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Petrography and Mineralogy of the iron ore from Nawgwezany Mishao area– Shalair Valley, KRG - Iraq: Insights on the Genesis

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Abstract

Iron ore deposits have been identified from Nawgwezany Mishao in the Shalair Valley area within the Iraqi Zagros Suture Zone (IZSZ) at NE-Iraq. The iron ore is mainly hosted by the Shalair Metamorphic Rock Group calcschist. The transmitted and reflected light microscope study and X-ray diffraction of the calcschist revealed that the predominance minerals are calcite, and sillimanite, while muscovite, graphite, k-feldspar, and opaque mineral represent minor constituents. Meanwhile, skarn host rock as a second host rock shows the mineral assemblages of clinopyroxene, quartz, hornblende, epidote, plagioclase, sericite, garnet, and opaque minerals. The field and petrographical data indicated that the iron ore includes magnetite, hematite, pyrite, martite, goethite, and limonite. Magnetite and hematite constitute the predominant minerals of the ores, which display variable shape sizes (from < 1 cm to > 10 m) and chiefly occurred as massive, veins, veinlets, and disseminated grains. Based on some magnetite grains, filled veins in the host rocks support the hydrothermal ore-forming processes. The paragenetic sequence of iron ore and the presence of dendritic manganese texture on the surface of some of the skarn host rocks, as well as the petrographical identification of calcite twins in calcschist of types one and two, are the three reasons that point to the hydrothermal skarn origin of the iron ore. Overall field evidence, morphology, mineralogy, textures, calcite twins, and dendritic manganese texture on the surface of calcshist host rocks suggest that the Nawgwezany Mishao iron ore is related to the hydrothermal skarn deposit.

Keywords: Iron ore, Shalair Metamorphic Rock Group (SMRG), Nawgwezany Mishao-Shalair valley, Hydrothermal-skarn, Kurdistan Region.

بتروكرافية و معدنية رواسب خام الحديد في منطقة ناوگويزانى ميشياو – وادي شلير، إقليم كردستان – العراق : تأكيد على اصل و منِشأ الخام

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تم اكتشاف رواسب خام الحديد في ناوگويزانى ميشياو في منطقة وادي شلير التابعة الى النطاق الزاكروس العراقية القاطعة (IZSZ) – شمال شرق العراق. الصخور كالكشيست من مجموعة الشلير المتحولة و الصخور السكارن يستضيف هذا خام بشكل أساسي . ، اضهرت دراسة الخام الحديد و الصخور المضيفة باستخدام المجهر الضوئي المستقطب و المجهر الضوئي المنعكس ، بلاضافة الى استخدام حيود الأشعة السينية بأن المعادن السائدة و المكونة للصخور كالكشيست المستضيفة هي الكالسيت ، بينما يمثل المسكوفيت والجرافيت والفلدسبار والمعادن المعتمة تمثل المكونات الثانوية. اما الصخور المضيفة من نوع السكارن تتكون من كلينوبيروكسين ، كوارتز، هورنبلند ، إبيدوت ، بلاجيوكليس ، سيريسيت ، كارنيت ، والمعادن المعتمة. تبينت الدراسة الحقلية والبتروغرافية للخام الحديد وجود انواع متعددة من اكاسيد وهايروكسيد الحديد مثل المغنتايت، الهيماتيت ، والبيريت ، المارتيت ، والجيوثايت ، الليمونيت ولكن المكون الاساسي والسائد هي المغنتايت والهيماتيت والتي تتميز بأحجام معدنية متغيرة (من <1 سم إلى> 10 م) . تتواجد الخام الحديد باشكال مختلفة منها شكل كتلية massive, عروق Vein و حبيبات منتشرة disseminated grains داخل الصخور المضيفة والاكثر سائدا هي الشكل الكتلي. تواجد بعض العروق المملوءة بحبيبات المغنتيت في الصخور المضيفة تدعم بأن الخام الحديد في منطقة الدراسة تكونت بفعل االسوئل الحرمائية (Hydrothermal). بالاضافة الى ذلك تسلسل باراجينيتيك لتمعدن الحديد , ظهور النسيج الشجيري على سطح بعض صخور سكارن المضيفة , تحديد توائم الكالسيت من النوعين الأول والثاني في الدراسة الصخرية للكللكشست يشير إلى أن منشأ الخام الحديد يعود الى المحاليل الحرمائية. بصورة عامة تشير الدلائل الحقلية الشاملة ، مورفولوجية الخام , معدنية الخام ، النسيج ا، وتوائم الكالسيت ، ووجود المنغنيز الشجيري على الصخور الكلكشست المضيفة بأن الخام الحديد في ناوگويزانى ميشياو تكونت بسبب المحاليل الحرمائية.

1. Introduction

Iron ore is a naturally occurring material that is utilized to extract metallic iron under existing economic and technological conditions. Iron is an abundant element in the crust of the earth, ranging from 2 to 3% in sedimentary rocks to 8.5% in gabbro and basalt, which ranks iron as the fourth most abundant element in the earth's crust [1]. Up to 98% of iron ore is utilized as the major raw material in the production of steel, with the remaining fraction going to processes such as cement manufacturing and coal washeries [2]. Moreover, over 300 iron contains minerals, but the top four primary sources of iron are hematite, magnetite, goethite, and pyrite.

The Nawgwezany Mishao iron ore is situated in the Shalair Valley area within the Iraqi Zagros Suture Zone (IZSZ) at the border of Iran and Iraq (Figure 1a). The exposed rocks in the studied area belong to Shalair Zone, the most interesting area for metallic mineralization in Iraq. The study area evidenced a lack of geological details because of political instability in the last decades. Hence, this area is needed a systematic study for a better understanding from economic point of view. Tectonically, Shalair Zone runs parallel to the Zagros Fold-Thrust Belt (Figures 1b and c). The host rocks were composed of calc-schist and skarn lithologies and held iron ore in the form of magnetite and hematite with different concentrations. In this paper, we constrain the mineralogy, textures and morphology of iron ore and the host rock to provide important insights into the genesis of the Nawgwezany Mishao iron ore. The research begins with a strategy to gather seventeen samples of iron ore and ten of their host rocks in the area. Thin sections and polished sections were prepared for a petrographical study. In addition, mineralogical analyses were performed by using XRD.

The investigated iron ore in Nawgwezany Mishao - Shalair Valley has not been studied previously due to the area remoteness and being a sensitive region located on the Iran-Iraq border. The Shalair valley rocks in the Zagros Suture Zone have been classified into two groups: Penjween series and Shalair phyllite series [3], and the granitic intrusions on both limbs of the

Shalair anticline which is trondhjmetics differentiation of the ophiolite [4]. The Shalair Metamorphic Rock Group (SMRG) and Katar Rash Volcanic Group (KRVG) were studied by [5] for their petrology, geochemistry, and tectonic environment. Furthermore, petrology of the Mishao granitoid intrusive bodies were studied by [6], and petrogenesis and geochronology of Mishao peraluminous I-type granites were considered [7]. [8] discussed the stratigraphy of the previous igneous units of the Penjween area (including Shalair valley) and their relations with Kolosh Formations, and they proved that they are sedimentary succession belonging to Walash and Naoperdan Formations (Groups). [9] They studied the origin of quartz veins associated with Shalair group and concluded that these quartz veins originated from hydrothermal fluid, possibly MVT. Consequently, no single study exists about Mishao iron ore. The absence of publishing about Mishao iron ore in Iraq was attributed to inadequate work. So, the current study is a unique academic work about iron in that area.

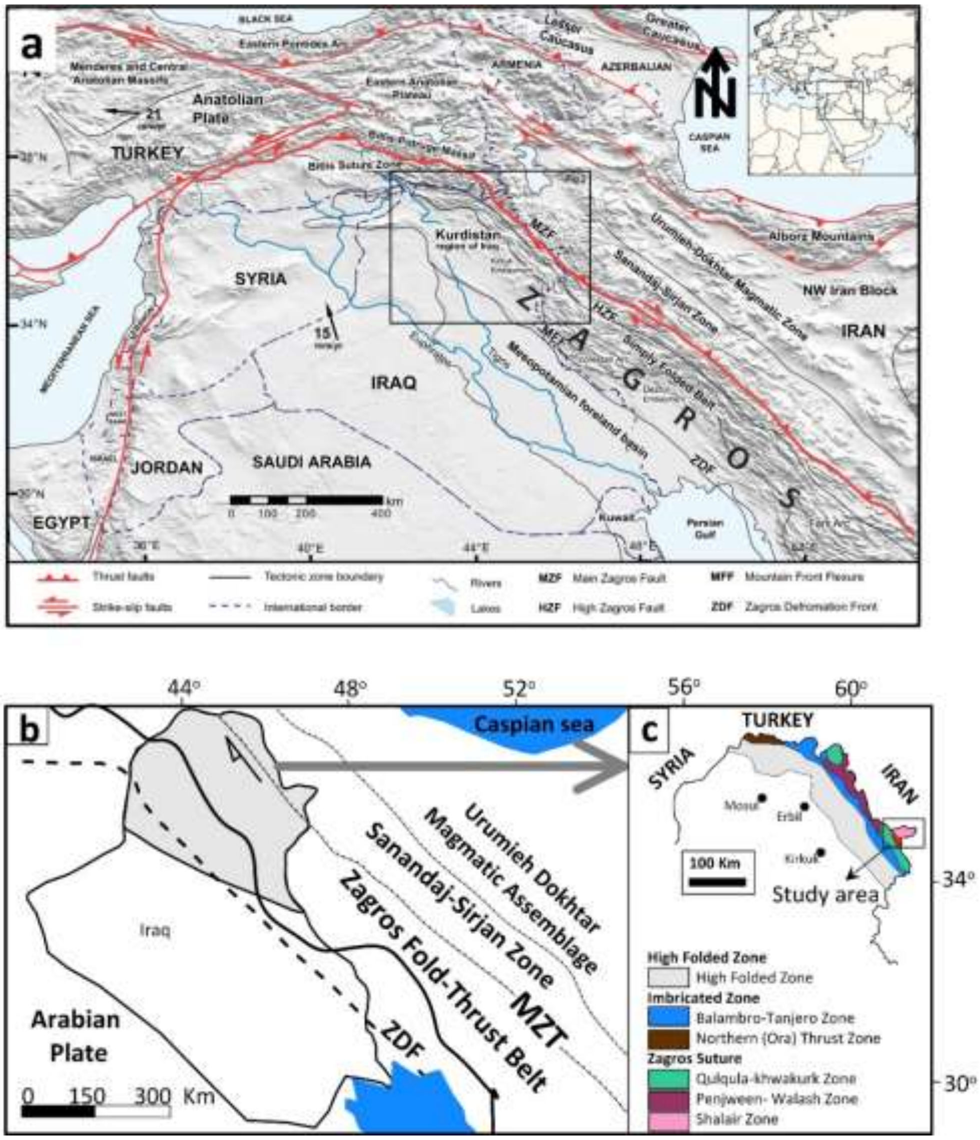

Figure 1: (a) Regional tectonic map of the Arabian Plate (After [10]) ; (b) The primary tectonic units that constitute the Zagros Orogenic Belt (Modified from [11]). ZDF: Zagros Deformation Front; MZT- Main Zagros Thrust; (c) Tectonic zones in Iraqi Zagros Suture Zone (Adapted from [12]). Illustrating the distribution of igneous and metamorphic rocks.

2. Geological setting

The Zagros Orogenic Belt (ZOB) is a part of the Alpine-Himalayan Orogenic Belt. ZOB formed as a result of subduction, obduction, and collision processes, that are connected to the opening and closing of the Neo-Tethys Ocean beneath the Iranian Plate [13]. Northern and northeastern Iraq are regarded as a part of the (ZOB), which extends from southeast Turkey to northern Oman through northeastern Iraq and northwestern Iran [11]. The research location is situated in the Shalair Valley within the Iraqi Suture Zone in extreme northeastern Iraq, close to the Iranian border. There are three units in the Zagros Suture Zone in northeastern Iraq: the Qulqula-Khwakurk, the Penjween-Walash, and the Shalair units [12].

The Shalair unit, also known as the Shalair Terrane [14], is considered as part of the northern Sanandaj Sirjan Zone (SSZ) of Iran and is found within the Iraqi Zagros Suture Zone (IZSZ). The SSZ is believed to represent the highest thrust sheet located in the Shalair Valley (Figure 2a). The majority of the SSZ occurs in Iran, a narrow area between Iraq and Iran that is approximately 1500 km long and 150–250 km wide [15, 16] [17]. The Zagros Thrust Zone represented the tectonic boundary between the Arabian and Iranian plates, and is considered major metallogenic zone accumulation that has been deformed significantly due to plate tectonics [18].

The Shalair Valley has a complicated topography and highly thrusted fault that has moved from the northeast to the southeast along low angle thrust plane, including rugged mountains and extremely steep valleys. It is structurally an eroded asymmetrical east-west large anticline gently plunging toward the east [19, 20]. The dip value is between 20° and 40° for the northern limb and between 30° and 70° for the southern limb. The tectonostratigraphic of Shalair valley, represented by the Mishao complex, consists of granite intrusions[7], Darokhan limestone in the core of Shalair anticline, Shalair metamorphic rock group[5], rhyolite and andesite of Katar Rash volcanic group, and Piran limestone.

The Shalair Metamorphic Rock Group (SMRG) is located in the northern exposure area in Iraq with a range of lithological units and forms part of the western boundary of the active Iranian plate. Three lithological units characterize the SMRG. These are metapelite (slate and phyllite), metacarbonate (marble and calc schist), and metaarenite (greywacke). The low-grade metamorphism of the greenschist facies is a regional metamorphic transformation of all these rocks [3, 5, 19]. The SMRG (Aptian – Cenomanian) is the largest stratigraphic unit inside the Thrust Fault Zone.

The Shalair group covers most of the Shalair Valley, including 2000 m quartz-sericite schists, sericite schists, slightly clayey schist, slightly metamorphosed limestones and tuffaceous slates. It has relatively rare recrystallized limestones**,** with some lenticular limestone and felsic volcanic rocks [12, 20, 21] [22].

The iron ores are cropping out within the Shalair group (also known as the Qandil Group[22]). The contact with the overlying Katar Rash group is unclear, and it could be either gradational or a low-angle unconformity [12]. Based on microfacies analyses of limestones in the upper part of the Shalair group underlying the Katar Rash series, the estimated age of the Shalair group is Aptian-Cenomanian [12]. To confirm this age, geochronological research is necessary. The Shalair group, formed in a fore-arc basin in front of the subduction zone that dips underneath the SSZ, continues into the SSZ [12]. The Aulan, Sirstan, Laladar and Mishao granites are four intrusive granitic bodies that are found along the limbs of the Shalair anticline within the Katar Rash volcanic series. Based on their U-Pb zircon dates, these granitoid rocks are 110 Ma for the Sirstan granitoid rocks [6] and 108 Ma for the Aulan rocks[23]. The

Dammana body, an intrusive body that appears from the Shalair group in the core of this anticline, records zircon U-Pb dates ranging from 364 to 372 Ma [24]. The Mishao granitic consists of three bodies situated south of Mishao village, within the Katar Rash volcanic rocks and surrounded by schist [7] (Figure 2b).

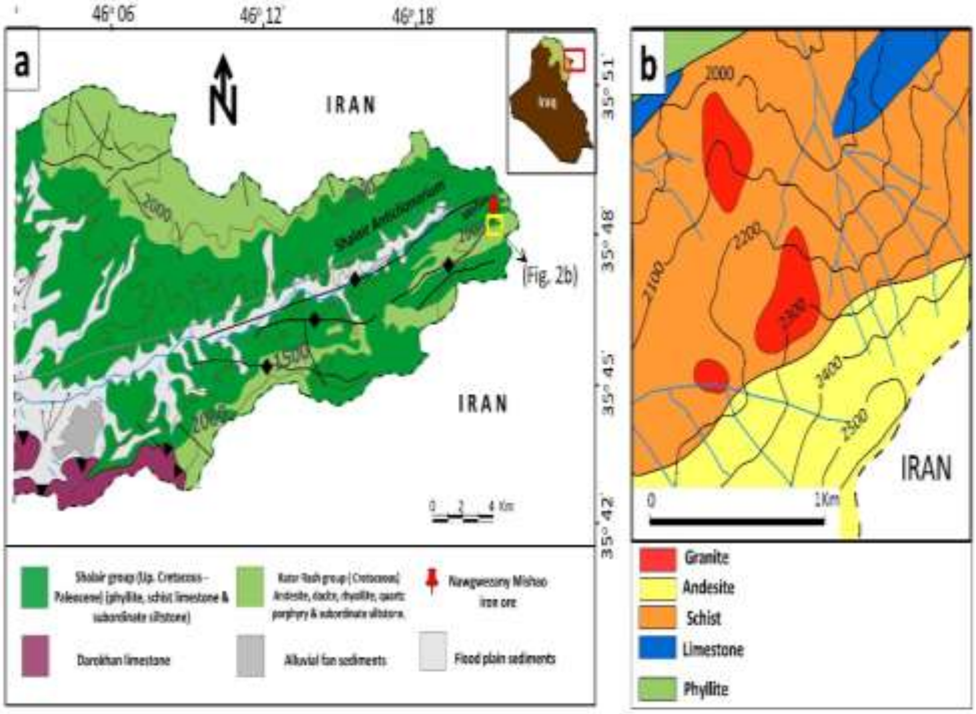

Figure 2: (a) Shalair Valley location on a geological map from [25]; (b) The Mishao granites (MG) sample locations are displayed as solid circles. (after [7, 21]).

3. Analytical techniques

Extensive fieldwork and sampling were carried out around the studied iron ores and their host rocks to comprehend the petrography and mineralogy in the Nawgwezany Mishao. Ten thin sections were prepared in the Geology Department Laboratory of Sulaimani University in the Kurdistan Region, besides six polished sections at the Kurdistan Institution for Strategic Studies and Scientific Research in the Kurdistan Region. Thin sections and polished blocks were examined using Meiji optical Transmitted and Reflected light microscopy to determine the mineralogy and textural relationships of host rocks and ore minerals, focusing on the morphology and texture of iron and associated minerals. Petrography was followed by laboratory work, whereas three samples of host rocks (two calcschist, one skarn rock) and six samples of iron ores were chosen for X-ray diffraction (XRD) analysis to discriminate their mineralogy. The XRD analysis was done at the Scientific Research Center (SRC) of Soran University in the Kurdistan Region.

4. Result

4.1 Field observation of Nawgwezany Mishao iron ore

The iron ore of Nawgwezany Mishao samples is visible along the southern limb of the Shalair anticline within the Shalair metamorphic rock group and is represented by magnetite, hematite, pyrite, goethite, and limonite. This study focused only on magnetite and hematite iron ores. The thickness of the W-E trending iron ore varies from 1 to 15 m and 30 m in length (Figure 3a). Two different types of host rocks for iron ore in the studied area have been distinguished, represented by calcshist and skarn. The calcschist and skarn host rocks are distributed near or along cracks of iron ores and between a few centimeters to a few meters in thickness (Figure 3c). Magnetite, the predominant iron ore in the study area, is commonly exhibited as massive, prominent veins, veinlets, and disseminate, with their dimensions varying from 5 cm to 10 m (Figures 3b, c, and e). Hematite is the second main iron ore in the present work, displaying massive and brecciated-like texture with variable sizes (from < 1 cm to > 10 m) (Figure 3d). The secondary iron oxide is goethite, produced by the weathering of magnetite and hematite (Figure 3b). In addition, small yellowish-brown limonite occurred between hematite ores (Figure 3d). Moreover, manganese oxides were observed as a dendritic texture on the surface of some of the skarn rock host beds (Figures 4a, b, and c).

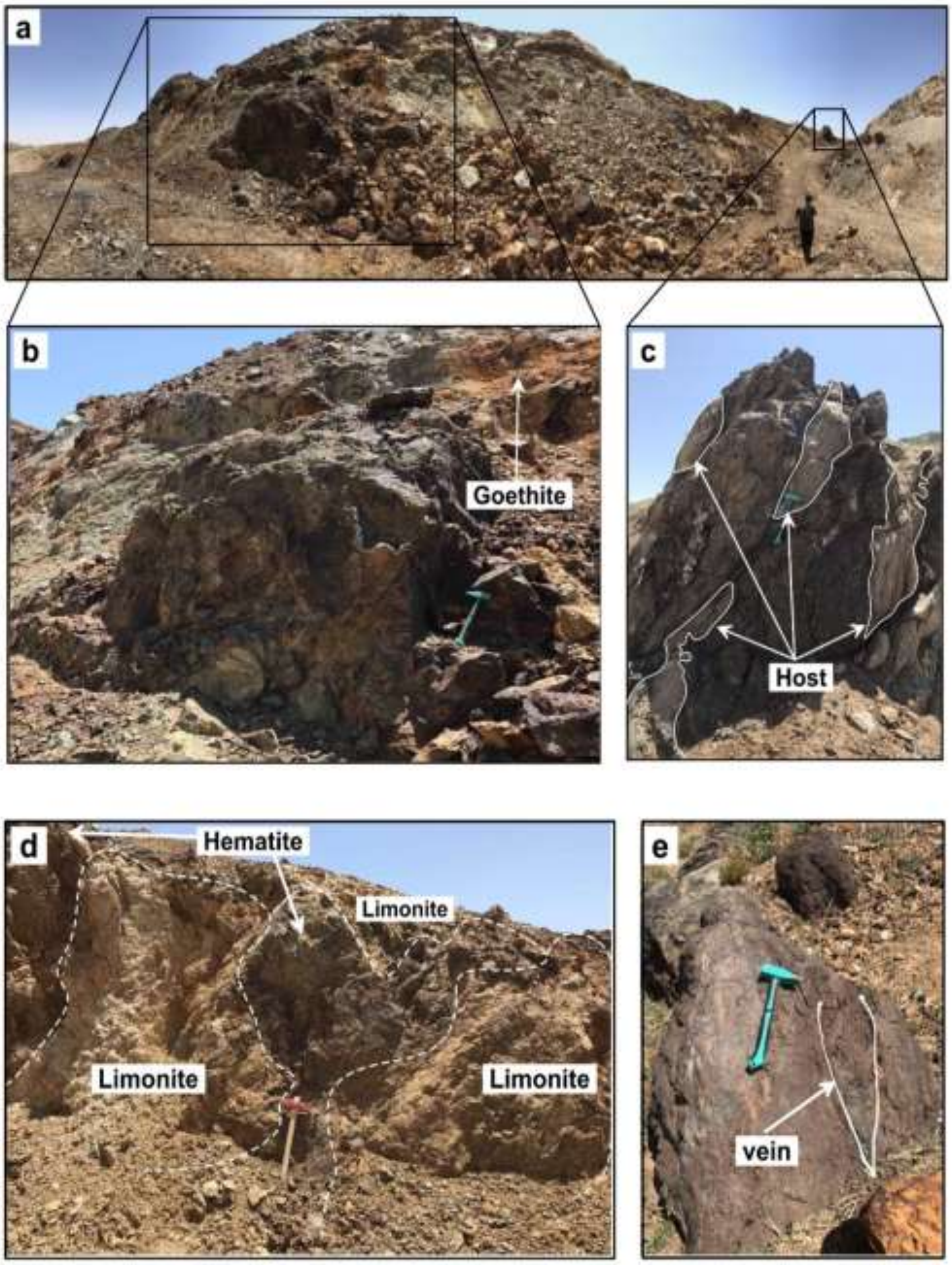

Figure 3: (a) Field photographs of the Nawgwezany Mishao iron ores showing; (b) Goethite iron ore above massive magnetite ore; (c) Calcschist rocks along cracks of magnetite ores; (d) Yellowish-brown limonite between hematite ores; (e) Magnetite ore exhibit as vein.

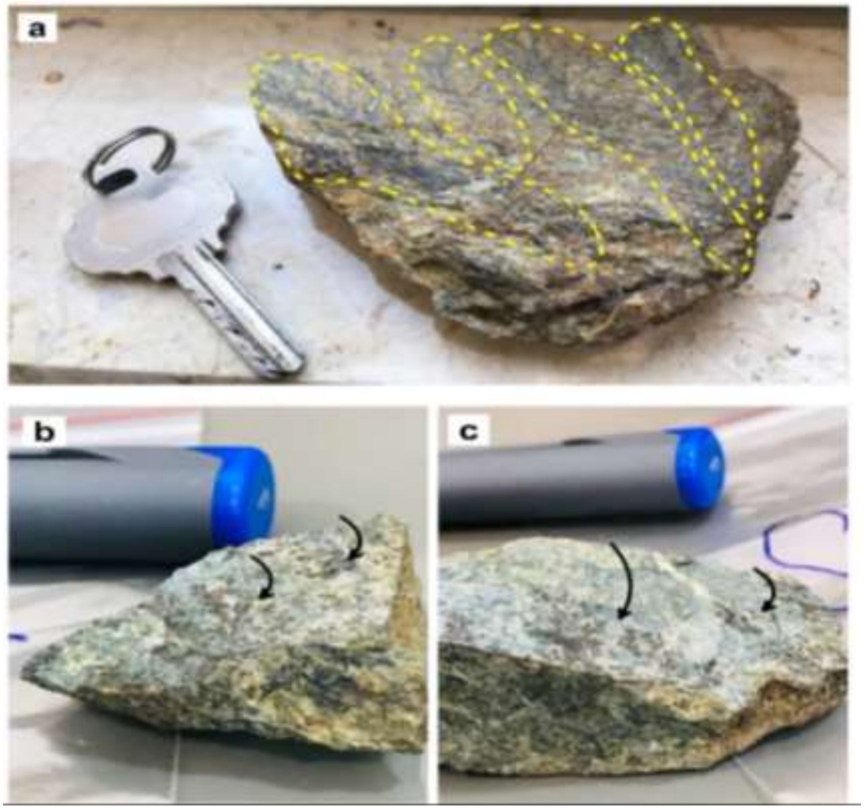

Figure 4: (a), (b), and (c) Shows dendritic texture on the surface of some of the skarn host beds taken from Nawgwezany Mishao.

4.2 Petrography

4.2.1 Petrography of the host rocks

Two different types of host rocks in the Nawgwezany Mishao were identified, It included calcschist and skarn rock. Calcschist is the primary host rock that represents Shalair metamorphic rock group. The petrography of the Nawgwezany Mishao host rocks is more complex than in other places due to the intense thrust-related deformation in the area and the unclear original stratigraphic relationship of the Shalair Group with others (lack of field data). The XRD data and petrography of the calcschist showed the predominance of calcite with the minor occurrence of muscovite, graphite, k-feldspar, and opaque mineral (Figures 5a and b). In contrast, skarn rock consists mainly of plagioclase with traces of epidote, quartz, clinopyroxene, hornblende, and opaque minerals (Figure 5c). The calcschist is the main host rock in Nawgwezany Mishao. Calcschist is constituted of calcite, k-feldspar, and magnetite grain porphyroclasts in fine-grained graphite, sillimanite, biotite and white muscovite matrix (Figures 6a and b). The white muscovite, elongated sillimanite and small amount of graphite mineral assemblage on the mylonitic foliation texture indicate an initial activation of the shear zone and exhibit helicitic texture (Figures 6c and d). In addition, the opaque magnetite octahedral crystal forms were recognized along the foliation in different sizes from 0.2 to 0.5mm (Figures 6e and f). The micro faults cross-cut the veins-filled calcite (Figures 7a, b, c, and d).

The microscopic study of the calcschist consists mainly of calcite. Due to the location of part of the calc-schist in the shear zone in the area, calcite exhibits a deformation twin texture, with lamellae twining and crossing parallel to the rhomb edges (Figures 6g, and h). Based on studies, it is known that with increasing deformation temperature, the thickness of calcite twins increases. The stability of the relationship and its case of use have resulted in the morphology changes in the twins in calcite (Burkhard, 1993) (Figure 8). [26] classified the calcite twin according to the appearance of the calcite twining into three types; thin twins at a temperatures less than 170 °C, and thick twins at temperatures above 200 °C. Accordingly, these two calcite twins were recognized in the studied calcschist samples, represented by types 1 and 2 (Figures 6g and h).

Skarn rock is the second host rock observed in the current area, composed of a green-colored rock and microscope characterized by porphyritic texture. Moreover, the phenocryst mineralogical composition of skarn rock consists mainly of plagioclase and hornblende with sizes ≤1 mm. The phenocrysts are surrounded by a fine-grained groundmass of clinopyroxene, quartz, diopside, epidote, and opaque minerals (Figures 9a-h). The plagioclase crystals compositions range from albite to oligoclase. The plagioclase crystals display evidence of alteration to sericite, fracturing, and granulation and exhibit vitrophyric texture (Figures 9a, c, and d).

Furthermore, clinopyroxene is mainly found as small inclusions (> 0.2 mm) with the quartz (Figures 9a and b). As a result of the deformation, the quartz grains show wavy extinction, their dimension ranging from 0.1 to 0.2 mm. Also, the shear zone in the area resulted in skarn alteration and led to the formation of aqueous minerals such as epidote. Epidote developed as an aggregate filling open spaces next to sericite (Figures 9c and d). Moreover, some magnetite grains filled veins in the host rocks (Figures 9e and f). In addition, garnet occurs as euhedral to subhedral fine to coarse-grained crystals (0.5–1 cm; Figures 9g and h). Greyish green diopside grains mostly appear as stubby prisms elongate, basal cross sections show the two cleavages at ~87°, anisotropic, simple twining (Figure 9i, and j).

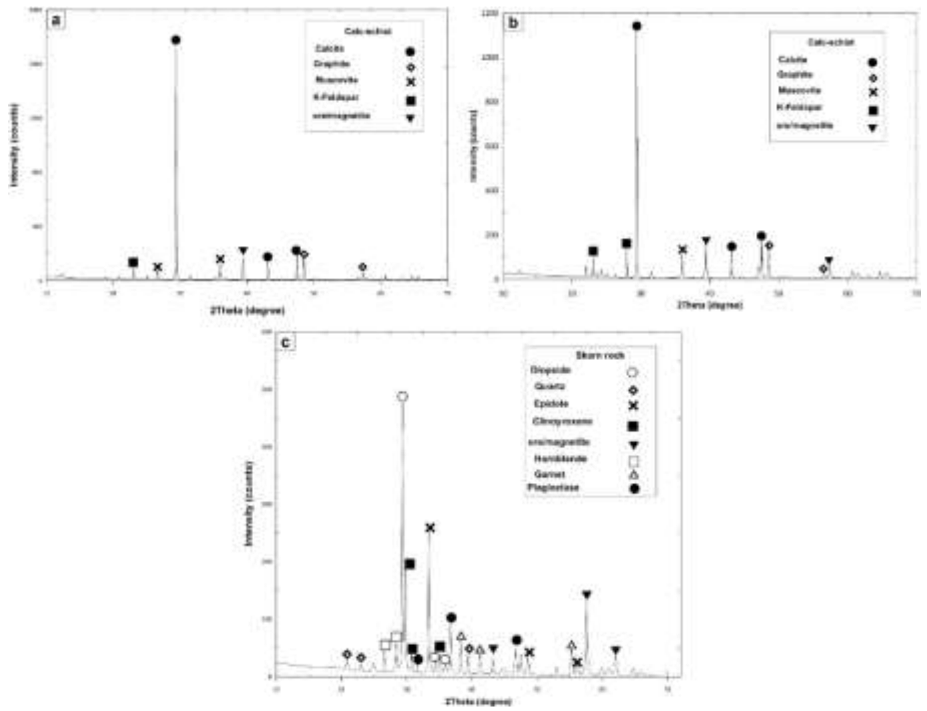

Figure 5: Diffractograms from using X-ray diffraction for the host rocks; (**a**) and (**b**) Calcschist; (**c**) Skarn rock.

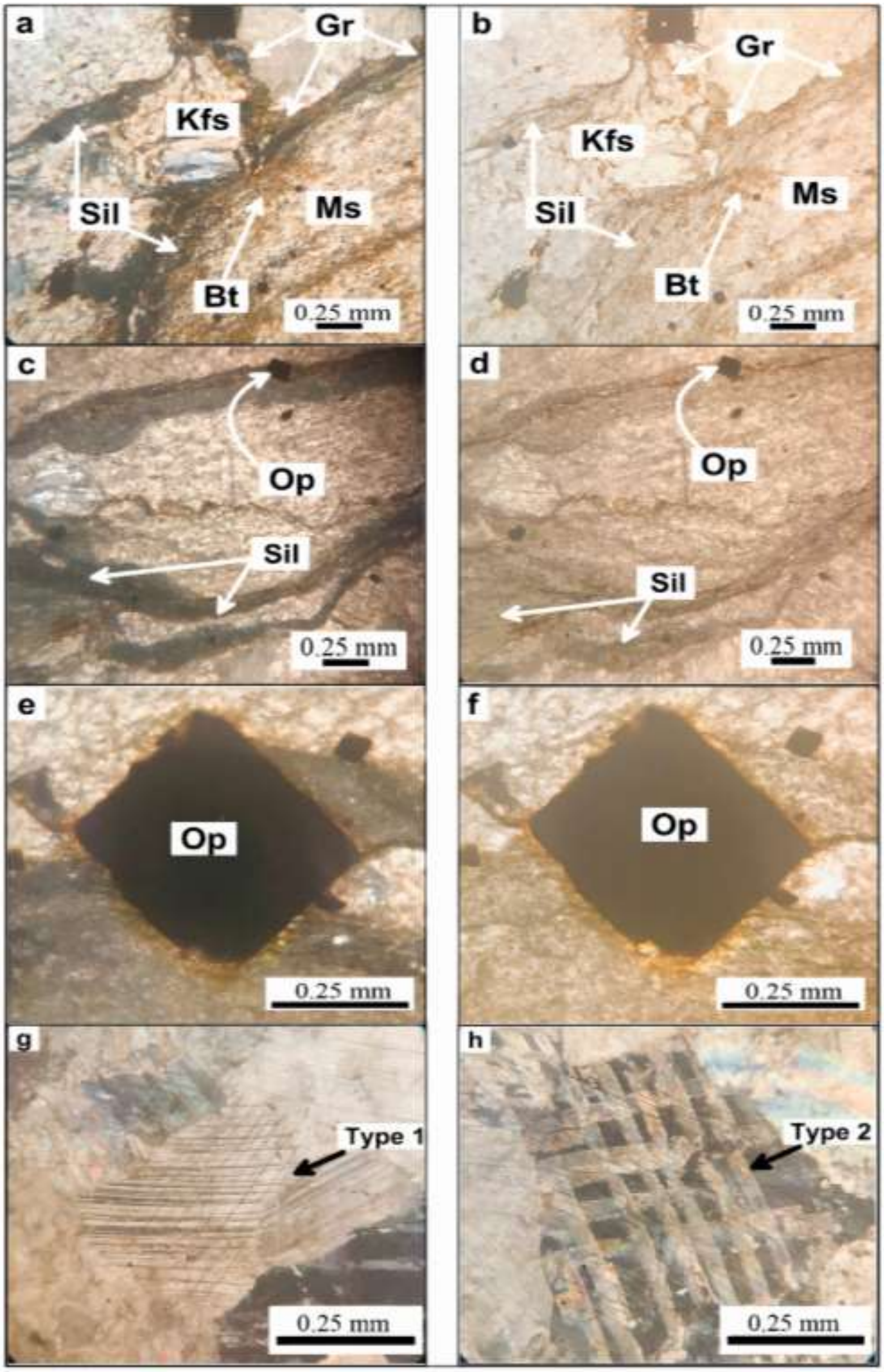

Figure 6: Photomicrographs were taken in both cross-polarized light and plane-polarized light showing mineral assemblages of calc-schist; (a) and (b) fine-grained muscovite, sillimanite, graphite, biotite and white mica matrix within mylonite texture; (c) and (d) Helicitic texture; (e) and (f) Opaque magnetite octahedral crystal; (g) and (h) Mechanical models type 1 and 2 in calcite samples in the shear zone of the Nawgwezany Mishao area. Mineral abbreviations: Gr, graphite; Kfs, k-feldspar; Op, opaque minerals; Ms, muscovite, Sil, sillimanite; Bt, biotite

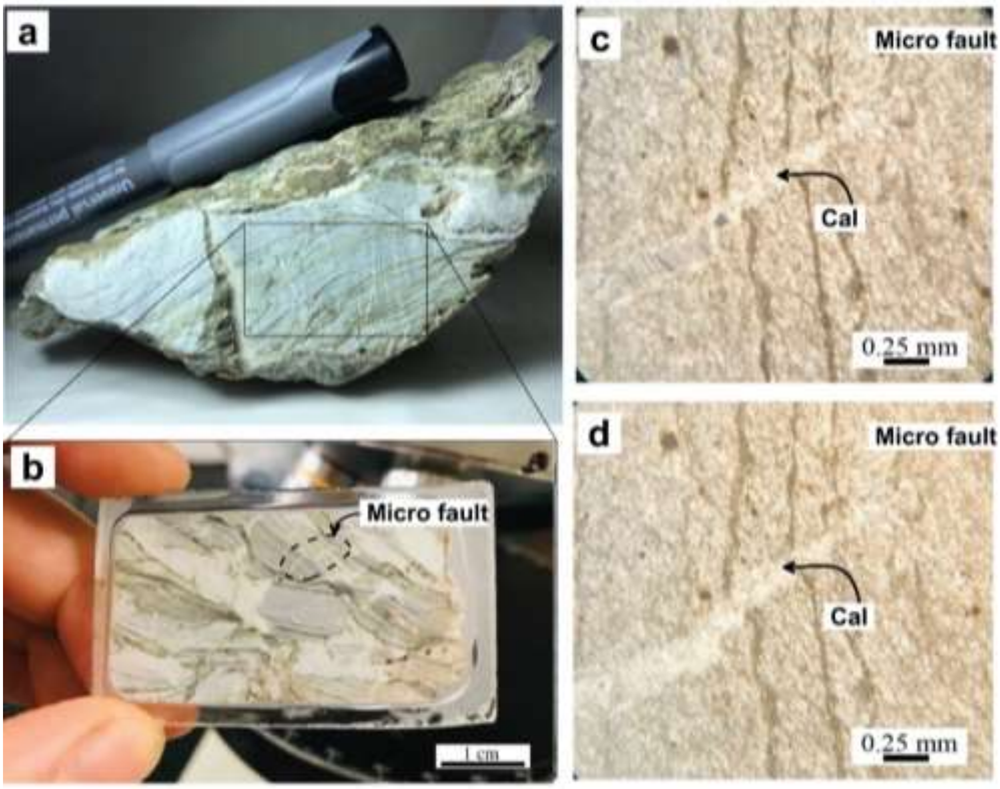

Figure 7: (a) Shows samples of calc-schist taken from Nawgwezany Mishao; (b) Displays micro fault within Calc-schist; (c) and (d) Photomicrographs taken in both cross-polarized light and plane polarized light showing the micro faults were filled with the calcite.

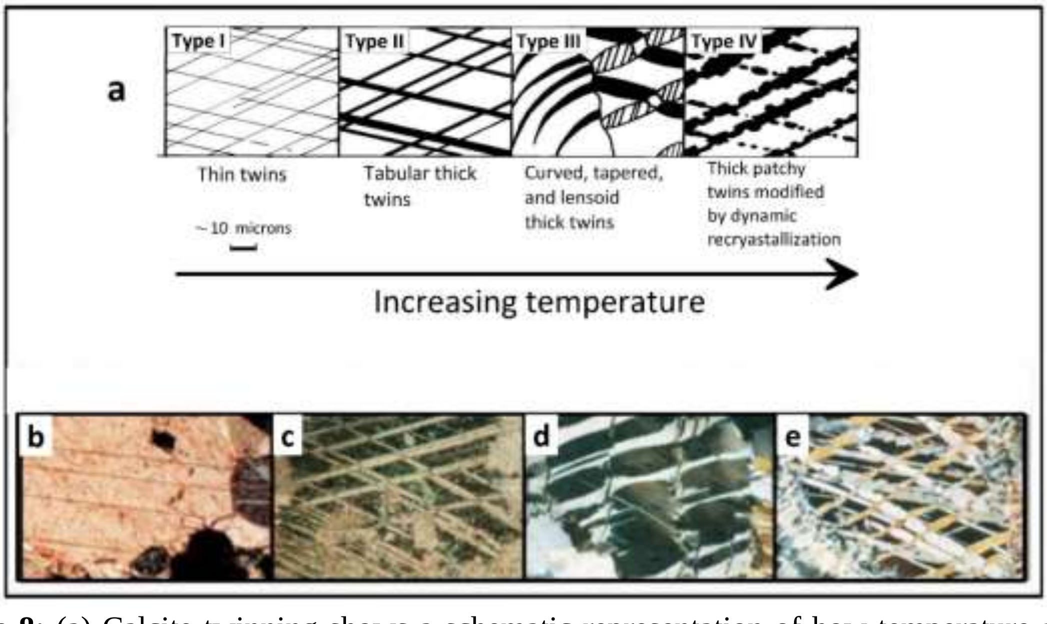

Figure 8: (a) Calcite twinning shows a schematic representation of how temperature affects deformation after [27] ; (b) Type I twins from the northern Subalpine Chain, France [28]; (c) Type II twins from the Great Valley, Central Appalachian Valley, and Ridge Province from the North Mountain thrust sheet [29]; (d) Type III twins from the Diablerets nappe of the Ardon thrust slice in the Helvetic Alps [30]; (e) Type IV twins from the Doldenhorn nappe in the Helvetic Alps [30].

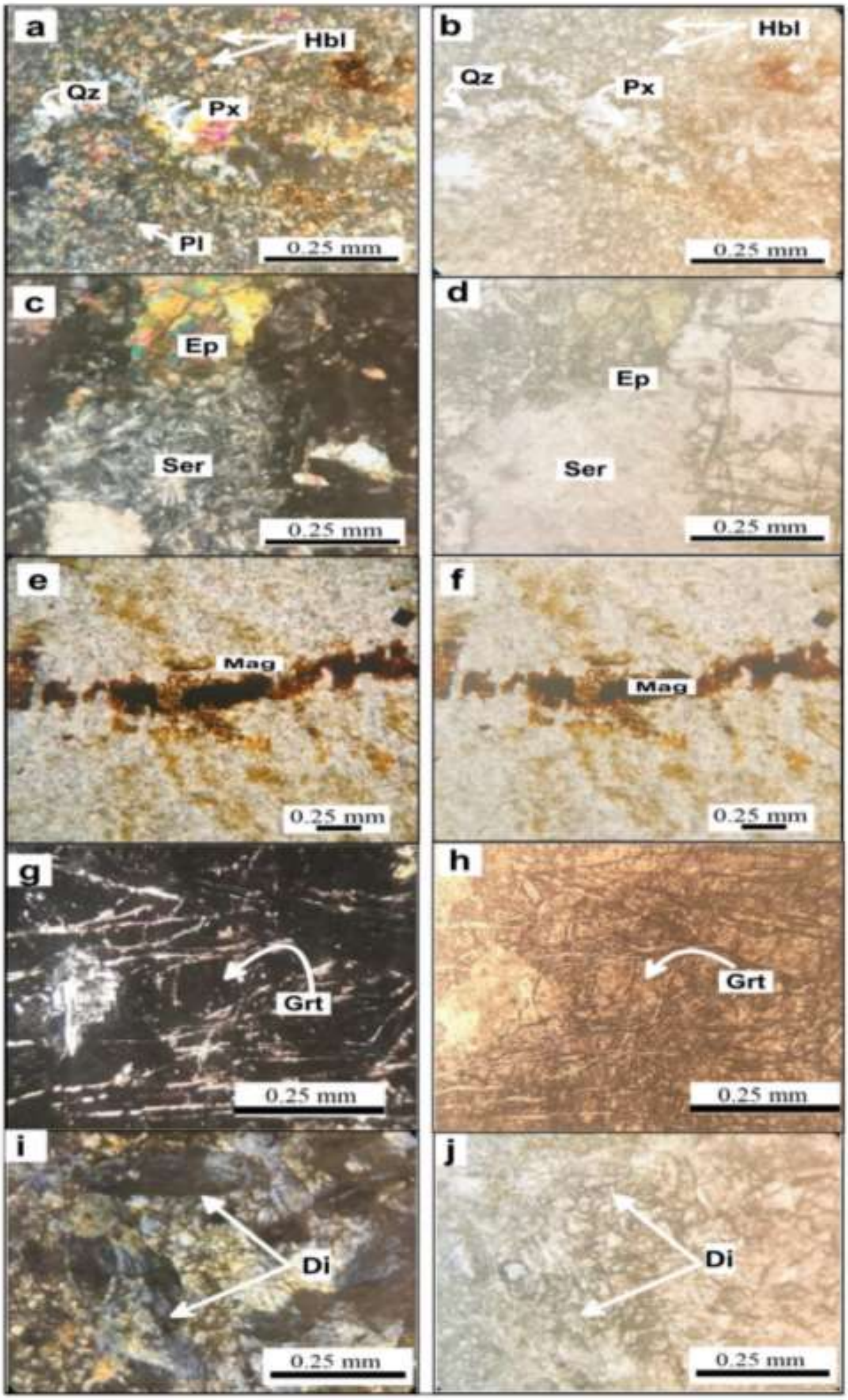

Figure 9: Photomicrographs under cross-polarized light and plane-polarized light showing mineral assemblages of skarn rock; (a) and (b) Porphyritic texture containing quartz, plagioclase, hornblende, and pyroxene; (c) and (d) Sericite alteration with epidote; (e) and (f) Vein of magnetite within skarn rock; (g) and (h) Euhedral to subhedral garnet; (i) and (j) Greyish green diopside; Mineral abbreviations: Qz, quartz; Pl, plagioclase; Hbl, hornblende; Op, opaque minerals; Ser, sericite; Ep, epidote; Cpx, clinopyroxene; Grt, garnet; Di, diopside .

4.2.2 Petrography of the iron ore

The dominant iron-ore minerals are represented by magnetite, hematite, pyrite, goethite, and martite (Figures 10a, b, c, d, e, and f). Along with hematite, pyrite, and goethite, magnetite is the principal and most prevalent ore mineral studied in the polished sections. The magnetite of the Nawgwezany Mishiao area is characterized by massive and replacement texture. Their crystal size ranges from 1mm to 3mm (Figure 11a). Two types of magnetite in the selected studied area were distinguished. The first type is amorphous and spotty; it appears that the host rocks are formed by the substitution event (dissolved magnetite) (Figure 11b), and the second type is massive magnetite (Figure 11c). Magnetite contains a variety of inclusions, ranging in size from tiny inclusions (micro to nanometer) to large, irregular ones (0.1mm), which are distributed at random (Figure 11d). It is occasionally possible to see crystals with dimensions of a few millimeters. Furthermore, martitization is a process after the formation mineralization is often formed from the margin of beginning to fracture grain or within the center of the grain, causing martitic texture (Figure 11b). [31] explained the martitization as follows:

$2Fe^{+2}\ Fe^{+3}\ O_4$(Magnetite)+ $0.5O_2 = 3Fe_2^{+3}O_3$ (Hematite)

Fe_3O_4(Magnetite) +2H = Fe_2O_3(Hematite) + Fe^{+2} + H_2O

The above reaction is not an oxidation-reduction reaction but a conversion of magnetite to hematite due to the leaching of Fe^{+2}, indicating that an acidic environment has occurred. This reaction may be the main mechanism for oxide transport iron in nature, especially in hydrothermal environments [32]. Many magnetite skarn deposits are translocations of hematite primary to magnetite and magnetite to secondary hematite. These transformations are possible without an oxidant reduction [32].

The second type of magnetite, which has a massive texture, is more readily seen in areas (Figure 11a). Silicate minerals are this type of magnetite's most common gangue minerals (Figure 11e). Moreover, the hematite content is less than magnetite in the Nawgwezany Mishiao area and has different textures. The visual expectation of studied polished sections shows that the hematite content is less than 30%. By analyzing selected studied samples under a reflected light microscope, two types of hematite were distinguished, primary and secondary (Figures 11e and f). Along with fractures, primary hematite appears as an open space-filling texture. Two factors could have caused the brecciation; (1) Structural factors, influenced by the local fault controlling mineralization activity. (2) Hydrostatic pressure caused by mineralizing hydrothermal fluids [33]. In some samples, primary hematite mineralization can be seen as separated tabular crystals (Figures 11c, d, and e). In comparison, the secondary hematite shows a highly variable martite texture (Figures 11b and f), indicating that the silicate host rocks dissolved hematite.

Pyrite is the most prevalent iron sulphide mineral in studied iron ore samples. The pyrite sizes range between 1.0 and 3.0 mm and are exhibited as amorphous and hypidiomorphic. Some pyrite grains, which are in contact with silicate minerals, their margins are replaced by goethite. Based on microscopic studies, two types of pyrite are identified in the Nawgwezany Mishao deposit. Pyrite type 1 (Py1) is euhedral to subhedral their size varies between 50 microns to more than 1 mm. This type of pyrite is highly affected by faulting and shearing, and it displays severe fragmentation and brecciations (Figure 11g). Pyrites type 2 (Py2) crystals were observed in the shapes of subhedral to anhedral, with sizes ranging from 200 microns to more than 2 mm (Figure 11h). Magnetite crystals surround pyrite crystals in a texture that fills space. The percentage of pyrite minerals in the samples studied ranges between 1 and 3 % crystals. Pyrites, such as goethite and limonite, are marginally oxidized and changed into Fe-oxyhydroxides in such a way that some exhibit complete transformation (Figures 11i and j). Goethite is an abundant iron hydroxide mineral and can be found in ore body fractures. Microscopic sections revealed the collform-textured mineralization, which significantly decreases with increasing depth (Figures 11i and j), which has been observed with a boxwork texture.

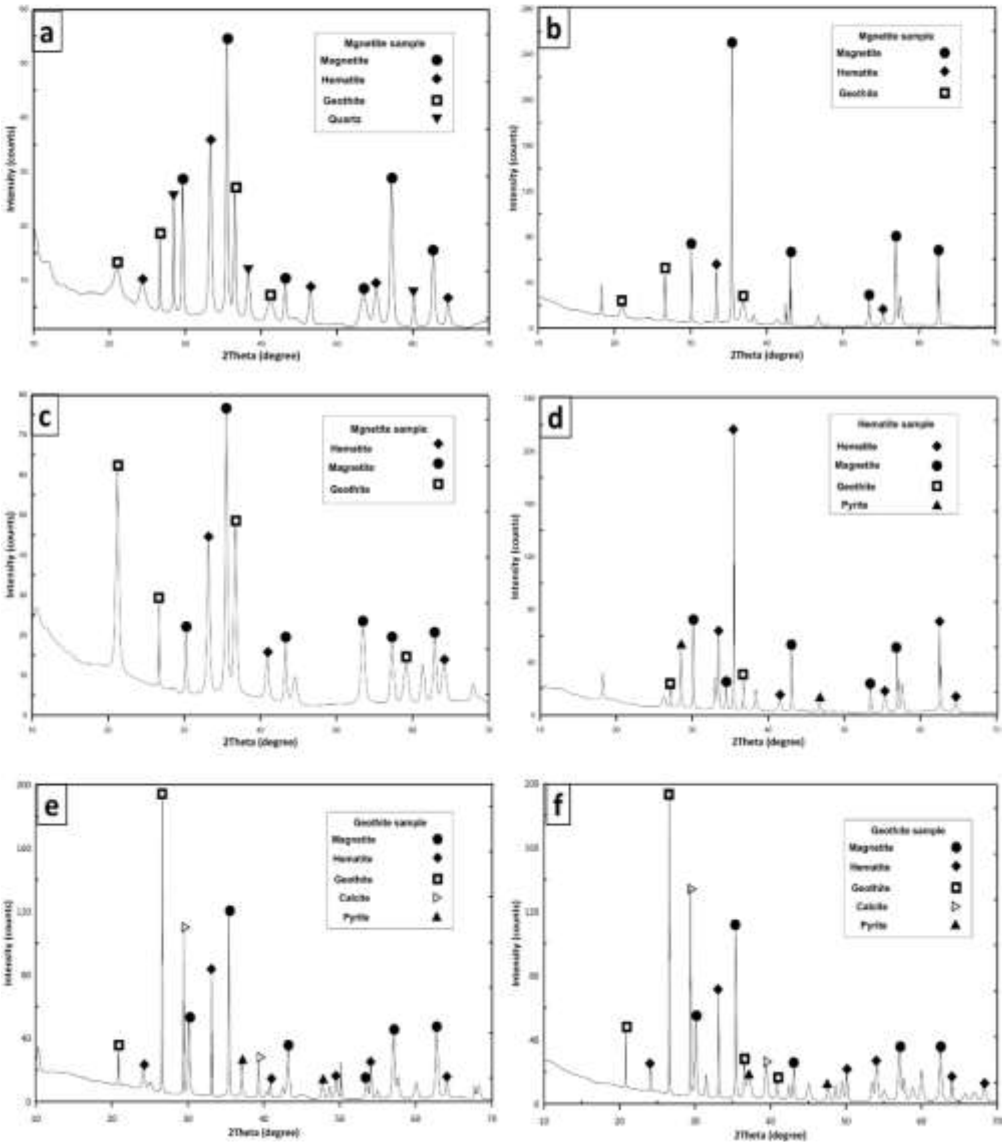

Figure 10: (a), (b), (c), (d), (e), and (f) Shown the XRD diffractograms for the iron ore in the present area.

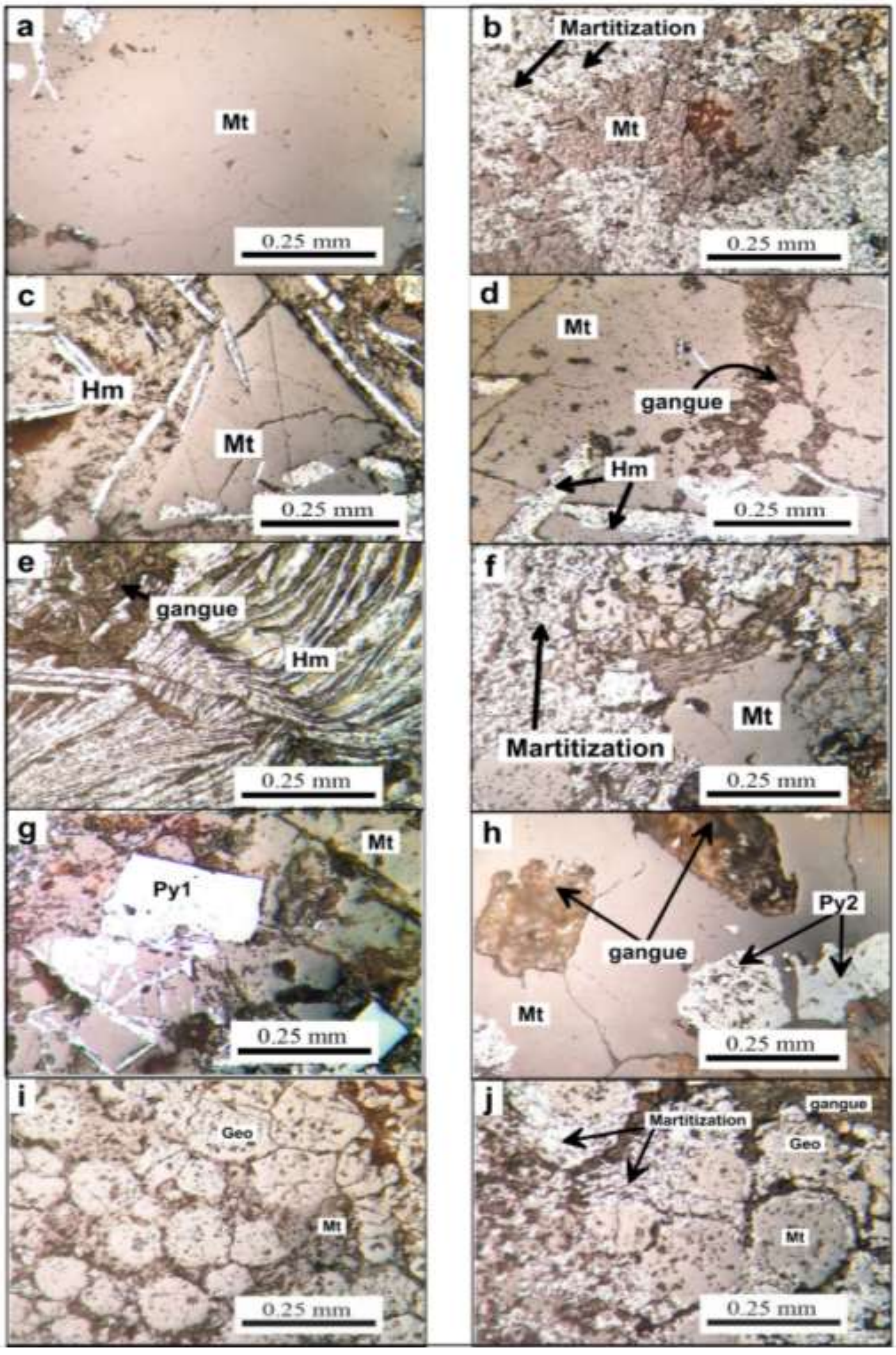

Figure 11: Reflected light photomicrographs of the Nawgwezany Mishao iron ore; (a) Massive magnetite ore; (b) Dissolved magnetite ore and martite. (c) Primary tabular hematites with magnetite; (d) Massive magnetite ore with inclusions of gangue minerals with primary tabular hematite; (e) Hematite tabular specularite crystals with open space filling primary texture have filled pores between brecciated fragments of the host rock(gangue); (f) Massive magnetite ore and martite; (g) Euhedral to a subhedral textural feature of pyrite types ore minerals; (h) Subhedral to anhedral pyrite types ore minerals; (i) and (j) Showing boxwork texture of dehydration of goethite which is formed from hematite; Abbreviations; Mt; magnetite, Hm; hematite, Py; Pyrite, Geo; goethite.

5. Discussion

Field description and petrographic study show that magnetite is the main iron ore mineral in the studied area, which is accompanied by hematite and pyrite. Garnet, plagioclase, hornblende, diopside, epidote, calcite, and quartz are present as gangue minerals; goethite was formed during the supergene processes. Under similar physiochemical conditions, magnetite is affected by several factors that affect its element contents (temperature, pressure, redox changes) [34] [35, 36]. Temperatures recorded for hydrothermal iron are approximately 100° to 300 °C for BIF hosted high-grade ore, 300° to 800 °C in porphyry deposits [35], range from 300 to 500 °C temperatures of skarn deposits [37], and > 500 °C in iron oxide ± apatite (IOA) and iron oxide-copper-gold (IOGC) type [38]. Based on these workers, the iron ore type of Nawgwezany Mishao represents the skarn ore type. The calcite twin can support this, classified as type one and two, using petrography (Figures 6g and h). Silicate melts or hydrothermal fluids can both be the source of iron ore [36]. Some researchers [39] suggested that iron oxide melts directly crystallized into vein-type magnetite ore bodies in sharp contact with host rocks, which are thin or have no alteration halos. In contrast, other authors [40] suggested that the fluid immiscibility from crystallizing silicate magmas allowed these vein-type sharp ore bodies to precipitate from iron-rich fluids. This was made possible by a rapid decrease in temperature and pressure when the fluids fluxed into the fractures [41].

Field and petrographic evidence strongly support the idea that the Nawgwezany Mishao iron deposit did not originate directly from an iron-rich melt due to: (1) the presence of host rock breccias and the absence of amygdaloidal structures, tubes, and gas bubbles that would have been occupied by other massive crystals [42] ; (2) absence of oxidation-exsolution of ilmenite lamellae on magnetite grains, which are typical signs of magnetite crystallizing in magmatic systems [43] ; (3) the presence of slight hydrothermal alteration associated with the magnetite, and calcite veins are points to influence of hydrothermal activity [44] (Figures 7c, and d).

The presence of dendritic texture on the surface of some of the skarn host rocks was a good indicator of high Mn in the rock samples of Nawgwezany Mishao may have resulted from the substitution of Fe by Mn in magnetite and hematite structure that can be a sign of hydrothermal skarn (Figures 4a, b, and c ; [45]). The major host rock microscopic profile, influenced by relatively strong tectonic forces, has become a mylonite texture with intermediate-grade metamorphism (Figures 6c and d). Furthermore, the dominant opaque mineral within the host rock is mainly characterized by magnetite; some magnetite grains fill veins in the host rocks. This type of mineralization indicates support for the hydrothermal ore-forming processes [46] (Figures 9e and f). The presence of skarn alteration and development of epidote as an aggregate filling open space (Figures 9c and d) also support that the Nawgwezany Mishao iron ore origin mainly represents a hydrothermal skarn deposit.

5.1 Paragenesis

Based on the studied samples' mineralogical data, four steps can be used to summarize the paragenetic process: 1) effect of the granitoid intrusive body; 2) applying contact metamorphism; 3) prograde and retrograde alteration; 4) iron deposited in host rocks. Iron ore occurs at the stages of prograde, retrograde (skarnification), and supergene. Skarnification can be divided into two general stages: 1) prograde skarn (anhydrous calc-silicates) and 2) retrograde skarn consisting of the hydrous calc-silicates accompanied by ore-hosting quartz veins/veinlets. They formed through metasomatic and predominantly hydrothermal fluids. Calcite, quartz, k-feldspar, and epidote were formed during the prograde stage. During the retrograde alteration, due to lower temperature, the minerals such as calcite, sericite, epidote, and hornblende are formed because of the alteration of the previous stage. Magnetite and hematite are formed at both prograde and retrograde stages. Martite and goethite are formed in alteration stages (retrograde and supergene). Pyrite is an iron sulfide ore mineral formed in the prograde and retrograde stages, while goethite and limonite represent supergene alteration products of iron oxide and pyrite minerals (Table 1).

Table 1: Paragenetic sequence in Nawgwezany Mishao minerals.

Paragenetic sequence			
Minerals	Metasomatic Alteration		Supergene alteration
	Prograde stage	Retrograde stage	
Quartz	▬▬▬	▬▬▬	▬
K-feldspar	▬▬▬		
Calcite	▬▬▬	▬▬	
Sericite	▬	▬▬▬	▬▬
Pyroxene	▬▬	▬▬	
Epidote	▬▬▬	▬▬	
Hornblende		▬▬▬	▬
Magnetite	▬▬▬	▬▬	
Hematite	▬▬▬	▬▬	
Martite		▬▬▬	▬▬
Goethite		▬▬▬	▬
Pyrite	▬▬▬	▬▬	
limonite		▬	▬▬

6. Conclusions

1-The results represent a preliminary attempt to describe the geological features and occurrence of iron ore in the Nawgwezany Mishao, which are mainly hosted within the calcschist of the Shalair Metamorphic Rock Group (SMRG) in the Shalair Valley area within the Iraqi Zagros Suture Zone (IZSZ) close to the Iranian borders in NE Iraq.

2- From the XRD and petrography studies, it is concluded that the host rocks display mineral assemblages such as clinopyroxene, calcite, diopside, quartz, plagioclase, garnet, hornblende, graphite, magnetite, martite, hematite, goethite, pyrite.

3- The dominant opaque mineral within the host rock is mainly magnetite; in some cases, magnetite grains filling veins in the host rocks. This type of mineralization indicates support for the hydrothermal ore-forming processes.

4- Two types of calcite deformation twin texture in calcschist host rocks were recognized, represented by types 1: thin twins at a temperature less than 170°C and thick twins at a temperature above 200°C.

5- Iron ore occurs as lenses, veins, veinlets, and disseminated grains in the field with variable thickness. The field observations and XRD of the Nawgwezany Mishao iron ore show that the main iron ores in the studied area include magnetite, hematite, goethite, and pyrite.

6- Two types of magnetite in the selected studied area have been distinguished, represented by amorphous and spotty; it appears that the host rocks are formed by the substitution event (dissolved magnetite), and the second type is massive magnetite.

7- The paragenetic sequence of Nawgwezany Mishao iron is summarized in four steps: 1) effect of the granitoid intrusive body; 2) applying contact metamorphism; 3) prograde and retrograde alteration; 4) iron deposited in host rocks. Consequently, magnetite grains filled veins in the host rocks, and paragenetic sequences of Nawgwezany Mishao iron ore indicate that the iron ore occurred s as a hydrothermal skarn deposit.

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