

# Economic Geology of the XIV Iron-Oxide Prospect, Bafq Mining District, Central Iran: A Preliminary Approach

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## Abstract

This paper presents an overview about the XIV iron-oxide prospect which is located in the Bafq mining district, central Iran. The prospect and its host rocks were investigated by field observations together with mineralogical and geochemical studies. According to these investigations, the XIV prospect is similar to Kiruna-type iron deposits and demonstrates a magmatic source for the ore forming processes with a metasomatic overprinting.

## Keywords

Magnetite, Metasomatism, Magmatic Iron, Kiruna, Central Iran

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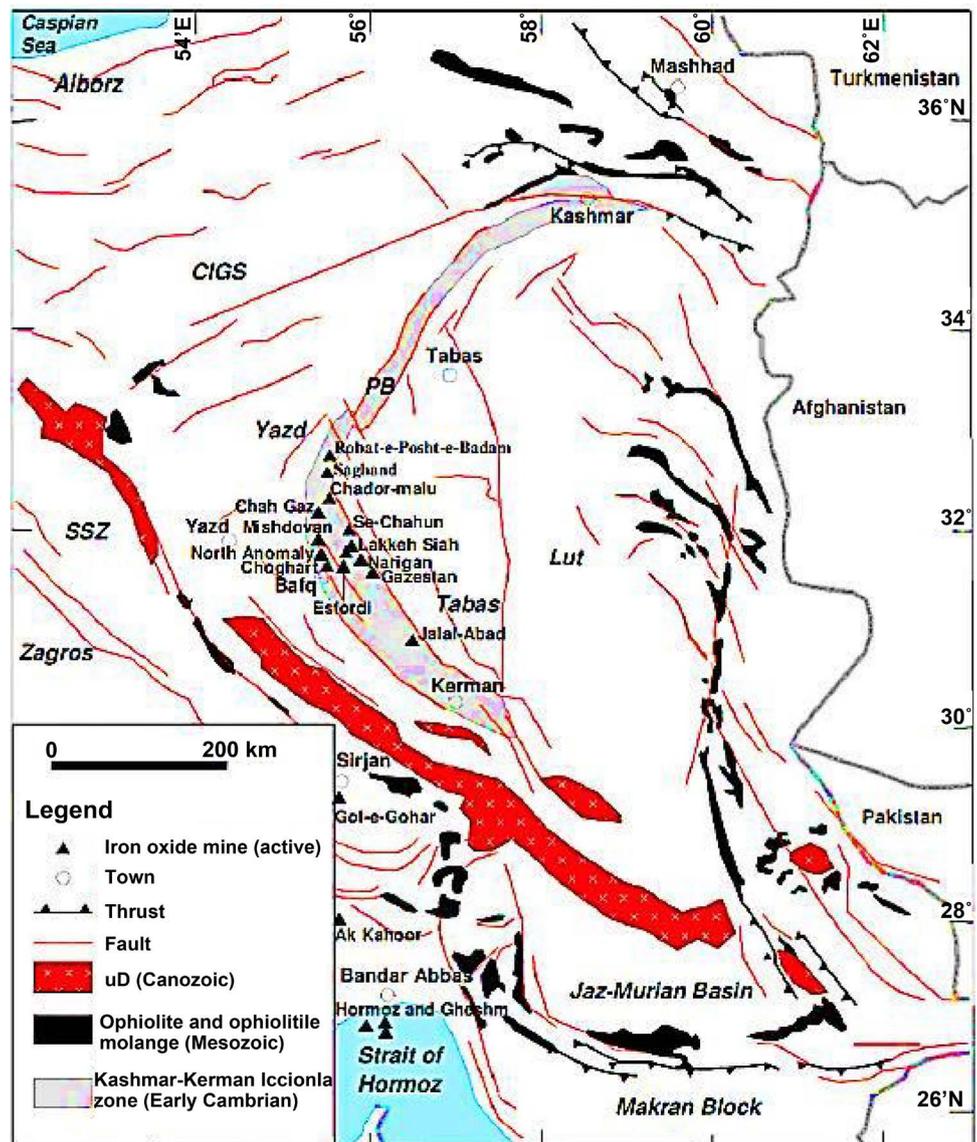
## 1. Introduction

The XIV (or No.14) iron-oxide prospect (geographic coordinates: 55°28'E - 55°30'E and 32°04'N - 32°07'N) is located 8 km north of Chah Gaz magnetite deposit (also called as anomaly XIVA) and 60 km north of Bafq city (**Figure 1** & **Figure 2**). The prospect was first discovered and reported by Kumel in 1941. This prospect is divided into three ore zones (northern, central, and southern orebodies). According to the data obtained from drilling cores, the main orebody (northern zone) is continued down to 300 m below the surface. The iron content of the phosphorus-poor magnetite ore is 62%. The northern ore zone mainly occurs in an aplite dome (caused by late differentiation of granite which is called "leuco-metasomatite") and is composed of the massive magnetite and hematite ore bodies, and actinolite, all of which located in the northern and southern parts of the area. The origin of the Bafq district deposits is the subject of longstanding

debates and remains controversial. In this regard, the XIV iron-oxide prospect and its characteristics have so far received little attention. This paper presents the outcomes of the preliminary economic geological research on this prospect.

## 2. Geologic Setting

The XIV iron-oxide prospect is located in the Bafq district, which as part of the Central Iranian Micro-plate (CIM), composes the central part of the Alpine-Himalayan orogenic system. A series of intersecting regional-scale faults have divided the Central Iranian terrane into three major crustal domains, namely the Lut, Tabas, and Yazd blocks, among which lies an arc-shaped and structurally complex belt with more than 1000 km



**Figure 1.** Structural map of CIM (including the Yazd, Posht-e-Badam block (PB) as well as Tabas, and Lut blocks) and CIZ (Central Iranian zone) ([1]-[7]) and location of major iron oxide-apatite deposits in the Kashmar-Kerman tectonic zone (KKTZ).

length and up to 80 km width. This belt is called the Kashmar-Kerman volcano-plutonic arc [1] [2] and hosts the Bafq district and the early Cambrian volcanic and plutonic rocks of Central Iran (Figure 1 & Figure 2).

The local geologic setting and structure of the XIV iron prospect is presented in Figure 1 and Figure 2. It is based on both surface mapping and examination of shallow

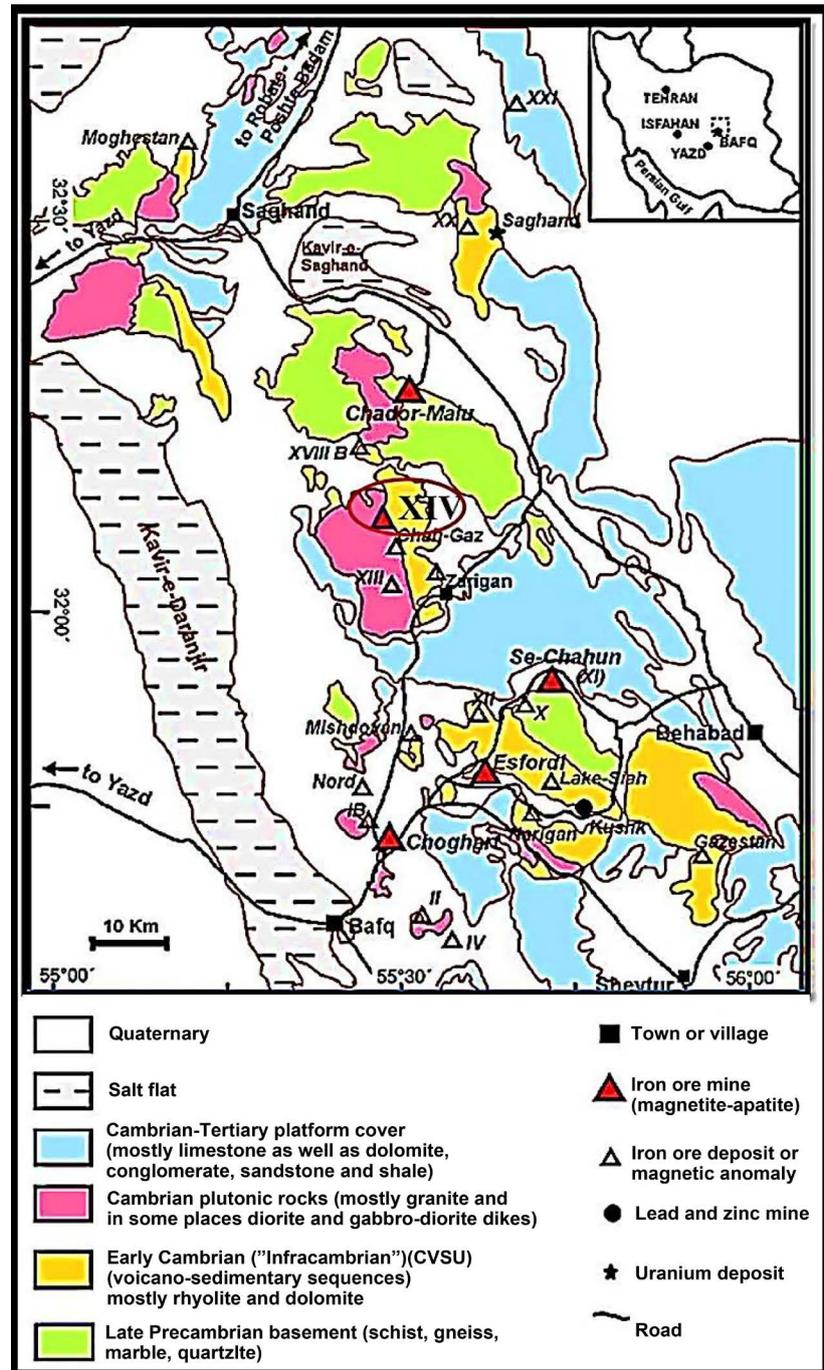


Figure 2. Simplified geological map of the Bafq mining district and location of ore deposits and igneous rocks ([6] [7] [8] [9]).

exploratory core drilling from the vicinity of the deposit. The mineralization is hosted by the middle sequence of felsic to mafic volcanic and plutonic rocks (locally intruded by aplite and dolerite) and intercalated sedimentary rocks of the Esfordi formation [3]. The main host rock of the diatreme is aplite (the result of late differentiation of granite which is called “leuco-metasomatite”).

An aplite dome with approximate dimensions of 100 m × 400 m, is situated around the mineralization (in northern zone, **Figure 3(a)** & **Figure 3(b)**) and has a sharp contact with the ore body. A small outcrop of cherty dolomites of Esfordi formation was found on the southern margin of the XIV iron prospect. Massive granite-gabbro diorite outcrops have been exposed in the south, central, and north-eastern parts of the XIV prospect, while the metamorphic rocks are present in the south of the area in the contact of gabbro and granitic rocks (**Figure 5(a)** & **Figure 5(b)**).

The intrusive rocks and the iron ores have been regionally metamorphosed with preservation of their primary structures and textures. Presence of minerals like chlorite, epidote, actinolite, and albite in the mafic rocks indicates the occurrence of a green schist facies. According to the field observations, the ore body is associated with an extensive fault zone. Local deformation and recrystallization are caused by reactivation of the fault system. Quartz and carbonates were probably introduced during the deformation. This also has caused the formation of foliated regions in the ore. The volcanic succession which contains the ore is approximately 6 km thick. The iron oxide mineralization is situated on the contact zone of a plutonic sequence composed of granitic and gabbro rocks (central part and south of the area) and the aplitic unit (north of area). The majority of these are altered and their chemistry has changed from alkali-rich to low-content alkaline series.

### 3. Mineralization of the Ore Body

Mineralization at the XIV iron prospect occurs predominantly within the actinolite-rich metasomatic rocks, granitic, and aplitic rocks and gabbro. The northern (zone) ore body (**Figure 3(a)** & **Figure 3(b)**), is characterized mainly by a massive mineralization style. This orebody shows sharp and linear contacts with the host rocks (**Figure 3(a)** & **Figure 3(b)**).

The orebodies of the XIV prospect is mainly in massive, stockwork, and breccia forms. The XIV iron ore is dominantly composed of magnetite and hematite. The ore contains rare apatite (mainly fluorapatite) together with poor contents of actionolite, local biotite, calcite, quartz, sphene, talc, and albite.

The iron-oxide-rich breccias usually occur at the top of the massive ore. The breccias consist of angular fragments of the metasomatic host rock cemented by iron ore (**Figure 4**). Stockwork iron ore locally occurs as irregular cross-cutting network of veinlets of magnetite and hematite, which commonly cut the massive orebodies as well as the associated volcanic rocks. The veinlets vary in thickness, from a few millimeters to a few centimeters. Locally, the magnetite and/or hematite bodies contain feldspar and quartz phenocrysts, whose abundance decreases towards the center of the ore bodies.



**Figure 3.** (a) The northern massive orebody in the XIV iron prospect. This orebody shows sharp and linear contacts with the host rocks, (b) the massive ore body in south of the study area.



**Figure 4.** The breccias consist of angular fragments of the metasomatic host rocks cemented by iron ore.

Although disseminated magnetite and/or hematite are widespread around the ore in the volcanic and plutonic rocks, most of the abovementioned disseminated magnetite is commonly concentrated around the massive orebody. Most plutonic and volcano-sedimentary host rocks are altered and the original chemistry of these rocks is strongly

modified by sodic (and sodic-calcic), potassic, and calcic overprint.

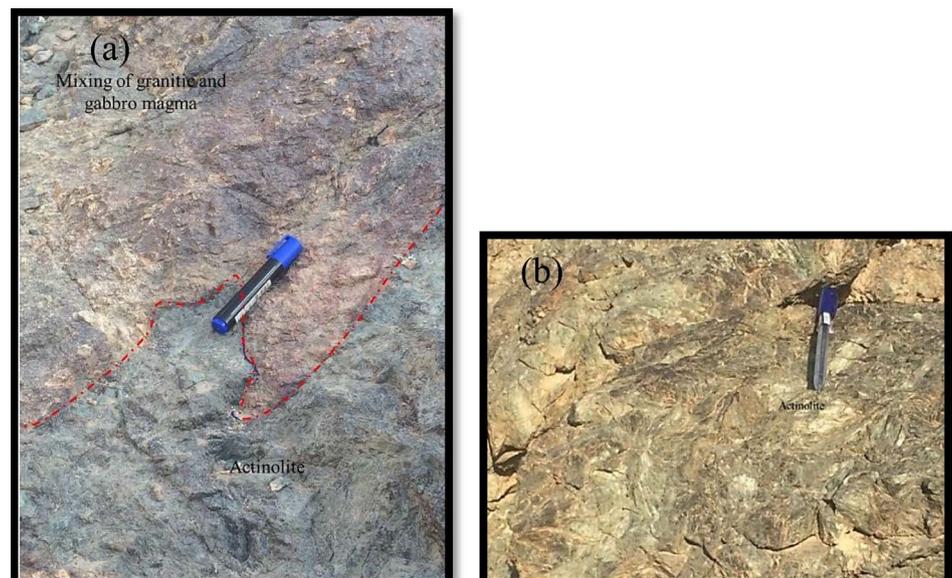
Some fine-grained crystals of apatite are locally visible in thin section of rocks but are invisible in the massive magnetite bodies or in the ore-breccia zones.

Actinolite is the most important silicate mineral present in the iron deposit (**Figure 5(a)** & **Figure 5(b)**). It occurs in the form of euhedral to subhedral grains and demonstrates a continuous series with tremolite, indicating variable degrees of iron metasomatism of the host rocks. In the XIV iron prospect, actinolite occurs in massive bodies (the so called green rock) adjacent to or interfingering with magnetite ore. A massive thick actinolite layer has been developed in the contact zone between the granitic rocks and gabbro (**Figure 5(a)** & **Figure 5(b)**). Other hydrothermal minerals are quartz, calcite, albite, k-feldspar, sericite, chlorite, talc, sphene, and epidote.

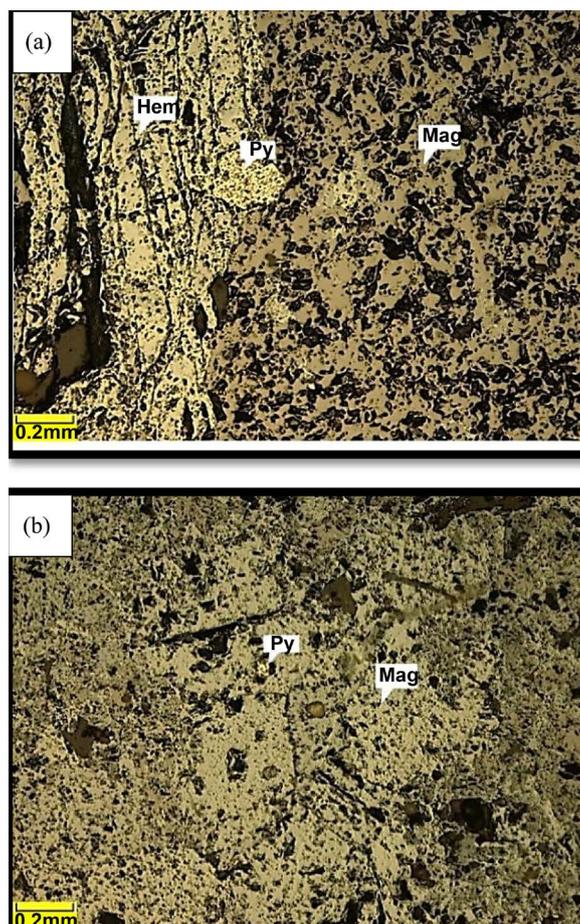
Sulfides are rare. Only some pyrite and few fine-grained chalcopyrite crystals were observed in some drilling cores (**Figure 6(a)** & **Figure 6(b)**). Goethite and other hydrous iron oxide minerals occur near the surface, but disappear rapidly towards deeper levels.

#### 4. The Alteration of the XIV Iron Prospect

The alteration assemblages associated with the iron ore deposits are evidence of an important metasomatic component in the ore-forming process, where the alteration mineralogy is controlled by the bulk chemistry of rock, the composition of the mineralizing fluids, and P-T conditions of formation. However, alteration at the XIV iron prospect shows a general transition from sodic alteration (albite-rich) at deeper levels especially in the plutonic rocks or their adjacent volcanics, to potassic alteration (potassium feldspar + sericite) at intermediate levels (in the plutonic), to sericitic and silicic alteration (sericite + quartz) in the uppermost portion of the system. Actinolite (sodic-calcic



**Figure 5.** (a) A massive thick amphibole layer has been developed as the contact zone between the mixing of granitic rocks and gabbro, (b) massive actinolite grains.



**Figure 6.** (a) and (b) General paragenesis of the iron minerals (Py: pyrite; Mag: magnetite; Hem: hematite).

alteration) also occurs widely in the southern and western parts of the area, locally associated with albite as Na-Ca alteration at deeper levels, or as patches or massive bodies in contact zone between the gabbro and granitic rocks due to hydrothermal metasomatism.

## 5. Discussion

### 5.1. The Age of the Ore

The XIV iron ore is outcropped by aplite domes. Ramezani and Tucker [1] defined an age of  $525 \pm 7$  Ma and  $529 \pm 16$  Ma (U-Pb on zircon) for the Zarigan and the Chador-Malu granites, respectively. Stosch *et al.* [10] determined the U-Pb apatite age for major iron oxide apatite deposits in the Bafq district (527 - 539 Ma). These ages fell entirely within the age range of the felsic plutonic rocks of the Bafq district dated by Ramezani and Tucker [1] (525 - 547 Ma; U-Pb on zircon). The XIV iron ore is overlain in sharp contact by aplite domes which is probably younger and/or synchronic in age with the aplitic rocks. All results show that the XIV iron mineralization was completed before 507 - 542 Ma.

## 5.2. Genesis of the Mineralization

The origin of the massive iron oxide deposits related to igneous rocks has been the subject of a long-standing and hot debate for the last hundred years. Among these deposits, the so-called Kiruna-type ores have attracted the most attention. Several genetic models have been proposed for this specific type of massive iron oxide deposits. Today researchers put forward two different genetic models involving magmatic [11]-[17] and hydrothermal processes [18]-[27].

The origin of the Bafq district deposits is the subject of longstanding debate and remains controversial. Different ore genesis models have been proposed for these ore deposits. Some researchers have proposed an IOCG affinity for the Bafq district deposits [6] [7] [11] [24], after the classification that was defined by Hitzman *et al.* [20]. Evidence for an IOCG association includes the presence of hydrothermal alteration with the characteristic zoning of the IOCG deposits (as defined by Hitzman *et al.* [20]) and magnetite chemistry [6].

Jami [4] developed a three-stage model for the hydrothermal evolution of the Esfordi deposit based on apatite textures, fluid inclusions, and isotopic data; however, the initial stages in the generation of the proto iron oxide-apatite body was largely speculative and involved the immiscible separation of a Fe-P melt (in response to a possible magma mixing in the Esfordi area) and its subsequent equilibration with fluids near 400°C [5]. Some researchers have proposed that the source of Fe is the pre-existing mafic minerals (iron-bearing amphibole and pyroxene) of the Precambrian rocks of the region which would decompose in the early stages of regional-scale hydrothermal fluid circulation to supply Fe to the system [25] [26] [28].

Based principally on the flow and quenching textures observed in magnetite, liquid magmatic models have been ascribed a prominent role at Kiruna and El Laco [9] [29]. This textural evidence was reported from the Bafq district deposits and interpreted as their direct magmatic origin by Förster and Jafarzadeh [10]. Magmatic models involving immiscibility between silicate and iron oxide-rich melts have widely been proposed for the genesis of Kiruna type deposits [12] [13] [30] [31] [32].

The Bafq district deposits, of which the XIV iron deposit is typical, are remarkably similar to the Kiruna-type iron oxide-apatite deposits. They consist of massive to brecciated and conformable lenses of magnetite-hematite, which are mainly hosted by felsic volcanic rocks, very similar to the classic Kiirunavaara deposit (northern Sweden), in terms of morphology, ore mineralogy and host lithology; the latter ranging in composition from felsic to intermediate for the Swedish counterpart [19]. The volcanic hosts of both districts (Bafq and Kiruna) have undergone intense alteration and formed similar assemblages including actinolite and albite [4] [6] [19] [33].

## 6. Conclusions

Based on the field relationships and ages reported for rocks of Bafq district, the XIV iron prospect has probably occurred before 507 - 542 Ma. The ore is surrounded by apatite. The deposit is composed of a concordant body of magnetite and/or hematite ore

which contains circa 5% apatite and some accessory minerals. Different alteration events from sodic (and sodic-calcic) to potassic, sericitic and silicic have occurred in the deposit.

The spatial association of the XIV iron prospect with intrusive and extrusive igneous rocks clearly indicates a genetic relationship between magmatism and iron-oxide ore formation. The field relationships and the overall geological evidence at the XIV iron occurrence indicate that the aplitic host rocks were roughly synchronous and coeval with mineralization. The magnetite-hematite ores of the XIV iron prospect were probably formed by magmatic differentiation and magma mixing of the gabbro and granitic magmas. Moreover, the Fe-melt has been derived from it by liquid immiscibility which separated from a silica-rich melt.

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