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RESEARCH ARTICLE

GEOLOGICAL, GEOCHEMICAL AND MINERALOGICAL OF THE IRON ORE DEPOSIT OF SABAH, AL-BAYDA'AAREA, YEMEN.

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Sabah, iron ore deposits, magnetite, hematite, geophysics data, band ratio.

Abstract

The Sabah Fe ore deposits are located in Al-Bayda'a area, about 220 km SE of Sana'a Capital City. Iron associated and confined in marble beds and meta andesite. Mineralogical studies by XRD analyses and petrographic examinations under reflected light of iron ores show they are composed essentially of magnetite and hematite minerals.The results of chemical analyses for iron ore in the Sabah area show that, the iron oxide ranges from 64.3% to 86%, with an average of 76.7%, and iron has an average 57.5%.The Magnetic map of Al-Bayda'a – Mukayras block illustratedlarge and clear anomaly of ore deposit. The band ratio 5/4 of ETM+ and ASTER highlight rocks rich in ferrous iron as bright pixels compared to other rock units.The band ratio 3/1 of ETM+ highlight iron oxides as bright pixels. The band ratio 5/7 of ETM+ and its equivalent 4/6 of ASTER image highlighted the regions which are dominated by the hydroxyl and silicate-bearing rocks as bright pixel.

Introduction:-

The Precambrian basement complex of Yemen represents the southern extension of the Arabian shield. Al-Bayda Governorate represents a part of the southern basement block. The studied area lies 5 km SE of Thie-Na'emTown, about 220 km SE of Sana'a Capital City. Sabah area is a part of the high plateau mountains of the central and western parts of Yemen. The area lies in the eastern edge of the central plateau. The elevation above sea level is 1800- 2100 m, generally 1900 m, with a topographic relief mostly less than 2000 m.

The mountain ranges in the area stretch in a north-east-south west direction. Geologically the area lies at eastern of the flank of the north-northeast trending Sawadiya anticline that belongs to the Precambrian basement complex. The strata exposes in the area from Sawadiya southeastwards to Thie-Na'em area suite of migmatites and magmatized metamorphic rocks. The degree of metamorphism changes southeastwards from higher to lower grade(Minerals&Metal.,2008,Sakran, 1993).

Deposition of iron ore bodies in Sabah area is always related to the intercalated marble beds in the meta-andesites or the intrusion of the diorites(China Team,1978). The ore consist mainly of magnetite partly with hematite and small quantities of siderite and limonite(Minerals&Metal.,2008).

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Most skarn deposits are directly related to igneous activity, and there is a systematic correlations between the composition of causative plutons and the metal contents of the related Skarns(Simon,et al.,2004,Chang,et al.,2004,Meinert, et al.,2005, Yucel-Ozturk,et al.,2005, Sun, et al.,2015). Iron skarns are mined for their magnetite content and although minor amounts of Cu,Co,Ni and Au may be present, iron is typically the only commodity recovered (Meza-Figueroa,etal., 2003,Foster, et al.,2004,Pons,et al.,2009). There are many other types of skarn which historically have been mined or explored for a variety of metals and industrial minerals (Okay,et al.,2004, Ray,et al.,2007, Franchini, et al.,2007).Pyrometasomatic or skarn deposits are high temperature hydrothermal ore deposits of Fe, Cu, Zn and other metals(Burt, 1977, Chang,et al.,2008,Ray,etal.,2007).

Band ratio is a powerful technique in remote sensing, which is used to enhance the spectral contrast of specific absorption features between bands and reduce the shadow effects caused by topography (Sabins, 1999,Gupta, 2003,Jensen, 2005). The selection of bands for use in the development of band ratio images depends on the spectral characteristics of the surface material to be analyzed and the abundance of this material relative to the surrounding features of the surface (Thurmond, et al., 2006).This study aims at examining the geological, geochemical and mineralogical properties of the iron ore to determine mineralogical constituents, and to define their economic potential.

Geological Setting:-

The Arabian – Nubian shield is a part of the east African orogeny , formed in the late Proterozoic (900 -550 Ma) by accretion amalgamation of oceanic and continental magmatic arcs and accretionary prisms during closure of the Mozambique ocean, suturing East and West Gondwana (Bentor, 1985, Kroner, et al., 1987, Stern, 1994, Al Selwi, 2005). In correlation with the accretionary history of the shield Saudi Arabia, northern Somalia and in Eritrea, the Neoproterozoic basement of Yemen is a part of the Arabian shield composed of a number of accreted arc terrains and inter arc suture zones (Beydoun, 1970, Gass, 1981, Al-Shanti and Gass,1983,Stoesser and Camp, 1985, Agar, etal., 1992). Sabah area is a part of the Al- Bayda'a district in Yemen. The basement rocks in the study area from a NNE- SSW striking belt, made up mainly of migmatized gneisses, ophiolites and metavolcanics (Al-Khirbash, et al.,2000).The zone is located very close to the limit between Al-Bayda'a formation and the Al Ma'den sequence. The AlBayda'a formation present biotitic schist, crushed granites, talc schist and orthogenesis, grading westwards in to migmatitefacies. It is in faulted contact with the volcano sedimentary sequence of Al Ma'den. The latter comprises from west to east, crushed meta tuffs and meta dacites, carbonate facies(marble with bounded cherts, calcareous meta tuffites) and more or less schistose porphyritic meta andesite(Fig.1).

Al Ma'den sequences are intruded by small massifs of very schistose microdiorites and monzonite in Sabah region. These rocks are associated with facies typical of a thermal metamorphis:

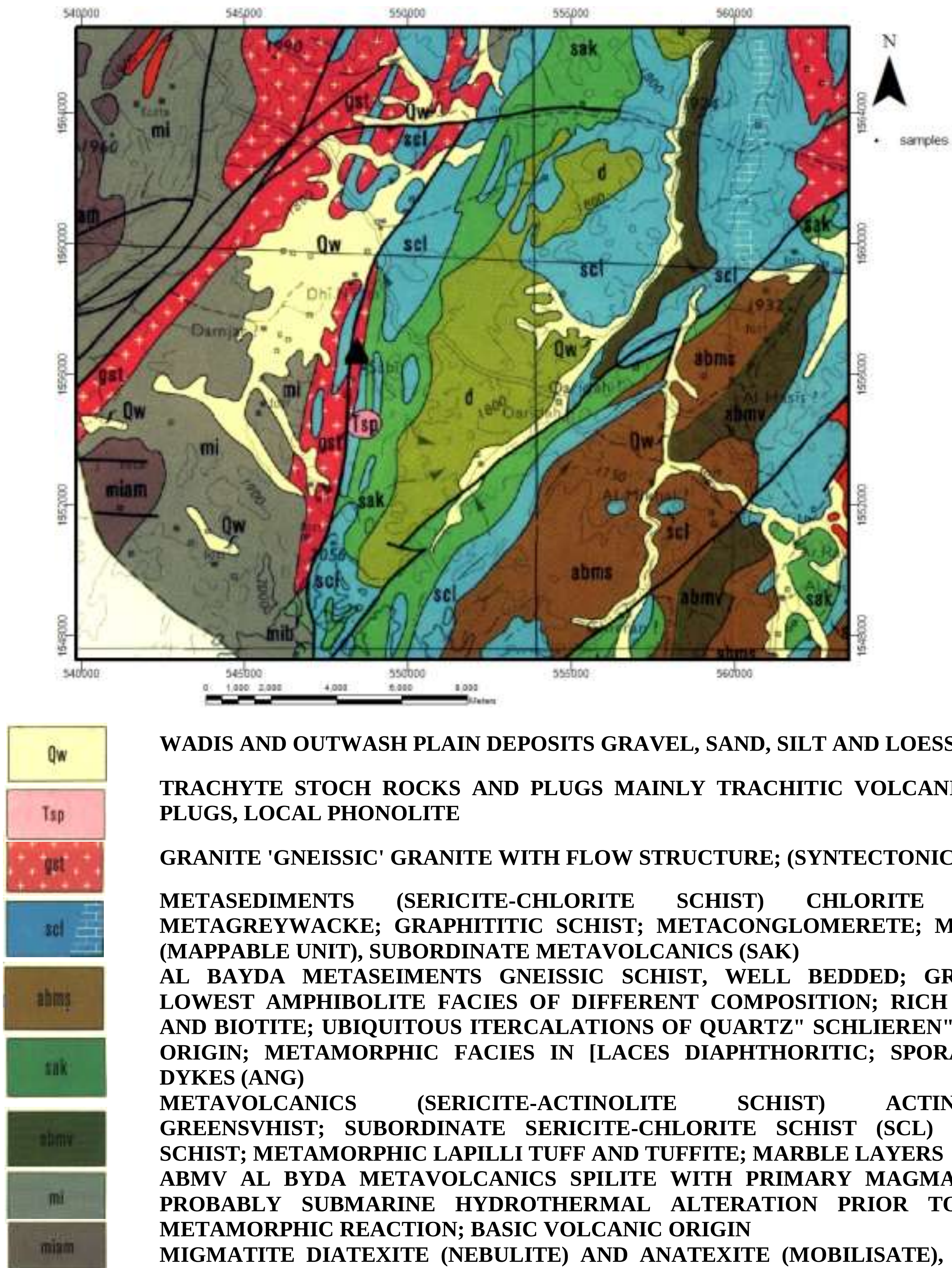
1. Epidot-actenolite-hornfels developing from the meta andesite, meta dolerites, metatuffs.
2. Skarnoidfacies deriving from the metamorphism of the carbonates and bearingDiopside-epidote-garnet-magnetite paragenesis(Minerals& Metal Mining, 2008).The general structural configuration of the area has been preliminary determined to be a steep monocline striking north east and dipping west. In the area faulting is quite well developed several sets of a fault that intersects often cutup the strata in to fault block of different size of these faults, those of NNE trend are the biggest in extent, but they formed later.The mineralized zone is related to two types of facies:

a. Epidote – garnet-diopsideskarn. In which magnetite and subordinate sulphides from Scattered patches or beds of between a few millimeters to a centimeter.
b. Chloritized marbles with iron carbonates which host massive magnetite.

The iron ore bodies are exposed between Sabah, Shab to Habaj are discontinuous lenses, beds associated and confined in marble beds and meta andesite. They extend over a length of15 to20km along the strike direction of main rock formation(Minerals & Metal Mining, 2008).

The iron mineralized zone in Sabah has a total length of 900 m and a width of about 200 m, consisting of 9 ore bodies(China Team,1978).

The ore bodies have a general trend NNE-SSW to N30 E to S30 W. They dip 60-65 toward the west. The iron ore is mainly magnetite, other sulphides like pyrite, pyrrhotite and chalcopyrite are associated as secondary minerals.



WADIS AND OUTWASH PLAIN DEPOSITS GRAVEL, SAND, SILT AND LOESS

TRACHYTE STOCH ROCKS AND PLUGS MAINLY TRACHITIC VOLCANIC STOCKS AND PLUGS, LOCAL PHONOLITE

GRANITE 'GNEISSIC' GRANITE WITH FLOW STRUCTURE; (SYNTECTONIC)

METASEDIMENTS (SERICITE-CHLORITE SCHIST) CHLORITE GREENSCHIST; METAGREYWACKE; GRAPHITITIC SCHIST; METACONGLOMERETE; MARBLE LAYERS (MAPPABLE UNIT), SUBORDINATE METAVOLCANICS (SAK)

AL BAYDA METASEIMENTS GNEISSIC SCHIST, WELL BEDDED; GREENSCHIST TO LOWEST AMPHIBOLITE FACIES OF DIFFERENT COMPOSITION; RICH IN AMPHIBOLE AND BIOTITE; UBIQUITOUS ITERCALATIONS OF QUARTZ" SCHLIEREN", SEDIMENTARY ORIGIN; METAMORPHIC FACIES IN [LACES DIAPHTHORITIC; SPORADIC GRANITIC DYKES (ANG)

METAVOLCANICS (SERICITE-ACTINOLITE SCHIST) ACTINOLITE-EPIDOTE GREENSVHIST; SUBORDINATE SERICITE-CHLORITE SCHIST (SCL) AND GRANITIC SCHIST; METAMORPHIC LAPILLI TUFF AND TUFFITE; MARBLE LAYERS

ABMV AL BYDA METAVOLCANICS SPILITE WITH PRIMARY MAGMATIC TEXTURES, PROBABLY SUBMARINE HYDROTHERMAL ALTERATION PRIOR TO LOW GRADE METAMORPHIC REACTION; BASIC VOLCANIC ORIGIN

MIGMATITE DIATEXITE (NEBULITE) AND ANATEXITE (MOBILISATE), INTERCALATED WITH MIGMATITIC BIOTITE GNEISS OR MIGMATITIC AMPHIBOLE; ANATECTIC GRANITIC MELTS

MIGMATITIC AMPHIBOLE GNEISS

AMPHIBOLE GNEISS, WELL BANDED; IN PLACE MIGMATITIC; BASIC ORIGIN

Fig.1:- Geological map of the Thie-Na’em region, showing the studied locality of Sabah, southwest of Thie-Na’emtown. The map is adapted from the geological map of Bayhan sheet, prepared by Roberston Group PLS, the Natural Resource Project, 1990.

Methodology:-

Sevensamples were collected from the several localities of orebodies, samples were analyzed by reflected light microscope and X- ray diffraction at the laboratories of the Geological Survey and Mineral Resources Board, Sana'a, Yemen.

The chemical analyses were carried out for selected ore samples at the laboratories of the Geological Survey and Mineral Resources Board.The band ratios of Enhanced Thematic Mapper Plus (ETM+) 5/7, 5/4 and 3/1, the band ratios of Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)image: 5/4 and 4/6 were applied in this research which are integrated with the geochemistry and geophysics data for study the Iron ore deposit in Sabah area.

Geochemistry:-

Chemical analysis of twelve selected ore samples representing the iron ore to determine the major oxides contents, and to calculate the exact percentages of iron oxides and later the Fe percentages. Six samples were selected to investigate some of the importance trace elements.The chemical analysis was carried out using Perkin Elmer atomic absorption instrument and by X-ray fluorescence.

Major Elements

The results of chemical analysis of iron ore in Sabah area indicated that concentration of iron oxide is variegated from 64.3 to 86% with an average of 76.7%, and silica oxide from 0.53 to 12.8% with an average of 7.15%, Cao from 1.57 to 14.2% with an average of 6.86%. The average grade of the iron 57.5%.

The results of chemical analysis are listed in table-1.

Table 1:- Chemical analysis data of iron ore samples from Sabah area

Sample.No	SiO_2	Al_2O_3	Fe_2O_3	Fe	MnO	CaO	MgO	Na_2O	K_2O	Total%
Oss-1	9.63	2.4	71	55.6	0.15	7.78	1.24	0.42	0.004	92.63
Oss-2	3.21	2.4	86	68.5	0.24	5.68	1.35	0.18	0.004	99.06
Oss-3	7.49	2.8	80	57.5	0.16	5.25	1.3	0.38	0.004	97.38
Oss-4	6.42	2.4	82	57.8	0.2	5.6	1.18	0.46	0.188	98.44
Oss-5	6.95	2.8	78.6	54.2	0.24	7.17	1.14	0.21	0.004	97.12
Oss-6	8.56	5.5	73.3	63.8	0.32	8.31	1.4	0.21	0.004	97.60
Oss-7	4.01	6	69.7	62.3	0.24	10.3	1.45	0.34	0.377	92.47
Oss-8	12.3	6.1	64.3	42.7	0.24	7.7	1.76	0.29	0.094	97.78
Oss-9	3.21	5.9	82.2	57.8	0.24	5.33	2.59	0.23	0.094	99.79
Oss-10	0.53	5.8	75.1	53.7	0.24	14.2	2.09	0.08	0.094	98.13
Oss-11	12.8	2.4	75	53.5	0.2	3.5	0.71	0.2	0.094	94.90
Oss-12	10.7	1.4	84	61.9	0.1	1.57	0.69	0.2	0.094	98.75
Average	7.15	3.82	76.7	57.5	0.21	6.86	1.41	0.27	0.087	

Trace element:-

The Sabah iron ore have Cu contents ranging from 888 to 1410 ppm with an average of 1156.8 ppm. The concentrations of Zn, Pb, Bi, Sr, Ti ranging from 31 to 440 ppm, 5 to 145 ppm, 2.53 to 199 ppm, 1.23 to 66 ppm and 180 to 360 ppm respectively.

Elements S and P ranging from 0.043 to 0.154, 0.04 to 0.118% respectively. The results of chemical analysis include some of trace elements listed in table-2.

Table 2:- Chemical analysis results show some of important trace elements Concentrations from iron ore from Sabah area

Sample. No	Cu ppm	Zn ppm	Pb ppm	Bi ppm	Sr ppm	Ti ppm	S%	P%
1	1160	31	5	2.53	1.23	360	0.154	0.111
2	888	299	n.d	190	46.1	180	0.043	0.025
3	893	440	75.8	198	17.6	245	0.124	0.076
4	1410	378	138	185	56	141	0.098	0.061
5	1290	390	145	199	46	320	0.062	0.118
6	1300	420	120	195	66	350	0.07	0.04
Average	1156.8	326.3	80.63	161.6	38.8	282.7	0.0918	0.0718

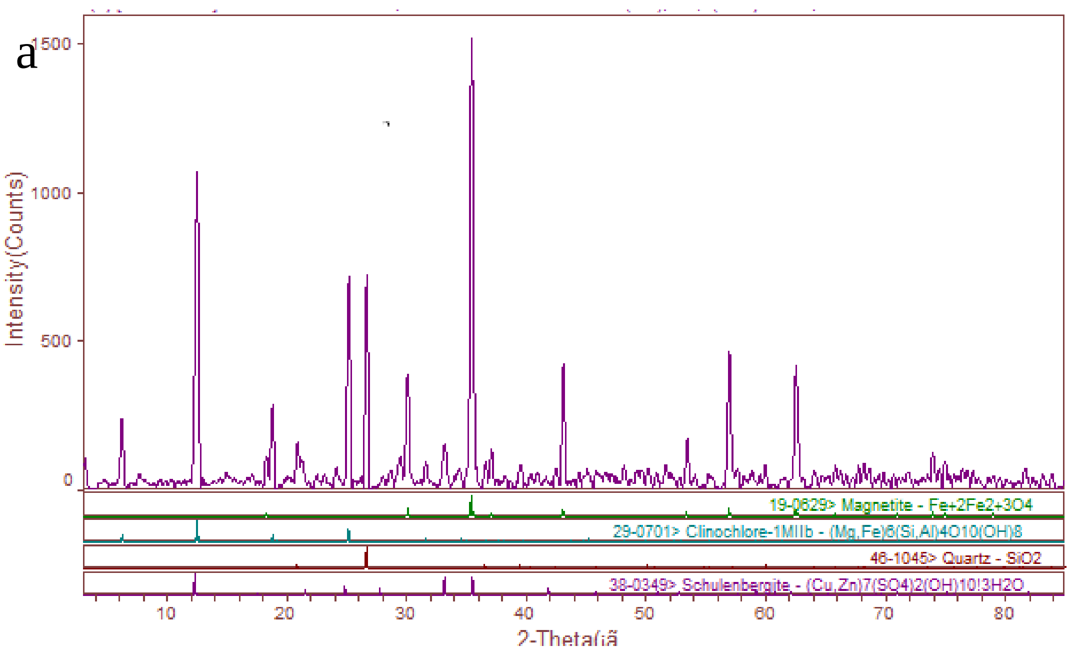
n. d= not detected.

Mineralogy:-

X- ray diffraction

Two samples of the Sabah mineralized skarnwere analyzed by x-ray diffraction.X-ray diffraction was used for the routine determination of mineralogy in samples. This method has a high degree of accuracy and can readily be used to identify individual minerals(De Villiers, et al, 2008).An experienced mineralogical assemblages of iron ore were investigated using x-ray diffraction. Selected XRD for iron ore given in table (3) respectively magnetite, hematite and quartz contents seem to be the highest in iron ore . XRD sheets are shown in (Figs.2). This was inferred from their high peaks intensity in the XRD charts.

a



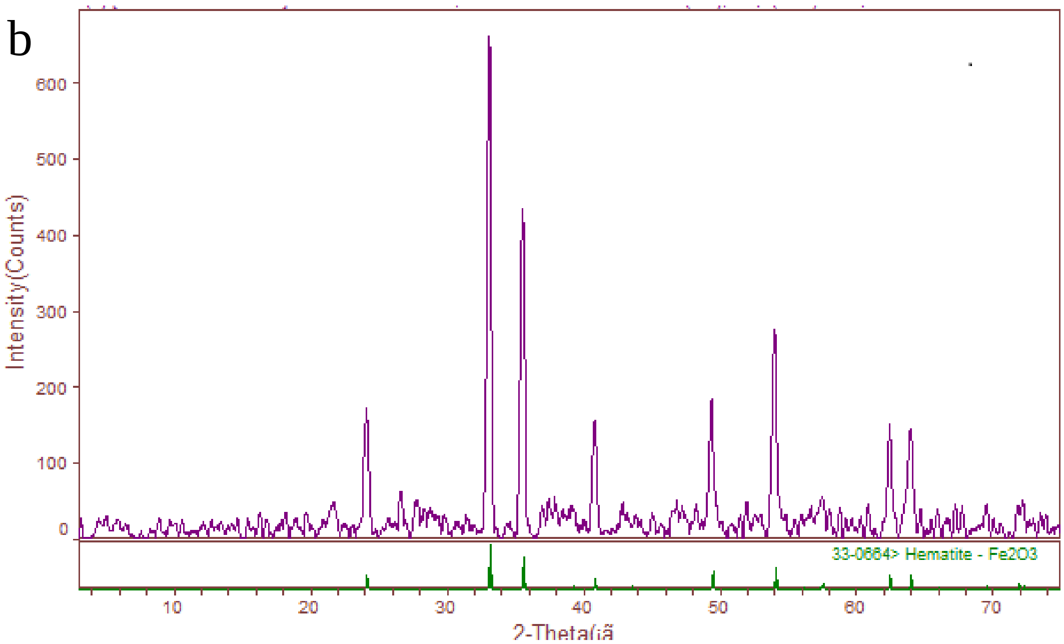


Fig. 2 (a, b):- Diffractograms from powder XRD for bulk samples from Sabah iron ore

Petrography:-

Sevensamples were studied by reflected light microscope.Qualitative characterization of iron ores is typically performed by visual examination under the reflected light microscope. The most common iron bearing minerals(magnetite, hematite)can be visually identified on reflected light microscope through their distinct reflectances (Gomes, et al.,2010). The Sabah iron ores have a simple mineralogy, generally involving magnetite, hematite and some gangue minerals, mainly quartz. Practically all of them are of the magnetite prevailing type.Ore minerals include magnetite, hematite and pyrite.

Magnetite:-

Magnetite is the dominant mineral in the ore of Sabah. It occurs mainly as subhedral –anhedralcrystals with grain sizes from 0.1 to 2 mm. Magnetite crystals are martitized to various degree along the octahedral plans and grains boundaries

(Fig.3 b, a). This crystals enclosed small silicates (Fig. 3 b, a, c). Magnetite and hematite isintergrown with pyrite (Fig.3d). Some magnetite crystal altered togoethite (Fig. 3 d).

Hematite:-

Hematite is a strongly anisotropic mineral. It presents bireflectance. It occur as subhedral-anhedral crystals with grain sizes from 0.01 to 1 mm(Fig.3b,c,d).

Pyrite:-

Pyrite is usually cube shaped and is yellowish in reflected light. It occurs as smalleuhedral-subhedral with fine grained and is intergrown with hematite. Pyrite is secondary mineral in Sabah iron ore (Fig.3 d).

Ta

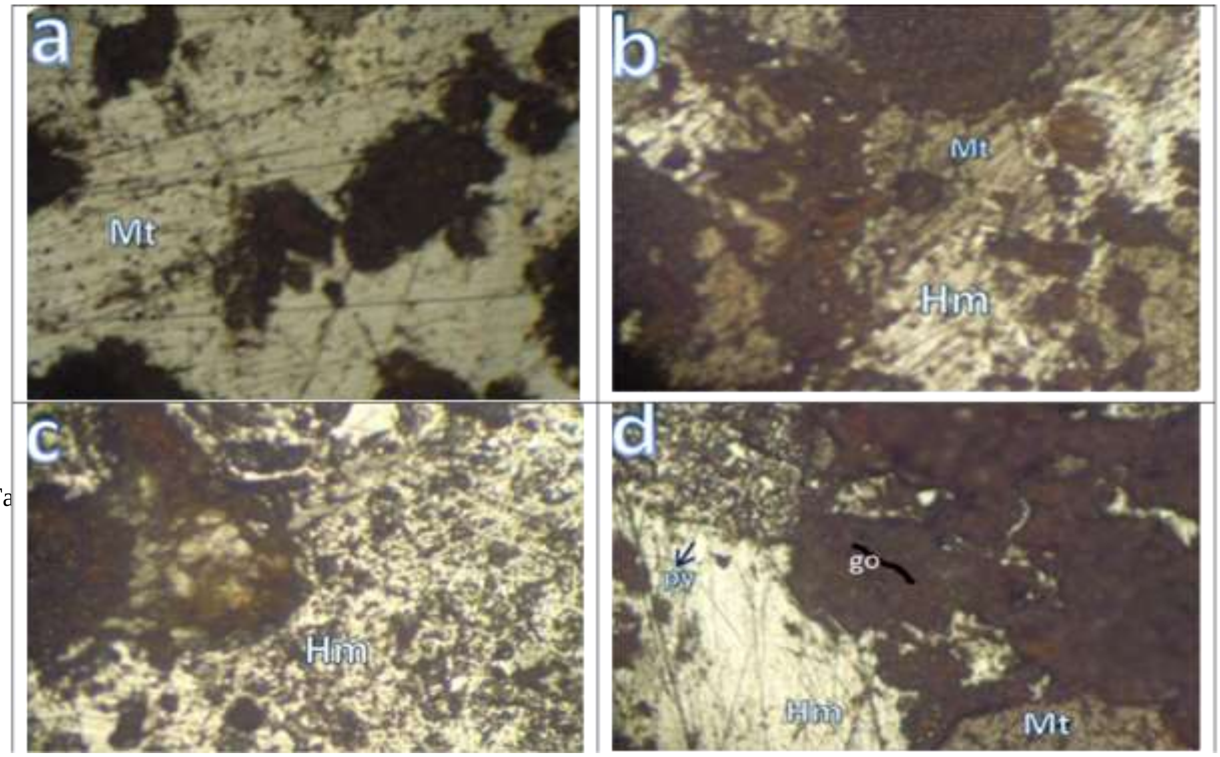


Fig.3:- Microphotographs of samples from the Sabah iron ore: a) magnetite subhedral enclosed silicates RPL., b) magnetite martitization, RPL., c) hematite crystal enclosed silicates, RPL., d) hematite is intergrown with pyrite and magnetite crystal altered to goethite, RPL . All photographs are 2 mm wide. Mineral symbols: Mt- magnetite; Hm- hematite; Py- pyrite ; go- goethite.

Geophysics and band ratio:-

The results of geophysics survey (BRGM) proofed the occurrence of the ore deposits of magnetite under the service as lenses and bodies with different extends (BRGM, 1980). The teams of BGRM recommended to drill the exploration hole for follow the extend of bed under the magnetite ore. The Magnetic total field map of Al-Bayda'a – Mukayras block showed the occurrence of large anomaly of iron ore deposit magnetite(Goeonex, 1993, Al-Huzaim, 2005) (Fig. 4).

The band ratio 3/1 of ETM+ highlight iron oxides as bright pixels, the spread of iron oxide isa result of the effecting of weathering and erison on banded iron deposits in and around Sabah area (Fig. 5). The band ratio 5/4 of ETM+ and ASTER highlight rocks rich in ferrous iron as bright pixels compared to other rock units (Fig. 6,7.The band ratio 5/7 of ETM+ and its equivalent 4/6 of ASTER image highlighted the regions which are dominated by the hydroxyl and silicate-bearing rocks as bright pixel (Fig. 8, 9). The combination band ratios of 5/7, 5/4 and 3/1 of ETM+as R-G-B, respectively illustrated the hydrothermal alteration iron oxides as blue and the altered rocks which are dominated by the hydroxel and silicate bearing rocks as darkcolour. Altered rocks with more Fe occurrences (ferrous iron) showed as green to pink colour(Fig. 10).

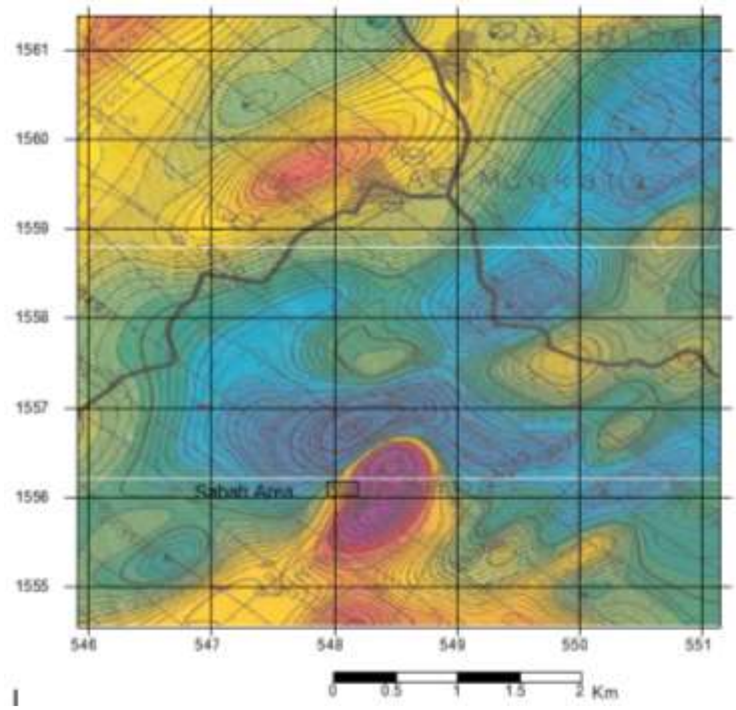


Fig. (4):- Magnetic total field map of Al-Bayda'a – Mukayras block

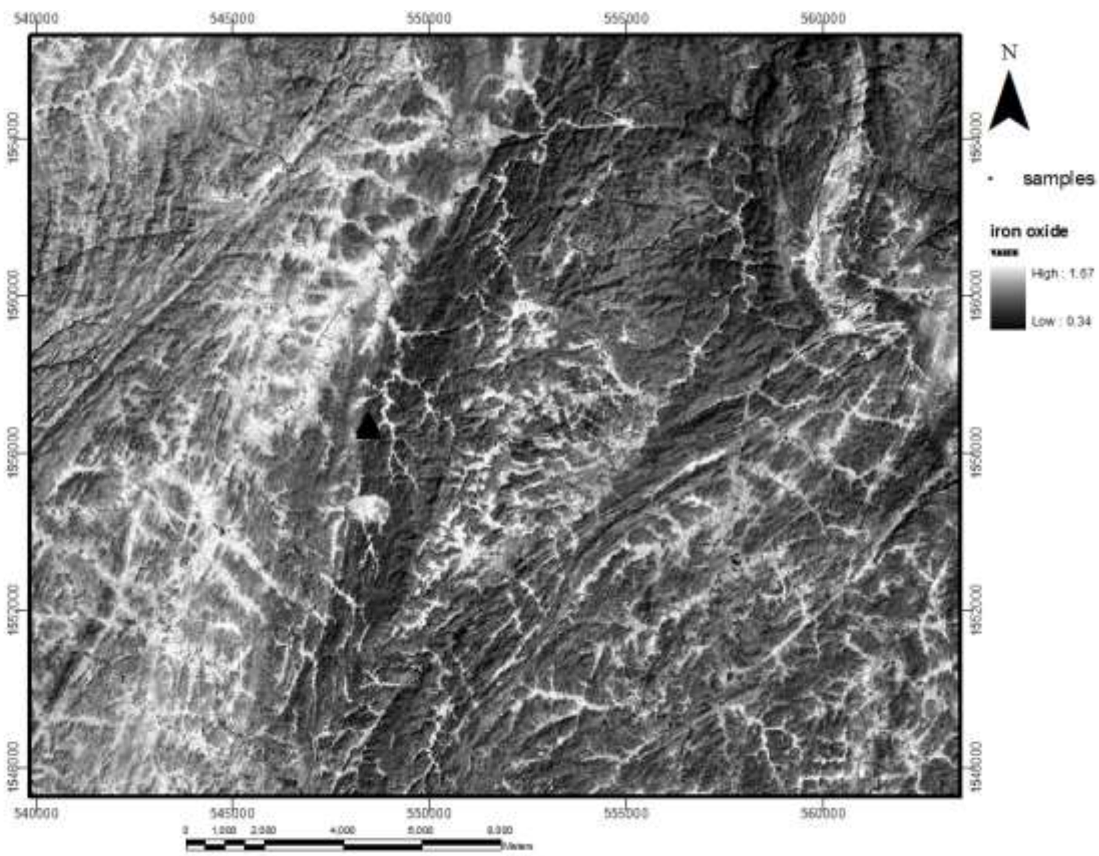


Fig. (5):- Ratio 3/1 of ETM

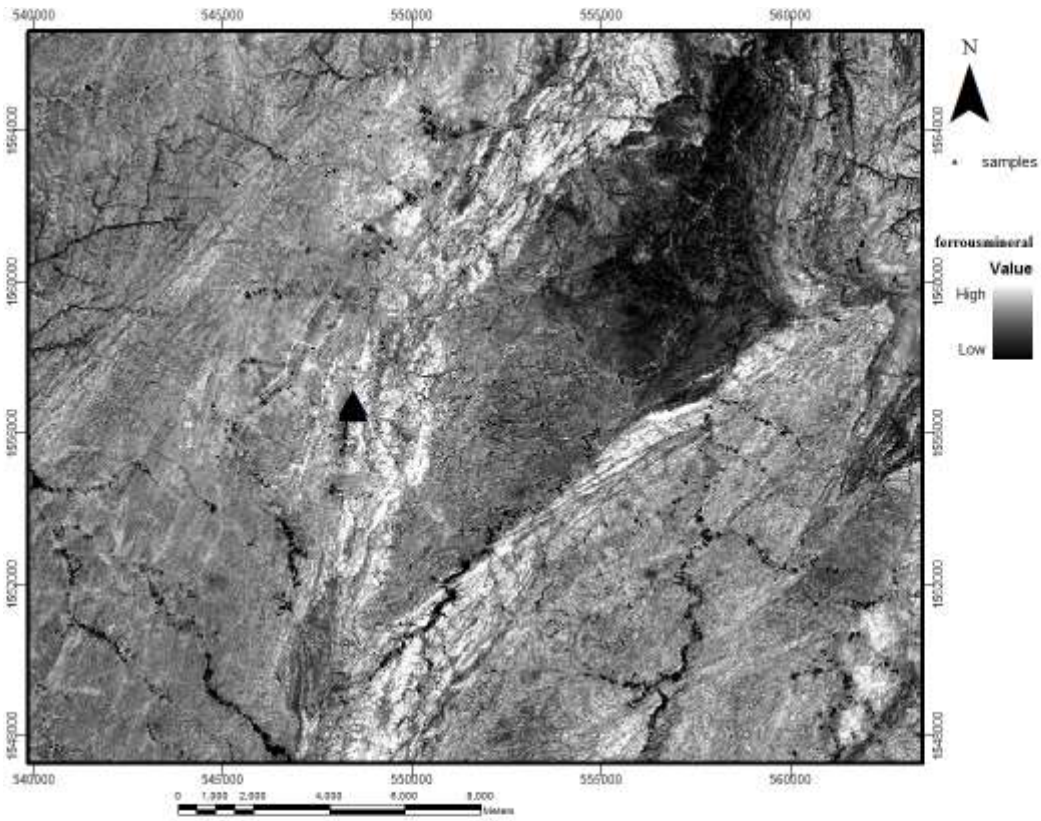


Fig.(6) Ratio 5/4 of ETM+

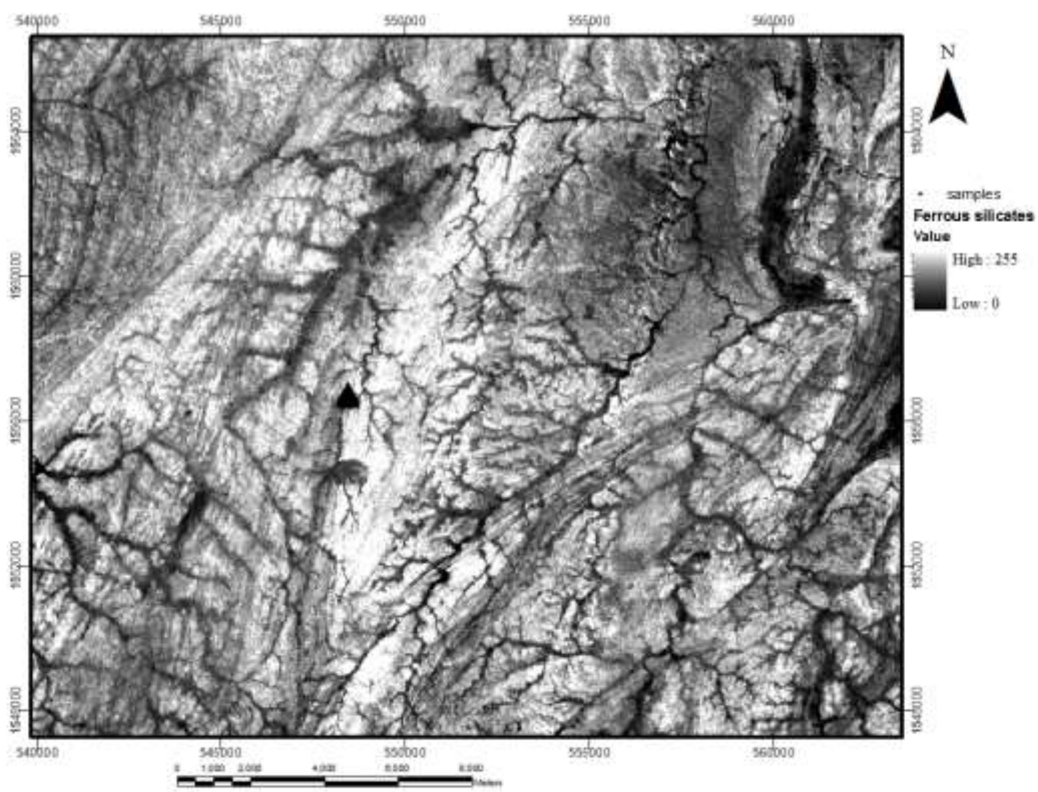


Fig.(7):- Ratio 5/4 ASTER

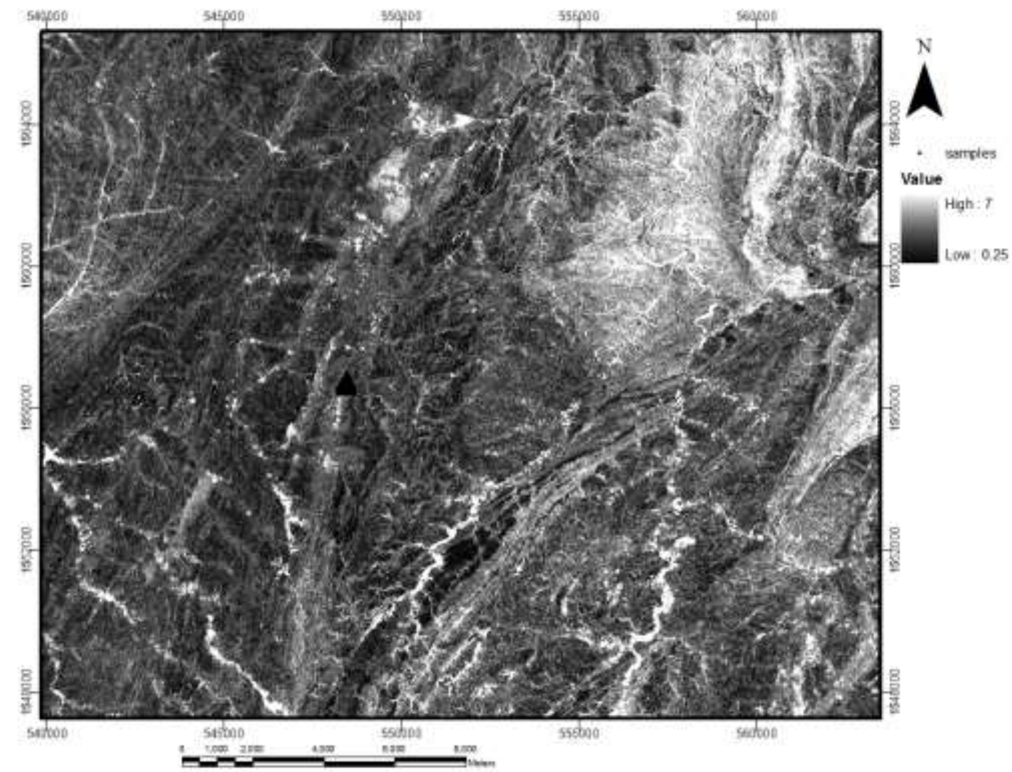


Fig.(8):- Ratio 5/7 of ETM

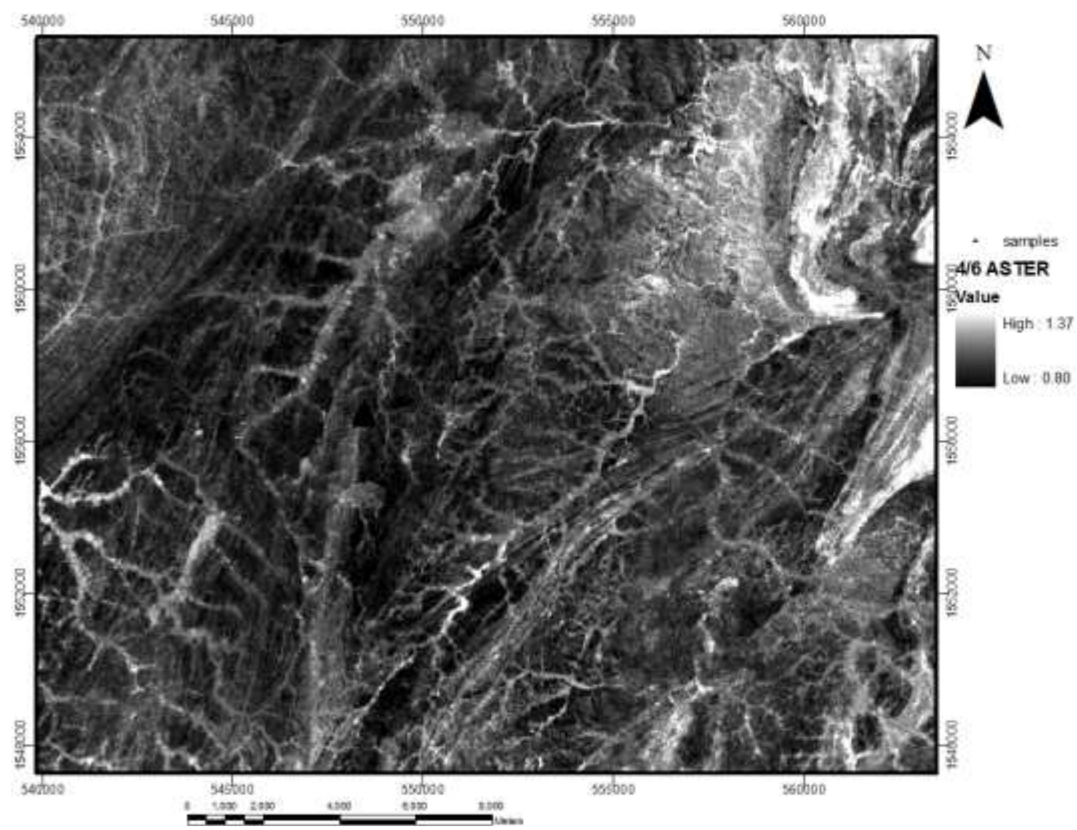


Fig. (9):- Ratio 4/6 of ASTER data

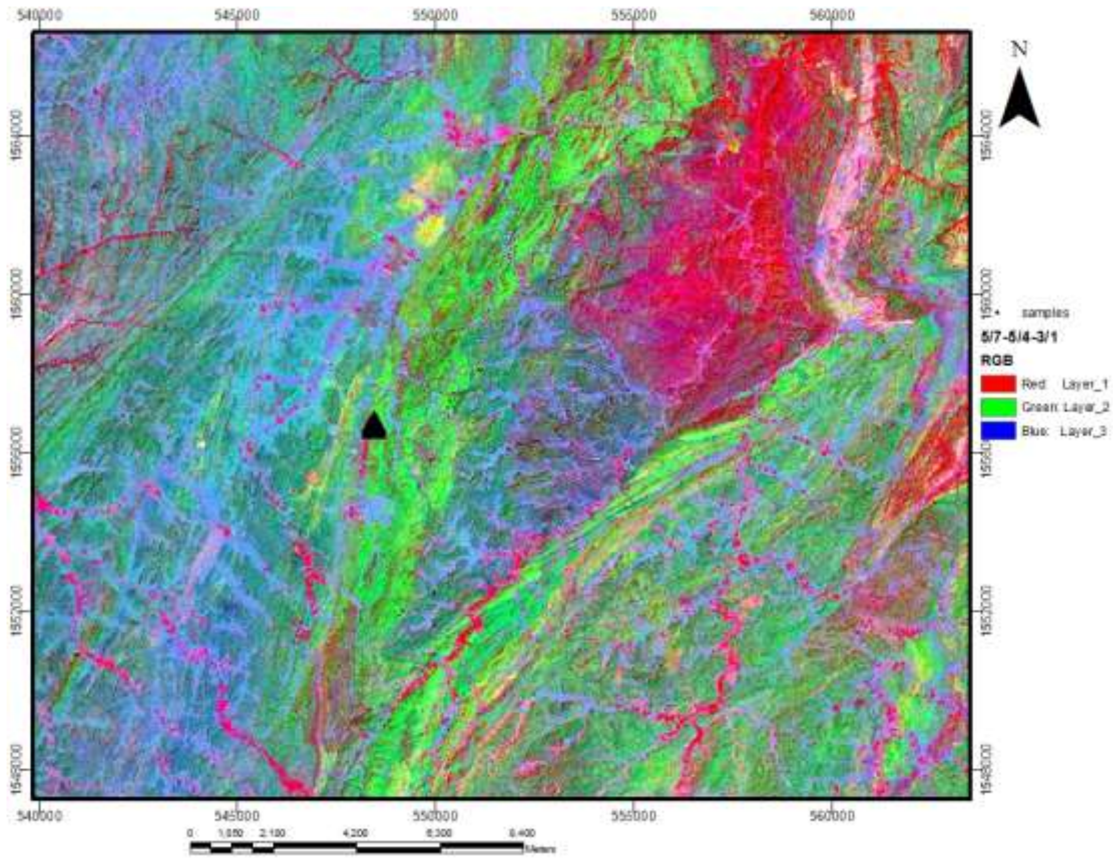


Fig. (10):- Combination ratios 5/7, 5/4 and 3/1 of ETM+

Discussion and Conclusion:-

Pyrometasomtic affects many factors including the redox gradient between the causative magma and the wall rocks, the composition of the magma and the derived magmatic hydrothermal fluids, the formation depth and temperature, the compositions of the wall rocks, and the organic carbon content of the wall rocks(Burt,1977,Blevin, 2004.,Meinert, et al. 2005, Sun, et al., 2015).

The concentrations iron occurrences indicates that the present area is characterized by favourable geological conditions for iron ore formation, and provides grounds upon which further search for iron deposits of the same type can be undertaken the area.The study of Sabah deposits provides evidence that the iron ore pyrometasomatic with high temperature hydrothermal ore deposits.

The results of chemical analysis for iron ore in Sabah area showed that they contain iron oxide (64.3%- 86%) with an average of 76.76%, and iron has an average 57.5%. The results of the geochemical analysis of the trace elements show the presence of a series of important elements in the studied ores. These are: Cu,Zn,Pb,Bi,Sr.

Mineralogical studies of the Sabah ore samples indicate that they are composed basicallyof magnetite, hematite, clninochlore and quartz. Hematite results from partial martitization of original magnetite, which probably occurred during hydrothermal event.

The studied iron ore were evaluated through the chemical analysis and mineralogical study to show their suitability for the industrial uses.For increasing ore reserve, the iron ore should be traced in the area, also there should be geophysical studies to investigate the ore in depth. The way of opening mines must be done in a systematic way and to have useful mineral waste.In addition to above area, there are some more promising zones at Habak and a plan for exploration and developing the deposits by drilling boreholes.

Analysis of Band ratios of ASTER and ETM+ images have showed high efficiency for detecting and predicting distribution of iron oxides, ferrous irons and the hydrothermal alteration zones.

Based on the different analyses of the geochemistry, geophysics and band ratio, it is concluded that the rocks of the study area are affected by hydrothermal alteration and is a promising field for mineralization. We recommended continues study of the economic minerals and follow the extend of the anomaly of iron ore deposit in and surrounding areas.

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