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Petrography and Geochemistry of the Ore-bearing Gabbro Intrusion of the Jabal Hamir-Juban Locality, SE Yemen

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ABSTRACT

Juban region is located about 183 km southeast of Sana'a City. The Juban gabbroic layered intrusion is associated with Fe-Ti formation Banded iron ores are hosted in a gabbroic intrusion of Tertiary age, which is injected within Cretaceous Tawilah sandstone group. Petrographic examinations of gabbro rocks show that they are composed essentially of olivine, plagioclase feldspar and magnetite minerals. The olivine mineral is present in high percentages which lead to classify the gabbro as troctolite type. The olivine is presented by fayalite, foresterite minerals in different proportions. The feldspar is present as plagioclase minerals of bytownite and anorthite compositions.

The results of chemical analysis of the major oxides present in the ore-bearing gabbro in the Jabal Hamir–Juban area show that, the iron oxide ranges from 21.05% - 49.01% with an average of 44.30%, the titanium oxide ranges from 1.86% - 7.71% with an average of 6.78%, and silica oxide has an average 23.76% .

Geochemistry of the examined gabbroic rocks are economically promising deposits for some trace elements in addition to the iron and titanium ores.

Key words: gabbro, intrusion, iron ore, geochemistry, Juban.

INTRODUCTION

Jabal Hamir lies at Juban area, directly north of Al-Lumayheyah Village, 50 km south of Rada'a Town, in the southeast of Yemen between latitudes 15 5900 – 15 5700 N and longitudes 48 2000 - 48 5000 E UTM. The mountain is extending for at least 3 km E-W direction, and 2 km N-S direction, which covers an area of 6 km (Figs. 1&3). Layered intrusions are key to understanding the genesis and chemical evolution of mafic-ultramafic magmas and the processes associated with the formation of Fe-Ti-V and platinum group element deposits[1, 2, 3, 4, 5].

Layered mafic intrusions and their stratiform Fe-Ti oxide and chromitite layers are very significant for understanding the chemical processes and physical mechanisms of magmatic evolution in a large, sheet-like magma chamber [6, 7, 8, 9, 10]. It is widely accepted that the formation of chromitite layered intrusions is associated with fractional crystallization or magma mixing [7, 11, 12, 13, 14]. However, although the Fe-Ti oxide layers in layered intrusion are commonly interpreted as accumulations of Fe-Ti oxides in late magmatic fractionation stages [4, 15, 16], some researchers have argued that they are associated with a Fe-rich immiscible liquid segregated from mafic magma [9, 16, 17, 18 , 19]. The parental melts are believed to have been derived from a mantle plume and to have been contaminated by interaction at relatively shallow depths with enriched lithosphere mantle [20]. Enrichment of the lithosphere suggests that the mantle was modified by ancient subduction of an oceanic slap [5, 20].

Jabal Hamir gabbro pluton is composed of sequences of layered rock hundred or thousand of meters thick from the bulk of the larger lopolith of funnel-shape intrusion. The plutonic rock body considered here is lopolithic type layered body and are derived from such basaltic magmas were modified, and they occupy the some tectonic setting as the basalts [10, 21, 22]. Specifically, the gabbroic body occurs in the roots of volcanic arcs, underlie volcanic mountain chains from over mantle plume and rift zone, and mark eroded zones of interaction between transform faults and continental crust [10]. Lopolithic and related layered intrusions are limited in number but are widely distributed. This stratiform body represents and area of exposure of about 6 km. This study aims at examining the petrography and chemical properties of the ore-bearing gabbro intrusion to determine their mineralogical constituents, textures and structure, and to define their economic potential.

METHODOLOGY

The methods of this study include the field work and the laboratory analyses. Field work was carried out to define the gabbroid rock units. Systematic sampling, and examination of whole the rock.

Twenty two rock samples were systematically collected from a surface the selected sections and thin section slides were prepared according to the procedure listed in [23]. The thin-sectioned slides were studied under professional petrographic microscope type (Carl Ziess). The rocks are cutting perpendicular to the layering bands of the gabbros to identify different bands of the rock forming minerals. Microphotographs illustrating the mineralogical constituent, crystal shapes, textures and the structures of ore-bearing gabbro were taken. The chemical analysis were carried out for sixteen selected rock samples representing the ore-bearing gabbro rock and other sixe also were selected rock samples to investigate some of importance trace elements. Major oxides were determined by X-ray fluorescence spectrometry (XRFS), selected trace elements were determined by WD-XRFS on pressed powder pellets.

Geologic Setting

The Juban area implies three types of rock units: the Tawilah Group, intrusive bodies and volcanic trap series. Tawilah Group composed of clastic rocks of terrigenous sediments. This group is composed mainly of sandstone rocks interbedded with little shale and claystone rocks [22]. They are of shallow marine to fluvetile origin, they are thick bedded have normal and tabular cross beddings. The age of this group is ranged from Cretaceous to Paleocene as listed in [24]. It is distributed around and southwards of the Jabal Hamir locality (Figs. 1&3). The two types of intrusive bodies are present in the Juban area, the first type is basic gabbroid body found in the south (the aim of this study), the second type is acidic granitic body found in the north (outside of study area). They occupying an area of 6 km and elevated more than 350 m height, which is composed basically of gabbroic rocks (Figs. 1&2). The rocks are of iron bearing ores, with of banded habit. The gabbroic rocks are layered and imply banded iron formation (Fig. 2). The rocks show inclined layering at the edge of the body due to the injection within the sandstone host rocks.

There is a sharp contact between the gabbroic body and the hosted sandstone rocks and implies disconformable contact (Figs. 1&2). The contact is represented by the hornfels aureole, surrounding the intrusive body (Fig. 1&3).The second occupies the northern part where the intrusive body is composed basically of granitic rocks.

The volcanic rocks are exposed northwest wards of Jabal Hamir and northward of granitic intrusion. The tertiary volcanic rocks are composed basically of basic igneous rocks (basalt) (Figs. 1).The Tertiary intrusive bodies are intruded within the Tawilah group (Fig. 1&3).

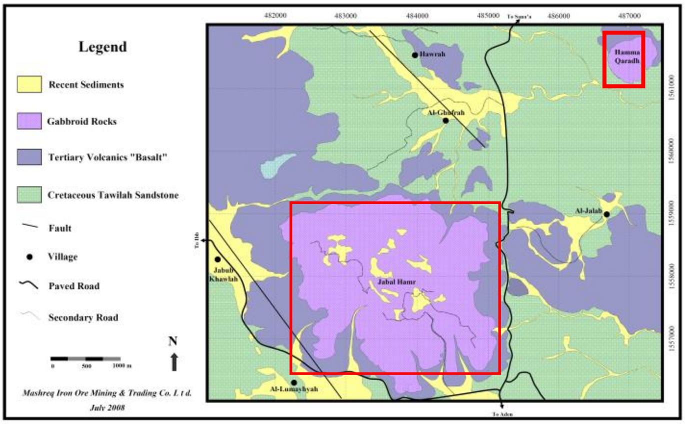

Fig. 1: Geological map of the Jabal Hamir, Juban area, SE of Yemen .The map is adapte from the Geological map of Jabal Hamir, [25].

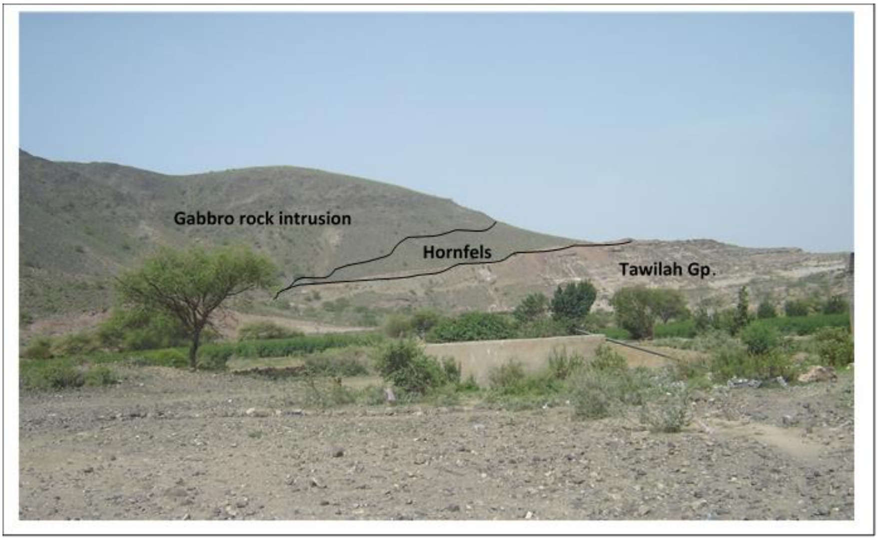

Fig. 2: Shows the exposures of the rock units at the edge of the gabbroid intrusion, which reveals the contact between Tawilah Group (at the low), Hornfels rocks and the main gabbro pluton, in Jabal Hamir view General -Juban area.

pluton, in Jabal Hamir view General -Juban area.

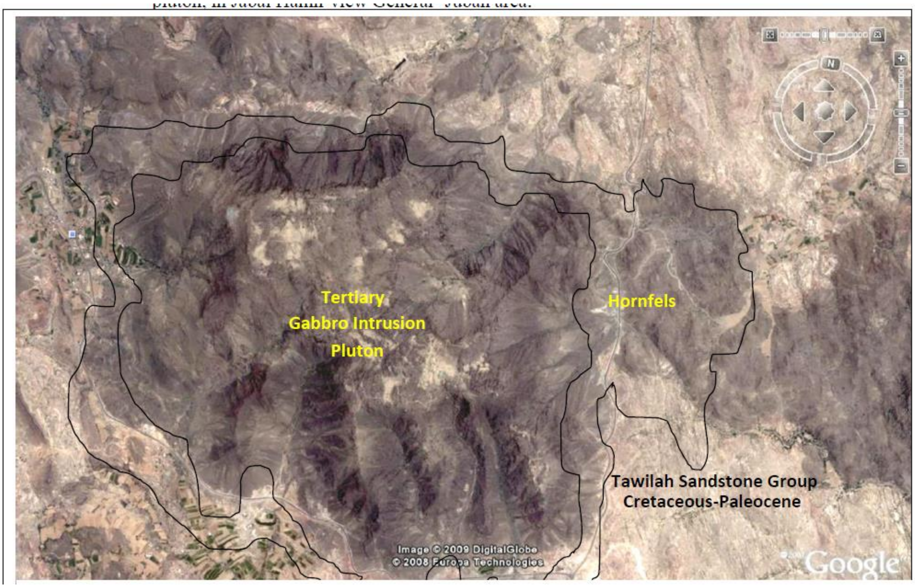

Fig. 3: Satellite image shows the gabbro bearing iron-ore intrusion with other surrounding exposed geological units in Juban area, SE of Yemen.

Petrography

Petrographic examinations shows that, the gabbroic rocks are composed of olivine, plagioclase and magnetite, respectively. Accessory minerals are present in low percentages and represented by illmenite and chromites [22].

Olivine

Olivine crystals vary in size from 0.2 – 5 mm and appears as subhedral to euhedral. Olivine is the essential mineral shows percentages ranging from 25% - 60% with average of 45%, olivine mineral present in two distinctive types in these area; foresterite (Mg-olivine), fayalite (Fe-olivine). The most abundant olivine type is fayalite mode of composition. The mineral is present in prefect, six sided and large crystals. In some slides the olivine crystals present very large in size (Fig. 4 A, B, D, F, G, H, I).

Plagioclase

Plagioclase occurs as euhedral - subhedral with grain size ranging from 0.1 – 10 mm. Plagioclase mineral shows percentages ranging from 10 - 40%. Bytownite and anorthite are the main types of the plagioclase series, which were recognized in thin section (Fig. 4 A, C, E, F, G, I). Opaque minerals are magnetite and ilmenite [22]. Both cumulus and intercumulus opaque minerals occur in these rocks.

Magnetite

Magnetite mineral shows percentages ranging from 5.0 - 25% with an average percentages of 15%. Magnetite present in large and almost of perfect crystals, six sided crystals (Fig. 4 A,C, E, F, G, I) [22].

Ilmenite

(Fe-Ti oxide) is present in low percentage (about 1-5%) and of six sided crystals (Figs. 4 F, G, H). While chromite is present in very low percentages and occurs in subhedral crystals [22]. Minute octahedral chromite crystals are found (Fig. 4 G, H) [22]. According to IUGS classification [26, 27], the petrographic analysis and the results the olivine percentages in the studied rocks, these rocks are classified as troctolite-gabbroid type rocks. This represents the main plutonic intrusive body, while the surrounding rocks are spotted hornfels type and comprise the contact with the host sandstone rock

Texture

The common is cumulate textures in the layered gabbroic rocks. In such textures, early formed and transported crystals , the cumulus crystals are surrounded by post cumulus crystals that crystallized form, or recrystallized through interaction with an inter cumulus liquid. Cumulate textures in the mafic rocks have intergranular, allotriomorphic-granular, hypidiomorphic–granular, poikilitic appearance, depending on the nature of the crystallization processes involved textures in gabbro are ophitic and many are cumulate textures (Fig. 4 D, F, G, H, I).

Accumulation of early crystallizing phases by gravitational settling was an idea advanced by Lewis [28] for the Palisades Sill. similar, settling and filter pressing were advocated by [29], both as general processes and as specific explanations of the origins of banded gabbro, that simply stated, solid crystals will be heavier than the liquid magma and sink to the bottom of the magma chamber, where they accumulate.

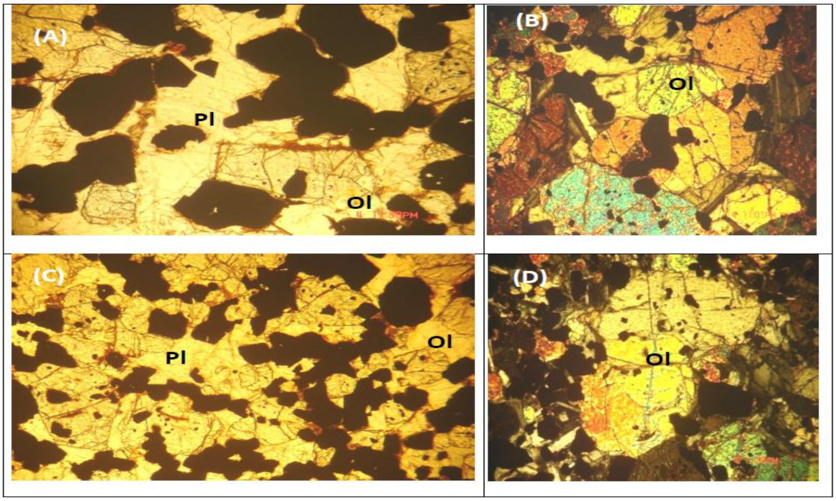

Fig. 4: Microphotographs of samples from the Jabal-Hamir Juban area, SE, Yemen Show: (**A**) Cumulus olivine, plagioclase and opaque minerals (black crystals), PP-40X. (**B**) Olivine and plagioclase minerals with opaque minerals (black) in olivine gabbro, CN-40X. (**C**) Troctolite containing grains of cumulus olivine, plagioclase and intercumulus opaque minerals, PP-40X. (**D**) A large olivine crystals and plagioclase minerals with opaque minerals (black), CN-40X.

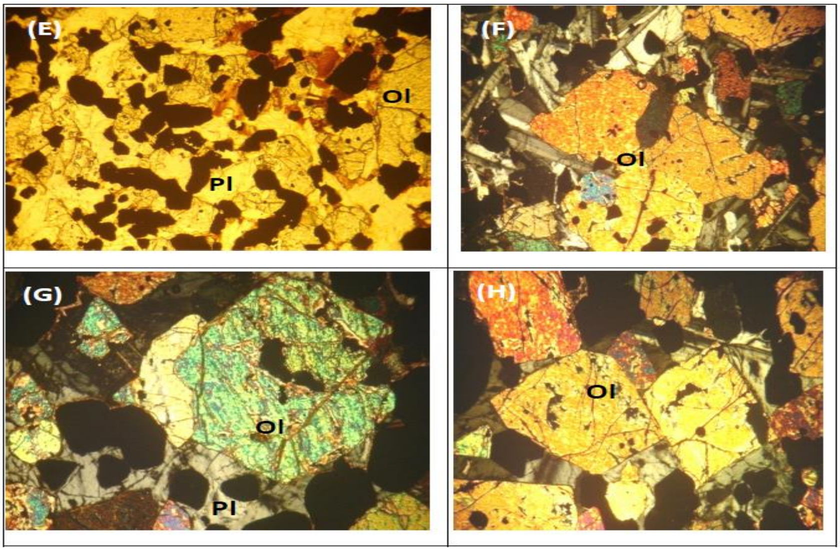

Fig. 4: (**Continue**): . (**E**) Troctolite with grains of cumulus olivine, plagioclase and intercumulus opaque minerals, PP- 40X. (**F**) A large euhedral to subhedral olivine crystals and plagioclase minerals with opaque minerals in olivine gabbro, CN-40X. (**G**) A large olivine crystals and plagioclase with intercumulus opaque minerals, CN-40X. (**H**) Euhedral to subhedral olivine and plagioclase minerals with interstitial opaque minerals,CN-40.

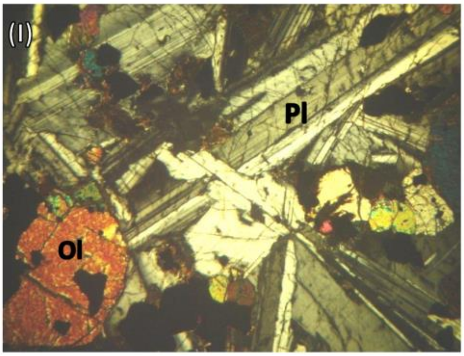

Fig. 4: (**Continue**): (**I**) Euhedral plagioclase feldspar of anorthite with interstitial olivine and opaque minerals, intergranular texture. Mineral symbols: Ol, olivine; Pl, plagioclase

Geochemistry

Chemical analyses of sixteen selected rock samples representing the ore-bearing gabbroic rock were chosen for major oxides as well as six rock samples selected to investigate some of the important trace elements, have been carried out at the laboratories of the Geological Survey and Mineral Resources Board, Sana'a, Yemen and in the laboratories of Al-Amri in Saudi Arabia, The results of chemical analysis are listed in Tables (1&2).

Major elements

The results of chemical analysis of ore-bearing gabbroic rock in the Jabal Hamir area indicated that concentration of iron oxide is variegated from 21.05 - 49.01% with an average of 44.30% and TiO_2 from 1.86 - 7.71% with an average of 6.78%. Whereas MgO varies from 7.45% - 11.06% with an average of 9.29%. Eventually the average of silicon oxide concentration is 23.76%. These results indicated that, the source of the gabbroic intrusion ore in Jabal Hamir area is basaltic magma.

There is no systematic variation of major oxides through the studied intrusion. In the ore-bearing gabbro, Al_2O_3, total alkalis (Na_2 + K_2O) and CaO increase with increasing SiO_2, whereas MgO, Fe_2O_3 (as total iron) and TiO_2 decrease (Fig. 5), Fe_2O_3 and TiO_2 are clearly positively correlated and show slight different trends (Fig. 6).

Trace elements

The concentration of V, Cr, Co, Ni, Cu ranging from 420 - 869 ppm, 37 - 139 ppm, 69 - 241ppm, 185 - 531ppm, and 197 - 559 ppm respectively Table (2). Early–formed cumulate rocks, such as olivine gabbro, are rich in both V and Ni. Vanadium shows a positive correlation with Ni (Fig. 7). Vanadium is strongly partitioned into titanomagnetite and shows a positive correlation with TiO_2 (Fig. 6). Elements Pt, Pd, Au, Ag and Ge show an average, 0.5ppm, 1.108 ppm, 1.12 ppm, 76.98 ppm, and 3.94 ppm respectively. The concentration of different types of trace elements are listed in Table (2). On an AFM diagram, the rocks in the Jabal Hamir intrusion show a tholeiitic Fe-enrichment trend (Fig. 8).

Table 1: Chemical analysis show the major oxides percentages of the selected ore –bearing Gabbro samples in Jabal Hamir- Juban location.

Sample. No.	***Major Oxides wt.%***										
	Fe_2O_3	**Fe**	**TiO_2**	**SiO_2**	**CaO**	**MgO**	**Al_2O_3**	**Na_2O**	**K_2O**	**MnO**	**P_2O_5**
1	41.01	28.68	6.53	25.51	3.07	8.34	10.01	2.41	0.78	0.31	1.49
2	42.67	29.84	7.00	24.68	3.08	7.34	9.96	1.90	0.69	.363	1.43
3	45.28	31.67	7.10	22.81	2.74	7.66	8.77	2.09	0.66	0.38	1.38
4	47.03	32.89	7.46	21.94	2.40	8.82	7.69	1.55	0.59	0.39	1.43
5	45.61	31.90	6.78	22.65	2.33	9.79	7.58	2.09	0.70	0.41	1.57
6	45.64	31.92	7.23	22.28	2.26	9.85	7.67	2.20	0.56	0.39	1.41
7	46.96	32.98	7.38	22.01	2.31	9.54	7.52	1.53	0.49	0.40	1.35
8	47.15	32.98	7.25	22.30	2.23	9.77	7.25	1.34	0.56	0.39	1.28
9	47.59	33.29	7.00	21.99	2.06	10.87	6.88	1.18	0.56	0.41	1.23
10	46.90	32.80	7.00	22.80	2.09	11.06	6.75	1.23	0.48	0.41	1.22
11	47.71	33.37	7.20	21.92	2.14	10.29	6.92	1.21	0.48	0.40	1.26
12	49.01	34.28	7.71	21.17	1.97	10.02	6.33	1.30	0.45	0.41	1.16
13	41.32	28.90	5.53	26.99	3.28	8.38	9.45	1.82	0.85	0.38	1.57
14	47.00	33.25	6.80	20.90	1.94	10.00	6.60	1.20	0.45	0.37	1.24
15	46.20	31.87	7.01	22.10	2.10	9.50	7.20	2.00	0.49	0.39	1.47
16	21.05	14.72	1.86	38.17	9.21	7.45	13.76	4.10	1.22	0.24	1.87
Average	44.30	30.90	6.78	23.76	2.80	9.29	8.15	1.82	0.63	0.38	1.40

Table 2: Chemical analysis results show some of important trace elements concentrations ore-bearing gabbro samples from Jabal Hamir –Juban location.

Sample No.	***Trace elements ppm***									
	V	**Cr**	**Co**	**Ni**	**Cu**	**Pt**	**Pd**	**Au**	**Ag**	**Ge**
1	780	71	241	481	212	-------	------	------	-----	-----
2	542	37	221	259	240	1.30	-----	0.85	19.90	3.62
3	654	69	241	332	247	------	-------	--------	-------	-------
4	682	57	233	427	248	-------	-------	-------	-------	------
5	869	73	236	531	197	2.10	4.15	3.45	334	14.40
6	420	139	69	185	559	------	2.50	2.37	108	5.62
Average	657.80	74.33	206.60	369.20	283.80	0.50	1.11	1.12	76.98	3.94

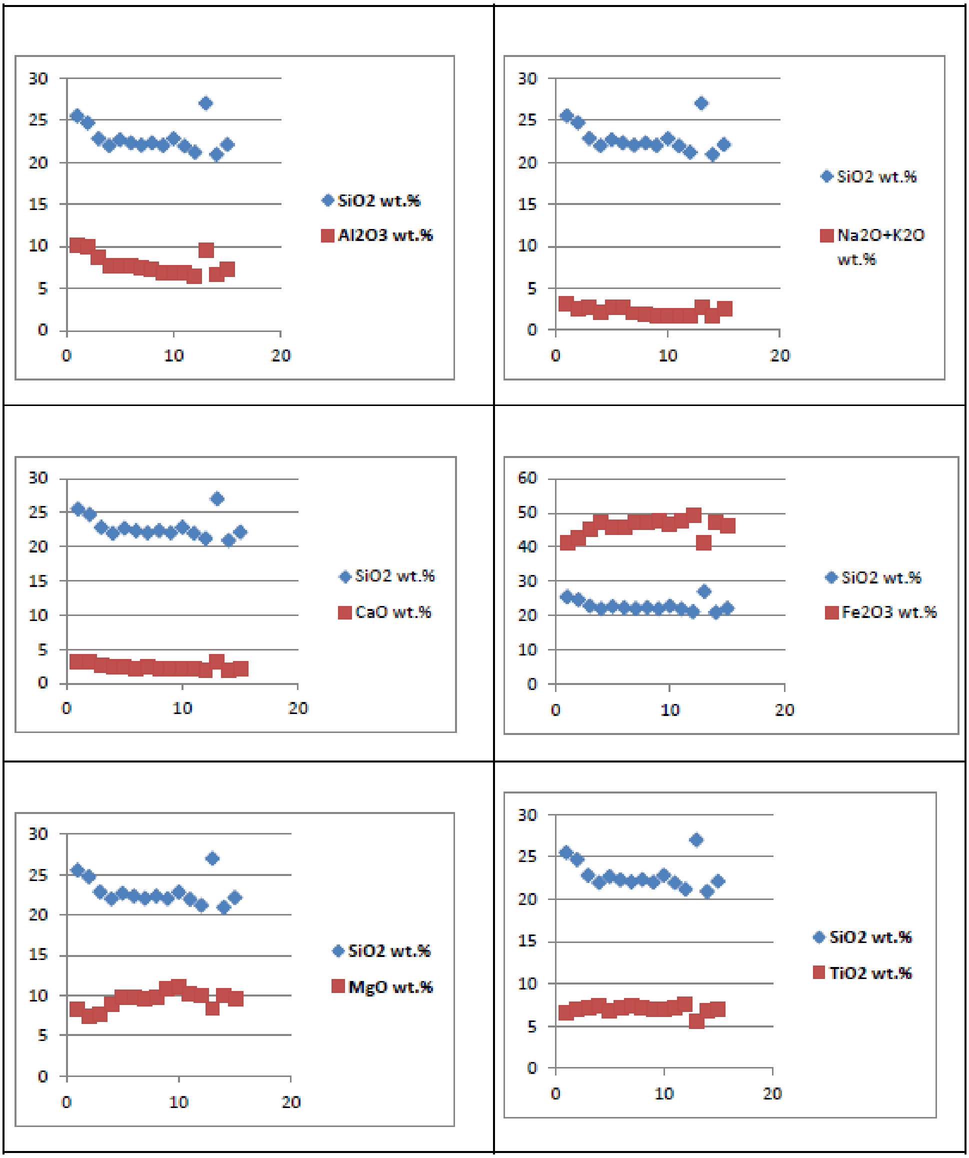

Fig. 5: SiO_2 versus Al_2O_3, $Na_2O + K_2O$, MgO, CaO, Fe_2O_3 (as total iron), TiO_2, for rocks of the Juban intrusion, SE Yemen.

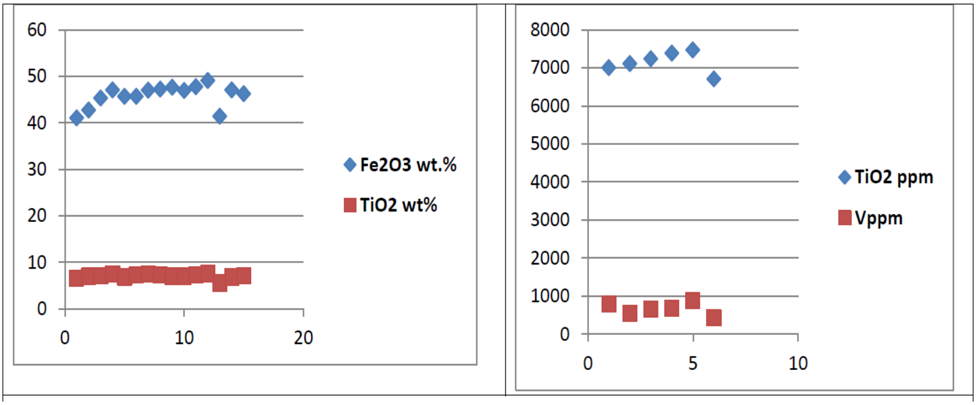

Fig. 6: TiO_2 vs Fe_2O_3 (as total iron) and V in the Juban Intrusion, SE Yemen.

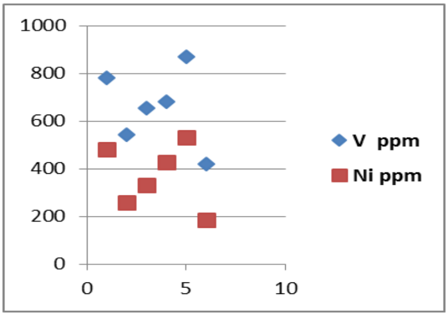

Fig. 7: Shows relationships between Ni and V of the Juban intrusion**.**

DISCUSSION

Geochemical study of major and trace elements of the Juban intrusion as previously mentioned indicates that primary magma for the Juban intrusion which have SiO_2 content variegated from 20.90% - 38.17% is a basaltic magma. The percentages of magnesium, calcium and aluminum oxides refer to the presence of olivine-forresterite and plagioclase minerals.

The textural relationships between the Fe-Ti- rich gabbros and oxides ores in the Juban intrusion support crystallization of the magnetite and ilmenite from oxide ore melts.

The assays on the surface samples show the average grade iron ore (up to 30.9% Fe), with 7% TiO2, in addition to good for Pt (1.30 - 2.10 ppm), V (420 - 869 ppm), Ni (185 - 531ppm) and Cu (197 - 559 ppm).

The fact that layered mafic plutonic of gabbro body in Juban area consist of concentrations of magnetite, chromites and olivine minerals that support the idea of gravitational settling [10, 30].

Tectonic rifting resulted in the intrusion of basaltic magma may have had olivine and chromite crystals, as well as small amounts of sulfide droplets, in suspension during it intrusion [31, 32]. Olivine and chromite settled out because of their higher density. However, a narrow conduit and rapid velocity of magma can keep the suspended crystals from settling down directly to the base of the magma chamber. In this case, magma differentiation is controlled by flow differentiation that concentrates the cumulus minerals in the central part of the conduit [33, 34, 35].

The low density mineral plagioclase-feldspar reveals grading channeling and stratifications, were deposited by currents on the floors of magma chambers [4, 7, 10, 21].

Most layers are formed where the density factor is overcome by movement processes driven by gravity. In such cases, slumping and flow of crystal-rich density currents physically transport plagioclase and crystalline phases along the bottom of the magma chamber, where they are deposited in layers [22, 36]. As the crystals develop and are deposited on the base of the magma chamber as cumulus phases, crystallization at the magma cumulate interface also occur [21, 35, 37].

Lopolithic and layered provide, the most extensive and impressive examples of fractional crystallization. These structures represent magma chambers, which are subjected to longer and extensive differentiation, evidences of fractionation in lopoliths are provided by the regular, usually cyclic, rhythmic layering that characterized these bodies [22, 36]. The rocks of the Jabal Hamir intrusion become more evolved in chemistry upward and follow a tholeiitic differentiation trend with enrichment in Fe, Ti and V.

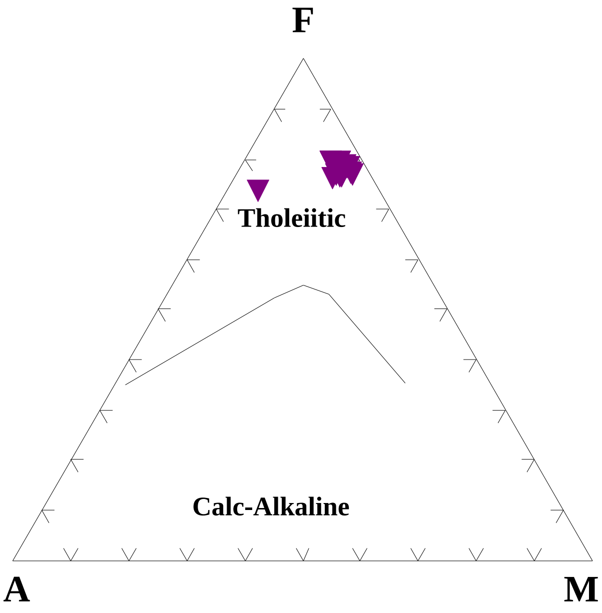

Fig. 8: AFM (**Na2O+K2O, FeOt, MgO**) diagram showing geochemical variations in the Jabal Hamir intrusion**.** The tholeiitic Fe-enrichment trend,[38].

CONCLUSION

Petrographic study of gabbro rocks show the following characteristic features:

- Gabbro is composed of olivine, feldspar and magnetite minerals.
- The olivine mineral is founded in high percentages which leads to classify the gabbro as troctolite type.
- The olivine is presented by fayalite and forresterite minerals.
- The plagioclase is presented by bytownite and anorthite.

The results of chemical analysis for ore-bearing gabbroic rocks in Juban area showed that, they contain Fe_2O_3 (21.05 - 49.01%) with an average 44.30%, TiO_2 (1.86 - 7.71%) with an average 6.78%, SiO_2 (20.90 - 38.17%) with an average 23.76%.

The geochemical analysis of the trace elements indicated that, the presence of a series of important economic elements in the studied rocks, these are: V, Cr, Cu, Ni, Co, Pt, Pd, Ag, Au and Ge. When we keep on studying via depths according to the magmatic differentiation processes, the ore in Jabal Hamir, it is possible to predict an increase of concentration Fe, Ti and trace elements. Further study of these rocks should shed additional light on the processes of magmatic evolution and the formation of massive Fe-Ti-V oxide deposits.

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بتروجرافيا وجيوكيمياء الجابرو الاندساسيه الحاوية للخام في منطقة جبل حمير – جبن جنوب شرق اليمن

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ملخص

تقع منطقة جبن على بعد 183 كم جنوب شرق مدينة صنعاء . مندسات جابرو جبن المتطبفه ترتبط بمتكون خام الحديد والتيتانيوم الشريطي والمستضاف من مندسات الجابرو ذات العمر الثلاثي ، هذه المندسات حقنت داخل مجموعة الطويلة الرملي للعصر الطباشيري.

اظهرت الدراسة البتروجرافيه لصخر الجابرو بأنه يتكون بشكل اساسي من معادن الاوليفين، والفلدسبار البلاجيوكليزي ومجنتايت. يتواجد الاوليفين بنسب عالية وهذا يقودنا لتصنيف الجابرو كنوع تروكتولايت . ويتواجد معدن الاوليفين بشقيه الفيالايتى والفوروستريتي وبنسب مختلفة.

نتائج التحليل الكيميائي للأكاسيد الرئيسة للجابرو المضيف للحديد في جبل – حمير منطقة جبن اوضحت ان اكسيد الحديد تتراوح نسبته من 21.05% الى 49% وبمعدل 44.30%، واكسيد التيتانيوم يتراوح من 1.86%الى 7.7% وبمعدل 6.78% واكسيد السليكا بمعدل 23.76% .

اوضحت الدراسة الجيوكيميائيه لصخر الجابرو ان خام الحديد والتيتانيوم بالإضافة الى بعض رواسب العناصر النزرة بأنها واعده اقتصاديا.

كلمات مفتاحية: جابرو، اندساس، خام الحديد، جيوكيمياء، جبن .