GEOLOGY, GEOCHEMISTRY, AND SOME GENETIC DISCUSSION OF THE IIC ANOMALY, BAFQ DISTRICT, CENTRAL IRAN

GEOLOGIA, GEOQUÍMICA E ALGUMAS DISCUSSÕES GENÉTICAS DA ANOMALIA DA CII, DISTRITO DE BAFQ, IRÃ CENTRAL

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ABSTRACT

Zaqia IIC anomaly is located in the east of Bafq city in Yazd province. Alteration associated with mineralization has appeared within volcanic, intrusive and sedimentary rocks. The set of alterations of this anomaly consist potassium, sericitic and silicate alterations, with less sodic-calcic alterations. Iron minerals are observed in the form of veins and masses with various compositions in this deposit. Iron ore in Zaqia IIC anomaly is related to magma and hydrothermal fluids. A collection of accumulated zones is composed of high-temperature minerals at depth to subvolcanic assemblages on the surface. REE patterns in iron ores in IIC anomalies indicate LREE enrichment and Eu negative anomaly. The negative Eu anomaly shows the reducing conditions of the mineralizing fluid. Isotopic studies have been conducted to examine the source of the fluid. The mineralizing fluid source in this anomaly is sedimentary-metamorphism. Field observations, mineralogy, alterations along with ore geochemical data show that a magmatic fluid is turned to an iron-rich brine fluid; moreover, an IIC anomaly is formed.

KEYWORDS: GENETIC DISCUSSION, GEOCHEMISTRY, REE, IIC IRON DEPOSIT, BAFQ, IRAN.

RESUMO

A anomalia Zaqia IIC está localizada a leste da cidade de Bafq, na província de Yazd. A alteração associada à mineralização apareceu em rochas vulcânicas, intrusivas e sedimentares. O conjunto de alterações desta anomalia consiste em potássio, alterações sericíticas e silicáticas, com alterações menos sódico-cálcicas. Os minerais de ferro são observados na forma de veios e massas com várias composições neste depósito. A anomalia do minério de ferro em Zaqia IIC está relacionada ao magma e aos fluidos hidrotermais. Uma coleção de zonas acumuladas é composta de minerais de alta temperatura em profundidades até assembléias subvulcânicas na superfície. Padrões REE em

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minérios de ferro em anomalias IIC indicam enriquecimento LREE e anomalia negativa Eu. A anomalia negativa de Eu mostra as condições redutoras do fluido mineralizante. Estudos isotópicos foram realizados para examinar a origem do fluido. A fonte de fluido mineralizante nesta anomalia é o metamorfismo sedimentar. Observações de campo, mineralogia, alterações junto com dados geoquímicos de minério mostram que um fluido magmático se transforma em um fluido de salmoura rico em ferro; além disso, uma anomalia IIC é formada.

PALAVRAS-CHAVE: DISCUSSÃO GENÉTICA; GEOQUÍMICA; REE; DEPÓSITO DE FERRO IIC; BAFQ; IRÃ.

INTRODUCTION

Iron oxide deposit classification has been performed with the main goal of exploring iron reserves for decades and even before (Hitzman, 2000). The diversity of iron reserves and the short time since the identification of this group of deposits have caused in different point of views about their emergence and the necessity of classify them. There has been a great deal of focus on the formation of iron ores in recent years; furthermore, questions have arisen by the scientists about the formation method of these ores, whether the fluids responsible for these systems were mainly derived from magmatism or were controlled by wall rocks (Barton, Johnson, 1996). This group of ores is genetically classified into magnetite-apatite (Kiruna-type) and iron Oxide-Cu-Au (Hitzman, 1992). While there seems to be a genetic connection between magnetite-apatite (Kiruna-type) sediments and Cu-Au iron oxide sediments, the evidence suggests that they form the end members of a chain (Hitzman, 2000). Iron oxide (Cu-Au) is one of the subgroups of deposits IOCG type that is continuously accompanied with the enrichment of rare elements (REE). That is an appropriate environment for examining the behavior of hydrothermal REE during and after mineral replacement contains REE (Hitzman *et al*., 1992; Hitzman, 2000). They are in the form of small, high temperature masses with the components of magnetite-fluoropathite-calc-silicate silicate, which undergo the regional alteration of albite-actenolite ± K-feldspar and phyllite as a result of regressive or transitional changes. They are often associated with intrusive masses, although the nature of the relationship between intrusions and IOA (iron oxide-apatite) deposits is an arguable one. Metasomatic alkaline is very common in hydrothermal systems and has occurred in a variety of environments and geological periods,

from Archean to Cenozoic. Although the mean of U and REE in alkaline metasomatism-related minerals are not as high as in other iron ores, this indicates a promising exploratory purpose. Since the sources of these sediments are relatively large; in addition, it has a significant irregular mineral system despite occurring around the world (Cuney *et al*., 2012). Metasomatic and hydrothermal processes are influenced by solutions that concentrations of radioactive elements, mainly uranium reach appropriate concentrations due to endogenous processes (Titayeva, 1994). The hosts rocks of iron ores are usually modified from hydrothermal rocks and metasomatized that are formed as interlayers with volcanic-sedimentary sequences, or with large subvolcanic and volcanic units (Daliran, 2002). These intrusive masses have a medium to felsic composition (Ramezani, Tucker, 2003, Poorbehzadi et al., 2019).

Intermediate transport fluids trace elements (REE) in certain geochemical systems, moreover, the results of the analysis data of many fluids in the fluids involved in metasomatized rocks indicate an increase in the concentration of REE. Nevertheless, the mobility of REE elements is restricted; furthermore, the presence of REE elements as special processes for modeling is unusable, such as the alteration process in rocks (Henderson, 1996). There was no relationship between the degree of REE mobility and the type of rock or the degree of metasomatism, but rather the relationship between mineralogy and fluid (Humphris, 1989). Regarding the non-mixing of magma, a genetic model of hydrothermal brine rotation is proposed for the formation of iron oxide deposits which shows that apatite can cause in REE separation after deposition (Yazdi et al., 2017, Heidarian *et al*., 2018).

Studies on Central Iran have been ongoing for more than 110 years (Förster, Jafarzadeh, 1994). Systematic studies of iron ore resources in the Bafq region initiates in 1968 by the discovery of NISCO (National Iranian Steel Company) with the contribution of Soviet geologists. The results were compiled in a series of internal reports by NISCO between 1969 and 1980. Fundamental questions remain about the origin of iron ore despite extensive geological and exploratory information (Daliran, 2002, Baratian et al., 2020). The present

article deals with the description of the petrology and geochemistry (with emphasis on REE) of iron ore of IIC deposits, from BMD (Bafq metalogenic region), Central Iran. The main purposes of these studies are as follows: 1. the introduction of iron ore in IIC anomalies, 2. Interpretation of ore geochemical data in IIC anomalies, 3. Conditions for ore formation and discussion and presentation of a genetic model for Fe mineralization by using the interpretation of geochemical and mineralogical data in IIC anomalies.

GEOLOGY OF BAFQ

The Bafq block is located in the zone of eastern part of the Central Iran and is considered as one of the oldest areas of Iran. It is exposed in layers of Late Precambrian destructive-sedimentary rocks and Precambrian-Paleozoic rifting series. Late Cambrian-Neoproterozoic rocks consist phyllites, slates, quartzites and mafic volcanic rocks of Tashk Formation that covered by a shallow marine sequence containing Ediacaran facies and a bimodal volcanic unit (Figure 1a). The oldest exposed rocks in Central Iran have a combination of volcanic, volcanic-detrital, detrital and carbonate rocks, especially dolomite. The composition of volcanic rocks differs from basalt to rhyolite; however, their large volume include medium to acidic rocks such as andesite, dacite, rhyodacite, rhyolite and trachite. These rocks are called as Rizzo series, or Esfordi Formation, or Kooshak series rocks and belong to Late Proterozoic and Early Cambrian. These rocks are cut by different intrusive masses with a combination of granite to gabbro (most acidic species). These intrusions are the host of most of the Bafq metallurgical minerals. It is noteworthy that the volcanic-sedimentary rocks in the study area belong to the Rizzo series (Neoproterozoic and Early Cambrian period). Rhyolite and dacite flows and tuffs related to lower andesite are among the most common volcanic rocks in the area. A significant component of this region (Bafq) is the Cambrian volcanic-sedimentary unit, which is composed of dolomite, limestone, sandstone, shale and dual volcanic rocks (Ramezani, Tucker, 2003). Volcanic rocks appear mainly in the form of rhyolite-dacite alkaline felsic domes in the area (Mohseni *et al*., 2015, Bazoobandi et al., 2016). The close spatial and temporal association between IOAs and

apatite-rich rocks with Late Cambrian volcanic rocks shows that mineralization and magmatism are simultaneous and related to Late Cambrian (Daliran, 2007). Current studies indicate that the age of subduction to beneath of the Central Iranian subcontinent and the opening of the Proto-Tethys is late Cambrian (Ramezani, Tucker, 2003) (Figure 1b).
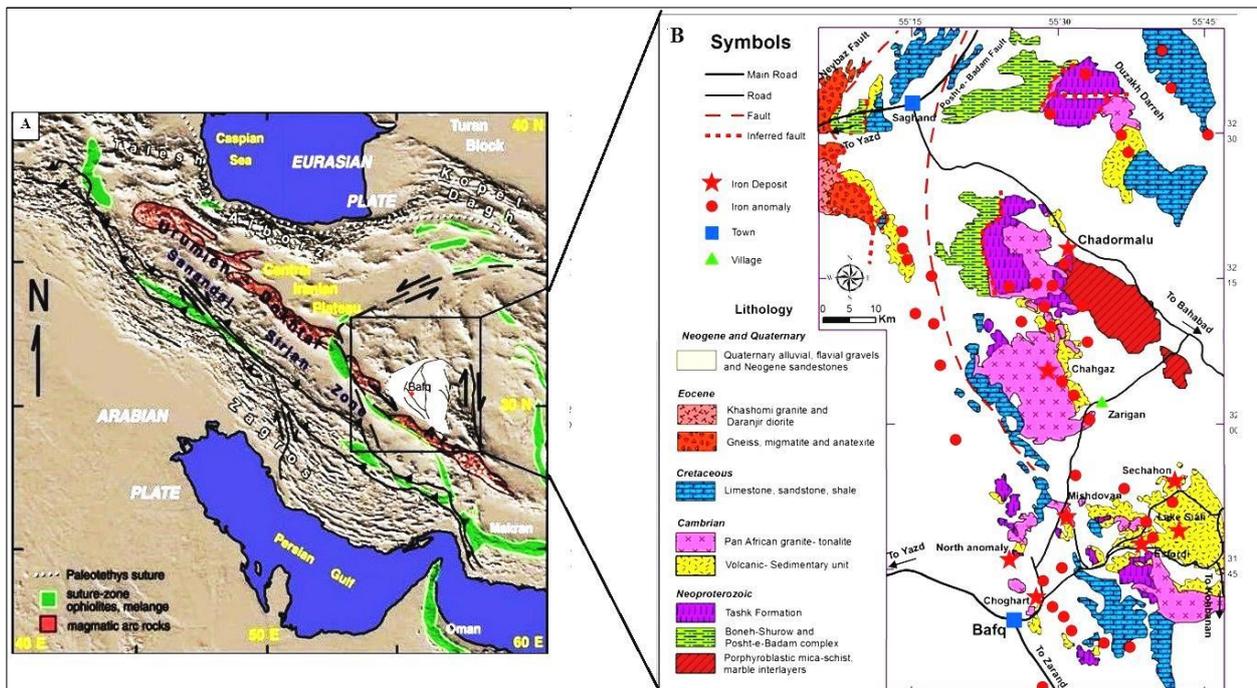
Figure 1. *a*. Location of Bafq in the structural zone of Iran; *b*. Modified geological map of Pousht Badam. Source: Ramezani and Tucker (2003).

IIC ANOMALY

Zaqia region is located 120 km east of Yazd city and 15 to 17 km east of Bafq city in Yazd province. The study area is in the coordinates of 55° 31' 30"to 55° 35' 38" east longitude and 31° 34' 40" to 31°37' 06" north latitude. This area is part of Bafq 1: 100000 plate. IIC anomaly is located in the east of Bafq city and is part of Zaqia area. The main rocks in the area and near study region and surrounding areas consist felsic intrusive volcanic rocks such as pink rhyolite and dacite locally, subvolcanic granites, as well as mafic intrusions, dikes, and schists. The deposits are zoned and stratabound. The rock area has a Fe-oxide-rich core and covered by metasomatism and breccia rocks, which is rich in magnetite and hematite. The

host rock of iron ore masses of IIC anomaly is volcanic and sedimentary rocks of Rizzo series. The composition of volcanic rocks varies from acidic to medium rocks. The rocks in this anomaly consist a series of volcanic-sedimentary units (Rizzo series), volcanic, plutonic and metasomatic units. The oldest IIC anomaly rocks are mainly volcanic-sedimentary rocks (Rizzo series); moreover, sedimentary rocks of the region include dolomite, calcite, greywacke and argillic-arnite (sandstone). Volcanic units compose acidic volcanic rock units such as rhyolite and dacite. Plutonic mass with a predominantly granite composition is quite common in central Iran; furthermore, Narigan granites are among the IIC anomaly plutonic rocks. Younger rocks (rhyolite and dacite) have penetrated into the old rock units. Quaternary sediments have covered the upper Cambrian units.
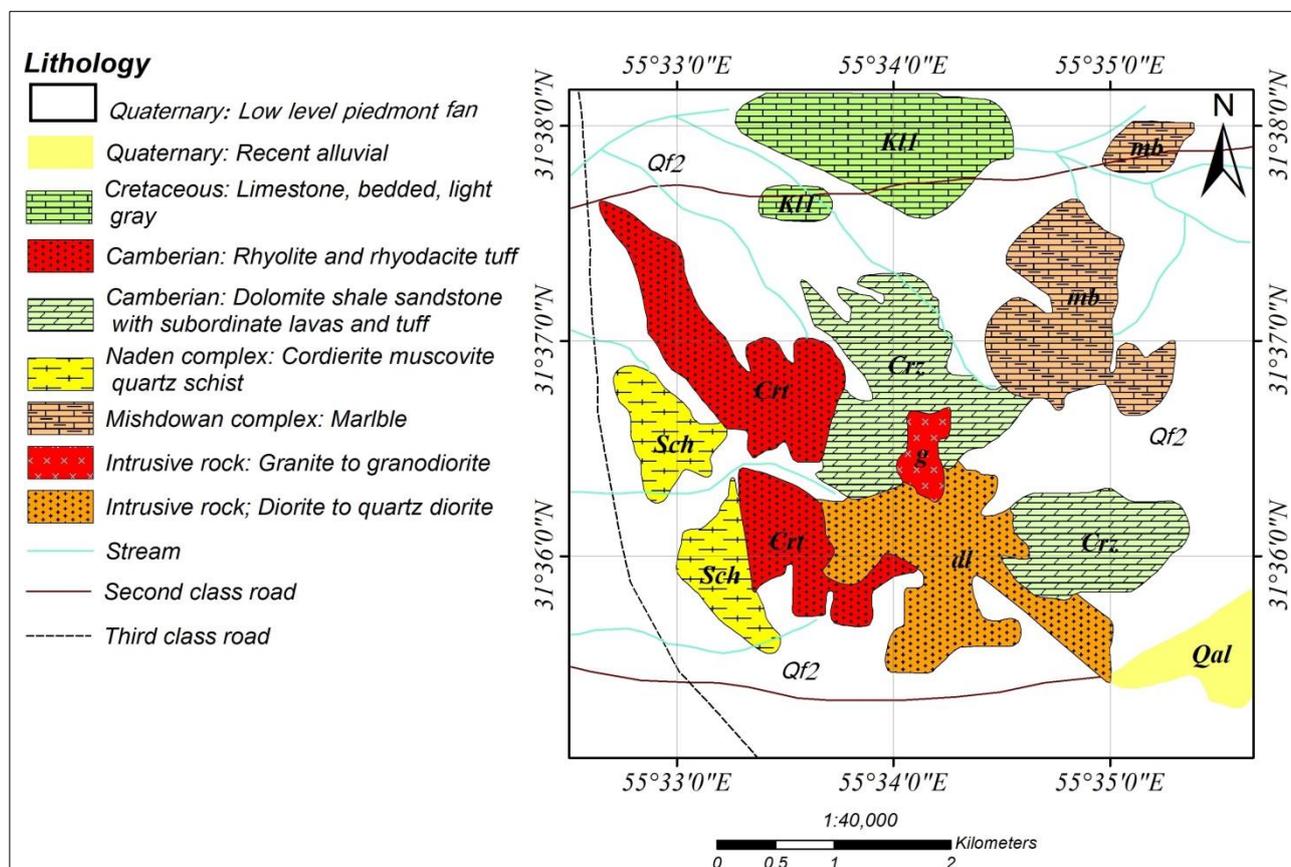
Figure 2. Geological map of Zaqia region. Adapted from the 1: 100,000.
Source: Esfordi Geological Map (1991).

METHODOLOGY

These studies are conducted according to observations and sampling of host ores and rocks. Detailed petrographic and geochemical investigations of surface samples and boreholes drilled in the area have been carried out. Thirty rock and 20 ore samples were sent to Zarazma Mineral Studies Company (Tehran, Iran) for ICP-MS, XRF and XRD instrumental analyzes. In addition, 30 samples were chosen for petrographic and mineralogical examinations (thin and polished sections). Samples of the ore containing magnetite and pyrite have been sent to the Environmental ISOTOPE Lab Geoscience Department, University of Arizona for isotopic examinations.

LITHOLOGY

The volcanic-sedimentary unit consists of dolomite, calcite, and greywacke and argillic arnite sandstone. The magmatic rocks of the region are mainly felsic, consisting of rhyolite, dacite and subvolcanic rhyodacites from above. The minerals of rhyolites consist quartz, feldspar and sphene (titanite) (Figure 3a). In rhyolites, quartz and feldspar have an intergrowth texture and have created a flistite texture in the rock. Feldspar minerals are kaolinized and mixed with dark clay materials. Titanite is found as an alteration mineral in banded magnetite ores in the form of large, amorphous to wedge-shaped grains with high relief and honey yellow to brown color. The specific color of titanite in the IIC anomaly is due to the presence of iron (Fe 2+) in the titanite structure instead of Ca. The formation of titanite from titanium-iron ores also occurs during delayed alteration processes (Rumble, 1981). Intrusive rocks consist diorite, monzogranite, granite, gabbro and diabase dikes. Some granite appears as monzogranite and has mafic minerals (biotite) and felsic minerals, along with medium grain quartz and phenocryst feldspars. Intruded rocks contain fine-grained minerals consisting set of minerals called quartz + feldspar + mica ± tourmaline. Quartz is found in free, dispersed and intruded veins in sandstones, iron ores and dolomitic limestones. In the structure of plagioclase and ferromangezin minerals have been replaced by chlorite

and sericitic alteration. Tourmaline has a clustered texture that is visible in thin sections. The association of tourmaline with sericitic is probably formed by the reaction of Fe-B-rich fluids with plagioclase, alkaline feldspar and chlorite (Figure 3b). Actinolite is another significant mineral in IIC anomalies. Amphibole metasomatism rocks contain amphibole semi-shaped and shaped crystals. These amphiboles are from the actinolite series based on their optical properties and refractive indices (Shelly, 1993). Actenolite includes large and sometimes elongated crystals with magnetite in metamorphic rhyolites. The green color of actinolite is a reflection of the high iron content and could mean that it is probably from the ferroactinolite group. These rocks are originated from intense actinolitization and replacement of most of the pre-alteration minerals in the primary rock (Figure 3c). Actinolite and magnetite are embedded in albite plagioclase and produced in paste (Jafari, Yazdi, 2014, Heidarian *et al*., 2017). Metasomatized rocks have plagioclase crystals with microgranular texture.

Plagioclase crystals are often semi-shaped and shaped; moreover, most of them are albites with polysynthetic twin. These minerals are mainly altered into clay, chlorite and sericitic minerals. Phosphorus is reduced in the IIC anomaly, indicating type I granites; in addition, phosphorus is completely incorporated into apatite (Figure 3d). Albite crystals are often subhedral to euhedral and most of them are albite and albite-pericline twinning.
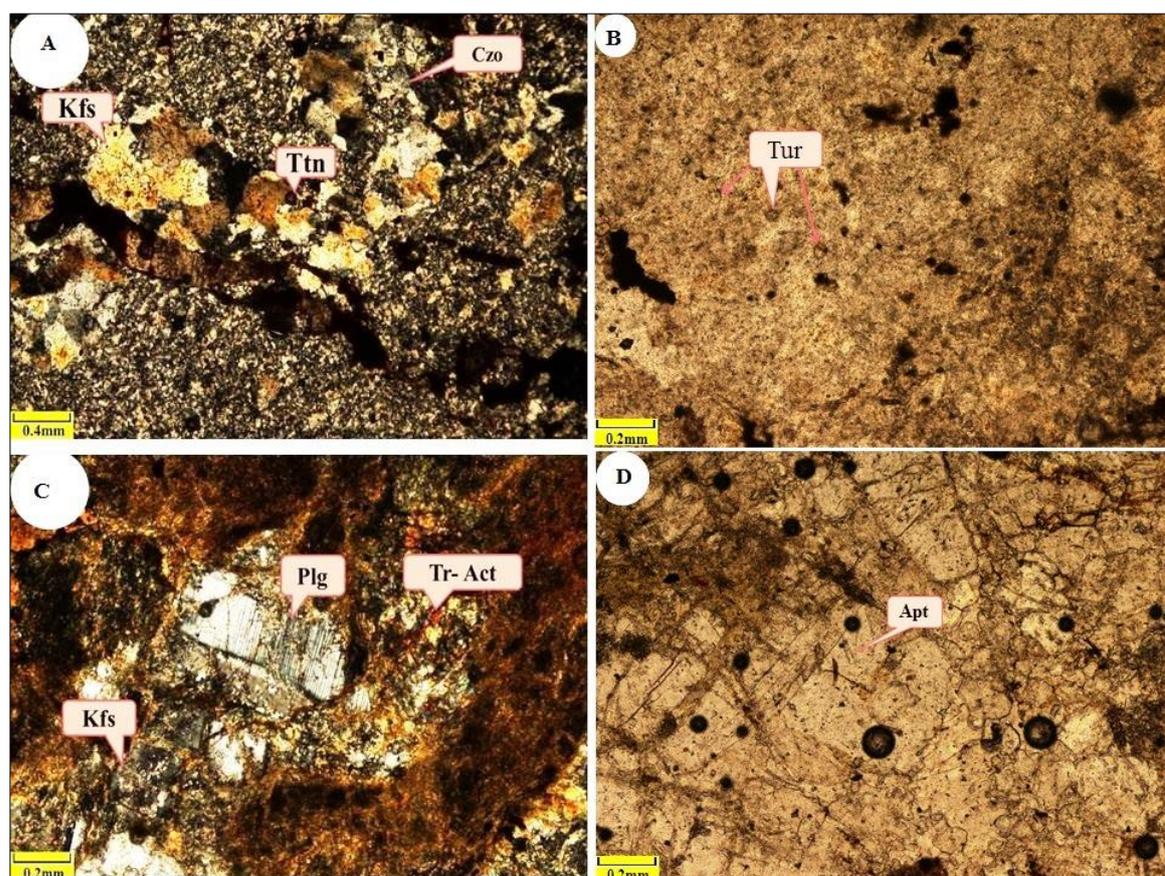
Figure 3. Photomicrograph of iron host rock in IIC deposit; *a*. Karlsbad twin in interfacial tissue of feldspars, brown sphenes and epidote (CPL); *b*. Association of tourmaline with sericite in host rock (PPL); *c*. Altered plagioclase crystals to sericite (CPL); *d*. Expansion of apatite needles on feldspar (PPL).
Source: M.shirnavard shirazi, M.Lotfi, Nima Nezafati, A.gourabjiripoor,(2019). Genetic implication modal in Πc and Zaghiya Iron ore anomalies based on trace and rare element (REE) (Bafgh- centeral Iran). Thesis of Department of Earth science, Science and Research Branch, Islamic Azad University, Tehran, Iran.

ORE MINERALS

Mineralization in IIC anomaly includes two parts, namely exposed and non-exposed. Iron ores in IIC anomaly consist magnetite and hematite. Other minerals compose martite, specularite, limonite, goethite, and pyrite. Magnetite is common in igneous, metamorphic

and sedimentary rocks as a mineral and can be observed as a mineral in many types of deposits (Dupuis *et al*., 2011). Magnetite is associated with apatite, calcite, quartz and actinolite. Magnetite is one of the most important minerals in the deposits of the Bafq mineral area. In IIC anomaly, magnetite is seen differently. Massive magnetites are a group of magnetite that are observed in a hexagonal shape and are located next to each other due to the accumulation of magnetite crystals (Figure 4a). The effect of metamorphic phenomena on these ores led to the crystallization of small non-crystalline nuclei of magnetite; moreover, the primary amorphous crystals grew and formed granoblastic tissue with increasing pressure and temperature during the later stages of metamorphism. In a group of massive magnetite that have lost their boundaries due to grain compaction, an integrated magnetite mass is formed, which indicates a higher concentration of iron ions than other minerals. Magnetite is sometimes observed in the form of vienlets and veins and grains scattered across sections (Figure 4b).

In this type of magnetite, the ores are with the characteristics of massive magnetites; however, the shape of the magnetite is formed as elongated grains in the empty space created in the host rock. This magnetite is created by the action of hydrothermal fluids at fracture sites and weak surfaces. Magnetite ores are usually fine-grained. Magnetite is also found as small islands (remnants) in pyrites. Magnetite coexists with actinolite and is formed in other phases due to the continuous intrusion of Fe-rich fluids (Figure 4c). Martitization is a special type of substitution phenomenon in which magnetite is replaced by hematite. Martitization is considered as a process after ore formation (Figure 4e). Martitization begins at the margins of magnetite grains and along fractures and surfaces, and in more advanced stages develops into the inner parts of the ore so that sometimes only traces of magnetite are stained. Some are left and sometimes the magnetite ore is completely converted to hematite. Fluids in the marginal substitution of magnetite cause in martitization and eventually lead to convert to maghemite (Figure 4f). Sometimes the magnetite grains have a mosaic texture in which the tiny cleavages in it are in a martitized state. Moreover, in some

areas, the magnetite itself is converted to martite while it is converted to meghamite, and the remnants of the martite and martitized magnetite fragments can be seen inside the meghamite.

Maghemite is formed in the last stage; moreover, martitization is formed before the formation of maghemite. The ore mass consists of magnetite and hematite, which have replaced rhyolite. The empty space in the host rock is filled by actinolite and quartz. Sometimes weathering and supergene factors cause hematite to break down. Progressive dissolution leads to residual tissue to form. In the examined samples, amorphous to semi-shaped granules of magnetite are becoming martitized and sometimes completely transformed into hematite (specularite) filaments to the extent that the red color inside them is clearly visible. Primary hematite, in the form of massive veinlets and veins, forms and cuts the host rock during the operation of the mineralizing alteration fluids. While similar shapes show banded magnetites on macroscopic scales. Blade hematites, unlike veinlet-vein hematites, which are amorphous masses, have been transformed into plate and plate-like (mica-like) shapes due to special conditions. Specularite is observed in acoustic greywacke carbonate host rocks with moderate dispersion along with quartz, pyrite and magnetite. Such features are indicative of the endogenous and mineralizing environments of specularite due to their association with magnetite by relatively oxidizing solutions (Figure 4D). Chalcopyrite mineral is observed in small quantities amorphously with second generation pyrites in magnetite mineral and in the form of scattered crystals in the host rock mineralized by magnetite and also with hematite in the form of fine-grained crystals (quasi-star texture). The coexistence of chalcopyrite with first generation pyrites is a sign of the simultaneous formation of sulfide minerals with each other. Scattered grains of chalcopyrite can also be observed in these sections. Chalcopyrite grains are also converted to iron hydroxide, consisting goethite, under oxidation and weathering conditions, creating substitute marginal tissues and residual or island tissue. Only a small part of primary chalcopyrite remains. The remains of which are traced as an island by goethite by-products (Figure 4g). Goethite (α-

FeO (OH)) is one of the alteration products of magnetite and hematite. Goethite is the last product of magnetite alteration and the most stable of them under free surface oxidation conditions. Goethite in oxidized samples shows vesicular chloroform, and box tissue. Vesicular tissue often has hydrothermal, weathering, and sedimentary origin prior to the formation of chloroform tissue. Most iron hydroxides have a chloroform texture and replace the previous crystals. In some samples, magnetite is converted to iron hydroxide such as goethite and lipidocrocite due to weathering and oxidation. Moreover, in the end, the decay intensity was so high that no trace of the primary sulfide was left. In this anomaly, pyrite is seen as having no magnetic intermediates and is completely self-shaped and cubic (Figure 4h). The growth of this group of pyrites in open spaces during recrystallization leads to the formation of layered shapes in the host rock. The pyrite grains are completely self-forming throughout the banded shape. If the primary sulfide nuclei are large and close together, they are formed during processes such as the metamorphosis of fully crystallized tissues. The resulting sulfides, after undergoing these steps, are completely subhedral and act as a kind of equilibrium tissue that also affects silicate minerals. Some types of pyrite are usually amorphous and are found in banded magnetite ores (Figure 4i). Trapped magnetite intermediates within amorphous pyrites indicate asynchronous oxide and sulfide phases. The sulfide phase appears to act delayed after the formation of the magnetite and surrounds them. Some of the pyrites in this group also follow the general shape of the layer, which seems to have cut off the magnetite ore; furthermore, subhedral has been broken and crushed by subsequent processes.
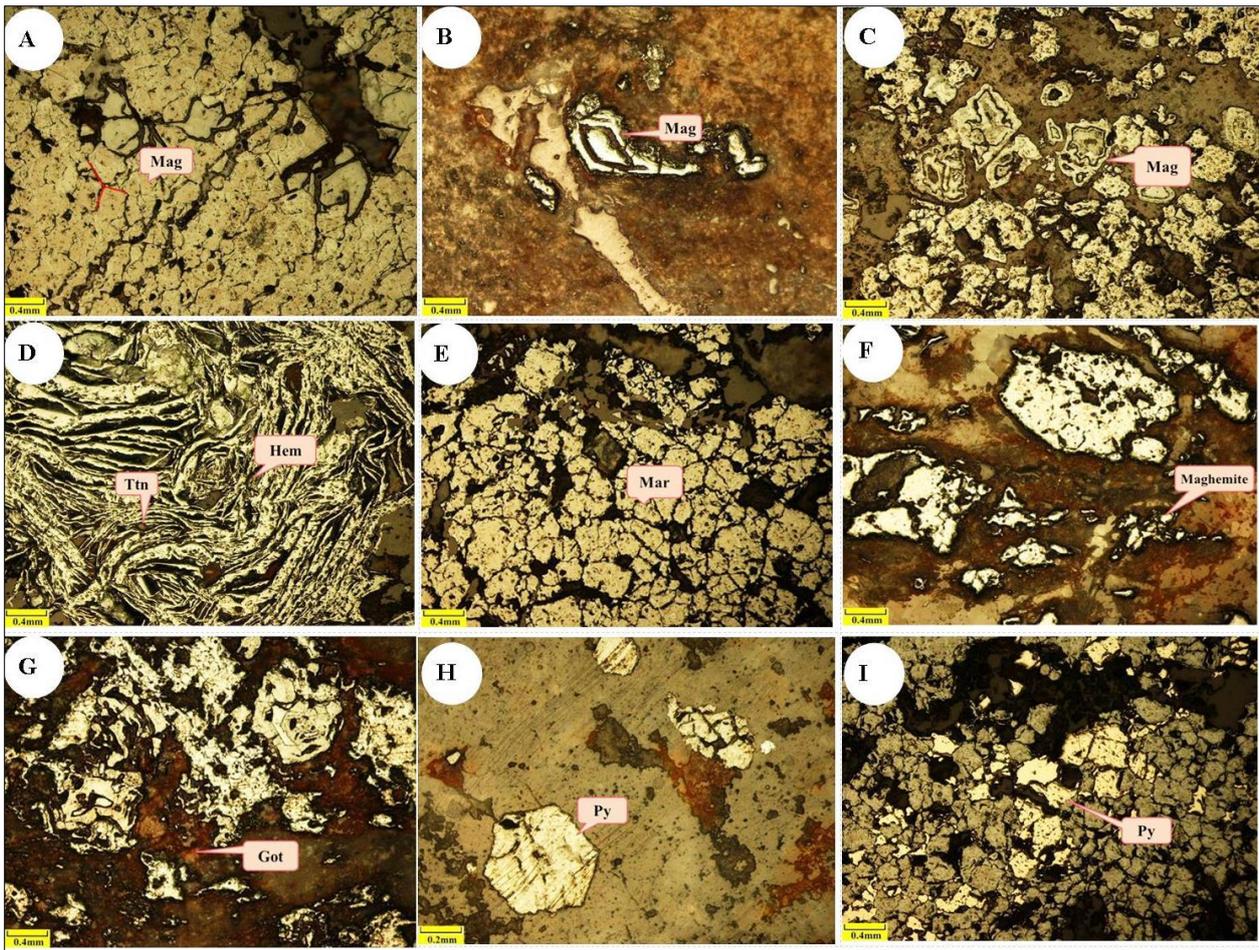
Figure 4. Microscopic images of iron host rock in IIC deposit; *a*. massive magnetite with triangular connective tissue; *b*. Layered magnetite and formation of elongated magnetite grains between the ducts created in the host rock; *c*. diffuse magnetite in carbonate host rocks; *d*. Specularite in acoustic greywacke carbonate host rocks with moderate dispersion accompanied with quartz, titanite, and magnetite; *e*. Magnetite crystals from the margin or center turning into hematite (martite); *f*. Martitized magnetite inclusions inside the maghemite, G. Goethite initiating from weathering and alteration of magnetite; *h*. pyrites lack magnetite intermediates and are completely self-shaped and cubic; *I*. first and second generation pyrites are crushed due to tectonic and deformation processes.

Source: M.shirnavard shirazi, M.Lotfi, Nima Nezafati, A.gourabjiripoor,(2019). Genetic implication modal in ∏c and Zaghiya Iron ore anomalies based on trace and rare element (REE) (Bafgh- centeral Iran). Thesis of Department of Earth science, Science and Research Branch, Islamic Azad University, Tehran, Iran.

ORE GEOCHEMISTRY

The trend of calcium changes versus Fe2O3 has a relatively negative trend in IIC anomaly ore, since the size and properties of calcium are different from Fe3+ and Fe2+. Moreover, it cannot be expected that this element can enter the magnetite network

significantly (Figure 5a). High levels of calcium in low-grade samples are probably due to the presence of calcium-containing minerals such as actinolite and residual amounts of unsubstituted calcites. Substitution of Ca2+ instead of Fe2+ is possible in a magnetite structure. Cobalt and nickel are also very close to Fe2+ in terms of ion radius and easily replace it. However, nickel has more tendency than cobalt (Taylor, 1967). So far, many studies have been conducted by using the two elements Co and Ni in ores in order to determine their source (Bajwah *et al*., 1987). These samples are located in the range of hydrothermal iron reserves. The Ni / Co ratio reduces during magmatic subtraction while the Fe / Co ratio increases (Figure 5b). High Co / Ni ratio in hydrothermal fluids is a special feature of hydrothermal magnetite (Williams et al., 2005). The relationship of Cl to Fe2O3 in ore is an inverse relationship. In other words, most of the chlorine formed in igneous rocks is found in hydroxylated silicate minerals and apatite. Based on Nash (1976) studies, Cl concentration in apatites is high in the early stages of subtraction and is at its lowest concentration in delayed subtraction types. Therefore, the IIC anomalous apatites are most likely related to the early stages of magmatic subtraction (Figure 5c). Based on studies, REEs with larger ion radii (LREEs) preferably enter the magnetite crystal lattice. The majority of magnetites show Eu anomalies, which is most likely the result of Eu2+ separation from the magnetite network. The LREE / HREE ratio is high in magnetite; moreover, a Eu anomaly is usually negative. LREEs enter the structure of magnetite instead of Ca2+. Since their ionic radius is very close to the ionic radius of Ca2+. On the other hand, the reason for the negative anomaly of Eu in magnetite indicates the decreasing conditions in the region. Comparison of Eu anomalies in the IIC anomaly samples shows the temperature of >250 ° C or decreasing fluid conditions. On the other hand, the enrichment of this element can be due to its depletion in the surrounding rocks in the form of hydrothermal. The decrease in the concentration of this element in IIC anomaly samples can be due to a decrease in fluid temperature or a change in oxidation-reduction conditions during deposit formation. Subtraction and separation of Eu from REEs may happen in high-temperature hydrothermal alteration, such as midocean

ridge systems. Since the divalent stability of the element occurs during these processes. An incomplete rift has occurred in the IIC anomaly region, so this separation in Eu may also be related to its tectonic environment (Figure 5d).
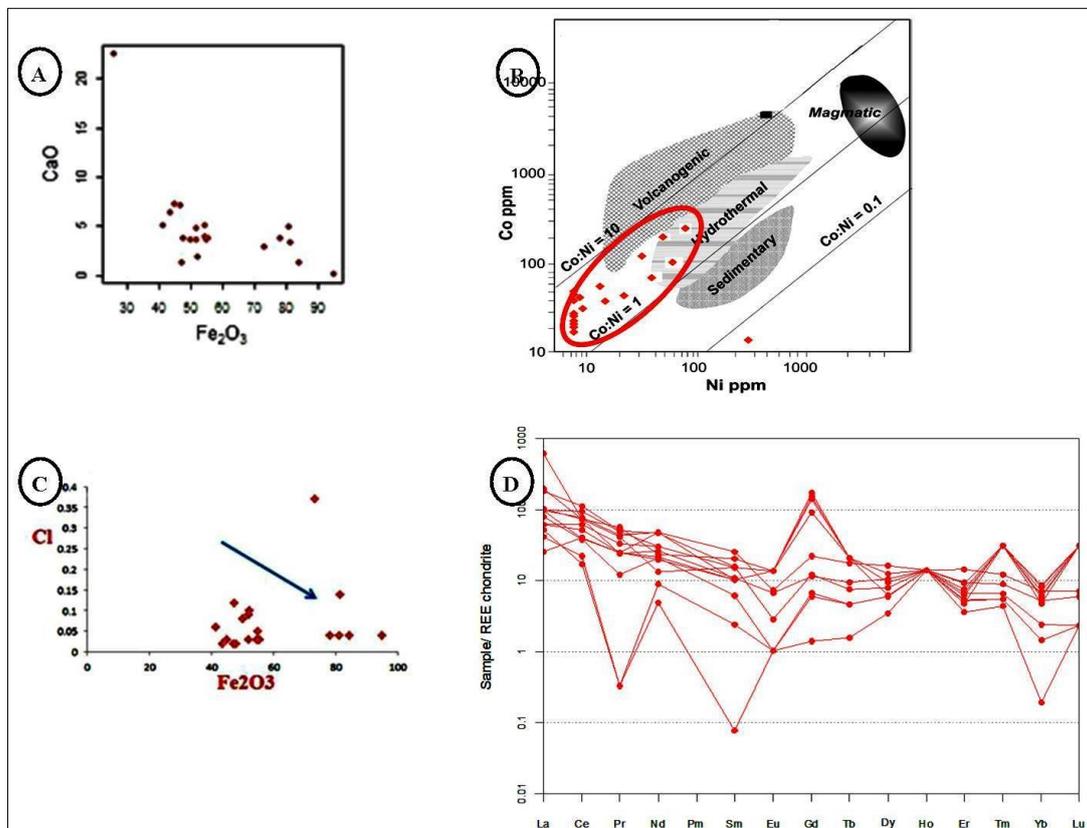
Figure 5. Diagram of geochemical changes for ores of IIC deposit, A. Diagram of changes trend in *CaO* with respect to *Fe₂O₃*, B. Diagram of determination of origin of iron ores using Ni values to Co (Bajwah et al., 1987), C. Inverse relationship of chlorine with ore, D. Normalized magnetite samples with IDMS chondrite values based on Boynton's data (1984).
Source: M.shirnavard shirazi, M.Lotfi, Nima Nezafati, A.gourabjiripoor,(2019). Genetic implication modal in Пc and Zaghiya Iron ore anomalies based on trace and rare element (REE) (Bafgh- centeral Iran). Thesis of Department of Earth science, Science and Research Branch, Islamic Azad University, Tehran, Iran.

ISOTOPIC STUDIES

One of the main purposes of the stable isotope study of sulfur in geology is to prepare an instrument for better recognition and understanding of the origin and conditions of sulfide deposits (Faure, 2005). Sulfur isotopic values in the IIC anomaly indicate an approximate range from + 19.3 to + 20.6 (Table 1). It is essential to have sufficient knowledge

and information about the values of sulfur isotopic composition in different geological environments, and its behavior in mantle, crust, magmatic pollution, subtraction, oxidation-reduction processes and different fluids in order to know the origin of sulfur in magmatic-hydrothermal systems. Regarding the range of sulfur isotope changes in the IIC anomaly, and its overlap with isotopic ratios in sedimentary environments, and concerning the available geological units, a sedimentary fluid source can be considered effective in the S34 isotopic composition changes in this deposit (Figure 6).

Oxygen is the most abundant element in the Earth's crust and mantle. The isotopic composition of oxygen in these minerals presents valuable information about their origin and formation conditions. The isotopic behavior of oxygen in the mineralization of the region has been evaluated in order to identify the origin of mineralizing fluids, and also to investigate the possibility of atmospheric water mixing with magmatic fluid. The analyzes were conducted by continuous gas flow method in MAT 253 mass spectrometer. The results of the analysis of these samples are illustrated in Table 2. All data had positive values between 6.39 and + 8.32. This range of oxygen isotopic ratios is consistent with oxygen isotopic ratios of metamorphic and sedimentary origin (Figure 7)

Sample	Mineral	$\delta^{34}S$‰
94.Bz.14	Pyrite	+20.0
Bz.5	Pyrite	+19.3
94.Bz.6	Pyrite	+20.6

Table 1. $\delta_{34}S$ isotopic values in IIC anomaly in comparison with CDT.

Sample	Mineral	$\delta^{18}O/^{16}O$
BZ-6	Magnetite	6.49
BZ-14	Magnetite	6.39
BZ-16	Magnetite	6.73
BZ-19	Magnetite	8.32
BZ-18	Magnetite	6.72

Table 2. $\delta^{18}O$ isotopic ratio in different minerals of IIC anomaly.
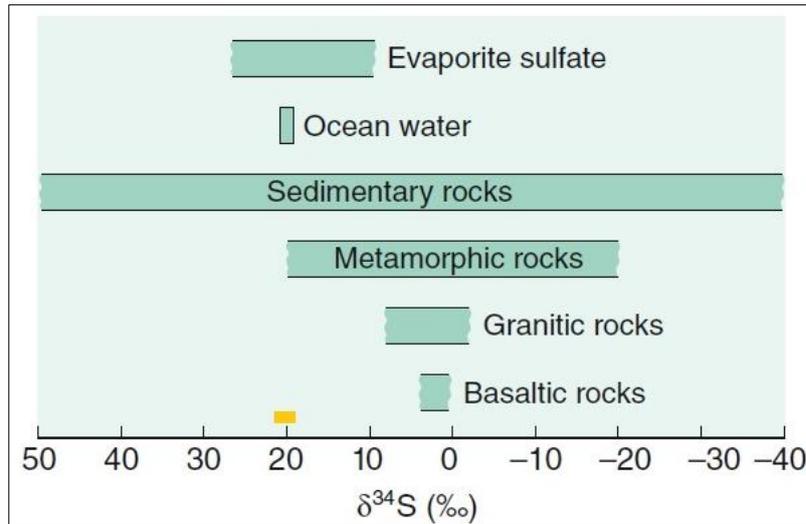
Figure 6. The value of **δ³⁴S** in important geological sources
Source: Hoefs (2015).
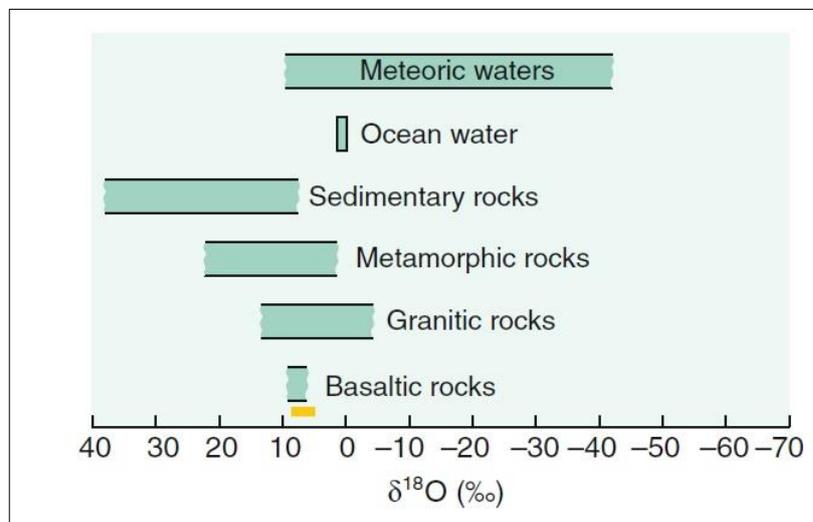
Figure 7. δ18O value in important geological sources.
Source: Hoefs (2004).

DISCUSSION

Alterations from deep-to-surface consist sodium-calcium, potassium, and silicic-sericite and argillic. Extensive sodium-calcium alteration in these rocks has caused mineralization in the host rock. The process of fluid withdrawal is possible from intermediate melts and even mafic melts (Robb, 2005). The smaller the volume of the fluid in comparison

with the Felsic melts, the more fluids will wash, transfer, and focus of metals such as Fe, Cu, and Ni. In addition, the presence of amphibole in the host rock shows that the magma water content was at least 3%. Crystallization of amphibole + magnetite + plagioclase inside the intrusive mass can indicate the water content in magma 4.5 to 6.5. Actinolite needles are the most important alteration mineral in IIC anomaly source rock. Actinolite is formed in active hydrothermal systems in intermediate to mafic rocks at temperatures above 300 ° C and is a sign of an alteration associated with intrusive mass. Thus, this magnetite is a secondary mineral that has been formed simultaneously with this alteration. The emergence of magnetite crystals in actinolite and the presence of actinolite in magnetite is the reason for this claim. Basically, sodium-calcium alteration occurs at temperatures below 600°C (between 400 and 600°C) and as a result of the fluid returning to the inside of mass or passing through the pre-formed minerals. Moreover, washing the mass also enriches the fluid with iron.

The Na / Ca ratio at temperatures above 600°C in the fluid is in equilibrium with the underlying minerals, especially feldspars. Nevertheless, as the temperature reduces, this equilibrium disappears. It seems that the reduction in temperature in the hydrothermal fluid in the source rock of IIC anomaly has led to this alteration. Hydrothermal fluid reacts to achieve equilibrium with the underlying minerals (sedimentary fluids) under such conditions. Therefore, the Na / Ca ratio in the fluid is reduced. The fluid then begins to lose Ca in order to return to equilibrium. Actinolite + titanite + epidote minerals are the product of this step. Sodic -calcic alteration at the top causes in potassium-sericitic alteration, which contains a set of potassium-containing feldspars + sericite + biotite + quartz (Hitzman *et al.*, 1992). Subsequent cooling of silicate-sericitic (retrograde fluids) occurs at low temperatures between 300 and 400°C. The fluid separated from the intrusion mass is a chlorinated, sulfide-rich, iron-rich, relatively neutral (Eh ~ 0) and acidic (pH$\leq$6) fluid with a temperature above 400° C and has a high ratio in its composition of Na / Ca. This fluid has the ability to carry iron in the form of FeCl2. All of these properties are characteristic of type I or A magmatic

fluids (Williams, 2005). Due to the fact that it is separated from magma with an intermediate composition; therefore, this fluid has a low fluid to rock ratio. This reduction in proportion has prevented halos of alteration from spreading in the region and, if formed, to be obscured by subsequent metamorphic processes. The mobility of iron is lower than that of all elements in the early stages and at high temperatures; moreover, a decrease in temperature reduces its mobility and leads to the accumulation of magnetite masses. In the final and low temperature stages, iron is completely removed; furthermore, sulfur and copper react to the group of mobile elements with iron compounds and form sulfide phases. In the IIC anomaly in the final stages, there is a deposition of sulfides that show its effects in the form of pyrite and chalcopyrite in microscopic specimens. Fusion of magmatic, metamorphic and sedimentary waters and changing the chemical composition of the mixing fluid causes the addition of CO_2 to the magmatic fluid and thus reduces the activity of ligand-forming anions carrying Fe and REE (Fe-REE-Cl). It should be noted that the solubility of many elements at high CO_2 pressure due to the reduction of H_2O activity, causes a decrease in dielectric constant and ultimately the deposition of minerals in the form of substitution (Smith et al., 2000). Such a fluid, which changes its acidic state to alkaline due to physical and chemical changes, also causes the mobility of REE elements in the host rock. In systems with low fluid to rock ratios, the mobility of in the REEs is possible under alkaline pH and the presence of chloride ions in solution (Lottermoser, 1992). Such conditions were also common in the study area; therefore, aqueous fluid is formed with the lowest amount of Si in contact with carbonate host rock (dolomitic marble) and the supply of Ca and Mg elements from it in a relatively restricted amount simultaneously with magnetite, actinolite mineralization. Actinolitization in the region is due to the influx of aqueous fluids rich in iron and silicate and the presence of CaO and MgO in the environment, which has occurred together with layered magnetite ores. The formation of magnetite with actinolitization in the host rock of the IIC anomaly due to the influx of silica-rich hydrogen fluid and iron chloride complex is stated as follows (Seward, Barnes, 1997):

The development of hydrothermal fluid towards shallower surfaces, temperature drop, and expansion of fluid oxidation conditions cause in lack of formation of actinolite and high temperature minerals with iron mineralization; moreover, they are replaced by lower temperature minerals such as chlorite, epidote and muscovite (formation temperature between 200 and 300 ° C). With reduction of the Na / Ca ratio in the final fluid, the conditions for increasing K-H2O and in fact the muscovite deposit with hematite increase. This process often leads to the formation of minerals with a high Fe^{3+} / Fe^{2+} ratio (such as hematite), which is associated with chlorite, sericitic, and epidote. The presence of specularite is due to the function of oxidant hydrothermal fluids rather than oxidant. Specularite mineralization is formed in intermediate to shallow environments from low-temperature hydrothermal fluids and oxidant sediment or by the reaction and mixing of $FeCl_3$-rich gases with water vapor (Cornell, Schwertmann, 2003). Hematit is observed along fractures and joints. This shows that hematitization is more widespread in the surface fragile zones. It seems that with the approach of the fluid to the surface and the release of volatiles such as CO_2, the former alkaline fluid has also become somewhat acidic. Decreasing the temperature and pH causes in intensification the REE elements' mobility in the host rock (Lottermoser, 1992).

CONCLUSION

Finally, the model that can be presented for IIC anomaly mineralization is a distinct and predominant genetic manifestation of these reserves that show a concurrence with continental rifting. According to what has been mentioned, IIC anomaly indicates the most similarity to this model. Fluid production in this model is due to magmatic, metamorphic, sedimentary processes, surface and deep basin water. These fluids have deposited metals at different crustal levels and along deep shear zones to surface fractures. This anomaly is extensively located in the range of temperature and pressure conditions of green schist to granulite facies in formable and brittle structural regimes. In these environments, crustal thickening, deformation, and metamorphism all play a significant role in the origin of mineralizing fluids and the concentration of upward fluid flow within the crust. The

hydrothermal-substitution model is presented for deposits similar to the IIC anomaly with respect to the made substitutions and the observed alteration halos.

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