



Mineralogical and geochemical investigations of the Mombi bauxite deposit, Zagros Mountains, Iran



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ABSTRACT

The Mombi bauxite deposit is located in 165 km northwest of Dehdasht city, southwestern Iran. The deposit is situated in the Zagros Simply Fold Belt and developed as discontinuous stratified layers in Upper Cretaceous carbonates (Sarvak Formation). Outcrops of the bauxitic horizons occur in NW-SE trending Bangesan anticline and are situated between the marine neritic limestones of the Ilam and Sarvak Formations. From the bottom to top, the deposit is generally consisting of brown, gray, pink, pisolitic, red, and yellow bauxite horizons. Boehmite, diasporite, kaolinite, and hematite are the major mineral components, while gibbsite, goethite, anatase, rutile, pyrite, chlorite, quartz, as well as feldspar occur to a lesser extent. The Eh–pH conditions during bauxitization in the Mombi bauxite deposit show oxidizing to reducing conditions during the Upper Cretaceous. This feature seems to be general and had a significant effect on the mineral composition of Cretaceous bauxite deposits in the Zagros fold belt. Geochemical data show that Al_2O_3 , SiO_2 , Fe_2O_3 and TiO_2 are the main components in the bauxite ores at Mombi and immobile elements like Al, Ti, Nb, Zr, Hf, Cr, Ta, Y, and Th were enriched while Rb, Ba, K, Sr, and P were depleted during the bauxitization process. Chondrite-normalized REE pattern in the bauxite ores indicate REE enrichment ($\Sigma\text{REE} = 162.8\text{--}755.28$ ppm, ave. ~ 399.36 ppm) relative to argillic limestone ($\Sigma\text{REE} = 76.26\text{--}84.03$ ppm, ave. ~ 80.145 ppm) and Sarvak Formation ($\Sigma\text{REE} = 40.15$ ppm). The REE patterns also reflect enrichment in LREE relative to HREE. Both positive and negative Ce anomalies (0.48–2.0) are observed in the Mombi bauxite horizons. These anomalies are related to the change of oxidation state of Ce (from Ce^{3+} to Ce^{4+}), ionic potential, and complexation of Ce^{4+} with carbonate compounds in the studied horizons. It seems that the variations in the chemistry of ore-forming solutions (e.g., Eh and pH), function of carbonate host rock as a geochemical barrier, and leaching degree of lanthanide-bearing minerals are the most important controlling factors in the distribution and concentration of REEs. Several lines of evidences such as Zr/Hf and Nb/Ta ratios as well as similarity in REE patterns indicate that the underlying marly limestone (Sarvak Formation) could be considered as the source of bauxite horizons. Based on mineralogical and geochemical data, it could be inferred that the Mombi deposit has been formed in a karstic environment during karstification and weathering of the Sarvak limy Formation.

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1. Introduction

Bauxite deposits are derived from alteration and chemical weathering of parent rocks, which are rich in aluminosilicate minerals. Genetic models, mass changes, elements mobility and ore textures of bauxite deposits around the world have been studied by a number of authors (e.g., Bárdossy, 1982; Bárdossy and

Aleva, 1990; Liaghat et al., 2003; Mameli et al., 2007; Esmaeili et al., 2010; Liu et al., 2010a, 2013; Zarasvandi et al., 2008, 2010, 2012, Gu et al., 2013; Hanilci, 2013; Mongelli, 2002; Mongelli et al., 2014). Some studies have recognized various ore textures such as oolitic, pisolitic, bedded and massive, as well as different genetic models including high and low level bauxites, laterite, Tikhvin and karst-types (Bárdossy and Aleva, 1990; Zarasvandi et al., 2010). According to the mineralogy, geochemistry and bedrock lithology, bauxite deposits can be classified into three main categories (Bárdossy, 1982; Bárdossy and Aleva, 1990), namely: (1) Lateritic-type bauxites that are generally formed by in-situ lateritization from the underlying aluminosilicate rocks (Horbe and Costa, 1999; Mutakyahwa et al., 2003), (2) Tikhvin-type bauxites that are detrital

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bauxite deposits overlying the eroded surface of aluminosilicate rocks and are the erosional product of lateritic bauxite deposits (Hanilci, 2013), and (3) Karstic-type that are bauxites lying on carbonate rocks regardless of whether the bedrock surface was more or less karstified or the degree of karstification was minimal (Bárdossy and Aleva, 1990; Mameli et al., 2007). Taken as a whole, the parent rock composition, climate, drainage, topography, groundwater chemistry, microbial activity, location of the water table, and the duration of weathering processes are the most important factors in determining the extent and grade of the bauxites (Bárdossy and Aleva, 1990; Gu et al., 2013).

The present study deals with a deposit that shows the characteristics of the latest group, which is karst bauxite type. Laznicka (2006) believed that karsts can play a significant role in bauxitization in two principle ways; (i) as a secondary modifier of the primary carbonates that host bauxites, and (ii) as an agent for the generation of voids (e.g., cavities and solution collapse breccias) and basins (depressions, sinks) that become filled with bauxite materials. These two phenomena increase the economic importance of bauxite deposits, which can be exemplified by those in the Zagros fold belt of Iran (Zarasvandi et al., 2012). It seems that the source of the karst-related bauxite deposits formed in orogenic and simple folded belts may be ancient weathering products derived from different rock types in the provenance basin and from the carbonate rocks subjected to karstification (Bárdossy, 1982; MacLean et al., 1997; Zarasvandi et al., 2010). These deposits have been divided into autochthonous, para-autochthonous, allochthonous and para-allochthonous subtypes (Bárdossy, 1982; Combes, 1990). Unlike the lateritic bauxite deposits, the geochemistry and genetic implications of karstic bauxite deposits have been well documented (Bárdossy, 1982; Esmaeili et al., 2010; Karadag et al., 2009; Liaghat et al., 2003; MacLean et al., 1997; Taylor et al., 2008; Liu et al., 2010a, 2013; Zarasvandi et al., 2008, 2010, 2012; Mongelli et al., 2014). Despite the economic significance of karstic-type bauxites, understanding the ore-forming processes and finding source rocks remain ambiguous. To reveal how different karstic-type bauxite deposits came to existence, various ways of handling chemical data are applied by authors, including using Eu-anomaly vs Ti/Cr; using Eu-anomaly vs $\text{TiO}_2/\text{Al}_2\text{O}_3$ diagrams (Mameli et al., 2007; Mongelli, 1997); using the accumulation coefficient (R) of trace elements; using the ternary plot of Ga, Zr and Cr (Özlü, 1983), and using immobile element ratio (Maclean, 1990; MacLean and Kranidiotis, 1987) and isovolumetric methods (e.g., Brimhall and Dietrich, 1987).

More than 129 bauxite deposits and occurrences have been recognized in the Zagros Simply Fold Mountain Belt (ZSFMB) (Nasibpour, 2000), amongst which Sar-Faryab, Deh-now, and Mandan are the most important ones. These deposits occur between the limestone units of the Sarvak and Ilam Formations in the Zagros stratigraphic column. Almost all known bauxite deposits in the ZSFMB are located in karst cavities and fractures of gray light massive neritic rocks of the Sarvak Formation (Zarasvandi et al., 2010). Although no major bauxite deposits are studied in the ZSFMB, several karstic bauxites were recently studied and described by Zarasvandi et al. (2008, 2010, 2012).

The Mombi bauxite deposit is one of the known bauxite deposits in ZSFMB. This deposit is located at $31^\circ 05' \text{N}$, $50^\circ 02' \text{E}$ in the northwest of Kohgiluyeh and Boyer-Ahmad province, 160 km northwest of Dehdasht city (Figs. 1 and 2). Several bauxite occurrences were recently explored in the central part of the ZSFMB area by the Geological Survey of Iran. Nevertheless, Mombi and other prospects in this area of the ZSFMB have not yet been studied. Therefore, it is necessary to obtain detailed knowledge of geological, mineralogical, textural and geochemical characteristics of the known karstic bauxite occurrences to shed new lights on identifying other prospects for bauxite deposits in the ZSFMB area. The aim of the present paper is to describe the mineralogical, textural, and geochemical

characteristics of the Mombi bauxite deposit in order to reveal the depositional environment, conditions of bauxite mineralization, as well as study the aluminum content and behavior of REEs and other immobile elements (such as Ta, Zr and Nb) throughout the bauxitic horizons.

2. Geological setting

The Zagros orogen is a part of the extensive Alpine-Himalayan orogenic belt formed during collision of the northeastern margin of the Arabian continental plate with the Central Iranian micro-continent in the Cretaceous-Tertiary (Berberian and King, 1981; Alavi, 1994; Mohajjel et al., 2003; Taghipour and Ahmadnejad, 2015). This orogen consists of three distinctive parallel structural zones from the northeast to southwest (Fig. 1). They are consist of (1) the Tertiary Urumieh-Dokhtar Magmatic Arc (UDMA); (2) the Sanandaj-Sirjan Zone (SSZ), and (3) the Zagros Fold Belt (ZFB) (Alavi, 1994, 2007). The Zagros fold belt, which hosts Mombi and other bauxite occurrences, is a major NW-SE trending structural zone that extends southeast for nearly 2000 km from southeastern Turkey through northern Syria and northeastern Iraq, to western and southern Iran (Alavi, 2007) (Fig. 1).

Considering the regional geology in southwestern Iran indicates that there is good and distinct relationship and coexistence between Cretaceous carbonate rocks and bauxitic-lateritic deposits in the Zagros Simply Fold Belt (ZSFMB). So far, several residual deposits (e.g., Sar-Faryab, Mandan and Deh-now bauxite deposits; Zarasvandi et al., 2012) in relation with Cretaceous carbonates have been recognized in the ZSFMB. Formation of karstic-type bauxite deposits in this area are related with several local and regional unconformities (Zarasvandi et al., 2010). In addition, thickness and facies variations in the ZSFMB have been related to incessant convergence and reactivation of deep-seated faults in the Zagros basement between Late Cretaceous and Early Miocene times (Sepehr and Cosgrove, 2004). Stratigraphically, during the Upper Cretaceous, the study area was dominated by widespread shallow water neritic carbonates of the Bangestan Group (Alavi, 2004). The Bangestan Group includes the Sarvak, Surgah, Ilam, Gurpi, Pabdeh, and Asmari Formations from Cretaceous to Miocene in ages, which form a progradational-retrogradational package of strata bounded by at least three major unconformities (Alavi, 2004). The most important bauxite horizons in the ZSFMB, with Cretaceous age, occur between the Sarvak and Ilam Formations. In the study area, the Ilam carbonate is located directly on the eroded surface of the Sarvak Formation. In addition, some of the bauxite deposits in the ZSFMB occur as karstic filling within the Sarvak Formation.

A detail overview on the features and regional geology of the study area has been provided by Zarasvandi et al. (2008, 2010, 2012) and Hajikazemi et al. (2010). The oldest stratigraphic units in the area are marly limestone and bituminous shale of the Sarvak Formation (Albian–Turonian), which are overlain by carbonates (marly limestone with interbedded of shale) of the Ilam Formation (Santonian to Campanian) and calcareous shale of the Gurpi Formation (Upper Cretaceous). The latter is covered by a series of marl and calcareous shale of Eocene age (Pabdeh Formation). Miocene marl and limestone (Asmari, Gachsaran and Mishan Formations) and Quaternary alluvial sediments overlie the above sequence (Fig. 3).

The Mombi deposit is situated in the northern limb of the Bangestan anticline (Fig. 2). Distinct features of Karstification and bauxitization processes in the Bangestan anticline could be observed in the Mombi bauxite deposit. These processes are controlled by drainage patterns, fractures and faults (or) by geomorphologic and tectonic processes. Generally, Karstification was a key diagenetic process that affected the formation of bauxite deposits in the upper parts of the Sarvak carbonates. Karst char-

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