Ore Geology Reviews 78 (2016) 138–150

Contents lists available at ScienceDirect

Ore Geology Reviews

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

Intrinsic geological model generation for chromite pods in the Sabzevar ophiolite complex, NE Iran

Mehrdad Soleimani [a], Behshad Jodeiri Shokri [b,*]

[a] Faculty of Mining, Petroleum and Geophysics, Shahrood University of Technology, Shahrood, Iran
[b] Department of Mining Engineering, Hamedan University of Technology, Hamedan, Iran

ARTICLE INFO

Article history:
Received 8 August 2015
Received in revised form 15 March 2016
Accepted 16 March 2016
Available online 6 April 2016

Keywords:
Chromite
Mathematical – geological genetic model
Intrinsic geological unit
Critical genetic factor
Critical reconnaissance criteria

ABSTRACT

The Sabzevar ophiolite, with its colored mélange zone, is a highly disintegrated ophiolite complex located at the northern boundary of the central Iranian microcontinent. A large number of chromite pods occur in this area, which needs to be explored. In this study, a mathematical – geological genetic model is advanced as an exploratory tool that provides information for further exploration activity. A petrogenetic model of chromite ore was established on the basis of a geodata information database. This database consists of information from similar chromite mines from around the world. A detailed investigation of the geological, mineralogical and petrological characteristics of chromite pods in the Sabzevar region was conducted along with detailed petrological samplings, thin section studies and mineralogical analysis. In the next step, we developed a conceptual genetic model that defines areas with a high probability of the existence of chromite pods. The model was later refined using such parameters as a critical genetic factor (CGF) and critical reconnaissance criteria (CRC). Next, a linear function, which is a combination of these factors, provided promising regions as intrinsic geological units (IGU). Finally, a 3D model of lithological units depicting the IGU for chromite pods exploration is proposed.

1. Introduction

On a regional scale, geological knowledge can be effectively represented and spatially queried in 2D geographic information systems, whereas knowledge of ore genesis is useful in the analysis and interpretation of mineral deposit exploration models in 3D. Geological modeling in 3D is important for understanding geological settings and metallogenesis and for targeting new mineral deposits (McCuaig and Hronsky, 2014).

Exploration models are divided into subjective and objective models based on the type of data used (Carranza, 2015). The subjective mineral ore exploration models use predefined and less flexible ore genetic theories whereas the objective models are based upon multiple geological observations. Data integration approaches in model development include these two types of models together and mutually use information from both ore genetic theory and geological observations in the delineation of promising areas for mineral exploration (Porwal and Carranza, 2015). These promising areas are typically known as intrinsic geological units (IGU) (Pan and Harris, 1992a). It is also called the intrinsic unit, because this feature is not detected through direct mineral deposit observations. The IGUs formally consists of some critical genetic factors (CGF) as necessary conditions for mineral deposit formation (Pan and Harris, 2000). The IGU was introduced as an evolution of intrinsic sample (IS) or sum of probable valuable geological areas (Pan and Harris, 1992b). An appropriately delineated IGU contains geological bodies that are genetically linked to the given mineral resource (Pan, 2010). The IGU proposal improves the methodology of target identification and delineation which, in turn, improves the results of mineral resource assessment. The IGU theory paved the way for a new platform to gather target identification attributes for mineral resource exploration (McCuaig et al., 2010).

The IGUs for a region consists of four major steps. In the first step, multiple geodata are used to establish the structure of the CGF and the recognition criteria for the deposit type of interest. In the second step, using the geological observations, occurrence probability values of the recognition criteria are estimated. In the third step, a synthesized occurrence probability is measured for each CGF. This probability is defined by an optimum linear combination of the probabilities estimated in the previous step. Finally, in the fourth step, the IGUs are delineated by optimally discretizing the probability values of the CGFs (Eberle et al., 2015).

The aim of this study was to construct a 3D geological model to visualize the intrinsic ore body and the hosting lithologies. Particularly, the model is for investigation of controlling structures on the deposit scale to determine the continuity of relevant geological units, including the ore zone, and to obtain a better understanding of the 3D structure and structural evolution of the ore district. Successful 3D modeling of exploration targets depends on recognition of the geological, geophysical, and geochemical criteria of a deposit model from relevant exploration datasets (Wang et al., 2015).

---

* Corresponding author.
E-mail address: b.jodeiri@hut.ac.ir (B. Jodeiri Shokri).

http://dx.doi.org/10.1016/j.oregeorev.2016.03.013
0169-1368/

In this study, a genetic deposit model was developed to facilitate chromite mineral exploration in the Sabzevar ophiolite region in NE Iran. After considering whether the exploration targeting criteria were representative, comprehensive, and accurate, we constructed geological objects in 3D space to model the existing knowledge of chromite metallogenesis in the Sabzevar district.

The main objective for establishment of this model was defining the CGFs, critical recognition criteria (CRC) and intrinsic parameters. These parameters were further used to create the conceptual genetic model (CGM) for chromite mineralization in the area. The CGM was developed based on the geological settings, geochemical and lithological properties of the mineralization zone and surrounding rocks and mineralogical analysis of the Sabzevar ophiolite lithological units. In addition to performing a full field data analysis, auxiliary data were collected from the results of previous studies in nearby areas, accompanied by construction of a medium scale information database of characteristics from similar mines around the world.

1.1. Petrogenesis and genetic models of podiform chromites

Alpine type chromite ore deposits comprise an integral part of the mantle sequences observed within many ophiolite complexes (Pagé and Barnes, 2009). Significant chromite deposits have been reported in the Philippines (Tertiary), Albania (Jurassic), Turkey (Jurassic–Cretaceous), and Kazakhstan (Silurian) along with the occurrence of many small deposits in the Caledonian–Appalachian orogeny (Kuno and Matsuo, 2000; Beqiraj et al., 2000; Parlak et al., 2002; Yiğit, 2009; Shafaii Moghadam et al., 2010a). Regarding the host rocks, almost all chromite pods are hosted by harzburgite and dunite rocks. In most of these samples, chromite ore bodies are bordered by dunite envelopes of variable thickness which show transitional boundaries to harzburgite host rocks (Shafaii Moghadam et al., 2013). Generally, podiform chromites in ophiolite sequences contain a large number of inclusions, such as silicates, sulphides, arsenide and fluid inclusions (Mondal et al., 2006; Proenza et al., 2001).

Several different hypotheses have been offered for the alpine type chromite genesis. Like the dunites to which they are clearly linked, chromite pods in ophiolite have been considered as magmatic cumulates settled at the base of the magma chamber (Gale et al., 2013). On the other hand, some other researchers proposed deposition by gravity settling in mantle ‘mini-chambers’, accumulation from the raising basaltic melt and tectonic insertion inside the peridotites (González-Jiménez et al., 2014). The later could explain various factors contribute in chromite and olivine crystallization including drop in temperature or increase in oxygen fugacity (Zabihi and Bozorgmanesh, 2014).

1.2. Geological setting

The geology of chromite deposits and the economic significance of the chromite producing regions of Iran have been discussed in several publications (Ghazi and Hssanipak, 1999; Ghazi et al., 1997; Hassanipak and Ghazi, 2000; Jannessary et al., 2012; Najafzadeh et al., 2008; Najafzadeh and Ahmadipour, 2014; Peighambari et al., 2016; Rahgoshay et al., 2006). Ophiolite complexes and colored mélanges in Iran have been divided into four settings and locations: (1) in northern Iran along the Alborz mountain range; (2) the Zagros suture zone, (3) the Makran region and (4) boundaries of the internal Iranian microcontinent (CIM) block, including the Sabzevar ophiolite (Fig. 1a) (Pournamdari et al., 2014).

The Sabzevar ophiolite is located between longitude 57 to 60° and latitude 33 to 37° in northeast Iran. The ophiolite builds up an east-west-trending mountain range approximately 200 km long with 3 to 22 km minimum and maximum widths, respectively (Fig. 1b). Fig. 2 illustrates the geological map of the study area. The three other boxes on the map show areas researched in other previous studies.

The Sabzevar ophiolite reveals a complete section typical of an ophiolite complex, with six exposures of ophiolite massifs (Shirzadi et al., 2013). In spite of being highly faulted and altered, the Sabzevar ophiolite is an example of outstanding ophiolites in Iran. It contains diverse types of igneous, metamorphic, sedimentary, hydrothermal and volcano–sedimentary rocks in different localities (Shafaii Moghadam et al., 2010b).

Results of previous studies reveal that this ophiolite is a small local branch of the Neotethys Ocean around the CIM in NE Iran. This branch was opened and closed during the late Cretaceous. Afterward, ophiolite complexes were formed as a ring structure around the boundary between the CIM and the Turanian Plate, as shown in Fig. 1a. The study area consists of small ophiolite zones belonging to the greater Sabzevar ophiolite sequence (Fig. 2). In this study, the northwestern part of the Sabzevar ophiolite complex was selected for genetic model construction. In the selected area, chromite disconnected lenses are scattered near the subsurface and are surrounded by the mafic and the ultramafic rocks. These country rocks are comprised of serpentinite, peridotite, dunite and harzburgite. The mantle rocks primarily consist of harzburgite and dunites, which are the principle rock types in the Sabzevar ophiolite (Shojaat, 1999). The sedimentary rocks of the complex consist of reddish pelagic fossiliferous limestone and radiolarian chert (Ghazi et al., 1997). The sharp lithological contacts between rock units are commonly faulted and highly tectonized. Chromite ore bodies usually occur within the dunite pockets inside the harzburgites (Hassan and Kassem, 2013). In the study area, the chromitite is always surrounded by an envelope of dunite, although this envelope can vary in thickness from less than 0.5 to several meters (Shojaat et al., 2003). Massive and nodular chromitites are occasionally stretched and appear as layers or as spindles due to their plastic deformation (Hassanipak et al., 1996; Rahgoshay et al., 2005).

1.3. Regional geology and petrology

Rock units of the Sabzevar ophiolite can be divided into ophiolitic and non-ophiolitic sequences. These groups, with different geologic units, are described in Fig. 1b.

1.3.1. Amphibolites and garnet amphibolites

The amphibolite and garnet amphibolite unit is likely the oldest basement of the area. It shows characteristic features of amphibolite faces, as produced by regional metamorphism. This type of amphibolites has been observed less frequently in the other ophiolitic zones in the CIM boundary. These rocks are sheeted in structure and have a gneiss banding texture (Ghazi et al., 1997).

1.3.2. Ultramafic associated rocks

Ultramafic rocks are widespread in the area and are known as the major lithology component acting as chromite host rock (Fig. 3). The overwhelming majority of rock types in this group are harzburgite and dunite, accompanied by lizardite, serpentinite, and pyroxenite (Fig. 3a, b).

Some outstanding outcrops of dunites are exposed in the southern part of the region, as large patches in harzburgite masses (Fig. 3c). Dunite rocks appear in patches that are dark brown, olive green, and often yellowish colored on the surface. However, they are strongly weathered, with poorly oriented veinlets on the surface (Fig. 3d). Lizardite and serpentinized lizardite occur at few localities and are not exposed as sharp units; rather, they only accompany other ultramafic rocks (Hassanipak and Ghazi, 2000). Serpentinites are highly oxidized and weathered in the area. In addition, they have slightly schistose texture and are light to dark green or brownish green, with deep reddish color in some parts of the area (Ghazi and Hssanipak, 1999).