chahgaz and Chahanjir felsic-siliciclastic-type, and Sargaz, Ghalerigi and Siahmadan bimodal-mafic-type deposits in the SSSZ; 2. Sabzevar Zone (SZ) in Central Iran: Nudeh, Chun, Garmab-e-Paein and Asbkehan deposits; 3. Kashmar-Kerman Zone (KKZ): Taknar and Nohkouhi deposits; 4. Urumieh-Dokhtar

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